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Digital Transformation in Industry

Digital Twins and New Business Models

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Preface

Drivers and Effects of Digital Transformation in Industry

The rapid development of information technology has led to limitless possibilities for collecting, processing and analyzing big data, which has changed approaches to managing production processes. The reasons for such changes lie in the need for fast and precise product modeling in conditions when the demand for customized products has increased significantly. In just a short period of time, the concept of digital twins has grown from an abstract theoretical idea into a mature technology that is widely used in a vast variety of industrial sectors.

We can confidently say that today digital design and digital twins are becoming drivers of digital transformation in industry. The effectiveness of digital doubles has been proven by world leaders. It is widely recognized that digital twins lead to significant effects throughout the product life cycle: design, production, after-sales service and disposal.

The digital twin is a system of interconnected digital models of a product and production processes, and the parameters of these models can be controlled completely in a virtual environment. The effectiveness of digital modeling is ensured by the thousands of virtual and full-scale physical tests. The digital twins "are learned" during operation, and it becomes "smarter." This process is accompanied by the replenishment of databases, datasets of decisions and knowledge, which ultimately leads to the creation of technologically related solutions and changes the production paradigm.

The 3rd Annual International Scientific Conference "Digital Transformation in Industry: Trends, Management, Strategies" (DTI2021) held in Russia (Ekaterinburg) on October 29 was devoted to digital design and modeling in industry, analysis of technological trends and economic effects of digital twins of equipment, technological processes and industrial products.

Traditionally, the conference aimed to assess the trends and prospects of digital transformation in industry and industrial markets, as well as to substantiate successful digital strategies. Every year, industrial enterprises and executive authorities, researchers in the field of economic, technical and engineering sciences take part in the discussion platform of the conference. *This book presents the best scientific studies of the conference. What conclusions did the conference give us?*

Firstly, we have seen that digital transformation is deepening. The authors consider the economic efficiency of digital twins, their role in the development of industrial sectors and value chains. The articles note that enterprises that use digital twins adapt faster to rapidly changing trends and events, increase their productivity and begin to manage resources more efficiently. And this directly affects their competitiveness. The scientific discussion has shown that it is possible to create a digital twin not only of production processes and products, but also of social and economic systems.

Secondly, the scientific studies of authors have shown that digital transformation in different industries is characterized by some common trends, but at the same time, each industry proceeds in its own way. This concerns technological features, labor productivity, industry risks and necessary investments. In the articles, you will see the features of digital transformation in metallurgy, energy, aviation sector, refrigeration and air conditioning sector, wood-furniture sector, etc.

Thirdly, in the book, you will find articles on the ecosystem approach to digital transformation. These are, first of all, digital ecosystems in industry, including such elements as manufacturing enterprises, suppliers, dealers, research centers, universities, associations, etc. In addition, the articles will focus on digital platforms in the industry. The ecosystem approach to digital platforms relies on autonomous agents who contribute to the value of the digital platform.

Fourthly, authors note significant regional peculiarities in the digital transformation in industry. The articles study the experience of the European Union, in general, and Italy, Germany and Portugal, in particular. The authors highlight the process, resource and institutional features in these countries. The Russian experience of digital transformation in industry is widely represented. You can also see an article dedicated to digital twins for the development of territories.

Fifthly, the authors of this book claim that not only technologies and production are being transformed, but also business models. You can find articles on the use of artificial intelligence in process management, an innovation business model for sustainable development, strategies for digital transformation by financial and industrial groups and SMEs. The authors also focus on human resources for Industry 4.0, personnel competencies and successful teams in the digital environment.

The articles are an integral structure that characterizes the main trends of digital transformation in industry. The book will be interesting for researchers, entrepreneurs and policymakers.

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About This Book

The book offers a selection of the best papers presented at the Annual International Scientific Conference “Digital Transformation in Industry: Trends, Management, Strategies” (DTI2021), held by the Institute of Economics of the Ural Branch of the Russian Academy of Sciences (Ekaterinburg, Russia) on October 29, 2021.

The focus of the conference in 2021 is on digital design and modeling in industry, as well as the analysis of technological trends and economic effects following the introduction of digital twins of equipment, technological processes and industrial products. The aim of the topics discussed is to create an idea of introduction mechanisms for digitization processes and specify successful strategies of digital transformation in all sectors of industrial enterprises. The experience of developed and developing economies, as well as of small and large enterprises in implementing IT and other technological innovations, is scrutinized.

Among the topics covered in the book are the perception of Industry 4.0 basic technologies and the extent to which they affect digitalization processes, modeling the procedure and structural links between digitalization components and its factorial influence on the entire industrial sector, as well as industrial enterprises and regions and exploring the practice of using digital twins in the energy, metallurgical, aviation and other industrial sectors, etc.

These topics will be of great interest to academics, researchers and practitioners.

Headliners

- Gives insights into the latest research in the digital economy
- Presented new trends in the development of digital twins and new business models
- Gathers valued experience in implementing IT and technological innovation in industrial production

Contents

About the Editors

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Dr. Victoria Akberdina is Deputy Director of the Institute of Economics of the Ural Branch of the Russian Academy of Sciences. She heads 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. The issues of digital transformation of the industry have become a focus in her publications in recent years. She is also Author of the computer program "Digital transformation of Regional industry." She is Author of more than 150 scientific papers, and more than 20 scientific projects have been implemented under her leadership over the past 5 years. Since 2015, she has been Full Member of the International Academy of Sciences of Ecology, Human Security and Nature (MANEB) in the section "Economics and Law." In 2019, she was awarded the title of Corresponding Member of the Russian Academy of Sciences.

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Digital Twins in the Industry: Maturity, Functions, Effects

Grigoriy Korovin

Abstract A digital twin is one of the most important technological concepts within Industry 4.0. The term is often used in current research and practice on industrial transformation. The article determines the place of a digital twin, highlights its most important characteristics, the technologies used, and evaluates the possibilities of application and effects for the industry. In the author's opinion, it is important to assess the twin maturity, which allows separating this concept from the means of industrial automation. The complexity studying this object predetermines the need to use the methodology of collecting fragmented data, systematization of scientists' opinions, and analysis of practical experience. The author identified definitions of the digital twin concept and formulated the necessary features of a digital twin, including a virtual multidisciplinary model of the object, automatic and bi-directional data exchange, and intelligent control capabilities. Maturity criteria were proposed for classifying digital twins; the key digital technologies were distributed on a maturity scale. In terms of the use of a digital twin in industry, the author proposed the structure of the main economic effects in improving the quality of business processes, creating a product, and implementing industrial innovation. An important area of further research is to analyze the economic security of the use of digital twins and data, as well as address the problem of information overload.

Keywords Digital twin · Industry transformation · Digital twin maturity

1 Introduction

The focus on Industry 4.0 is related to the scale of the impact of new digital technologies on the economic, social, and production fields. The implications of digitalization for industry, markets, and the economy are expected to manifest in improved process efficiency across the entire product lifecycle, the development of new business models, changing work environments, and transforming skill requirements. This

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is especially true for the process of creating complex industrial products, for which a new technological base of design became available, making it possible to integrate heterogeneous development tools, remote groups of developers, and suppliers of modules to implement at each stage of development verification and virtual testing of elements and the product as a whole.

The concept of a digital twin is already at the heart of industry transformation projects. The author believes that it will determine the trajectory of industrial development for a long period. Surveys of managers of industrial companies confirm the relevance of the topic both in Russia and worldwide. Research and Markets' study claims that creating a digital twin will soon become a standard procedure for manufacturing: 92% of professionals believe products need an interface to connect to digital twins, 36% see the benefits of digital twins, and 53% of them plan to use digital twins in their operations by 2028 [22]. PwC, based on a survey in 2018, revealed that 60% of companies are implementing or planning projects to introduce digital twins [21]. A survey of Russian companies confirms the importance of digital twin technology in achieving technological leadership, according to 52% of respondents to the survey [4].

The described trends allowed formulating the purpose of the study as defining the essence of a digital twin, its key features, and opportunities for application in industry, taking into account its maturity.

2 Methodology

The technological complexity of a digital twin and its importance for industry requires the search for new scientific approaches to study its application in industry, determine its types, main functions, assess the applicability and economic effects. The study of this object is accompanied by the constant development of the views of scholars and practitioners, a variety of standards. The complex of digital twin technologies is in the convergence field of digital and physical reality, including many new promising technologies with unexplored potential [20]. Lack of reliable statistical information on the experience of implementation and use of digital twin in the industry predetermines the use of scientific observation methods, analysis of publications, collecting information from company reports, summarizing the experience of development and application of digital twins, and evaluation of existing and prospective economic parameters of the digital twin market. We focused on articles on the use of digital twins in industry, where we can trace the level of maturity from industrial automation to digital technologies.

3 Results

3.1 Definition of the Digital Twin Concept

It is believed that the digital twin concept was first mentioned in 2002 in relation to new opportunities for cheaper product development. The peculiarity of this concept was the informational unification of "real" and "virtual" spaces [9]. Forerunners of the digital twin are the concepts of product avatar [13], intelligent product [30], digital blueprint [2], digital shadow [5], device shadow [26], digital thread [27], and others. A generalization of these and complementary concepts can also be found in Trauer's review article [30]. The main area applying this technology is industrial activity, despite the attempts to create digital twins of processes, living and inanimate natural objects, fields, stores, customers, cities, etc.

Generally, it must be said that the understanding of the digital twin is rather unclear at the moment. In a 2018 High-Value Manufacturing Catapult study, about 90% of tech professionals surveyed described a digital twin as a virtual copy of a physical object used to monitor its performance [12]. The study of scientific and practical materials allowed distinguishing several conceptions of the digital twin (Table 1).

Several concepts complement the digital twin concept like the "digital thread" [17] and "digital master" [15], but they cannot be considered equal [25].The most important and widely used concept in this field is the component part of the twin—the digital shadow. It is necessary to generalize the concepts to highlight the key features and meanings scientists and practitioners put into this technological phenomenon.

The technologies of computer support for modeling, analysis of technological preparation of production, and tools to track the technical state of equipment, models of physical objects have been widely used in the industry long before the concept of a digital twin. In the author's opinion, these technologies are characteristic of the pre-digital stage of industrial development. The key characteristics of the current stage of development of these technologies, in the author's view, are the use of integration means of these elements, the ability to process big data, the emergence of simulation, predictive, analytical capabilities in digital twins. The use of these technologies characterizes a high level of maturity of the digital twin.

3.2 Key Features of a Digital Twin

We can formulate the key features of the digital twin, which allow separating this concept from the automation tools widely used earlier in the industry. The first three features are mandatory and technical solutions that do not meet these features cannot be called digital twins with the necessary level of maturity:

Table 1 Approaches to the digital twin definition

Digital twin concept	Definitions of the digital twin concept
General	A digital copy of a living or inanimate physical entity, allowing a virtual entity to exist simultaneously with a physical one [24]
Virtual model	Digital dynamic model in the virtual world, fully corresponding to its physical object in the real world, with the ability to simulate its characteristics, behavior and performance [32] Simulation of the production system based on simulation rules as part of production forecasting and planning [23] Digital representation of an active unique product… that includes its selected characteristics, properties, conditions, and behavior through models, information… [29] Uses the best available physical models, sensors, and historical data to accurately reflect the life of its twin—a physical object [6]
Data exchange means with a physical object	A means of exchanging information between the two spaces via sensors, models, and actuators [19] A virtual dynamic representation of a physical system connected to it … for bidirectional data exchange [30]
Digital technological complex	A set of digital technologies applying approaches from statistical analysis, machine learning, chemistry, physics, control theory, reliability theory, mass service theory, numerical modeling, and optimization
The complex of functions	An exact virtual replica of a physical system that represents all of its functionality or is an element of a cyber-physical system presents data about the production system to employees [1, 8] A trainable system… making it possible to get the first live sample of a product that meets the requirements of the specification, as well as predicting its behavior Designed to reflect all manufacturing defects and updated to reflect wear and tear caused by operation; has smart management features (Deloitte)

- A model that represents the most accurate virtual representation of a physical object in the form of a model defining the design, functions, technological parameters, current technical state, the behavior of the physical object, and other its properties, refined based on real data obtained from the object;
- Automatic and bidirectional data exchange with a physical object, receiving sensor data from the physical object and transmitting control actions to the object;

- Using artificial intelligence tools, the ability to observe and simulate the behavior, predict the state of the physical object and diagnose potential malfunctions, and optimize performance;
- The model components can be data characterizing the life cycle stages of the object: from market research, design to the results of operation and disposal.

A digital twin can be represented in the form of basic elements and information and management links (Fig. 1). In this case, the sensors, in the author's opinion, should be included in the loop of the digital twin since they are an integral part, not being a necessary element of the physical object.

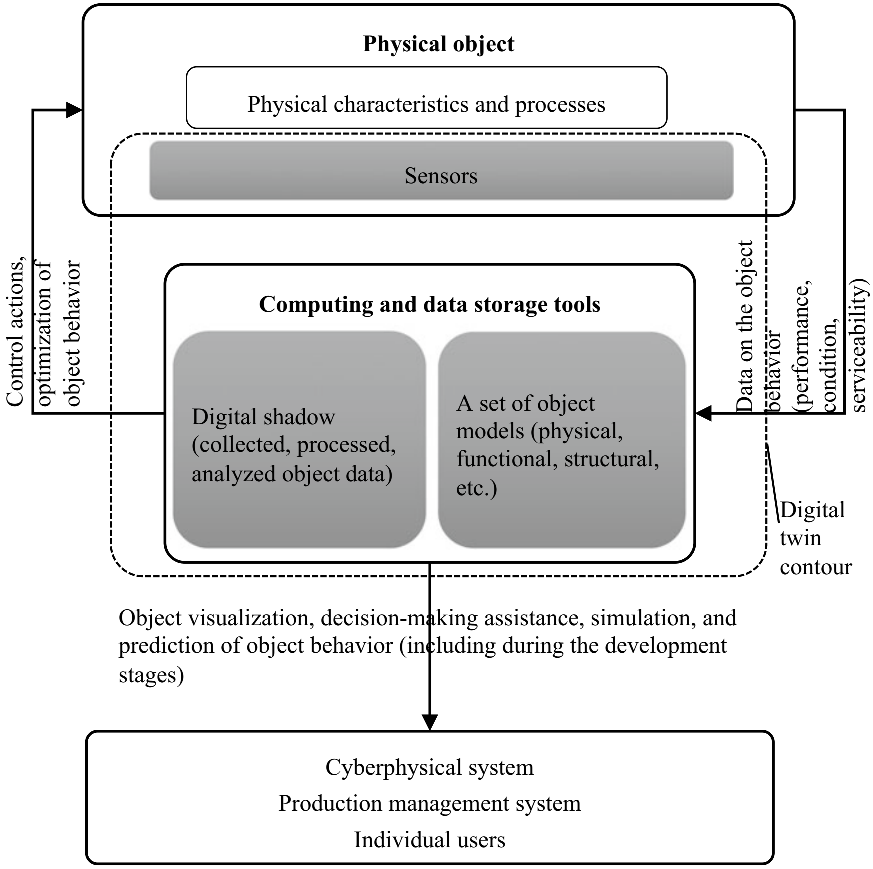

Fig. 1 Digital twin structure

Table 2 Digital twins maturity level features in the field of functions, and technological completeness (from low to high)

Digital twin technological completeness	Digital twin functions performed
High-precision digital model using physical process models Digital twin associated with a physical object Adaptive digital twin capable of updating based on data received from a physical object Intelligent digital twin with machine learning, event forecasting Digital twin that combines technical tasks for optimizing operational activities with financial models Autonomous digital twin controlling the object and making decisions about controlling the object [18, 20]	Object monitoring and diagnostics Technical data storage (individual physical processes, design, data on materials, on operating modes, on production and assembly technologies, customization possibilities; resource, financial constraints) [3] Interaction with a physical object Simulation of object states Prediction of future states Optimization of the production process based on data

3.3 Classification of Digital Twins by Maturity Level

The variety of approaches to the understanding of digital twins leads to various approaches to their classification [15]. Based on an attempt to combine the existing classifications and highlight the most significant criteria, this paper will not consider the criteria of the object complexity [28], the degree of integration [16], the level of efficacy [3], the stage of the life cycle [14], etc. The classification allows distinguishing the maturity level in the field of functions, and technological completeness characteristic of digital twins (Table 2).

Models of relatively simple objects, such as a single part, should be referred to a digital model and digital master rather than a digital twin as understood in this study. Functions related to the state monitoring of the industrial facility and process, the storage of production data also belong to industrial automation. According to the criterion of technological completeness of the physical processes model, data on the design, assembly features, and materials, on operating modes, separately are rather elements of the digital master—a digital model containing data for the product manufacture. The functionality and technologies used determine the maturity level of the digital twin.

3.4 Technological Base of the Digital Twin

It is difficult to limit the set of technologies related directly to the digital twin, but one can say that technologically, digital twins are becoming central elements of the cyber-physical system [1]. Summarizing the information on the creation of digital twins in the industry allowed presenting current technological directions:

- accurate modeling of geometry, physical properties, and behavior of a physical object;
- sensors and means of obtaining information about the object means of integration, storage, processing, and data interpretation from the physical object;
- means of interaction between a person and a digital twin;
- means of communication and data transmission;
- automation and remote control of a physical object.

The main technologies used in the digital twin are related to obtaining and processing data, building accurate models, and conducting analysis and simulations [16]. In the author's opinion, they can be placed on a maturity scale of the digital twin: from the level of industrial automation to the level of full autonomy (Fig. 2).

As already noted, digital twins of the initial type have been working in industrial automation for a long time. As for modern digital twins, they are not just a means of automating production but allow solving a set of issues associated with accelerating the development of prototypes, accelerating the product launch to the market, creating

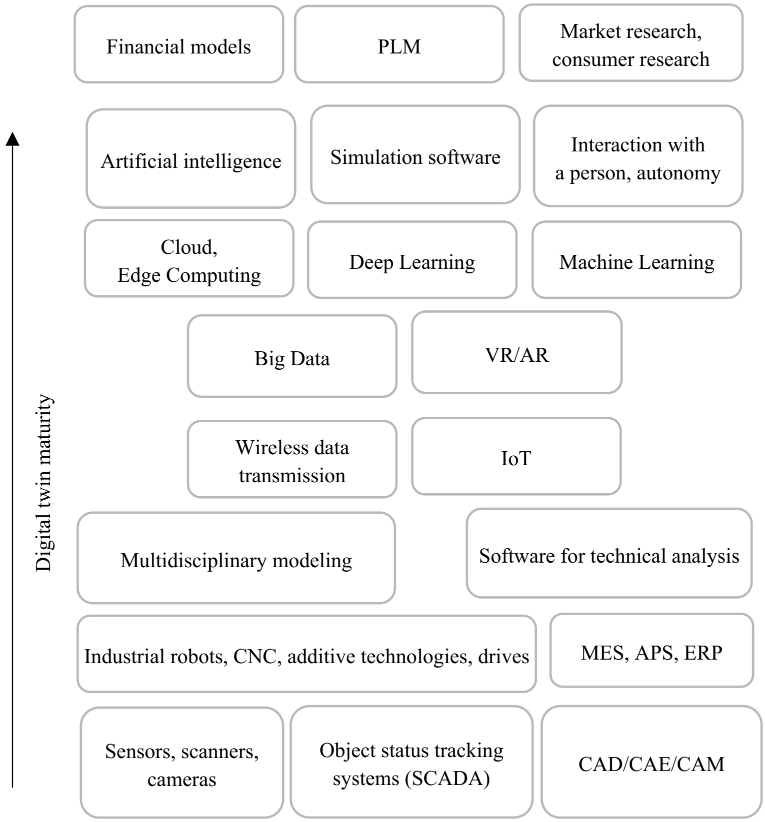

Fig. 2 Providing technologies on the digital twin maturity scale

and testing product modifications, reducing the number and cost of full-scale tests. A twin of a specific product part, even at the design stage, can identify the main design flaws with the help of digital visualization and analysis [7]. In the author's view, the pinnacle of technological development and the main feature of the digital twin is to ensure the autonomy of products, equipment, enterprises, etc. This autonomy must be ensured throughout the object's life cycle, including the development, production, and self-improvement of the object [23, 31].

3.5 Application of Digital Twins in Industry

Analysis of available public information shows that digital twins of varying maturity are used in many industries, and the scope of their application has expanded beyond the high-tech sector. It should be noted that often, companies can work to create digital twins, but information on this activity may not be available. Information is available on the use of this technology by aviation companies Airbus, Boeing, Russian UDK, OKB, shipbuilding companies Wartsila, Sredne-Nevskiy Shipyard, Malakhit, automotive companies, including world-leading companies, as well as KAMAZ PJSC. Digital drones of various maturity levels are used in train production and operation by Transmashholding, Alstom, and SimPlan AG. The companies ADNOC, Aker BP, Royal Dutch Shell, McDermott, and Russian Lukoil, Gazpromneft, and Sibur declared the use of digital twins. Siemens has developed a digital model of turbine operation and maintenance; General Electric has developed a power plant twin. GE Renewable and Arctic Wind introduce wind turbine solutions.

Table 3 Economic effects of using a digital twin

Scope of economic effect	Effects of using a digital twin
Business processes	Improving the company's business model based on reliable operational data on production Making proactive business and production decisions Production planning and overall quality improvement; effective integration of module developers and suppliers Providing access to remote and geographically distributed equipment
Creating a product	Early detection of product defects, based on actual data and operational scenarios Optimization of the structural safety margin Reduced design time, reduced costs due to virtual testing [10]
Innovations	Rapid prototyping, testing of innovative solutions Obtaining information about the properties of the future product, the ability to test the market prospects of the product Effective implementation of enhancements in the form of program updates and new modules based on operating data

The practice of creating and using a digital twin in the industry allowed determining the main effects of its use (Table 3). We believe, it should not be limited to the product life cycle stages but concentrate on the occurrence and nature of the effect.

Factors inhibiting the development of the digital twin market should be called a relatively high cost of projects of this type. According to estimates of The High-Tech Software Cluster, the cost of a project to create a digital twin is not less than 50,000 euros (up to 200,000 euros for complex projects), while it is projected to decline due to the technology and market development [11]. Overall, according to Credence Research, in 2018, the global market for digital twins was $3.76 billion. It is projected to reach $57.38 billion by 2027. The share of industrial production in this market is estimated at 25% [9]. Gartner predicts that by 2021, the share of large companies using digital twins will grow to 50%.

From the perspective of digital twin manufacturers, several companies in the Russian Federation can supply technology, components, developments in the field of mathematical modeling, and finished products. Traditionally, the Russian Federation has a strong position in software for modeling physical processes in the nuclear and aerospace industries. However, at the moment, the leading countries in the development of technology and the creation of digital twins can include the United States, China, Germany, India, Japan, South Korea, and Brazil.

4 Discussion

In our opinion, the use of the maturity criterion made it possible to distinguish a digital twin among the means of industrial automation. The importance of the maturity criterion has been demonstrated in the field of the functions provided and the technologies used. The proposed necessary features of a digital twin raise the question of whether we can call a digital twin individual industrial automation technologies, three-dimensional object models, and data sets.

The article does not sufficiently consider the issues of the effectiveness of the digital twin use. Reports about the need to invest additional large financial resources in the development of a digital twin cause doubts about the economic feasibility of using and the payback period of this technology. Perhaps the answer will be to reduce the cost of a digital double, to show the effect of a scale, or to choose separate industries where the use of digital doubles will be most applicable. In addition, the author considers it important to study the problems of economic security, data efficiency, information overload, the possibility of ensuring full autonomy of production based on digital twins.

5 Conclusion

The digital twin for industrial companies can potentially create new value, new sources of revenue, reduce costs, and provide new technological capabilities throughout the product lifecycle. The development of digital technologies, increased data transfer rates, growth of computing power, and the development of artificial intelligence will increase the efficiency and reduce the cost of digital twins. The industry is transforming towards autonomous industrial facilities, coordinated with each other, capable of self-diagnostics and troubleshooting. Digital twin technology will significantly impact the process of designing new industrial products, predicting their characteristics, possible operating conditions, reliability of materials, etc.

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Architecting Digital Twin-Driven Transformation in the Refrigeration and Air Conditioning Sector

Carolina Bandeira, João Barata, and Nuno Roque

Abstract Digital twins are a key pillar of the ongoing industrial revolution requiring a strategy tailored for each sector of the economy. However, contributions addressing the sectoral level of analysis are still nascent in the digital twin literature. This paper has a dual research objective of (1) identifying the digital twin potential at a sectoral level of analysis and (2) investigating whether the existent Enterprise Architectures (EA) approaches and languages meet the requirements for the creation of digital twin architectures. A design science research project was conducted in a leading business association representing the Refrigeration and Air Conditioning Sector (RACS). Our findings reveal that RACS digital twins will need to address the grand challenges of climate change and sustainability. Moreover, the digital twin-driven transformation of RACS will be more effective in cooperation between different supply chain segments, increasing the importance of business associations' role in the definition of reference architectures for their sector. Our results also extend recent research suggesting the use of ArchiMate language for digital twin developments. This contribution is relevant to sectoral digital transformations supported by digital twin technology, providing the foundations for future sectoral enterprise architecture frameworks.

Keywords Digital twin · Enterprise architecture · ArchiMate · Refrigeration · Air conditioning

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1 Introduction

The Digital Twin (DT) concept is evolving side by side with the disruptive digital transformation in industry. These digital representations of physical objects "*that support not only a prognostic assessment at design stage (static perspective), but also a continuous update of the virtual representation of the object by a real time synchronization with sensed data*" [1] are still emerging in different sectors of the economy. For example, in the refrigeration and air conditioning industry addressed in our research, DTs can leverage the digital transformation, helping digitalize energy systems aligned with efficient and sustainability strategies [2]. However, sectoral architectures that support DT developments are still lacking, for example, exploring the possibilities for Heating, Ventilating, and Air Conditioning (HVAC) systems throughout the lifecycle [3], at both design time and run time.

Enterprise architecture (EA) is a discipline attempts to capture the business and technology logic using models accessible to different organizational experts [4]. Through those models, enterprises can understand the "as-is" situation and establish a vision for the "to-be" architecture that will develop the business increasingly supported by information technologies [5]. There are influential EA frameworks to assist in the steps of architectural analysis and development (e.g., TOGAF [6]), but also languages like ArchiMate [7], suggesting a service-oriented and layered approach to EA. The most critical layers in ArchiMate are: strategy (courses of action, capabilities, and resources which can be used to model the strategy of an organization), business (e.g., processes), application (e.g., software), technology (e.g., hardware, networks), physical (e.g., equipment), and the implementation and migration (programs, portfolios, project management, and plateaus that can be used in gap analysis) that will guide digital transformation. Moreover, it is possible to model the motivation behind organizational change [8].

Enterprise architecture benefits are becoming more visible in Smart Manufacturing Systems (SMS), updating the business models and assisting companies in keeping up with innovative technology [9]. A SMS is defined as a "*highly connected, knowledge-enabled industrial enterprise where all business and operating actions are optimized to achieve substantially enhanced productivity, sustainability, and economic performance*" [10]. Industry 4.0 [11] and digital twins [12] give the first steps to incorporate EA models. However, there is a shortcoming of guidelines to adopt ArchiMate in the sectoral-level or product-level of DT developments. The gap found in the literature and contacts with industry experts gave a solid motivation to set up our research project. It started in cooperation with a national association for the refrigeration and air conditioning. The overall research objectives addressed in this paper are:

- *RO1: Identify the potential of digital twins in the refrigeration and air conditioning sector;*
- *RO2: Propose initial models for sectoral digital twin-driven transformation.*

The remainder of this paper is structured as follows. Section 2 presents background literature. Subsequently, the design research approach is presented, followed by the work conducted in cooperation with an important business association in Portugal. Section 5 discusses the findings and highlights design principles for sectoral digital twin architectures. The paper closes in Sect. 6, presenting the main limitations of our study and the opportunities for future research.

2 Literature Review

This section presents a bibliometric analysis of digital twin literature and the main trends in this vibrant field of research. Next, the link between enterprise architecture and digital twins is discussed.

2.1 Digital Twins

Several definitions for DT can be found in the literature, namely as being "*a digital representation of a physical element or assembly using integrated simulations and service data*" [13] and "*that mimics the real-world behaviour due to the data analytical and decision-making capability of DT*" [14]. Through the alignment between data integration and the application of data algorithms, the DT "*can perceive, monitor, synchronize mirroring, simulate, calculate, and test the behaviour*" [15] of the correspondent physical device. The different contributions in DT highlight (1) the crucial role of data obtained in the physical realm and providing the basis for digital processing and optimization, (2) the real-time communication between the physical and digital parts, and (3) the extension of product-service system value with new interactive layers available to their users.

Figure 1 reveals three relevant clusters of digital twin literature in Web of Science and meaningful keywords found in the sample of 2587 papers (search using "digital twin", all fields, no time restriction).

The analysis presented in Fig. 1, created with VOS Viewer [16], shows the co-occurrence of significant keywords (30+ occurrences; minimum cluster size of 8). Each node of the network shows a significant keyword in digital twin literature, and the lines illustrate the most relevant connections between them. The size and thickness of the elements are proportional to their relevance. The red cluster of papers (on the left) includes important industry 4.0 technologies (e.g., blockchain, BIM) and priorities for digitalization (sustainability, automation, integration). Sustainability is unquestionably one of the most critical strategies for digital twins [17] and also a priority to the refrigeration and air conditioning sector. On the top, the blue cluster includes papers from the system structure and architecture of digital twin advances.

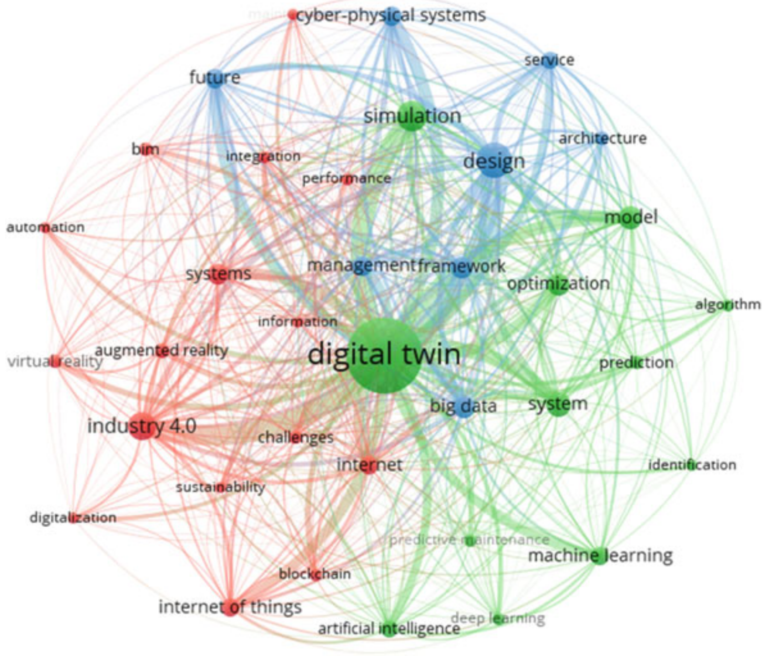

Fig. 1 Bibliometric analysis of digital twin literature in Web of Science

Finally, the green cluster emphasizes digital twins' predictive and intelligent perspective, namely, with the adoption of artificial intelligence and new models and algorithms to optimize systems and predict critical events in the physical realm (e.g., in maintenance).

2.2 *The Role of Enterprise Architecture in Digital Twin Design*

The EA can be referred to as "*a coherent whole of principles, methods, and models that are used in the design and realization of an enterprise's organizational structure, business process, information systems, and infrastructure*" [5]. EA helps find the alignment between business and IT goals to "*bridge communication gap between stakeholder, as well as manage control and evaluate the complexity of enterprises, processes, applications, and infrastructure*" [9]. Therefore, EA seems suitable to model the different layers and elements of the digital twin. For example, the sensors (technology), the functions or processes supported, the application components, or even the strategy of the digital twin development.

Many EA frameworks have been developed. For example, TOGAF, DoDAF, FEAF, or the Zachman framework. In general, the mentioned frameworks cover four correlated domains: Business architecture (business processes of an organization), Data architecture (structure of the logical and physical data resources), Application architecture (landscape of applications, their interactions, and relationships to processes), and Technology architecture (software and hardware capabilities required to support the business processes, data, and application services of the organization) [8]. Moreover, frameworks provide guidance and the key steps necessary to create an architecture and manage strategic change [18].

ArchiMate is a popular EA modeling language [7] EA models serve two important proposes: the first is to build a structure to align the enterprise strategy with the IT goals while providing ways of communication of the different involved stakeholders, considering the different perspectives; the second is to provide to the companies an overview of Industry 4.0 components to derive potentials for further improvements [11].

There are also some limitations in adopting these frameworks for our study. For example, it is possible to get inspiration from TOGAF and ArchiMate [7] to model digital twins in specific sectors of the economy. However, these essential tools do not fit precisely in the scope of digital transformation of an entire economic sector. Other examples, like FEAF [19], DoDAF [20], or the Zachman framework [21] were not built for creating the implementation (an instantiation) of specific artifacts like digital twins. Therefore, we could not find EA frameworks specifically created for manufacturing sectors like the refrigeration and air conditioning addressed in this research. Our requirements will include to (1) model the digital twin architecture with a language accessible to different experts, (2) propose a digital transformation methodology, (3) address data analysis requirements in the supply chain, (4) follow the strategic priorities of sustainability and climate change that are so crucial in the selected sector of the economy.

The authors of [22] propose a new methodology based on IT value, workgroup ideation, and Enterprise Architecture Management (EAM), as an approach for organizations to structure the introduction of Big Data. The methodology consists of the following steps: (1) developing ideas for Big Data usage, (2) assessing these ideas regarding their potential value, as well as the required changes to the organization architecture, and (3) implementing them coherently in the business. With this, EA can assist in developing emerging technologies like Big Data, an important part of the DTs of the future, and help the industry manage the digital transformation. In the scope of data analysis of the DT, there must be resourceful data sources that can be leveraged to optimize the performance of the DT.

As each sector has its own business scope, competencies, processes, skills, and administrative infrastructure, the IT operations must be targeted to its business strategy. Aligning the IT strategy with the business services potentiates the technology transformation of the business and serves the needs of the stakeholders [23]. Moreover, inspired by studies like [22] for the context of Big Data, our literature analysis confirmed the necessity to create EA modeling approaches to align business and IT with increasing volumes of data and leverage industry transformation supported by digital twins.

3 Research Approach

Design science research (DSR) is a popular research approach in studying information systems, aiming to produce knowledge with the design of artifacts [24, 25]. These artifacts can be "*constructs, models, methods, and instantiations*" [25] and generate new design knowledge to real-world problems [26, 24]. Therefore, DSR was considered suitable for our purpose to build a digital twin architecture in the sector of refrigeration and air conditioning.

Our work is depicted in Fig. 2, according to the DSR grid proposed by [26].

DSR starts with the problem formulation and evolves in building, evaluation, and theoretical development iterations [25]. The first research cycle had a problem-centered initiation [25] with a literature review on digital twins and enterprise architecture and contacts with industry experts of a leading national association representing over 500 companies. The design of digital twin models followed and the demonstration of its utility [17] with an evaluation made by experts in refrigeration and air conditioning.

Our case company is a private non-profit business association whose primary objective is to defend the common interests of its members, providing a wide range of services to member companies, covering all multidisciplinary fields relevant to the sector. Their mission is to promote the development of a favorable legal

Problem Digital twin architectures for specific sectors of the economy are still scarce	***Research Process*** Delimitation to the refrigeration and air conditioning industry; Modeling of a digital twin; Evaluation	***Solution*** The architecture of sector-specific digital twins modeled in ArchiMate
Input Knowledge Digital twin concepts; Sector-specific information; ArchiMate specification	***Concepts*** Digital twin; Enterprise architecture	***Output Knowledge*** Design principles to model digital twins with ArchiMate; Identification of key structural and behavioral elements of air-conditioned digital twins

Fig. 2 A summary of the selected design science research (Adapted from [26])

and regulatory environment and contribute to the development of the refrigeration and air conditioning sector. The activities of the companies represented by our case company are diverse: design, consultancy, energy certification, manufacturing, imports, representation, distribution, retail, installation, maintenance, technical assistance, building automation and control, and indoor air quality. The type of products and services includes ventilation, air conditioning, heat pumps, refrigeration (professional, commercial and industrial), renewable energies, and building automation control.

According to the business association, the building automation and control systems are more advanced in adopting digital twin technology. Their goal is to continuously monitor facilities equipment, ensure proper maintenance and cost reduction. Accordingly, sensing technologies are already adopted. However, the previous segments of the refrigeration and air-conditioning supply chain, namely, equipment manufacturers, distributors, and equipment installers, are not yet exploring the digital twin potential. Moreover, digital twins are not yet widely available to the end-users of this type of equipment (e.g., freezers, air-conditioned) at home.

Interestingly, a search in Google Scholar using the keyword combinations "air conditioning digital twin" and "freezer digital twin" returns 0 results, while "fridge digital twin" appears in one paper that presents it as an example [3], revealing the need for more studies in this area. As stated by [3], "*most research to-date focusses on the monitoring of production equipment or large assets*", which is insufficient for the needs of the industrial product service systems from the early stages of design and manufacturing to the end of life [3].

ArchiMate [7] was the language selected to model the digital twin-driven transformation of the selected sector. Two reasons justify our choice. First, the potential of ArchiMate to model Industry 4.0 systems [11]. Second, the recent studies emerging in the literature link enterprise architecture techniques in the design of digital twins. For example, the work of [12] proposing an enterprise meta-model that also models a digital twin with ArchiMate and the study presented by [27] that details the application layer of an intelligent transport system. However, there is a lack of studies addressing a sector-level of analysis, and none of the important papers found in our literature review addressed air-conditioning digital twins.

ArchiMate is a visual language offering "*an integrated architectural approach that describes and visualizes different architecture domains and their underlying relations and dependencies*" [7]. This language includes different elements representing behavioral, structural, motivational, and a composite architecture presentation. The ArchiMate framework can be used to develop an architecture of the enterprise strategy, business, application, technology, physical, and implementation and migration. As stated by the foundational work of Zachman "[w]*ith increasing size and complexity of the implementations of information systems, it is necessary to use some logical construct (or architecture) for defining and controlling the interfaces and the integration of all of the components of the system*" [28]. Therefore, an architectural approach to digital twin development can be valuable to industrial sectors of the economy investing in this concept.

The following section details the design and development stage of our DSR.

4 Architecting Digital Twins in the Refrigeration and Air Conditioning Sector

The work of [13] presents three key elements of DT developments, namely, (1) modeling, (2) connection, and (3) advanced data analysis. Under the scope of modeling, it will be necessary to create a 3D visualization of the object, where the user can interact with the virtual system and use the system service through the interface. This element is associated with the ArchiMate business layer, which models the usability processes of the DT for air conditioning. Connection refers to the integration of the data, which can be acquired (e.g., from temperature sensors, air quality sensors, humidity sensors, or pressure sensors) and saved in data clouds. This scope translates the technology layer, representing the conception of the DT and the configuration of the digital infrastructure. The following step is the data analysis, using intelligent applications, artificial intelligence (AI), analytics, and Big Data processing. The application of computer science algorithms allows to convert unrelated data into relevant usage information and decision making, contributing to address the problems of advanced planning and scheduling, product and process quality improvement, fault diagnosis, defect analysis [9], exploring the application layer.

This section describes the main steps of our exploratory research with the business association and the design and development stage evolving in steps of (1) strategic development, (2) holistic evaluation of the sector, and (3) product-level modeling example.

4.1 Digital Twin-Driven Sectoral Architecture—Strategy and Motivation

According to the experts contacted in our study, the vision of digital twin technology for refrigeration and air conditioning needs to contribute to several strategic goals, namely: sustainability, lower carbon footprints, energy performance optimizations, lifecycle planning, equipment durability, maintaining environmental conditions for health and wellbeing, continuous monitoring, and active and preventive maintenance. Moreover, policymakers must balance the environment's needs, economy, and energy reduction [29]. Therefore, the strategy and motivation layer of the architecture proposed will guide the next steps of the modeling process (Fig. 3).

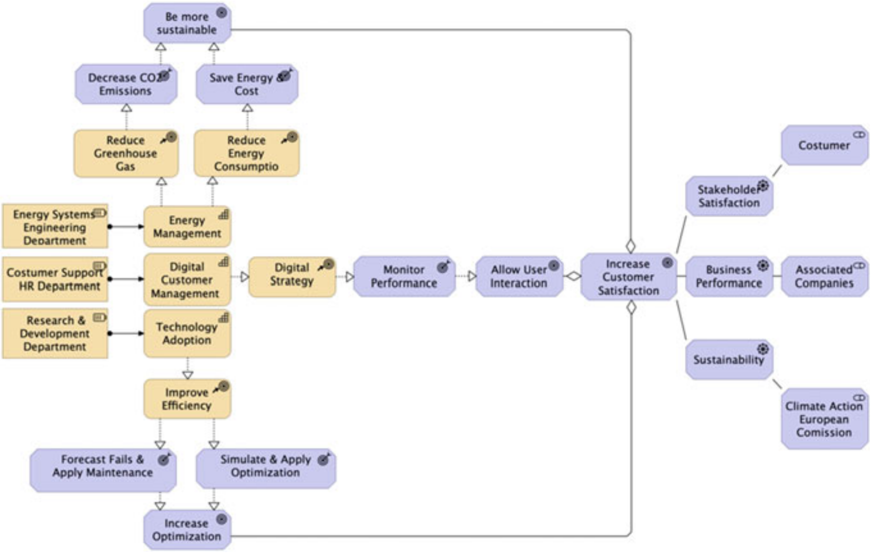

Fig. 3 ArchiMate model for the sectoral strategy and motivation (*Source* Own elaboration)

Figure 3 presents the strategy and motivation layer. On the right, the elements "Costumer", Associated Companies" and "Climate Action European Commission" present the key stakeholders interested in the sectoral EA and its digital transformation. On the left of these elements are represented the drivers, "Stakeholder Satisfaction", "Business Performance" and "Sustainability", that motivate the organization to implement necessary changes. The main goal is to "Increase Customer Satisfaction". Therefore, this element is connected to other three goals, from different scopes, that converge to the main goal: "Be more sustainable", "Allow User Interaction" and "Increase Optimization". The priorities for this sector are presented as a tangible outcome and connected to each set goal, being respectively: "Decrease CO_2 Emissions" and "Save Energy & Cost"; "Monitor Performance"; "Simulate & Apply Optimization" and "Forecast Fails & Apply Maintenance". The course of action presents the suggested tactics for the sector.

4.2 Sectoral Landscape for Digital Twin Developments

The strategy and motivation for sector-specific digital transformations will guide the investment priorities. Next, it is necessary to model the sectoral structure and behavior in the entire supply chain. Figure 4 presents the overall architecture.

There are four main segments in the refrigeration and air conditioning supply chain: manufacturers, installers, distributors, and technical management (also referred to as building automation and control systems). The supply chain and the

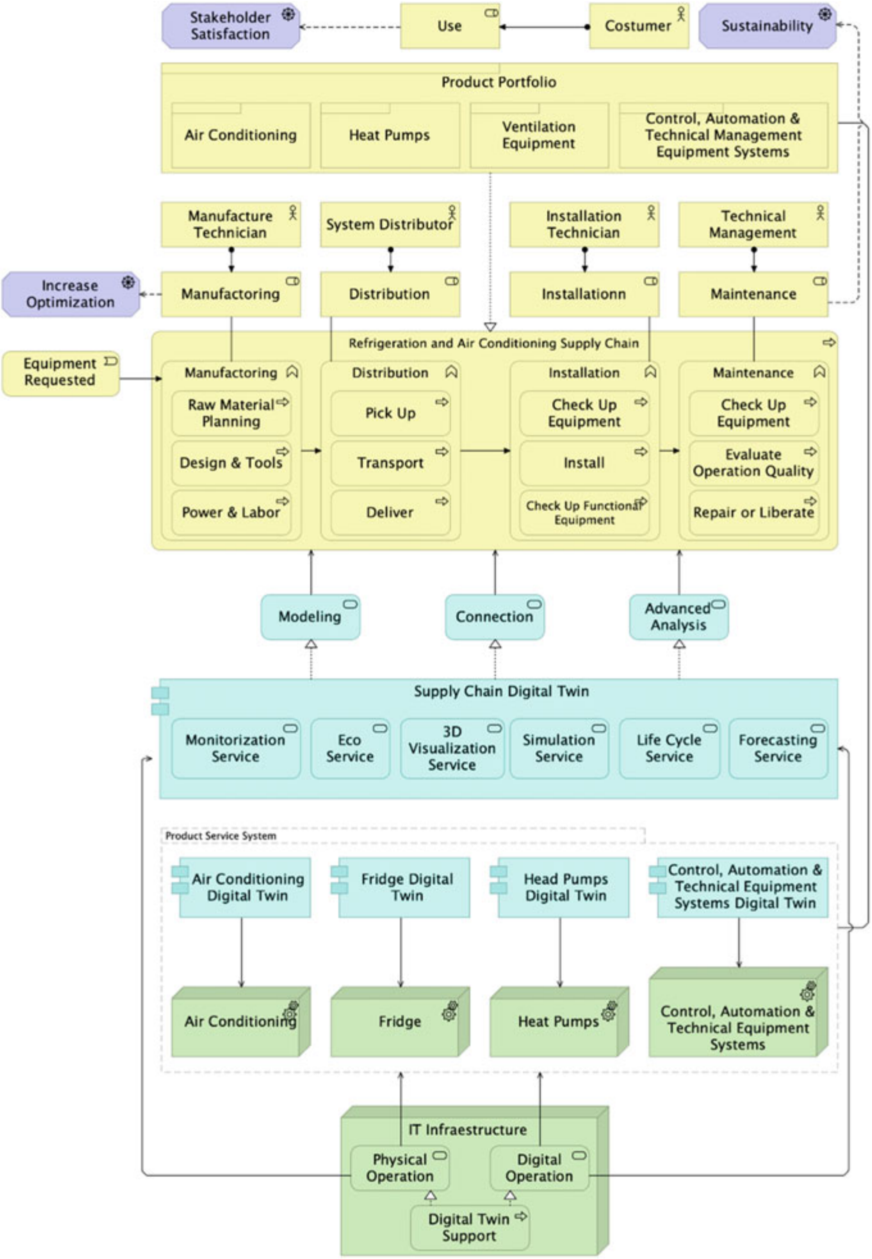

Fig. 4 Sectoral digital twin architecture for RACS (*Source* Own elaboration)

product portfolio are represented in the business layer at the top of Fig. 4 (yellow elements). For the sake of simplicity, only a few strategy elements are included in this model—identified in Fig. 3.

Each product requires a detailed analysis of the digital twin configuration, including physical and digital components. Ultimately, the sectoral product offer will be transformed into a product-service system that includes the physical value of the equipment and the digital support to their stakeholders (e.g., advice for energy reduction). The links between the application layer (blue) and the technology and physical layers (green) are bidirectional, as suggested in the work of [12]. On the one hand, the digital twin requires a cloud-based architecture and related software and hardware infrastructure. On the other hand, the digital twin will also serve the physical layer of the architecture (e.g., real-time monitoring and actuation). Both the products digital twins and the supply chain digital twin (addressing aspects like manufacturers equipment, transport, real-time monitoring of the fleet of digital twins of a specific brand) are essential to the sector. This high-level sector model offers the foundation for more detailed modeling of each product.

4.3 Air Conditioning Digital Twin Model

The model shown in Fig. 5 provides an overview of the Technology, Application, and Business layers for an essential product of this sector: air conditioning devices.

Figure 5 presents an ArchiMate model for the product level of analysis (air conditioning example). The model represents the core physical and digital components of the DT, the services it provides to the processes triggered using the DT, and

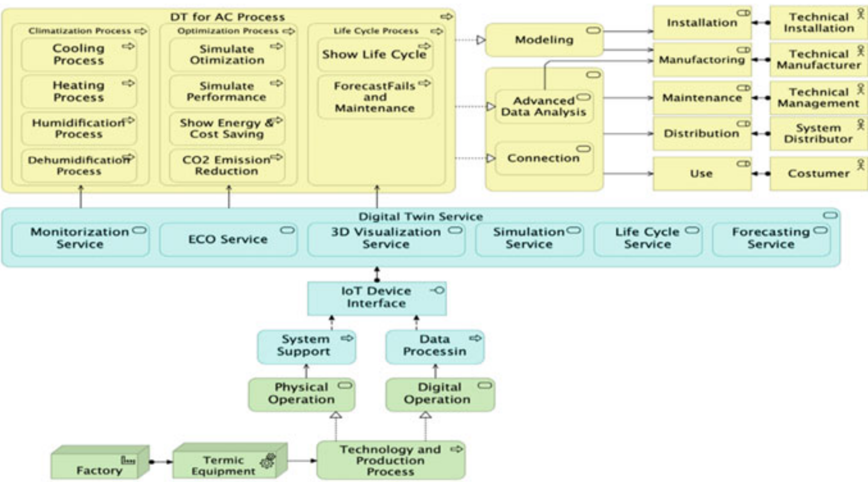

Fig. 5 Digital twin architecture for air conditioning products (*Source* Own elaboration)

the different stakeholders. Making a bottom-up interpretation, the Technology layer (green elements) represents the structure and behavior of the technology infrastructure and components of the DT. This layer serves the Application layer (in blue), composed of the software systems that will support the processes represented in the Business layer (yellow). In the Business layer are key stakeholders with direct interaction with the DT, already identified in the sectoral model. For example, the Customer, the Technical Management (also referred to as building automation and control systems Management), or the System Distributor.

Following the services that Air Conditioning can yield and the new services that can be achieved via Industry 4.0, the Business layer of the architecture models the process of using the DT of Air Conditioning. The "DT for AC" process (on the top-left) is triggered when the user powers the equipment and starts. Once the equipment is working, several functionalities are possible to perform in the context of Software as a Service—SaaS—to serve the Consumer. The Digital Twins processes architecture is grouped by equipment processes supported by the DT, namely: "Climatization Process", "Optimization Process" and "Life Cycle Process".

5 Discussion

Enterprise architecture is an exciting approach to identify the current landscape of an economic sector digitalization ("as-is") and identify opportunities for new developments ("to-be") [5]. Our exploratory study with the business association found that it is possible to expand the EA concept to the entire supply chain. The integration of different segments of refrigeration and air conditioning (e.g., manufacturers, installers, distributors, and facility managers) allows a broader perspective of the digital twin features, crossing the borders of a particular company. For example, a digital twin model for air conditioning manufacturers could identify opportunities to create a digital replica of the equipment, helpful to the end-user, and data collection from the fleet—interesting to evaluate or simulate the product performance under different operating conditions. However, it could miss digital twin opportunities for installers (e.g., product instructions) or technical managers interested in real-time warnings for system maintenance. Combining digital technologies with business models can generate significant value for enterprises [30], and business associations are interested in developing the value of data sharing within the entire supply chain. For example, digital twin operation data is valuable for manufacturers and technical managers, and simulation data is interesting for different segments.

Digital twins can be modeled with EA languages like ArchiMate. We decided to use the existing ArchiMate elements (e.g., actors, processes, components) in our test. Although this language was not explicitly developed for the economic sector's needs, it can produce comprehensive digital twin architecture, useful for communication with the experts. Nevertheless, the adoption of ArchiMate for digital twin modeling is still nascent, and new guidelines are necessary to assist enterprise architects. Our work may contribute to strategic enterprise architecture modeling [31] of sector-specific digital twins.

Developing EA models for different sectors of the economy is necessary. First, it is possible to identify similarities in different product types suitable for a digital replica. For example, air conditioning digital twins could inspire the development of digital twin models for smart fridges (e.g., evaluating the use of the equipment to propose energy-saving measures or automatically adjusting energy consumption according to the door opening profile, minimizing food waste suggesting meals). Second, sectoral digital twin models can assist companies with different aims (e.g., manufacturing, services, research), sharing the motivation to improve their economic sector. The models may be used to improve system performance, influenced by both design and control strategy [2]. Modeling digital twins for specific sectors of the economy offers an opportunity to link academics and practitioners in envisioning more impactful digital transformation, producing digital twins that serve the interest of different stakeholders. Sector-specific digital twins may also boost data market initiatives.

The lessons learned in our project allowed us to propose the following design principles useful for future sector-specific digital twin transformations.

- Design principle 1: Identify the grand challenges affecting the economic sector. Temperature increase and energy optimization are priorities for refrigeration and air conditioning, but other sectors may have other priorities (e.g., safety, resource conservation). The strategy and motivation layers (Fig. 3) of ArchiMate can be a good starting point.
- Design principle 2: Integrate the need of supply chain segments and regulatory compliance requirements. The models can be iteratively improved with more stakeholders' concerns identified and consequently more opportunities for new digital twin features.
- Design principle 3: Start with a top-down and upstream approach to improve the EA views, then check the bottom-up and downstream coherence. The first part of this principle suggests that the sector strategy should be followed by the business architecture structure and behavior (e.g., process modeling), then the application, technology, and physical layers. The upstream analysis will start from the needs of the society (e.g., governments) and end-users and then follow each segment of the supply chain until the earlier stages of raw material production. The suggested approach will produce models that give priority to the customers' needs. Then, it is necessary to identify if the sectoral model for the digital twin will have the necessary foundations (bottom-up modeling starting from the physical and technology layer) to produce the necessary data and physical-digital interaction relevant to all the participants in the supply chain.
- Design principle 4: Model the strategy, the sector, and the product portfolio. Sectoral models must represent all the sector actors and allow the identification of digital twins' integrated value. However, each product has particularities that need more specific models. For example, air conditioning has different digital twin features compared to smart fridges (out of the scope of our study).

The suggested principles complement the well-known practices for EA development lifecycles [5, 6], emerging from the design work conducted in this research.

6 Conclusion

This paper presented an architectural approach to evaluate the potential of digital twins in the refrigeration and air conditioning sector. ArchiMate language was used to model relevant views of the industry strategy, business, applications, and technology. Extending previous studies pointing to the applicability of ArchiMate in Industry 4.0 [11], our work reveals its utility for the design and communication of digital twins in critical economic sectors like refrigeration and air conditioning, highly motivated by climate changes and sustainability goals.

There are also limitations in our exploratory study that must be stated. First, this is our first attempt to model digital twins at a sectoral level of analysis. Therefore, the models are not yet complete, requiring an evaluation by different companies. Second, the results are restricted to the refrigeration and air conditioning sector. Third, ArchiMate was considered interesting for our purpose and valuable during our meetings with the practitioners, but other EA languages could be tested. Fourth, our EA approach addressed the main concerns of a sectoral association, but it is possible to include more stakeholders like governments or energy providers. Finally, the models provide a high-level digital twin analysis suitable for business associations, but more specific models and specifications are necessary for digital twin developers.

Future work in this area is promising. Besides the opportunities raised by the study limitations, it would be interesting to create a complete set of ArchiMate viewpoints for sectoral digital twin transformation. These templates could assist enterprise architects in envisioning the multiple implications of digital twin development at different levels of the architecture. Moreover, it will be important to compare the "to-be" architecture presented in this work with the innovation projects conducted by the companies pertaining to refrigeration and air conditioning. The business association participating in our work aims to follow their associates' digital transformation initiatives closely. Another opportunity is the creation of ArchiMate extensions for digital twins. Lastly, sectoral associations need new forms to design and communicate their associates' digital transformation opportunities and challenges. EA approaches can be tested for this purpose, but a sectoral enterprise architecture framework is a priority for future research.

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Practical Application of the Concept of Digital Twins in the Aviation Sector

Ekaterina Sycheva and Polina Shpak

Abstract Today, the issue of digitalization can be called the most relevant. Reengineering of business processes and progress in the field of information technology correlate with the relevance of creating innovations in the system between equipment and a human. The focus of attention is payed on the concept of a data transmission network—Internet of Things, technologically equipped physical objects for interacting with each other or with the external environment. One of the most promising new information technologies is the concept of digital twins. With the simulation of production processes using the digital twin concept, it becomes possible to monitor and identify potential failures even before they occur. The active formation of this system by extensive software and hardware complexes and the integration of their solutions are in demand and relevant tools for digitalization of the country's economy and, in particular, the aviation sector. In this article, the authors analyzed various indicators of the state programs of the Russia in the field of digitalization of the aviation industry, mainly representing the results of the involvement of integrated information systems in the activities of enterprises, as well as the impact of digital twins on the efficiency of technological processes.

Keywords Digitalization · Innovation · Digital twin · Aviation industry

1 Introduction

The increase in the main performance indicators, the increase in the productivity of industrial aviation enterprises, the reduction in losses in the production cycle become real only thanks to the use of the latest materials for the introduction of innovations in

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technological processes. Namely: the use of autonomous robots, augmented reality technologies, smart sensors in a full cycle of simulated production and operational processes. Internet of Things (IoT) contributed to the focus of the economy on the field of informatization. Deep Analytics and Big Data are the main drivers of growth for the country's economy, also act as a new resource for creating the most profitable supply chains, forming production ecosystems at the junctions of industrial market segments, and creating efficient production processes [1]. Every year, the number of leading enterprises in the aviation industry is growing, which actively use elements of a smart enterprise and the concept of digital twins for the most effective planning based on data coming from production online [2]. The authors emphasize the importance of this paper in the in-depth study of the prospects for the impact of digitalization on the economy of the aviation industry, this issue is especially relevant at the present.

The research on the impact of the COVID-19 pandemic on air transport markets has focused on the aviation sector of the economy, in particular, aviation enterprises. Their dominant goal is to discuss the Government's actions to mitigate the consequences of this crisis.

For example, from the point of view of studying the impact of air travel restrictions imposed during the COVID-19 pandemic on the aviation industry, real-time indicators extracted from social networks were monitored to measure how travel restrictions affected the relationship between passengers and airlines. In addition, a model was developed to predict passenger traffic during a pandemic [3]. The data of this model confirm that in the first quarter of 2020, the impact of aviation losses could lead to a decrease in global GDP by 0.02–0.12% [3].

With the onset of the crisis caused by the COVID-19 pandemic, there was great uncertainty about the continuation of the side effects of social integration on the demand for air transport. The sharp reduction in air travel in 2020, although global, had different intensity in different countries and was dictated by the unpredictable spread of new COVID-19 variants [4]. In addition, government restrictions as a response, such as the closure of enterprises or the temporary suspension of their work, were heterogeneous and in many cases far from effective. In this vein, we note that countries characterized by a low level of digitalization, among other factors, have taken less stringent measures. It should be noted that as a result, the increased unemployment rate caused by the persistence of the pandemic situation can lead to long-term socio-economic consequences for a large number of countries.

It is difficult for traditional business models to compete with the principles of digital platforms that allow aviation enterprises to easily penetrate the borders of various sectors and industries. Increasingly, traditional approaches, such as monitoring the work of competitors, are becoming less useful [5].

Those leading companies that actively use artificial intelligence and other information tools to obtain unlimited coverage of consumers receive a completely new level of impeccable service of their products.

The basis of "lean" production is the continuous improvement of control systems due to the digitalization of the aviation industry sector through the use of robotics [6]. Accurate mathematical models that predict demand allow companies to literally produce products to order, due to the fact that there is no need to manage working capital. The introduction of predictive maintenance, repair and operations (MRO) will bring the operational readiness of all equipment to one hundred percent [6]. In addition, the integration of own production processes of aviation industrial enterprises with customers and suppliers has become possible thanks to digital technologies. In the future, this will allow the most accurate prediction of additional functions or product improvements expected by the consumer, increasing the competitiveness of the company.

2 Background

2.1 Digital Technologies

A number of papers have been written on the topic of digitalization of aviation enterprises, as well as factors affecting the effectiveness of this process.

Thus, Oladyev [7] conducts a broad review of various new digital technologies designed to optimize and alleviate existing problems at air enterprises. In particular, the implemented technology "ADS-B (Automatic Dependent Serveillance-Broadcast) which is designed to conduct constant online monitoring of ground traffic on taxiways, displaying data on the altitude and speed of piloting" [7]. Also, the author notes that this "digitalization is designed to intensify flight safety, efficiency in the field of flight routing, the effectiveness of planning the activities of airlines as a whole" [7].

Zakharenkova [8] also singled out the ADS-B program among the advanced technologies for digitalization of aviation enterprises, noting "the feasibility of the fact of controlling the aircraft Independently of the presence of flight attendants". In addition, the author in his work considers the digital technology "NEXTT (New Experience in Travel and Technologies), this greatly facilitates the process of pre-flight inspection of passengers and luggage, thereby optimizing flight management to the fullest extent" [8].

Afanasieva and Vdovin [9] note that the central task of intensifying the aviation industrial sector of the economy is the integration of innovative digital technologies. In particular, these scientists provide analytical calculations on the implementation of the State Program of the Russian Federation "Development of the aviation industry for 2013–2025", also "a model of digital transformation of the aviation industry sector has been developed. In this regard, the authors note that the airlines must comply with the established rules of the new operation in order for the digital transformation to bring the most effective results" [9].

The problem of the introduction of innovative technologies from the point of view of ensuring security is addressed in his work by Elin [10]. In particular, the author focuses on the widespread use of the concept of digital twins due to their uniqueness and effective work, as well as on such an aspect of this issue as "legislatively fixed provision of information protection in the case of integration and further application of the concept of digital twins" [10].

Summarizing, we can note a certain consistency of the above-mentioned authors that the problem of effective implementation of innovative technologies, and in particular, the system of digital twins, is relevant, and is the most important modern tool for the intensification and optimization of all processes at the enterprise.

Automation has always been considered the most promising direction in the development of industrial enterprises. Increasing the economic performance of the enterprise, improving working conditions for personnel is possible due to the exemption from direct human participation in production processes, and concentration on basic operations. Automation can be effectively applied in production with mass production, as well as where the technological process is more labor-intensive. Due to the fact that developers of automated software systems are responsible for maintaining low prices, shortening delivery times, compact size, high energy efficiency and maintaining extended functionality, it can be assumed that the difficulties of implementing digitalization for product development organizations.

In this regard, we can say that without resorting to significant material costs and quickly enough to solve most economic problems—engineering modeling. Ensuring the profitability of the business with the help of modeling with full cost control becomes possible when making design decisions that allow optimizing various operational characteristics of the product.

Using a theoretical research method, the authors of this article analyze indicators that reflect the current practice of allocating costs under the state program, systematize ways to implement digitalization of aviation industrial production, and also, using synthesis, make up a rating of priority technologies for achieving technological leadership and the entry of Russian companies into international markets [11]. In addition to the above, the generalization method formalized the urgent tasks facing engineering modeling and the features of smart production.

The increase in the volume of digital technologies used leads to an increase in the density of placement of certain electronic sensors. This, in turn, leads to some difficulties related to energy consumption, weight, size and overheating of products. When creating intelligent products, engineers use software modeling tools that help them solve the most important tasks, with respect to some of the characteristics that are presented in Fig. 1.

Thanks to the capabilities of engineering modeling, developers of intelligent products are able to achieve significant success in various fields, finding and making balanced decisions during production, in terms of energy efficiency, weight, power and other key aspects of the manufactured product.

2.2 *Smart Production in Aviation Industry*

Modern trends in informatization and digitalization of industry (Industry 4.0) are primarily related to the integration of the idea of smart production. Two levels of

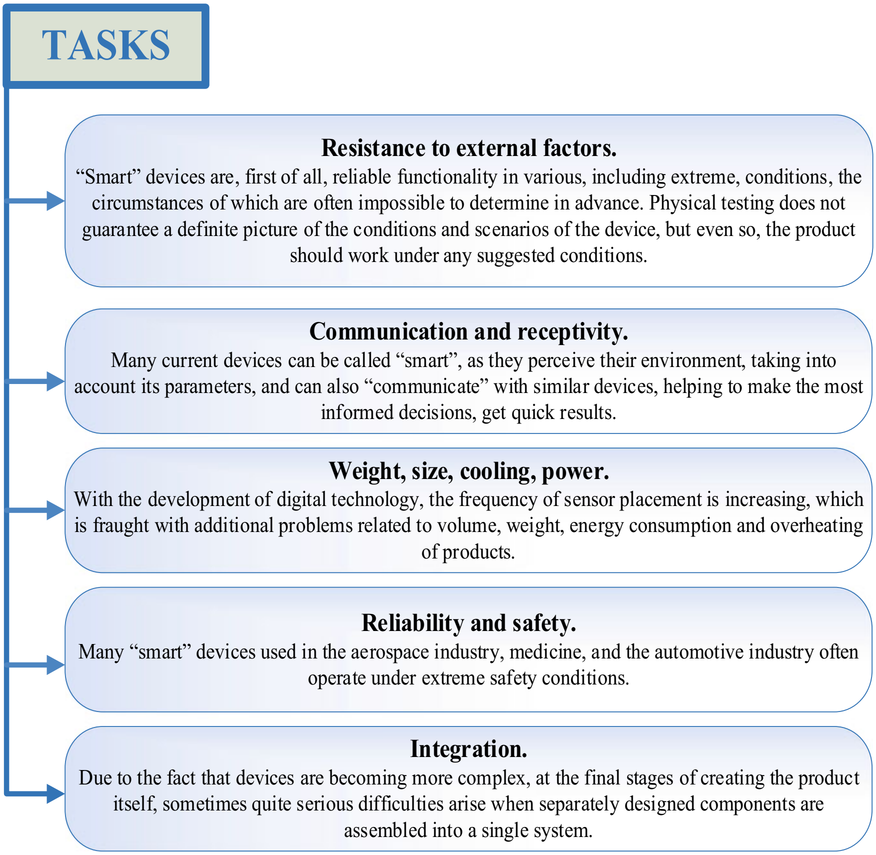

Fig. 1 Actual tasks facing engineering modeling [12]

integration include smart production systems, namely: horizontal and vertical integration [13]. When vertical—in a single network of operations within the enterprise, unification takes place at all stages of production. When horizontal—the enterprise, customers and suppliers are united in supply chains of any geographical scope.

The transition from a conservative automated system to a more flexible and fully integrated system that uses continuous data flows of production and operating systems to adapt to new requirements can be called a new stage represented by digital factories.

Combined into a single communication network elements for data interchange represent a smart production, which in turn allows you to actively make improvements at different stages of the production cycle, reduce losses and reduce costs from equipment downtime, promptly respond to new requests from consumers of the product, optimize supply chain management processes. It should be noted that in a competitive market for an aviation industrial enterprise, this serves as a factor in strengthening positions.

The authors believe that attracting investments in the development of smart production should begin with the presentation of certain opportunities and advantages of digital transformation. With ubiquitous digitalization, new advantages appear and horizons of opportunities expand, allowing manufacturers to begin transformation processes even with one piece of equipment, at any level. When mastering the technology, you can increase the scale of transformation by switching to other production processes or lines, eventually covering the entire enterprise or even the network. Individualization of the study of individual scenarios guarantees that the created smart production meets the needs of the enterprise.

It is also worth noting that it becomes obvious that it is possible to solve various issues in the development of smart production related to improving the quality of products, as well as the efficiency of equipment and reducing the costs of the enterprise as a whole. Such improvements, in turn, accelerate market entry and are able to increase the profitability of production. All components of smart production are capable of self-generation of extensive data sizes. After analyzing this information, you can find problems in the performance of the equipment that require adjustments. Corrective optimization precisely defines smart production, highlighting its significant advantages over conservative production [14]. The ability of self-optimization inherent in smart production allows you to quickly find the dynamics of quality deterioration, predict possible deterioration in the future, and identify the causes that may be related to equipment, the environment or the human factor. The authors consider the identified features of smart manufacturing according to Fig. 2.

Smart production can be organized in different ways—within or outside the production location. Meanwhile, there are a large number of options for using industrial and digital technologies, depending on the specific needs of the organization. The authors of this study have identified a set of new technologies that facilitate the movement of information flows between digital and physical objects [15].

These technologies are the basis for a digital supply chain, and also create various opportunities for digitizing production processes. Some key production processes of a smart enterprise, examples of digitization of the main business processes using various kinds of industrial and digital technologies in aviation industrial production are presented in Table 1.

The system of smart production of aviation industry enterprises makes it possible to integrate the technology of digital twins. This makes it possible to digitize all operations, going beyond the integration and automation itself to the stage of forecasting capabilities. As a practical example, we can cite the actively implemented concept of a digital twin of the aircraft climate control system. In order to design the climate control system most effectively, it was necessary to assess the degree of interaction of its components before conducting the tests themselves in the summer. The operation of the climate control system at the system level was investigated by employees of Tianjin University from China and Purdue University from the United States of America. They also carried out three-dimensional CFD calculations (Computational Fluid Dynamics) using a software package [1]. The research of the above-mentioned employees was presented within the framework of the CARE consortium to specialists from Commercial Aircraft Corporation of China (COMAC) and Boeing. It is

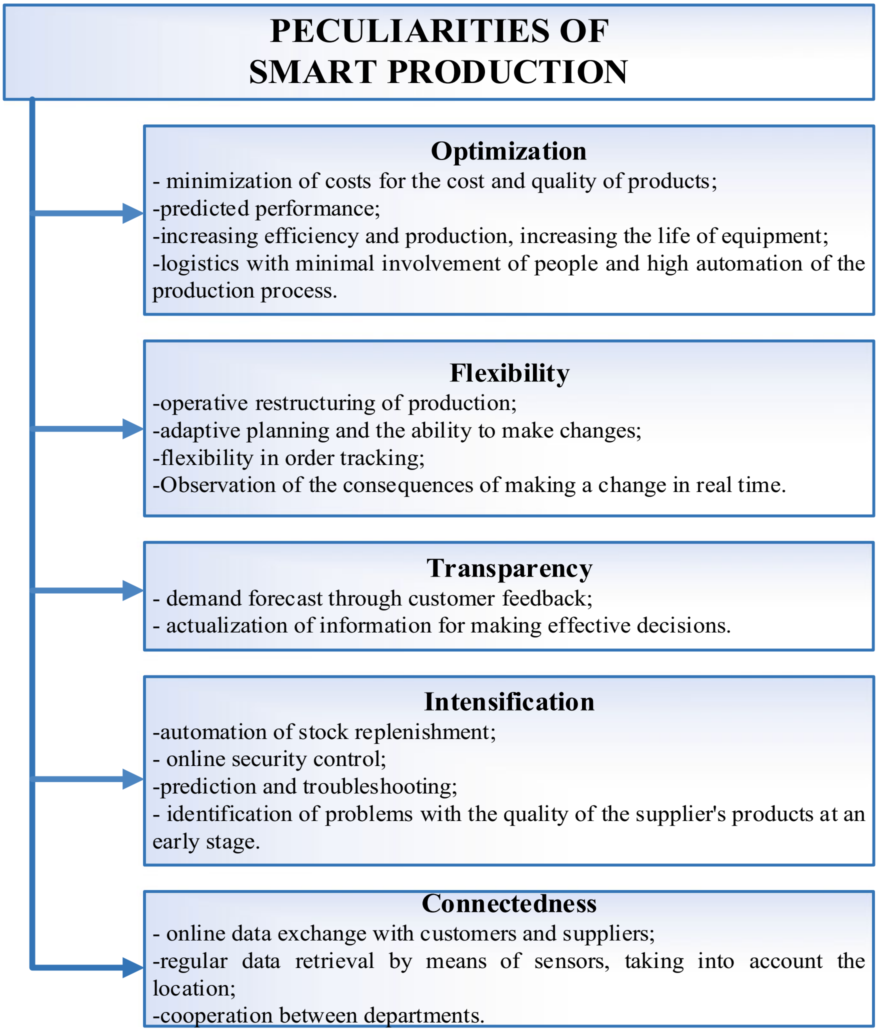

Fig. 2 Features of smart production [12]

assumed that these companies plan to create their own prototypes (virtual) for subsequent modeling of climate control systems. It is also planned to conduct experiments in order to confirm all calculations of the aircraft's climate control systems, which in turn will be able to improve the main characteristics of these systems. In addition to many of the results achieved in the aviation industry, attention should be paid to the indicator confirming that a group of scientists [2], using numerical modeling of the water intake device of the Be-200ChS model aircraft, was able to adjust the calculation model and lead to satisfactory results of matching experimental and calculated data, namely: up to an acceptable 12–15% for a set of control points, which in turn

Table 1 Ways to implement digitalization of aviation industrial production [13]

Process	Implementation methods
1. Maintenance	• Sensors on all equipment to track operation and predict the need for maintenance • Expert systems (augmented reality) that facilitate the implementation of their repair and maintenance functions by personnel
2. Production operations	• Digitization of the technological process using the digital twin concept • Autonomous robots for performing standard operations • Adaptation of production processes for the rapid production of spare parts and prototypes for aircraft • Use of online inventory and production data for advanced planning
3. Quality	• Control of all equipment parameters online in order to predict the possible occurrence of quality problems • Application of optical methods in the process of aviation production for quality control
4. Warehouse operations	• The use of autonomous robots when performing warehouse operations • Assistance to personnel using augmented reality during loading operations
5. Resource audit	• Analysis of stocks of raw materials and components for their optimization • RFID tags (sensors) for tracking the movement of finished products, tools, location of raw materials, etc.

contributed to the conclusion about the adequacy of the model itself for calculating hydrodynamic forces, designed by a hardware and software complex specializing in these tasks [2].

In addition to the above, it is necessary to note the high degree of interest of the Russian Government in the development of scientific research and digitalization of the economy and the aviation industry, in particular.

According to the state program “Development of the aviation industry for 2013–2025”, which was approved by the Decree of the Government of the Russian Federation No. 303 dated 15 April 2014, in terms of the subprograms “Aircraft Construction”, “Aircraft engine building”, “Helicopter Construction”, “Aviation units and devices”, “Aviation Science and Technology”, “Integrated development of the industry”, the main goal is to create a domestic competitive aviation industry, which should ensure the widespread involvement of the Russian Federation in the world economy, by increasing the volume of GVA in the aviation construction industry by 2.9 times compared to 2013 [16].

In addition, the focus is fixed on the development and preservation of Russian aviation science as the best scientific and experimental base capable of conducting research work not lower than the level of the world’s best scientific institutions, while ensuring regular certification tests for new aircraft models [16].

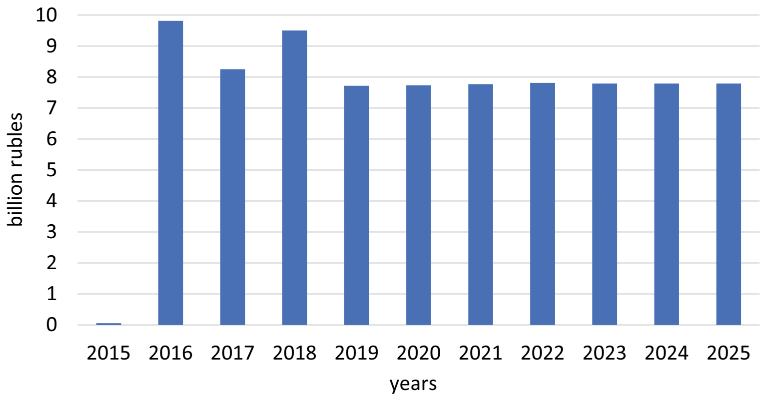

Fig. 3 The volume of budget allocations of the state subprogram 7 "Aviation science and technology" in the period from 2015 to 2025, billion rubles [16]

In accordance with the stages of subprogram 7 "Aviation science and technology", it is proposed to consider the amounts of budget allocations presented in Fig. 3.

The total amount of budget allocations under the subprogram is 8299 billion rubles. Figure 3 illustrates that the lowest financial flow occurred in 2015, while the maximum amount of budget resources was allocated in 2016 and 2018. It was also revealed that the main of the most important indicators characterizing efficiency is the stock ratio. As can be seen from the Fig. 3, there is no increase in the volume of budget allocations allocated by the Government of Russia. Based on the results of the authors' research [15], we note that in the period from 2018 to 2021, there is a tendency for the growth of the above indicator, which is due to a decrease in the number of employees involved.

Accordingly, by 2024, the Russian Federation is expected to complete research related to the study of the introduction of digital twin technology for aircraft engines [17]. The most difficult and time-consuming process in creating a digital twin can be called the development of a variety of highly specialized mathematical techniques and models for the operation of each part, of which there are thousands in an aircraft engine. Nevertheless, the use of digital twin technologies contributes to a significant reduction in the cost and reduction of the process of developing new engines [18]. The same time, the digital twin is able to reduce the cycle of creating power units to 5–6 years, reducing the cost of their design by 28.9%, i.e. by almost a third. In addition, certification currently takes time, including a whole range of tests for safety, reliability and confirmation of various characteristics; this, in turn, leads to the fact that all the necessary changes to the engine design can be made already at very late stages of its design [19]. Such work leads to a significant increase in the cost and timing of finishing the product. In the context of the above thesis, we note that from January 2022, it is planned to introduce a new standard in the field of digital doubles in the Russian Federation (GOST R 57700.37-2021 "Computer models and modeling. Digital doubles of products. General provisions" [20].

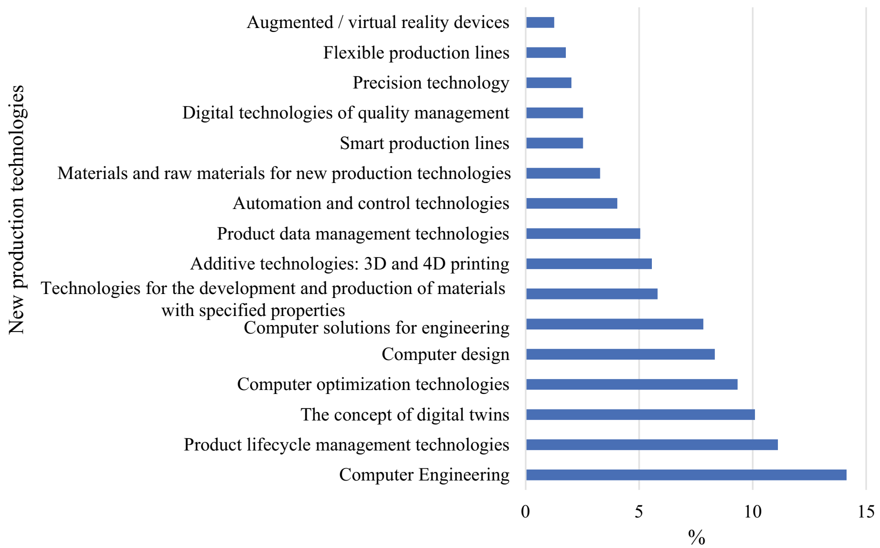

Fig. 4 Profiles of needs for new production technologies for 2019 [12]

In the future, the use of the digital twin concept helps to reduce the certification period [17]. This will inevitably lead to a reduction in risks and financial losses for developers of aircraft engines associated with inefficient use of production facilities and delayed entry into the market of products.

Based on the research conducted in 2019 [12], it can be confidently stated that the concept of a digital twin and its application in the aviation industry have great potential (Fig. 4) to introduce this innovative technology.

In comparison with other innovative technologies, the concept of digital twins shows a fairly high level of interest among such companies as PJSC United Aircraft Corporation (PJSC UAC), JSC TVEL, JSC United Engine Corporation (JSC UEC), etc.

The survey data presented in Table 2, which was attended by 127 experts, confirms the high demand for development and research in the field of digital twins technology. The main criteria for the selection of experts were the heads of departments and departments of aviation enterprises applying technological innovations in the field of engineering modeling. All the results of the experts' answers were summarized in a matrix of scores of the same scale. The error rate is 0.002%, the approximation confidence index (R^2) is 0.97.

The market for the concept of digital twins in the Russian Federation is at the initial stage of formation, however, it is already possible to conclude that several large projects have been implemented, most of which were initiated by state-owned enterprises or companies with state participation [21]. Thus, KAMAZ PJSC, Gazprom Neft PJSC, UEC JSC, Rosatom State Corporation, Rostec State Corporation have already launched pilot projects in this area [12]. Statistics record the following figures

Table 2 Rating of the most priority technologies for achieving technological leadership and entry of Russian companies into international markets [12]

Rank	Rating of the most priority technologies for achieving technological leadership	Percentage ratio (%)
1	Mathematical modeling, computer engineering	34
2	The concept of digital doubles (digital twins)	21
3	Optimization technologies (multiparametric, multidisciplinary, etc.)	16
4	Technologies for the development and production of materials with specified properties	15
5	Product lifecycle management technologies	14
Total		100

for the total volume of the digital twins market: Russian enterprises exceeded 111 billion rubles in 2018 [22]. According to the indicators of 2017–2019, the foreign market was at the level of $ 1.56 billion, according to the forecast, it should reach $ 17.54 billion by 2026, with an average annual growth rate of more than 35.32% [12].

The wide functional application of the concept of digital twins in the aviation industry determines the relevance of this study and the need to highlight the latest developments in this area. In this vein, the development of a hybrid digital twin is fully based on the concept of a complex digital twin [23]. Such modification implies, in addition to the generally accepted physical sensors, the use of virtual sensors that provide information about the measured parameters of an object based on mathematical modeling using a complex functional model.

3 Discussion

Summing up the results of the study, the main advantages of the hybrid digital twin system model should be noted:

- motivated presentation of the necessary requirements for new production equipment;
- the possibility of determining the quantitative deviation of many parameters of the equipment from the initial state in places where there are no physical sensors or they cannot be installed;
- reducing the impact of the human factor on the results obtained;
- availability of the ability to quantify the impact on the performance of the system and its efficiency of individual pieces of equipment;
- identification of the sufficiency of the quality and volume of maintenance work performed on equipment;

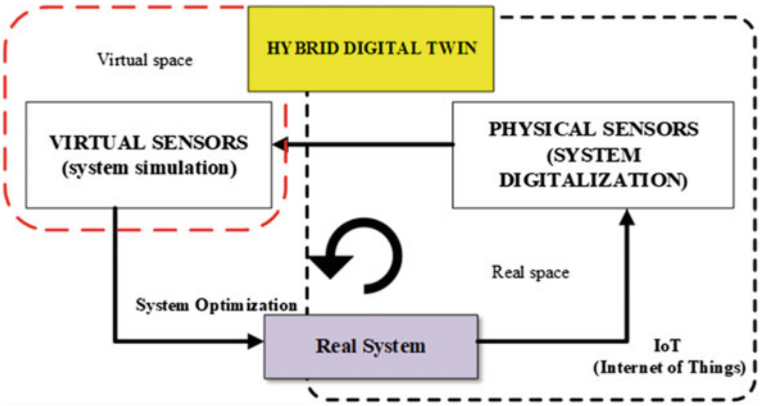

Fig. 5 The principle of operation of the hybrid digital twin concept

- confirmed performance planning of technological installations, taking into account the provision of the most optimal operating modes for all equipment included in their composition.

The system model of physical processes, which is part of an industrial solution, allows you to get a significant advantage over digital equipment counterparts, which are based only on industrial equipment technologies.

Figure 5 schematically shows the principle of operation of the hybrid digital twin concept.

It is an indisputable fact that the competitive advantage in the occupied market in the dynamic competitive struggle of designing intelligent devices is provided by one of the most important technologies—engineering modeling. Supply chains and production processes are increasingly permeated by Industry 4.0 technologies every year. However, only personal control by the company's management of all transformation processes is able to ensure the implementation of digital transformation of production in the shortest possible time.

4 Conclusions

The realities of the modern digital technology market are such that all modern airlines will soon have to adopt the concept of smart production and digital twin technologies to change existing business models, despite all the difficulties of the transition from conservative production to a new model.

Smart production is able to predict future results based on previously obtained data, as well as data coming online, which in turn will lead to an increase in uptime and prevent many security problems.

Digital twins are able to provide the Russian engine-building industry with a more effective response to various market needs and, probably, use a modern business model: to switch from engine supplies to the sale of flight hours.

Earlier, the authors of this study have already noted that the concept of digital twins is able to radically reduce the multiple costs of enterprises already at the initial stage of creating new models of engines. Among other things, in the Russian Federation, it is planned to simplify the certification procedure and launch serial production of power units.

Thus, having analyzed the general position of the Government of the Russian Federation in relation to the digitalization of the economy through the development of state programs, in particular, the state program "Development of the aviation industry for 2013–2025", the subprogram "Aviation Science and Technology", we can conclude that there is a high degree of involvement and interest in improving the results of the introduction of digital technologies and increasing overall competitiveness from their use. This positive trend has an impact not only on the aviation industry, but also on the entire economy of the Russian Federation as a whole.

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Digital Revolution in the Energy Sector: Effects of Using Digital Twin Technology

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Abstract The energy sector today is undergoing the digital revolution. The Internet of Things (IoT) and its subset, the Internet of Energy (IoE), that comprise, for example, smart meters, artificial intelligence (AI), or virtual reality (VR) with their practical application to the energy sector all together contribute to the enhancement of the smart energy grids of the future. Our paper focuses on the overview of the digital twins' technology that are increasingly used in the smart grids. We discuss their application and usefulness for the improvement of the safety, security and reliability of the energy networks that include a two-way flow of information and power. Furthermore, we examine various types of digital twins and show use cases related to design, operation, control and safety of systems, testing, regulation, operator training and maintenance planning for energy utilities. Our research provides some innovative examples that might become the inspiration for the policy-makers and stakeholders working in the field of energy economics and policy.

Keywords Smart grid · Digital twin · Energy and power sector · Industry 4.0

1 Introduction

We are now living in the times of the 4th Industrial Revolution, in which industries are changing at an unprecedented rate as a result of the advance of digital technologies and the 'Industry 4.0' is becoming a frequently-used term [5, 27, 50]. The digital revolution includes emerging innovations such as Internet of Things (IoT) [or its

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subset known as the "Internet of Energy" or (IoE)], data science, machine learning and cloud computing, smart grids [26, 42]. Technology has been adopted by all major industrial sectors in recent years, and the energy sector is no exception.

The digital revolution in the electric industry is the result of many new technologies and an exponential rise in data storage and processing. These technologies will continue to drive innovation and create new business models for energy delivery such as new ways to manage networks and shift demand highs from onetime of the day to another [35, 44]. Energy storage has become a central element of the energy system, and digital technologies make it possible to create virtual power plants in which aggregate electricity consumers can switch off the machinery needed to modify their demand to match supply [3, 9].

The most obvious signs of the shift from large-scale centralized, distributable energy to clean, decentralized, and personal energy can be seen in advances in renewable energy technologies such as wind and solar, but behind the scenes, a new digital backbone has been established that enables wind turbines, solar panels, and batteries to produce and store electricity in the workplace [12, 13, 38, 41].

Digital transformation is a key component of the energy transition, enabling the integration of more renewable energies into the electricity system, increasing grid reliability and helping to manage energy demand. With regard to the above, the use of digital technologies in the energy sector will bring a number of benefits. One can note that industrial users account for 40% of the world's energy consumption, so there is a great opportunity to increase energy efficiency and take advantage of the main trends in this sector. By using new technologies to reduce waste, we can reduce energy consumption in 5% of industries from 13 to 29%. Energy companies and consumers can benefit from the vast network of connected electronic devices not only phones and computers but also smart meters, fitness monitors, air quality meters and other technologies [45].

Technological development and the introduction of IoT in industry have to the novel emergence and trends in energy research [4, 6, 37, 40]. It is important for energy companies to implement the promise of digital innovation on a large scale and on a global basis. To meet these challenges, network operators must make the most of their opportunities, which requires energy companies to invest in the Internet of Things [7]. In the mining, oil and gas industries, IoT solutions that integrate machine data analysis to meet the requirements and to achieve operational efficiency will set energy companies apart from others. An MIT report entitled "Transforming the Energy Industry with AI" shows how companies are using artificial intelligence (AI) solutions in everyday operations such as oil exploration and cybersecurity applications to automate monitoring and detection of cyber-attacks [25].

The prevailing approach to digital innovation in energy has been to create point solutions by applying technologies to limited areas of application and changing the way people work. Energy companies often succumb to point solutions when they delegate digital IT functions to operate through a technology lens, lack mandates, or redefine other functions and their work. In addition, energy companies of all stripes expect to find value in digital technologies as tech-savvy organizations with a history of ingenuity. But when it comes to technology, they are trying to lay their foundations by invading the dreaded data lake and racing to use it. Moreover, energy companies have failed to generate significant business value with digital technologies because their approach fails to take into account the unique challenges they create and the extraordinary inertia. A major and growing impact on operations are cyber risks as the oil and gas industry increasingly depends on connected energy, automation and remote operations. These various scenarios do not capture how artificial intelligence and data science will continue to transform the energy industry. Industrial Revolution that shifted the humanity's approach to energy sources, created most of the issues we are facing today [39].

Thence, it can be stated that there is no way to predict with certainty how certain digital technologies will interact with certain energy systems and applications in complex real-world situations involving multiple policy objectives and uncertain unintended feedback. These reasons have led us to rethink the use of digital twin technology in the energy sector. We will take a step-by-step look at how digital twins contribute to the improvement of smart grids, how they affect energy efficiency and energy conservation. The conclusions are based on a literature review among the most cited publications. This approach is the main one in our study. Examples of the use of digital twins will constitute a collection of best practices that can be disseminated to achieve the goals of sustainable development. We are convinced that digitalization offers a rare opportunity to transform the energy system, which tends to change slowly [48].

2 Digital Twins in Industrial Energy Efficiency and Energy Saving

Digitalization offers energy companies the opportunity to establish new business models and sustainable strategies for energy generation and provision [17]. One of the tools is digital twins. Nowadays, digital twins' solutions find a more widespread use in the energy sector to combine machine learning, artificial intelligence, and software analysis of data from production facilities into digital simulation models [8, 15, 29].

There is a holistic digital production environment in which artificial intelligence is used to run virtual simulations with diverse data sources such as historical data, future demand forecasts and weather data, enabling multiple optimization scenarios. Sensors and models of local energy systems which are set up using digital twins using digital twins offer a number of advantages in the design and operation phases and facilitate energy sharing and trade based on different business models [46].

This means that digital twins are crucial for industries such as electricity, as they enable control over energy resources distributed over the network, with the appropriate software to analyze and visualize the data [2]. This information can then be used by high-performance computer models to predict which technologies like solar panels, heat pumps, smart thermostats and energy-efficient water heaters should be installed to save energy.

In fact, the tool called the Digital Energy Twin, reflects the actual performance and energy consumption of buildings by integrating information about the design and use of buildings with a wealth of real-time operating data ranging from buildings and software commands, sensor data, equipment levels, energy consumption and weather data. Once building operation is modeled with an accuracy of 98%, we can assess the impact of different energy saving systems and upgrades and empower building owners to make better investment decisions [30, 36]. For instance, continuous use models are precisely the type of models that are most advantageous for the production of energy efficiency in industrial machinery via the digital twins framework and the advantages can be applied to the entire plant, resulting in massive energy savings and reducing the environmental impact [24].

The latest digital technologies aim to provide decision-makers with the information required to develop smart solutions that identify the most effective and resource-efficient ways of reducing the use of fossil fuels energy in communities [43]. Just to provide an example, a prototype of a community interaction model enables real-time visualization of energy data from the Trent Basin community in Nottingham, England, including information on renewable energy production and storage, energy consumption data and general information on homes [19]. The digital twins analyze the changing areas of energy consumption and continuously evaluate energy sources. While asset managers want to make informed decisions about building investments and municipalities with strict emission reduction requirements, digital twin technologies that simulate building operations can be a valuable decision-making tool [21].

Data centers with digital twins can collect data from the entire plant lifecycle, from planning, construction, renovation, operation and demolition phases to improve sustainability and be resource-efficient in making economic and environmental decisions [34]. Furthermore, large sets of digital twins can be used to estimate energy demand and supply, indoor air quality, thermal comfort, carbon emissions, operating and maintenance costs, renovating and replacement needs of buildings (including recycled waste and building materials), the repayment periods of carbon emissions and life-cycle energy conservation measures.

Digital twins encompass both real and virtual space, and the flow of data between them allows us to experiment and carry out comprehensive analyses of the information [16]. Digital twins help users organize their information by providing a single view of truth, enabling faster maintenance and operational decisions and ensuring that decisions are based on the most accurate data available. Digital twins are at the heart of the progress of integrated information modeling, which enables asset-centric organizations to converge their technical and operational information technologies through immersive visualization and analytics visibility. Digital twins are a new form of intelligent management that makes networks more data oriented, seeking a global vision of the environment around them that makes them more demanding and dynamic.

In the energy industry, digital twin technologies enable the development and maintenance of intelligent networks with high-tech sensors, machine learning models and improved performance monitoring. It is envisaged that they will become the backbone of smart grid deployment, renewable energy management, better integration and more efficient transmission by bringing together mix of cyber, physical systems, cloud computing and smart industrial solutions [1].

The introduction of digital twins in the energy sector will make it possible to strike a balance between supply and demand, enable a proactive approach to operational issues and allow for a faster restoration of electricity supplies and a reversal of blackouts. Current methods and data infrastructures for industrial energy saving will be reviewed to demonstrate the potential of precise and effective digital twin infrastructure in the industry. The tendency to offer a promising future for the development of twin digital energy saving systems in the energy saving industry.

The combination of various services, large amounts of data and processes, the need for mobile access of information and compelling reasons to propose energy management solutions that work in the cloud all constitutes the open, live access to information and digital engineering model that companies need to implement in a networked data environment. Digital twin technologies can significantly reduce the associated costs and risks to the construction, maintenance and performance of the utility industry by investing in AI-driven IoT testing to increase the reliability and credibility of the offerings. Recording and structuring real-time and historical data enables the implantation of reliable digital twins to facilitate the control, simulation, efficiency and maintenance of equipment and extensions.

Digital twins are viable because of the abundance of high-quality data today needed and because it is possible to obtain data on a sufficient scale to provide sophisticated models based on this data, as the volume of data collected with digitalization exponentially increases. In any existing plant or energy facility, digital twins can first use reality models to capture conditions and link them with sensor information to understand operation and maintenance in context.

3 Visualization of Physical Assets in Energy Sector

Here, we will provide some examples of the operational digital twins. The first example is the Siemens COMOS (WalkInside) which represents a 3D virtual reality visualization software that provides virtual environments and immersive training for power plant operators. COMOS enables the use of 3D engineering data for the basic details of the engineering phase and the start-up phase of operation and provides transparent and real-time asset information throughout the asset life cycle. The use of intelligent 3D models enables COMOS to make plant construction safer and more efficient. In the energy sector, oilfield operators collect and analyze vast amounts of well data that they use to create digital models to guide drilling in real time [32]. Singapore used detailed virtual models for its urban planning, maintenance and disaster preparedness projects. Creative and motivating approaches include the use of EPCs, CAD models and system laser scanners to present the user with a 3D VR simulation of the working environment and navigate like a video game [11].

In addition, there is a Virtual Reality (VR) technology helps power the industry by providing training and education for workers in immersive environments. For instance, many oil and gas companies are finding innovative ways to leverage the benefits of VR for underground studies, training and simulations, and to develop improvised processes and products. Power professionals will use it for comprehensive operator training, engineering and design inspections, plant operation and maintenance, and crisis simulation. The cooperation will help to create interactive virtual environments and create digital representations of physical assets.

The true value of the digital twin capability begins with the tool of choice in the engineering toolbox, since it streamlines the design process by eliminating many aspects of prototype testing. Unreal enables engineers and architects to design and build virtual reality environments using a powerful editor, toolsets and interaction model for design and VR world building. In the context in which VR is present, it is a powerful technology that enables realistic and interactive visualization of our construction models and improves the communication process between the project participants.

Important components of digitalization such as the IoT, sensor technologies, virtual reality, intelligent platforms and networked solutions synthesize large assets and information. The software like the above-mentioned Siemens COMOS represent unified data platforms that provide plant designers, plant operators, companies and management solution partners with a continuous data flow to meet their specific needs in all the projects and disciplines involved. Digital twins are dynamic data models that contain data attributes of actual physical assets. The data attributes of the actual physical object are linked to sensors that measure multiple variables to represent real operational conditions and key information such as installation date and other important elements [28, 49]. Today, the technology can create an immersive VR environment in which a true 1:1 scale 3D model is created using repeatable millimeter-accurate data as input. The ability to explore and experience the 3D content as one was there with a digital representation of the physical assets and surrounding environment creates a seamless workflow between the environment and the reality captured by virtual immersion [10]. Risk assessments are useful to enable engineers and stakeholders to determine whether or not an early design is feasible, to identify potential problems and to make the necessary adjustments before physical assets are created. Asset owners by predicting asset failures and non-fulfillment using digital representations can improve availability and excessive physical repair costs and in some cases plan calendar maintenance and reactive repairs without increasing asset downtime.

The use of digital twins of life cycles simulates, predicts and optimizes product production systems so that digital representatives can invest in actual physical prototypes. In a networked data environment, the use of digital 3D engineering models for planning, design, commissioning, operation and maintenance is expected to reduce annual operating costs in the field by up to 30% [47].

4 Digital-Twin Energy Saving System in Smart Grids

Energy providers are expanding their use of software tools to evaluate and manage smart grids by digital twins. Digital twin technologies enable digital representations of physical network values, processes, systems and technical information, enabling us to better understand and model network performance. Virtual digital replicas can be created with information from vast amounts of design, manufacturing, inspection, repair, sensor and operating data. Using digital twins to model grids and substations, designers can scale up the equipment and predict how it will behave in different operating scenarios. Data exchange between large volumes of different software systems enables utilities to plan, operate and maintain their networks. Under the umbrella of cybersecurity, the digital landscape offers complete transparency at the machine, plant and fleet level, provides plant diagnostics, performance monitoring and operation optimization and creates new opportunities for utilities to manage and market their assets.

World's leading technological giants such as Bentley and Siemens are working together on several software solutions and collaborations including a digital twin for the power grid which will enable a common simulation and modeling environment for the power grid. Various asset-intensive industries, including utilities, use digital twins to manage and operate assets. Plant registers built on power plants, substations, plants and infrastructure can be transformed into BIM-enabled digital twins, for example with Bentley's iModel Technology, a dedicated container for the exchange of information and models on plant infrastructure. By bringing together a mix of cyber-physical systems, cloud computing and smart industrial solutions, digital twin technologies will become the backbone of smart grid deployment, renewable energy management, better integration and efficient transmission in the energy sector.

Utilities need to understand how to integrate distributed energy generation and digital power grids within the parameters of their regulatory environment. In a competitive and uncertain market, companies need to consider different scenarios and analyze real-time data streams to generate power plant operations, planning, and maintenance to save money. Accurate and dynamic digital twin models for plant generation, transmission and distribution of electrical networks and operators need to be trained to deal with a wide range of malfunctions encountered by operators in real life operations.

Digital twins can also optimize and help to save the energy in city planning and operation. For example, planners in the city of Versailles have used digital twins in the city's transportation network to model the flow of goods and logistics and formulate a plan to reduce congestion for suppliers, improve energy efficiency and reduce air pollution [18].

The current methods of data infrastructure for industrial energy saving, which are being investigated here, show the potential for a precise and effective digital twin infrastructure in the industry. The digital twin technology in the energy industry enables the development and maintenance of intelligent networks with high-tech sensors, machine learning models and improved performance monitoring.

By bringing together a mix of hyperphysical systems, cloud computing and smart industrial solutions it can become the backbone of smart grid deployment, renewable energy management, better integration and efficient transmission.

The introduction of digital twins in the energy sector enables a balance to be struck between supply and demand, enabling a proactive management of operational problems and a faster restoration of power supplies and a reversal of blackouts.

Digital twins can reduce the carbon footprint of new buildings by optimizing energy efficiency of construction process and monitoring and controlling the supply chain of materials and products to reduce carbon. In addition, digital twin technologies can significantly reduce the associated costs, risks, design, maintenance, and performance of the utility industry by investing in AI-driven IoT testing to enhance the reliability and credibility of supply.

At the urban level, the so-called virtual model of the digital twin of an urban system allows policymakers to test planning decisions that impact urban infrastructure, people and resource consumption, including energy efficiency. Digital twin technology simulates building operation as a valuable decision-making tool for asset managers who want to make informed decisions about building investments and municipalities with strict emission reduction requirements. For urban planners who focus on energy efficiency, the digital twin offers the opportunity to simulate how new developments, planning and changes in a city affect a range of energy-related indicators including solar radiation, traffic flows on roads and on foot, heating and cooling demands and many others. For example, if a company operates a cost-effective system for a specific location, a digital twin could decarbonize the energy system.

With digital energy twins, builders and building owner teams are able to understand the system capabilities they need at different occupancy and density levels. Digital twins are used to emulate the physical and operational characteristics of power plants and other utilities during construction to improve the operation, maintenance and service life of physical facilities. The tool that can be called the digital energy twin, reflects a building's actual performance and energy consumption by integrating building design and use information with a wealth of real-time operating data such as building automation systems (BAS), device command and sensor data, equipment levels, energy consumption and weather data.

A digital twin based on the Sphinx could open relevant systems to analyze changing energy consumption areas and carry out continuous assessments of energy sources. In the discipline of Building and Energy Management, a digital twin is a combined representation of a powerful building information model (BIM) and a real-time stream of data originating from building sensors [22]. Once the building operations are modelled with 98% accuracy, we can assess the impact of various energy-saving systems optimizations and upgrades and empower building owners to make better investment decisions [23].

A recent report by a professional services firm draws on case studies, including the Nanyang Technological University of Singapore who tested the use of Digital Twin on its 200-building campus to reduce energy consumption, water consumption, carbon emissions and waste. Digital Twin's data analyzed a five-year period to propose changes in the building operation, resulting in a 31% reduction in energy consumption and a 96-kiloton reduction in carbon emissions [14]. The technology was also used to test the performance of the first 3D printed bridge in the world, using data for future iterations of the design.

Digital twins are at the forefront of advancing integrated information modeling, enabling asset-centric organizations to bring together their engineering, operations, and information technologies through immersive visualization, analysis, and visibility. Utilizing research data on how each part of the system functions and reacts to the environment and supported by data provided by sensors in the physical world, it can be analyzed to simulate real conditions and to respond to operational changes.

Recording and analyzing real-time and historical data from various platform enables the implantation of reliable digital twins that facilitate the control, simulation, efficiency and maintenance of equipment and extensions. With a holistic digital twin production environment, artificial intelligence can be used to run virtual simulations using various data sources, including historical data, future demand forecasts, and weather data, enabling multiple optimization scenarios.

5 Conclusions

All in all, it can be stated that thanks to the ongoing digital revolution in the energy sector, digital twin technologies are finding ubiquitous and frequent usage in the development of the of smart grids. This process is likely to impact the formation and the shape of the smart grids of the future energy systems.

The introduction of digital twins in the electricity sector will allow for a balance between supply and demand, enable a proactive management of operational problems and enable a faster recovery and reversal of blackouts. Digital twin technologies in the energy industry will enable the development and maintenance of intelligent grids with high-tech sensors, machine learning models and improved performance monitoring. Digital twin technologies will significantly reduce the associated costs and risks to the construction, maintenance and performance of utilities as the industry invests in AI-driven IoT testing to build reliability and credibility of offerings.

Nowadays, in our digitalized and interconnected world, quite a few energy utilities already successfully developed the process of moving the data into the structures of the digital twin framework and equipping it with real-time data feeds for operation on the ground. However, an unknown number of private players are using digital twins to manage hydropower plants, nuclear reactors and power grids.

Therefore, it is necessary to be guided by some principles for the enhancement of smart grids. Governments should strive to provide technology-neutral delivery routes and neutral policy platforms for digital energy, for example in relation to the role of smart meters and other energy management systems, and allow a large number of companies to compete with each other and find new business models to serve consumers [33]. Policymakers should design a range of energy policies to ensure adequate flexibility in dealing with new developments in digital communications technologies that continue to develop in ways that are difficult to predict [31]. The ultimate goal of these recommendations is to change the state of the energy sector. We believe that digital technological will be make energy systems more connected, intelligent, efficient, reliable and sustainable [20].

Finally, we can conclude by saying that thanks to the advances in computer science and creative programming, digital twins can be used during construction to replicate physical and operating characteristics of power plants and other utilities, helping to improve the operation, maintenance and service life of these plants.

Research limitations are due to the applied methodological approach and the available data. We admit that the literature review is incomplete and some trends in the development of digital twins in the energy sector have not received sufficient space in the study. We see prospects for further research in the field of generalizing assessments of the effectiveness of using digital twins.

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Digital Twins in Russian Metallurgy: Prerequisites and Limitations of Use

Olga Romanova and Dmitry Sirotin

Abstract The most important factor in the systemic transformation of the productive sector of the economy is modern information and communication technologies, among which technologies for the formation of digital twins are becoming increasingly important. The article is devoted to studying the application of these technologies in metallurgy, one of the basic industries of the Russian economy. The article aims to identify the existing prerequisites and the most significant limitations of introducing digital twins in Russian metallurgy. The study hypothesizes that the technological level of modern metallurgy allows the use of digital twins as an effective tool of the modern organization of metallurgical production. The information base of the study was the indicators of state programs and industry strategies, industrial statistics data, materials of analytical and consulting firms. The methodological basis of the study consisted of the scientific works on digital and sectoral economics. The use of comparative, structural-logical, and statistical analysis allowed identifying the prerequisites for introducing digital twins in Russian metallurgy and substantiating the validity of considering modern metallurgy as a promising object of digital transformation. The emerging trend of metallurgical production intellectualization has been established. The authors have carried out a review of the best practices of the largest Russian metallurgical companies on the use of digital twins. The study reveals the limitations of the development and application of digital twin technologies in metallurgy. In the research process, it is substantiated that to implement the existing prerequisites for introducing digital twins in Russian metallurgy and removing the identified limitations, it is required to develop special measures to improve the legal and managerial support of this activity.

Keywords Digital twins · Metallurgy · Digitalization prerequisites and limitations · Intellectualization of production · Best practices

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1 Introduction

A global trend of world development is the construction of a digital society, the conceptual basis of which is the creation of a common platform of interaction between the subjects of the modern economy [1, 26]. Only based on such a platform, it is possible to solve the problems of implementing the latest production cycle, the basis for the formation of which is knowledge, information, big data, and communication. Among the latest information technologies that define the digital transformation of the productive sector of the economy, digital twin technologies are becoming increasingly important. The purpose of the article is to analyze the opportunities and identify the limitations of the development of digital twins in Russian metallurgy.

A review of research in the development of modern information technology [2, 10, 16, 22, 33, 40, 43], the digitalization of metallurgical production as one of the basic industries in Russia [7, 11, 23, 25, 27, 37, 38], and the generalization of the best practices of steel companies in this area were the basis for forming the hypothesis of this study. The idea of the hypothesis is that the technological level of modern metallurgy allows changing the traditional view of it as a conservative industry and justifying the prospects of using digital twins as an effective tool of the modern organization of metallurgical production. To confirm the hypothesis, it is necessary to establish the place and role of digital twin technologies among modern digital technologies; consider the validity of identifying metallurgy as an object of digital transformation and intellectualization of metallurgical production as a prerequisite for the introduction of digital twins; confirm based on the systematization of research on the use of digital twins as an effective tool for modern organization of metallurgical production; summarize best practices in the use of digital twins by Russian metallurgical companies; to formulate the limitations of digital twins in Russian metallurgy.

2 Prerequisites for the Development and Implementation of Digital Twin Technologies in Metallurgy

Digital transformation of industry based on the latest information technology is one of Russia's most important tasks of economic activity management. To solve it, numerous measures of both organizational and legal nature have been taken over the past decade, aimed at increasing the overall level of digitalization of the economy, developing specific information and communication technologies, and encouraging the implementation of end-to-end digital technologies. The adoption of such special organizational and legal measures is an important and necessary prerequisite for the digital transformation of the Russian industry as a whole and metallurgy – one of its most important industries.

2.1 Modern Metallurgy as an Object of Digital Transformation

Metallurgy, both worldwide and in Russia, has significantly changed its technological appearance. Today, this is an industry where considerable attention is paid to developing high-tech, customer-oriented production, digitalization, and ecologization [2, 22].

Modern metallurgy has the necessary prerequisites to identify it as one of the most important objects, where the implementation of the latest information technology provides different types of effects. This is due to the sufficient stability and high degree of debugging of technological processes in metallurgy, the constant introduction of new technological solutions in the current production, the presence of successful experience of experimental work, and many years of practice to modernize the existing metallurgical production. In metallurgy, there is a long positive experience of various kinds of optimization studies. They aim to generate various effects, including productivity growth, reduced waste, saving investments, and other resources. A large amount of data has been accumulated here, and various processing methods allow the industry to apply the latest information technology. Metallurgy is one of the leaders in the Russian manufacturing industry in the use of digital technology and the volume of investment in digitalization. In 2019, metallurgical companies invested more than 49 bln rubles for these purposes, which is more than 30% of the total cost of the manufacturing industry for digitalization.

Metallurgy plays an important role in successfully implementing the Strategy for Digital Transformation of Manufacturing Industries to Achieve "Digital Maturity" by 2024 and 2030 [15]. The need to achieve "digital maturity" in key sectors of the economy is emphasized, which is defined in the national goal "Digital Transformation." The methodology for assessing enterprises' "digital maturity" level was tested in January 2021 as part of a pilot volume that included 150 industrial enterprises of various industry affiliations. Among the leading companies, whose level of digital maturity exceeds 70%, with the average value of this indicator being 53.89%, the metallurgical enterprises (United Metallurgical Company JSC and Vyksa Steel Works JSC) are ranked second and third with the digital maturity level of 75.19% and 74.46%. This is significantly higher than the average value for industrial enterprises, confirming the possibility of effective development by metallurgical enterprises of the latest information technology, including digital twin technologies.

IT solution groups with different weighting ratios were formed to assess the digital maturity of enterprises (Table 1).

Table 1 shows that the group of IT solutions in the field of data sources has the maximum value of the weight ratio (3) in metallurgy, which is completely justified. It is followed by IT solutions groups related to systems for collecting, storing, analyzing, and visualizing data sets (2.9) and groups of IT solutions in the management of financial and economic activities of organizations (2.9), which is also unobjectionable. However, the weighting ratio of the IT solutions group in the field of project management, research, development, and implementation seems clearly

Table 1 IT solutions groups and their weight values

IT solution groups	Industries[a]		
	Metallurgy	Chemical industry	Machine construction
Project management, research, development, design, and implementation	1.8	1.4	2.6
Production activities management	2.8	3	2.8
Fixed assets and human resources management	2.3	2.3	2.3
Data sources	3	3	3
Financial and economic activities of organizations management	2.9	2.5	3
Managing the content of organizations	2.3	2.3	2.3
Systems for collecting, storing, processing, analyzing, modeling, and visualizing data arrays, ensuring the integration process	2.9	3	3
Other solutions	1	1	1

[a] The weight ratios are indicated depending on the priority of the IT solution within the industry on a scale from 1 to 3: 0—not used; 1—low; 2—medium; 3—high
Source Ministry of Industry and Trade of Russia [14]

undervalued (1.8). However, this ratio is higher than, for example, in the chemical industry (1.4); it is significantly lower than in mechanical engineering (2.6). At the same time, metallurgy is experiencing a growing rate of new technological solutions that are modernizing and transforming the industry. This increases the importance of decisions in the field of project management, research, development, and implementation and determines the need to increase the weight ratio for the marked group of decisions at least to the level of that in mechanical engineering (from 1.8 to 2.6).

2.2 Intellectualization of Metallurgical Production

The intellectualization of metallurgical production, as the authors understand it, is characterized by a whole set of indicators. They include the increasing share of creativity and creative work of industry workers in production, social and personal sectors due to the intensification of universal information links. The most important indicator of the intellectualization of metallurgical production is the use of the latest information technology in the industry, i.e., the achievement of its digital maturity. A new view of metallurgy as a modern industry, in which the intellectualization of production is becoming more apparent, is largely due to its successful development in countries such as Germany, Italy, China, etc. In these countries, metallurgy is not only largely prepared for large-scale digitalization but is already characterized by increasing digital maturity and is largely intelligent in nature. One of the companies that actively develops technologies for metallurgy under Industry 4.0 is the German company SMS group GmbH. A special place in its research is the development of a "smart smelter", where almost full autonomous and intelligent steelmaking is ensured.

Cooperation with the Italian company Danieli (Digi&Met division) is also of particular importance for the formation and increase in the level of digital maturity of Russian metallurgical enterprises. Its goal is to develop and implement new metallurgical enterprises based on using the latest information technology and implementing new business models. The company proposed an approach to creating a "digital plant", with its subsequent transformation into a "smart plant" [5, 35]. The functioning of a smart plant allows for reliable, efficient, flexible, customizable, and environmentally friendly metallurgical production that meets the requirements of intelligent production to a certain extent. The financial results of the digitalization of steel production, according to Digi&Met estimates, are an additional 2.7% revenue per year, with annual cost reductions of 3.2%. Return on investment in the project of digitalization of the metallurgical enterprise can be 55% over two years, for two to five years—37%, for the period over five years—8% [7, p. 34].

3 Digital Twin Technologies—The Basis of Modern Metallurgical Production Organization

The development of the latest information technology has actualized the emergence and the possibility of applying "digital twins" technologies for the digital transformation of the productive sector of the economy [11, 16]. A digital twin is a digital copy of a physical object, which can be created for any real production assets—steelmaking furnaces, rolling mills, machine tools, etc. [42]. The copying object transmits in real-time the data of various parameters that allow reproducing its state model. This approach considers the accumulation of experience based on a wide range of data, which contributes to forming an extensive Big Data database for modeling possible states and forecasts of changes in technological systems.

The previously unavailable capabilities served as the basis for forming the modern direction of metallurgical production organization and maintenance of metallurgical equipment, including its maintenance by current condition. Implementing such a strategy allows reducing maintenance costs by 25%, by 70%—the cost of eliminating accidents, by 35%—unplanned downtime while increasing labor productivity by 20% [21, p. 403].

Analysis of available statistics and publications in this area allows considering digital twins as a critical tool to improve production efficiency at different stages of the life cycle of metallurgical objects. In the period of design—it is the possibility to obtain its various models and the possibility to choose the most effective one; in the manufacture of products—evaluation of the accuracy of manufacturing of individual elements of the object and the object as a whole, the possibility of identifying faults; at the stage of operation of real production assets—monitoring the technical condition, identification of failure causes, which allows maintaining metallurgical equipment depending on the technical condition of each physical object [39, 44].

The use of digital twin technology allows determining the environmental impact of different modes of operation of metallurgical equipment. Such technological solutions in metallurgy are the first stage in solving the most important task—production of green metals and the transition to a carbon-neutral operation in the industry.

The General Electric Corporation and Siemens AG played a defining role in the development of the digital twin concept. At General Electric facilities, digital twins are used for product design, equipment monitoring, manufacturing processes, and aftermarket product support.

Digital twins are becoming increasingly common in Russia as well. Positive results in this direction have been achieved in metallurgy [24, p. 109].

4 Largest Russian Metallurgical Companies-Leaders in the Introduction of Digital Twin Technology

Russian metallurgists successfully cooperate in digitalization both with foreign companies and with Russian universities and academic science. For example, serious research is carried out at the Peter the Great St. Petersburg Polytechnic University. Among the research in metallurgy, it is important to note the creation of digital twin technologies for thermomechanical processing of steel, the main purpose of which is to control the structure and properties of hot-rolled and heat-treated steels with different chemical compositions. The industrial use of digital technologies of thermomechanical processing of steel is constantly expanding [5]. In Russia, the industrial development of digital twin technologies of thermomechanical processing of steel, developed at the Peter the Great St. Petersburg Polytechnic University, took place at Severstal PAO [28]. The use of the created digital twins was multipurpose and demonstrated their high efficiency. The use of digital twins allowed improving the mechanical properties of thick tube steel plate while maintaining the metal plasticity. In addition, the cost of rolled products was minimized by reducing the molybdenum content. The strength properties of the thick sheet were also improved due to the addition alloys, which reduced the content of expensive elements [28, p. 10].

Severstal PAO. At Severstal PAO, in addition to the application of digital twin technologies for thermomechanical processing of steel, the startup format considers the possibility of implementing a digital twin model based on statistical and physical modeling methods. This model allows predicting equipment failures and improves the efficiency of metallurgical production as a whole [29]. Severstal's divisions developed and implemented a digital twin of the continuous etching unit (CEU-3) at the Cherepovets Metallurgical Combine in 2019 [30]. The "Adelina" digital model used in this process allowed increasing the productivity of the CEU-3 by 5%. In 2020, this model was supplemented with an intelligent agent “Ruban”, which increased the productivity of the unit by another 1.5%. Unlike classical machine learning models, which accumulate knowledge from a database of historical data, “Ruban” learns by exploring the environment of a machine digital twin [31]. In 2020, Severstal implemented a project to introduce a digital twin created based on process mining technology to optimize business processes. This allowed the company to optimize the processes of procurement, external logistics, management of the so-called “master data”, i.e., data on identifiable objects, such as counterparties, materials, goods, processes, etc., shared in the interacting systems [32].

MMC PJSC. Magnitogorsk Iron and Steel Works PJSC is one of the industry leaders in the digital transformation of production. The MMC Digitalization Strategy is implemented here, under which about 200 projects will be completed by 2025, of which 48 will develop data analytics, 22 will be related to the application of digital twins, 51 to the industrial Internet of Things, 51 to the digitalization of internal communications. Net present income from the implementation of the Strategy, developed and implemented in partnership with Deloitte Consulting, will be 6.3 bln rubles by 2025 [12]. The topic of digital twins occupies a special place in this Strategy. Especially for their development back in 2019 in the scientific and technical center of the plant, the Group of Mathematical Modeling and System-Analytical Research was formed. In 2021, with the participation of the South Ural State University, the plant is implementing a project to improve the energy efficiency of power plants by introducing an automated system of digital twin power units. The system used reads up to 100 parameters of the unit and increases its efficiency [41].

JSC Holding Company Metalloinvest. As part of the implementation of the Strategy for Digitalization of Production, the holding held a startup competition in 2021 to find technically and economically feasible solutions in this area. One of the priorities of the competition was the development of digital twins, to which the organizers referred “the technology of augmented reality for assessing the state of assets, modeling the thermal balance of buildings and structures based on 3D” [13].

In 2020, ***EVRAZ PJSC***, together with The Boston Consulting Group, launched the Advanced Analytics program, under which projects with an expected economic effect of $12 million per year are implemented at six enterprises of EVRAZ Group. An end-to-end scenario-based production planning system was implemented earlier, which allowed creating a digital twin of the production line at the West-Siberian Metal Plant with an annual economic effect of 600 million rubles [8]. In 2021, more than a hundred projects were underway at EVRAZ’s facilities, coordinated by the company’s plans to digitize its operations through 2023 inclusive. Digital twin technologies, which have already proven their effectiveness, occupy a significant place in these plans [9].

The ***NLMK Group of Companies*** (Novolipetsk Steel Company) is also promoting digital technologies and creating a digital eco-environment. At their production sites, the group’s companies implement elements of digital twin technology. For example, the Stoilensky Mining and Beneficiation Plant has implemented an intelligent system for optimizing the mill operation during ore processing. It also uses a machine vision system to monitor the quality of incoming raw materials [19]. The implementation of the “Gefest” project allowed building an optimal logistics system for the steelmaking shop at Novolipetsk Steel Company with an economic effect of up to 100 million rubles per year [20].

The ***Pipe Metallurgical Company*** (TMK OAO) is actively working to create digital twin technologies. The digital twins implemented at TMK’s plants allow simulating production processes, virtually selecting equipment settings, testing them, and identifying the best option. As a result of such implementation at the Volga and Seversk pipe plants from 2018 to 2021, the economic effect amounted to about 500 million rubles.

Programs for mastering digital twins are currently being implemented at Taganrog Metallurgical Plant and Sinarsky Pipe Plants. Chelyabinsk Tube Rolling Plant (86.5% of shares owned by TMK since March 2021) plans to create a full-fledged system of digital twins. Back in 2019, the “steelworker assistance algorithm” was introduced, created based on machine learning techniques used to create digital twins. This allowed controlling the composition of steel, minimizing the consumption of raw materials in its melting, and getting an economic effect in one of the shops of the plant about 50 million rubles [4].

In addition to the purely economic benefits of digitalization of metallurgical processes, modern digital solutions play an increasing role in reducing the industry’s environmental impact. It is possible to note some achievements in this area of metallurgical enterprises. For example, NLMK is implementing a project to create automated environmental monitoring systems developed using machine vision technology. The systems allow continuous monitoring of air quality in the cities where the company’s production sites are located. NLMK Group companies pay great attention to the processing of technogenic formations with the elimination of the consequences of their storage. The implementation by Novolipetsk Steel Company of one of the projects in this area allowed processing 6 million tons of man-made mineral formations, restoring 25 hectares of land occupied by them, and reducing greenhouse gas emissions by 85 ktons. In 2021, all of these factors contributed to NLMK Group’s status as a Sustainability Champion, awarded by the Worldsteel Association [18].

The certain success of industrial, including metallurgical, companies in Russia in implementing digital twin technologies has allowed setting fairly high targets for the growth of the number of enterprises using these technologies. It is known that under the Order of the Ministry of Digital Development of Russia of November 18, 2020 No. 600 “On approval of methods for calculating target indicators of the national development objective of the Russian Federation “digital transformation”, the share of enterprises using digital twin production technology should increase from 15% in 2020 to 80% by 2030.

5 Limitations of Digital Twin Technologies in Metallurgy

Metallurgy is one of the most important industries in the manufacturing industry of Russia. Its development closely correlates with both metal-consuming and extractive industries. With the general correspondence of the directions of development of Russian companies to global technological trends, the pace of implementation of digital solutions lags far behind the pace of developed countries. According to the various experts' estimates, this has led to Russia lagging in the development of digital technology by 5–10 years [17, p. 4]. Therefore, the general state with the digitalization of all industries will be a kind of deterrent to applying digital twin technologies in metallurgy.

The use of digital twin technologies plays a defining role in forming an ICT ecosystem in which participants interact, share resources, and transform certain types of resources into others. In the course of its functioning, the inclusion of the ecosystem in the production process provides the emergence of additional income with their subsequent conversion into the human, technological, financial, and other resources of development [3, p. 95]. However, as long as the ICT ecosystem is only in its formation stage, the digital twins of intelligent metallurgical production will not realize their potential to effectively coordinate the innovative development of equipment, product manufacturers, and end-user requirements. The acceleration of the formation of an effective ICT ecosystem that affects the implementation rate of digital twin technologies depends on both internal capabilities of companies (human resources potential of metallurgical enterprises, technological level of production, etc.) and external conditions, the most important among which are the availability of the latest information technology, funds availability, the level of competition in the industry. The insufficient level of development of automated process control systems at many metallurgical companies, the lack of necessary digital maturity of production processes, the lack of required competencies and the low level of digital literacy of employees of metallurgical companies, the undeveloped practice of working with data, and the lack of skills in their management—all this creates serious limitations for the widespread implementation of digital twins in production.

It is known that today almost any function in metallurgy can be supported by digital systems. However, the main task is to determine each plant's readiness for digitalization since the risk of investing in production facilities with low digital maturity is considerable. The existing methodologies for assessing digital maturity need significant refinement, considering the specifics of metallurgy and the special role of digital twins in the further transformation of the industry. Intelligent metallurgical production with implemented digital twin technologies is interpreted by experts as the inevitable future of the industry [6, 36]. However, the key barrier to the future is, in addition to all of the above, the high cost of projects in this area, the lack of financial resources from metallurgical companies, and the quality of the business climate.

Legislation in the field of digitalization of the economy, aimed at stimulating the introduction of digital technology, is of particular importance. This problem is extremely important because, according to experts, over the next 3–5 years, hundreds of millions of "things" in the world will be presented in the form of digital twins, helping to improve production processes, increase their efficiency, replace traditional control and monitoring devices, etc. [34, p. 33]. However, the current regulatory system and business climate do not allow for proper support of metallurgical companies' interest in developing and implementing digital twin technologies. Solving these problems will contribute to forming a new image of steel companies as modern, high-tech companies with a fundamentally different system of organization of production.

6 Conclusion

The conducted research has confirmed the validity of considering the modern metallurgy of Russia as a promising object of digital transformation. The systematized experience of Russian metallurgical companies shows the feasibility of the wide application of digital twins in metallurgy, providing a variety of types of effects. The hypothesis is confirmed that the use of digital twin technologies is an effective tool and determines the modern organization of metallurgical production. It is shown that such an organization corresponds to the initial stage of production of "environmentally friendly metals" and will contribute to the functioning of the industry in the mode of achieving carbon neutrality. The general situation with digitalization of all industries in Russia is a limiting factor for the use of digital twins technology in metallurgy. It is concluded that to implement existing prerequisites for the widespread introduction of digital twins in the Russian metallurgy, special measures are needed both at the state and corporate levels to develop a digital culture and improve the organizational, legal, and managerial support of this activity. Further research should answer the question, which is the role of exports in the sector, has Digital Twins contributed to improve the external performance? It is also necessary to study the best practices of the largest metallurgical companies in the world from the use of digital twins was carried out.

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Digital Twin of the Social System: Calculating the Environment's Reaction to the Company's Activeness

Mikhail Samosudov

Abstract The paper discusses the possibility of calculating the reaction of the environment in the form of incoming resource flows to the actions of the company using a comprehensive mathematical model of a social system functioning in an active environment. The study focuses on calculating the expected trajectory of the company's movement for management and the marketing activities. The developed theoretical base allowed us to create an agent-based simulation model of a social system that was applied to compute the dynamics of the system. It can be used to create decision support systems for enterprises' managers of any scale and area of activity, since the specifics of a particular system is considered by combining the values of phase variables. The novelty lies in the fact that the research shows the possibility to calculate the environment's reaction, the mechanism for considering the cumulative activeness of agents, as well as the mechanism for converting messages that are invariants of the socio-economic space into information affecting of agents' behavior. The result of the calculation can be recorded in the digital twin of the social system and used to automate company management.

Keywords Digital twin · Mathematical model · Agent-based model · Active system · Automation of management

1 Introduction

The appearance of the Industry 4.0 concept stimulated discussion of the use of computers in various areas of activity and, in particular, in the automation of management of social systems. The basis of the concept is the inclusion of a virtual image of the social system in the production and management system in the form of a mathematical model or a digital twin of the enterprise [1, 8, 9, 13, 25]. One of the purposes of the digital twin is to increase control precision. But today digital twins are created mainly for technical objects used in the activities of enterprises.

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The social system is a strictly dynamic active system moving in a strictly dynamic active environment. That is, the system and the environment do not have stationary states, they are constantly changing, and the activeness of agents creates uncertainty in the dynamic characteristics of the values of separate parameters (phase variables), which is fundamentally impossible to eliminate. As a result, for sustainable functioning, control actions are fundamentally necessary to ensure the adaptation of the system to constantly changing conditions.

One of the most significant tasks of the organization of precise management of social systems is the calculation of the trajectory of its movement in the socio-economic space (SES), which ensures the preservation of the functional stability of the system and the achievement of the target state corresponding to the goals of the key participants of the social system.

The presence of such a trajectory is a principal condition for the possibility of precise management of the social system, which, in turn, is necessary for the implementation of automatic and automated enterprise management systems. Such systems can be both an "active adviser" of a decision-maker [4, 5] and a subject of management if the necessary data and legal grounds are available. But to do this, they must allow calculating the dynamics of the social system in the SES, considering the expected control actions of the subjects of management and disturbing environmental influences.

For organization of precise management of the social system, as shown in [19] and considering the results of [17], three indicators are sufficient (provided they are properly calculated)—the coefficient of functional sustainability, deviation from the calculated trajectory of movement, as well as the profile of activeness of key participants in the social system. The sustainability coefficient shows how much the system can maintain the ability to function (a detailed analysis of the influencing factors and a simplified calculation is shown in [17]). Deviation from the trajectory of movement allows determining the danger of falling into the areas of unacceptable and inexpedient states of the system and take timely measures to correct the movement. Considering the activeness of the participants allows making a forecast of the future state.

In turn, to calculate the trajectory reflecting the change in the phase variables of the system over time, it is necessary to be able to calculate the reaction of the environment to the state of the social system that has changed due to controlling and disturbing influences and, in particular, the change in its activeness. The experience of implementing computational approaches in management and marketing activities shows that the most rational is the creation of automated systems that calculate the reaction of the social system and the environment to the actions of managers and specialists of the company—numerical calculation manually is possible, but requires considerable effort and time, which significantly reduces the value of such a calculation. It is possible to achieve acceptable accuracy by forming the necessary qualifications of specialists, but this requires several years of intensive training of specialists in a special program, which is a significant deterrent for many companies.

But the automation of this work requires the creation of software solutions that differ significantly from those available on the market and, accordingly, calculation algorithms. In turn, this requires a special mathematical apparatus that allows considering all the factors affecting the evolution of the social system.

In general, the task of a social system is to form such an impact on the environment that will ensure the occurrence of an incoming resource flow (IRF) necessary to maintain its ability to function, as well as prevent the occurrence of undesirable activeness of agents (this is the impact that agents have on the environment, preventing the occurrence of an incoming resource flow, for example, a negative customer feedback). One of the components of IRF is incoming cash flow. The necessary resources are determined by the function and conditions of the functioning of the social system, including goals, objectives, expectations, and requirements of key participants in the social system. The impact on the environment is carried out through information and resource flows directed at certain participants of the SES. In the SES, there is a redistribution of resources controlled by agents, flows of resources and messages are formed, propagating through transmission channels. In turn, these flows affect other agents, change their activeness, which leads to a change in the aggregate resource and information flows in the SES.

Thus, considering the nature of social systems, to calculate the management impacts, it is necessary to be able to calculate the activeness of the company required to obtain a proper incoming resource flow. To do this, in turn, it is necessary to have algorithms that allow considering the cumulative activeness of agents (not only participants of the social system in question, but also of its competitors) and calculate its impact on the company's IRF.

Considering the above, the purpose of the article is to show the possibility of calculating the activeness of the social system and the result of this activeness in the form of resource flows originating from the SES point towards the social system, using the formed approaches. It also requires defining a mechanism for converting messages received by the agent into information that impacts the behavior of the agent at a point in the SES.

The novelty of the paper, in comparison with previously published ones, lies in the fact that the mechanism of accounting for the activeness of individual agents in determining the activeness of the social system in the SES is determined, as well as in determining the mechanism for converting messages transmitted by agents, which are invariants in the SES, into information impacting the behavior of agents at the corresponding point of the SES.

The structure of the article is as follows. First, we consider the general logic connecting the entities that determine the state of the social system and the result of its interaction with the SES-resources, the probability of the agent performing conditioned actions, message transmission channels and messages received by the agent from other participants through which they implement their activeness in the SES. Next, the mechanism of converting messages into information at a specific point of the SES and the influence of this information on the behavior vector of the agent's (the probability of him performing certain conditioned actions) is considered. This mechanism makes it possible to determine the result of the cumulative activeness of many agents who are participants in the social system, as well as participants in the SES.

2 Literature Review

A digital twin is often called a computer model that simulates the behavior of a real object [3, 8, 24, 26, 27]. Although, it is advisable to distinguish between the mechanism for calculating the dynamics of the system—a simulation model and the real digital twin—a digitized image of an object, information about the values of phase variables at specific points in time.

Agent-based models are increasingly being used to model social systems [2, 6, 7, 10, 14]. But there are disadvantages of the approaches used. The main ones, perhaps, are the following.

Information as an influencing factor is either not considered at all or limited and/or simplified—as an unchangeable entity, in the form of fixing the fact of receiving or not receiving information. In some works, the term "message" is used (see, for example, [11]), but, in fact, in the meaning of "information", which seems fundamentally incorrect. Information in the socio-economic space is not an invariant entity, it depends on the point of the SES. Invariant is a message, the interpretation of which generates information that impacts the development of the situation at this point of the SES. Thus, Klebanov and Antropov [12] noted that "different agents, due to their character traits, can perceive the same information differently". The influence of information on behavior is also confirmed by experiments of biologists (see, for example, [23]). Messages are often considered in a very restricted sense. For example, Kartvelishvili and Lebedyuk [11] interpreted "message" as a "control signal and feedback signal" without specifying the content of the message. In addition, in fact, the message is equated with the information received by the agent. At the same time, real messages in social systems, even pursuing the same goal of influence, may differ in style, language, etc. All this requires consideration in the simulation model. Therefore, it is necessary to form mechanisms to take into account the variability of information depending on the point of the SES.

The "rigidity" of the agent (agent model). It often does not imply variability—the agent has certain interests and desires, needs, attitude to risk, etc. At the same time, the real agent is changeable, and its main parameters depend on the information received, which is formed as a result of the interpretation of messages got by a person. The information obtained influences subjective assessments of incentives and restrictions associated with certain actions, which affects the likelihood of these actions.

In part, this is also implied by other authors. For example, the following agent characteristics are defined in [15]:

- independence, the ability to act autonomously and make decisions on issues of interaction with other agents and influence on the environment;

- ability to interact with other agents;
- the presence of a specific goal or goals that affect his behavior;
- variability and learning ability based on accumulated experience;
- the rules of the agent's behavior may change based on the experience gained.

At the same time, the choice of an agent is often significantly limited in models (see, for example, [28]), which seems to be a very significant simplification compared to reality. It seems more appropriate to consider the process of the influence of information flows on the agent and, for example, calculating the gradient, determine the most likely human behavior.

Another significant problem of traditional models is the limited number of types of resources under consideration. Economic models often solve the problem of financial resources, which, firstly, is a traditional and, secondly, an obvious and easily measurable resource. At the same time, the number of types of resources used in the activity is much larger—informational, material and conditionally material, spatial, social, intellectual, time. Moreover, for different situations, different types of resources have different significance, which determines the value of the resource for the agent.

An invariant is a phenomenon considered as a resource, but the value of a resource is an amount that depends on the point of space in which the corresponding phenomenon is regarded, on the subjective assessments of the agent.

Basically, the models are not comprehensive, taking into account all the factors affecting the dynamics of the social system. In part, this is due to the disadvantages of the theoretical base used, on the basis of which mathematical models are formed. For a comprehensive solution of the problem, a unified theory of the social system is needed, taking into account the whole set of laws that determine the dynamics of the social system in the socio-economic space.

3 Methodology

To solve such problems, the method of mathematical modeling, in specific, simulation modeling, is most suitable. The formed theoretical base [18, 20] and the model based on it allows us to consider any phenomena in any social systems, regardless of the forms, areas of activity and scale—companies, state and public organizations, informal social associations, etc. The specifics of the structure and activity of a particular social system are determined by a combination of values of phase variables (system parameters). But in this paper, we will use the terms "company" and "social system" as synonyms—it is possible to strictly prove the absence, from the point of view of their structure and functioning, of principal differences between social systems engaged in commercial and, for example, philanthropic activities, but this is not part of the objectives of this work.

For this paper, this statement should probably be considered as a hypothesis requiring confirmation. But it is based on the results of the author's long-term observations, as well as numerous thought experiments and the study of the construction of social systems (see [17]).

A comprehensive mathematical model of a social system functioning in an active environment is used to model the situation [18]. It consists of several particular models—"corporate person", "interaction of subjects", "occurrence of incoming resource flow" and "evolution of the system". This is an agent-based simulation model reflecting the dynamics of the social system in the SES. Here we will mainly consider a company or firm as a special case of a social system, the target function of which is the generation of incoming cash flow—one of the components of IRF. In general, if necessary, these arguments can be extended to any social system, including non-profit, state or public organizations.

The essential features of the model are considering the activeness of agents and the operating environment of the system,—SES,—as a set of agents, as well as the separation of the entities of the model into invariant, conditionally invariant (i.e., independent of the SES point within a specific task) and dependent on the SES point (on the parameters of the subjective subspace). Invariant entities are transmitted messages and resources. Conditionally invariant are artificial transmission channels created by agents and owned by them. And the value of resources and the information received from messages are entities that appear in the subjective subspace and depend on the point of the SES.

The dependence of the information transmitted and received by agents on the SES point is a significant difficulty in modeling. The approaches considered in the paper allow us to do this, which allows us to introduce a calculated approach into the process of making managerial and marketing decisions.

For the analysis of social systems, a resource-functional approach [20] is used, which presupposes the consideration of social systems as functional systems designed to implement a specific function, which requires a certain set of resources. Resources are considered in a broad meaning—not only financial and other material resources, but also all types of non-material resources—organizational, intellectual, social, informational, etc., which, as a rule, are not taken into account in account systems of organizations but are of great importance for calculating the activities and dynamics of social systems. The developed methodic approaches make it possible to quantify all types of resources, as well as to calculate the necessary number of resources for performing separate actions and activities in general. The source of resources is the participants of the system. They transfer resources by performing actions due to dissatisfaction with their situation and the emergence of an impulse of activeness due to the discrepancy between expected and desired benefits [17, 18].

The evolution of the social system in the SES, as Schmidt, Churyukin, Romanova and other authors note, is described by the Markov process [6, 16–18, 22]. That is, its future state depends on the current state and does not depend on the past. In general, this is explained simply—the resource base accumulated by the company is important for the future result; as well as the activeness and behavior vectors of agents at each point of the SES that have developed at this moment (arises due to the divergence of behavior vectors under the impacting of information flows, some of which are the company's information flows).

If the accumulated resource base allows you to perform actions that lead to a sufficient divergence of the behavior vectors of the SES participants so that the appropriate resource flows to the company arise, then there are resource flows originating from these SES points and directed towards the company, forming into IRF.

4 Results

The environment (SES) responds to the company's presence and activities with an incoming resource flow (IRF), including incoming cash flow. The response of the environment depends on the activeness of the company as a set of economic agents, which, in turn, is determined by the state of the social system.

The state of any social system and environment is described by a set of phase variables that make up four groups of system parameters—those that determine the behavior of participants, resource base parameters, institutional environment parameters and parameters of activeness. The social system is, in fact, an area of the SES isolated by an institutional cover, in which a definite functional concentration of resources is provided due to the structured activeness of agents. Some of the resources are expendable, which necessitates the receipt of such resources from the SES to support the functioning of the system. The institutional cover is, simply put, a set of rules that determine the order of interaction in this area of the SES. This is one of the factors structuring the activeness of the system participants. Another factor determining activeness is information flows.

The activeness of a company is determined by the activeness of its participants—the source of activeness in the SES is an economic agent, the SES point.

The general logic is as follows:

- The resources in the SES distributed among agents who could dispose of them. Agents, performing actions, exchange resources and messages that are distributed through their chosen transmission channels, because of which flows of resources $\hat{R}_j^k$ and $\breve{R}_j^k$ and messages $\hat{M}_j^k$ and $\breve{M}_j^k$, respectively, originating from the j-th to the k-th point and entering the j-th from the k-th point arise in the SES.
- The probability of an agent transferring resources controlled by him is determined by the probability of his performing the corresponding conditioned actions.

An action is an act of converting a resource base controlled by a person, as a result of which resources appear (are created) and disappear (are spent), change their form, spatial–temporal and social localization.

- The probability of an action depends on the information received by the agent before the action, the need for certain resources and its resource base—based on this, subjective assessments of stimuli, limits and the probability of consequences of the action are formed, which determines the probability of the action.

- The information received by a person is determined by the activeness of agents interacting with him and the interpretation of messages obtained from them, a set of formal and informal rules (the institutional environment of interaction), as well as auto-information—information formed by the person himself based on the information he received earlier to eliminate the uncertainty of the situation.
- The activeness of the agents is realized by sending messages through the selected channels. These messages are interpreted by the recipients in accordance with the alphabet they use, which leads to the appearance of information in the subjective subspace of these SES participants and, accordingly, the divergence of the behavior vector and their performance of certain actions.

Thus, considering the activeness of agents in the calculation, in particular the messages transmitted and received by the participants, we can determine the change in the behavior of agents receiving messages. And this, in turn, allows you to calculate the probability of their performing certain actions and, correspondingly, the resource flows emanating from them. The resource flow $\breve{R}_{\Omega}(t)$ entering the social system Ω will be equal to the sum of the resource flows coming towards this system from all k-th points of the SES:

$$\breve{R}_{\Omega}(t) = \sum\nolimits_{k} \hat{R}_{\Omega}^{k}(t) \tag{1}$$

Let us take a closer look at the mechanism of the impact of messages transmitted by active agents on the behavior of agents and, accordingly, the probability of resource transfer.

The behavior of an agent is the probability of certain conditioned actions being performed by him. In the model, behavior is considered by way of the behavior vector $B(O)$—a matrix of dimension $1 \times n$, each member of which determines the probability of a person performing the n-th action from the basis of the behavior vector O:

$$B(O) = (p(o_1), p(o_2), ..., p(o_k)), \;\; o_k \in O \tag{2}$$

Based on the analysis of information about human behavior [17, pp. 422–432], it was determined that it is equal to the probability of choosing an action, based on an assessment of the significance of resources received and lost when performing an action—stimuli and limits. It is essentially important to consider the dualism of action—a person not only decides which action to perform, but also chooses between “doing” and “not doing”, and for “not acting” there are stimuli and limitations that need to be taken into account in the calculation. For applied tasks, the value of the behavior vector component can be calculated using a simplified formula:

$$p(o_k) = \frac{S(o_k) + L(\neg o_k)}{S(\neg o_k) + L(o_k)} - 1 \tag{3}$$

where $p(o_k)$ is the probability of a person performing the action o_k; $S(o_k)$, $S(\neg o_k)$ are the total stimulus for action o_k and not the actions $\neg o_k$; $L(o_\mathrm{k})$, $L(\neg o_k)$ are the total limit for actions o_k and not the actions $\neg o_k$. The values of cumulative stimuli and limits are calculated as follows:

$$S(o_k) = \sum_m s_m(o_k),\ L(o_k) = \sum_n l_n(o_k) \tag{4}$$

$$s_m(o_k) = \left(\frac{r_{m\ hav.j} + r_{m\ rec.j}\, p(r_{m\ rec.j}, o_k)}{r_{m\ need\ j}}\right)^{\gamma_j} \tag{5}$$

$$l_n(o_k) = \left(\frac{r_{n\ need\ j}}{r_{n\ hav.j} - r_{n\ los.j}\, p(r_{n\ los.j}, o_k)}\right)^{\gamma_j} \tag{6}$$

$$p(r_{m\ rec.j}, o_k) = \frac{\nu_{rec.j}}{\nu_{rec.j} + \nu_{not\ rec.j}},\ p(r_{n\ los.j}, o_k) = \frac{\nu_{los.j}}{\nu_{los.j} + \nu_{not\ los.j}} \tag{7}$$

where $s_m(o_k)$, $l_n(o_k)$ are the stimulus-motive and limit-motive for action; $p(r_{m\ rec.j}, o_k)$, $p(r_{m\ los.j}, o_k)$ are the probability of obtaining and losing resources as an effect of the action (depends on the conditions of interaction—the behavior of active participants, the institutional environment); $\nu_{rec.j}$, $\nu_{not\ rec.j}$, $\nu_{los.j}$, $\nu_{not\ los.j}$, are the number of cases known to man of receipt, loss, non-receipt and non-loss of resources due to the fulfillment of an action o_k; γ_j are the coefficient of nonlinearity, depending on the characteristics of a person (for more information, see [17, p. 148]).

It is worth noting that the calculation of cumulative stimuli, limits, stimuli-motives and limits-motives for action is shown. For "non-action" values are calculated similarly.

We introduce an axiom defining that at any given time there is a nonempty set of conditioned actions of the *j*-th agent: $\forall t \exists O_j(t) \neq \emptyset$. Since an action is an act of converting resources, at any moment a person somehow uses the resources available to him, moreover, he spends part of the resources, and uses part without reducing their number, but at the same time he does not have the opportunity to carry out other actions that require these resources. At the same time, it should be considered that any action is accompanied by the transmission of a message to agents interacting with a person. Then, at any time, the resource base controlled by the participant is converted and flows of resources and messages flow from it towards the agents receiving resources and messages through the transmission channels selected by the active agent:

$$\forall t \exists o_n \in O_j(t),\ o_n : \left\{\Delta R_j, \hat{R}_j^k, \hat{M}_j^k\right\} \tag{8}$$

Messages are a set of signals by which a person encodes the transmitted information in accordance with the alphabet he uses. The alphabet of the *j*-th agent M_j is a matrix that defines the signals used. Signals are a set of primary elements of information (symbols, image, sound, color, etc.) applied to encode meaning when transmitting messages. Each signal μ_n, in accordance with the way of thinking of the *j*-th agent, determines the information that contributes to the fact that the *k*-th participant, after receiving the message, will transfer certain resources in exchange for the resources received from the *j*-th agent:

$$\mathrm{M}_j = \{\mu_1,\ \mu_2,\ \ldots,\ \mu_n\},\quad \mu_n : \mu_n \rightarrow \left\{\breve{R}_j^k,\ \hat{R}_j^k\right\} \tag{9}$$

From the viewpoint of the agent interaction in the SES, the meaning of any message is a set of stimuli and limits for performing certain actions or, in another way, a translatable vector of behavior.

The message flow $\hat{M}_j^k$ transmitted by the *j*-th agent to the *k*-th agent is formed based on his ideas about the perception of signals by the *k*-th agent and the resources desired by him:

$$\hat{M}_j^k(t) = \mathrm{M}_j \times \tilde{B}_j(t) \tag{10}$$

and the values of the elements of the signal selection matrix $\tilde{B}_j(t)$ depend on the resources needed by the *j*-th subject and his idea of the behavior vector of the message recipient in the basis of signal interpretation:

$$\tilde{B}_j(t) = \varphi\big(B_j(O),\ R_{j\ need}(t)\big) \tag{11}$$

In a simplified version, the elements of the matrix $\tilde{B}_j(t)$ are binary (1 or 0), that is, choosing or not choosing a certain signal from the alphabet to form a message.

The alphabet and, consequently, the understanding of signals is formed in a person during his activity as a result of receiving or not receiving resources after performing actions.

Once at the *k*-th point of the SES, the message is converted into information $\breve{I}_k(t)$, which influences the behavior of the *k*-th agent—a set of stimuli and limits for certain actions. It is important to emphasize that the message is an invariant in the SES, and the information received arises in the subjective subspace due to the interpretation of the message by the agent in accordance with the alphabet of the *k*-th agent M_k. Moreover, all messages received from all *j*-th agents at the time of decision-making matter:

$$\breve{I}_k(t) = \phi\Big(\sum\nolimits_j \breve{M}_k^j(t),\ \mathrm{M}_k\Big) \tag{12}$$

Accordingly, the change in the behavior vector $\Delta B_k\left(O_k,\ \breve{I}_k(t)\right)$ at time *t* under the influence of information $\breve{I}_k(t)$ is a matrix of dimension $1 \times n$, each element of which is a divergence of human behavior [21]:

$$\Delta B_k\left(O_k, \breve{I}_k(t)\right) = \left(divB_k^1(O_k),\ divB_k^2(O_k),\ ...,\ divB_k^n(O_k)\right) \tag{13}$$

$$divB_k^n\left(O_k, \breve{I}_k(t)\right) = \left(\frac{\partial B_k(o_n)}{\partial s_1(o_n)} + \cdots + \frac{\partial B_k(o_n)}{\partial s_x(o_n)} + \frac{\partial B_k(o_n)}{\partial l_1(o_n)} + \cdots + \frac{\partial B_k(o_n)}{\partial l_y(o_n)} + \right.$$
$$\left. + \frac{\partial B_k(o_n)}{\partial s_1(\neg o_n)} + \cdots + \frac{\partial B_k(o_n)}{\partial s_x(\neg o_n)} + \frac{\partial B_k(o_n)}{\partial l_1(\neg o_n)} + \cdots + \frac{\partial B_k(o_n)}{\partial l_y(\neg o_n)}\right),\ o_n \in O_j \tag{14}$$

And the vector of the agent's behavior at time t is defined as follows:

$$B_k(O_k, t) = B_k(O_k, t_0) +$$
$$+ \left(\int_{t_0}^{t} divB_k^1\left(O_k, \breve{I}_k(t)\right)dt,\ ...,\ \int_{t_0}^{t} divB_k^n\left(O_k, \breve{I}_k(t)\right)dt\right) \tag{15}$$

If the information received by the *k*-th agent due to the interpretation of messages received from active agents creates the necessary divergence of the behavior vector, then he will perform the necessary actions and there will be a resource flow from the *k*-th towards the *j*-th agent (or the social system under consideration).

The state of the company, in particular the totality of organizational resources, social institutions structure the behavior of its participants, which determines the activeness of the system in the SES. And its activeness in an environment with a certain state determines the response of the environment—IRF, part of which is incoming cash flow.

5 Discussion

The statement that the presented approach makes it possible to describe any phenomena and processes in any social systems is based on the observations and thought experiments of the author, as well as on the experience of decision-making in the management system of the Group of companies "Delicate Moving" (www.pereezd.ru) for more than 13 years. Now this is a hypothesis, and it certainly requires verification, which will be done in subsequent works.

The developed approach makes it possible to calculate the company's activeness in the SES as the total activeness of its participants. This makes it possible, using the agent-based modeling method and the laws of the social system's dynamics in the SES, to calculate the change in the activeness of agents receiving messages from the company, which makes it possible to compute the change in resource flows in the SES, including the incoming resource flow of the social system, which is the reaction of the environment to the company's activeness. At the same time, the activeness of the company is determined by the parameters of the system, and the trajectory of movement reflects the change in the values of the parameters over time. Thus, it becomes possible to calculate the reaction of the environment to a change in the company.

For such a calculation, reference information is required—parameters of information transmission channels (a set of agents receiving information through the channel, subsets by types of perception and life situations in which they are located, messages of other agents transmitted through this channel, distortions that the channel introduces into the transmitted messages); parameters of agents (the alphabet they use, the resources they have, the resources they need, as well as the behavior of agents in the basis of conditioned actions that determine the choice of a channel for obtaining information in various life situations, as well as the interpretation of signals used by the company to generate messages). It is also necessary to ensure that the content of messages received by these participants from the company and other active agents is recorded. They should be converted, using reference information (the alphabet of agents, their vector of behavior in the basis of conditioned actions for interpreting messages, etc.), into the values of stimuli and limits associated with certain actions (the translated vector of behavior) and based on this, the impact of the company on the environment is calculated. Accounting the activeness of agents in the company's information system will make it possible to predict changes in the state of the social system due to the reaction of the environment to its impact.

6 Conclusion

The developed model uses measurable entities, and dependencies involve operations on sets, differential and integral calculations, which makes it quite easy to implement computational algorithms. It is comprehensive and allows one to simulate the processes of interaction of agents, as a result of which it makes it possible to simulate the evolution of a social system in the SES, determined by the activeness of economic agents, as a change in the values of phase variables reflecting the state of the system. The simulation result, of course, will be probabilistic type, but the accumulation of data will gradually increase the precision of the calculation. The mechanism given in the paper takes into account the impact of any agents and the precision of calculations is determined only by the computational capabilities of the subject of management, as well as the availability of the above-mentioned reference information. To produce such information, it is advisable to organize research programs that allow obtaining information about the parameters of various types of agents. This is certainly significant work, but the availability of such information will significantly improve the precision of control actions, which will certainly lead to significant resource savings.

The developed model can be used to build a digital twin to the social system, which, in turn, can be utilized in decision support systems to model the consequences of managers' decisions. The accumulation of information about the values of the parameters of agents who are participants in the social system, about the resource base used, as well as the fixing of formalized and non-formalized rules of interaction in the digital twin will allow not only calculating control actions more precisely, but also ensuring continuity when changing managers, which will promote the sustainability of the functioning of companies.

The digital twin can also be used for the development of scientific activities. In particular, for the theoretical study of organizational pathologies (undesirable states of the social system characterized by a decrease in the speed of development of the organization) and possible ways out of crisis situations of social systems. In addition, it becomes possible to calculate SES parameters by modeling the dynamics of enterprises with known values of phase variables and comparing them with observed phenomena. This allows us to talk about the development of theoretical economics (by analogy with the development of theoretical physics at the beginning of the twentieth century).

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Networking in the Platform Development of Ecosystems

Svetlana Tsohla and Nataliia Simchenko

Abstract The article focuses on the issues related to the networking in the platform development of ecosystems based on the analysis of the experimental transformation of network structures in governance following the principles of the new systemic approach. The problem of networking is setting on the basis of platforms and varieties of the organizational structures according to the type of governance. The platform basis of the network structures development in governance has been rationalized from the methodological perspective and exemplified by such kinds of networks as distribution, franchise and outsourcing. The network structures are characterized by efficient performance and appeal for the potential participants willing to be integrated, which explains their expansion and popularity. The digitalization gives new opportunities to the companies which make for the use of the innovative forms of production, consumption and exchange via digital cooperation. New digital structures eliminate barriers between the industries, create potential for cross-functional products and service development. The results of the networking in the platform development of ecosystems confirm the experimental nature of the transformation in the network structures in governance, which makes the ground for further elaboration of the methodology applied for the systemic analysis in the ecosystems' economy development.

Keywords Ecosystem · Networking · Platforms · Organization structures of management · Experiment of networking

1 Introduction

Theoretical basis of the digital economy is developing under a new paradigm of networking in the ecosystems. The concepts of ecosystems are in focus of prominent scientists, international organizations and national governments worldwide. On the one hand, in many international publications the ecosystem is considered

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from the viewpoint of sustainability in the circular economy. The experts estimate that overall population growth leads to the increasing number of consumers and greater resource consumption required for sustenance. It is crucial to differentiate between the prospects of economic growth and prospects of raw materials and energy resources consumption. New technologies and transition to the circular economy provide for the opportunities and advantages of ecologically responsible growth when the resources are limited [2].

The research into the circular economy carried out by BEROC scientists provides evidence that R-imperatives lead to emergence of multiple risks which are inevitable and result from the different development patterns around the globe. Evidently, an effective tool to prevent possible conflicts may be differentiated responsibility attributed to different countries; respectively, the most developed ones will dominate in the development of circular systems whereas the developing ones will have to reassess the strategies and methods they use to address the current challenges while focusing on the introduction of circular economy models [6].

2 Literature Review

Current scientific papers encompass issues on the formation and development of entrepreneurial ecosystems which create new consumer value and emerge as transitional structures between a company and a market [1, 7–10, 12, 18]. Current conditions contribute to the greater interest in the study of network structures in managing technological business projects among the researchers in the global science; the competitive advantages of such projects are determined by an innovative digital (high-tech) idea. For instance, the research team of Danube University Krems (Austria) suggested a classification of the key indices of the digital entrepreneurship efficiency in order to identify its impact on the multidimensional digital transformation of the economic processes. Additionally, they carried out critical analysis of the digitalization and digital entrepreneurship indices taking into account the three dimensions of the modern innovative system: the entrepreneur, the entrepreneurial activity and the ecosystem [19].

In many cases, the best strategy for platform growth may be joining different networks with one another. The success of any platform business depends on attracting a big number of users and data collection on their interactions. Such assets remain valuable in a number of scenarios and on different markets. Companies using them and successful in one of the market segments often diversify their business and improve their economy [22].

3 Methodology

The study of the conditions for networking in the platform development of ecosystems was based on the use of analytical methods for reviewing the scientific interdisciplinary literature of the Scopus and Web of Science databases for the development of ecosystems and their impact on the economic development of organizations. The authors use the methods of organization analysis of digital transformation of networks, platforms and governance structures in specific companies, as well as methods of integration of heterogeneous economic data on the development of economic relations in the development of platform ecosystems.

4 Results

4.1 New Network Structures in Governance

The multiple interconnections in business processes are regulated through the organizational structure in order to create the company's most efficient mode of operation. The organizational structure is often designed in accordance with the governance principles set by the company. There are different kinds of organizational structure design which have developed and keep developing as the scale of the company development increases, the goals change and the external environment transforms (see Fig. 1).

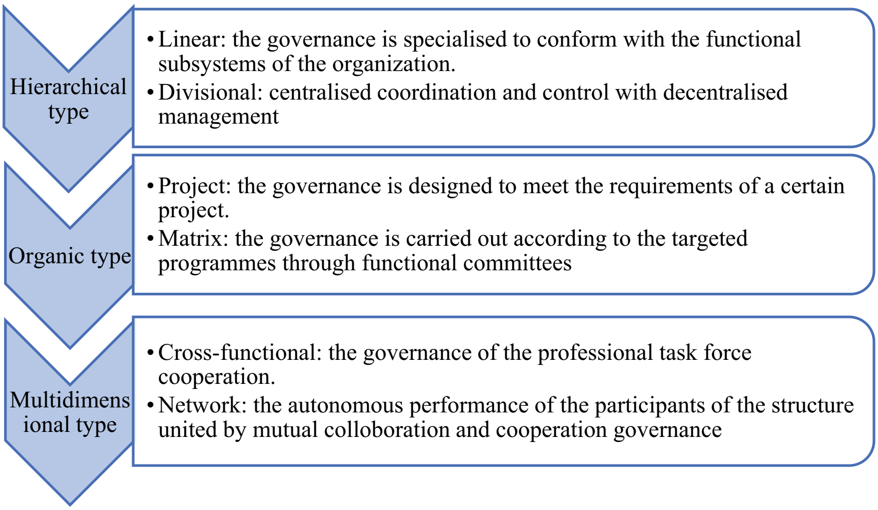

Fig. 1 Varieties of the organizational structures according to the type of governance

The hierarchical type of the governance structures which comprises the linear-functional and divisional governance structures defines the governance organization of the diversified companies for the purpose of their business diversification in the dynamically changing environment. Their implementation in big corporations requires giving certain independence to the business subdivisions.

The global market of goods and services leads to strong competition between the companies, high efficiency and quality of service and quick reaction to the external changes.

The formation of the organic governance structures (project, matrix) implies organization of the targeted functional cooperation between the internal subdivisions combined with project governance. Implementing them in national and transnational corporations allows changing the organizational form while adapting to the changing market environment.

The modern level of sensitivity to the changes in the environment and flexibility in the reaction to them contributes to the emergence of new upgraded organizational structures.

The multidimensional type of the organizational structure (cross-functional, network) is characterized by the multivariance and makes the foundation of the flexible approaches to the organization structuring and ability to react to the internal and external changes. Their implementation allows setting the mode of shared responsibility as per the structure elements, coordinate program execution and performance of the company's branches and regional offices [17].

Each organizational structure of any type displays a number of advantages which play an essential part in the company's performance once it has been implemented and, similarly, each structure has certain flaws which can become a determining factor when changing the organizational form.

The organizational structure always complies with the principles of the company's performance. As such, a structural organization does not guarantee strong performance and success in business, but it is targeted. When the business environment, internal or external factors change, new ideas have to be introduced for the sake of further efficient development.

4.2 Platform Base of the Network Structures Development

The companies responded to the modern-day challenges and desire to monitor the ongoing changes in the market by conducting experiments aiming at governance improvement and finding new organizational forms.

Network cooperation helps to find opportunities for building partnerships, start joint enterprises and define trajectories for business expansion. Various forms of cooperation allow developing multiple network structures characterized by different levels of administration and make beneficial connections within the framework of the internal cooperation as well as the cooperation between companies and groups of companies. The joint companies specialize in performing certain functions or doing certain kinds of activities when implementing the networking.

The most common kinds of networks are the following ones:

- distribution network, when the main company creates special conditions for cooperation whose goal is distributing goods by separate distributing companies;
- franchise network, it is a special form of partnership between the participants acting on certain purpose under the name of the franchiser;
- outsourcing network, it is a special form of partnership between companies focusing on performing separate functions (work and services).

Network structures are highly economical and attractive from the perspective of integrating participants, which, therefore, has provided for their spread and popularity.

The transition to the new technological mode and digital transformation of the economy have created environment for emergence of network organizations with a virtual structure. The digitalization opens up new opportunities for the companies which allow implementation of new forms of operation, consumption, cooperation and exchange via digital cooperation.

New digital structures break down sector-specific barriers and reveal prospects for cross-functional products and services.

Such a kind of structure is based on cooperation between independent functional partners from different sectors or functional areas through active use of modern information technologies which broaden the horizons of distant cooperation.

The companies do not differentiate between the internal and external members. The participants of such kinds of cooperation act as a team that has been formed according to the respective competences for further distribution of tasks targeting the creation of a unique product. Within the framework of the virtual network model all the stages of making a unique product turn into a complex of services provided for cooperation. All networks comprise a range of interactions among participants, a focus on governance involves the use of institutions and structures of authority and collaboration to allocate resources and to coordinate and control joint action across the network as a whole. The governance is fueled by the technology of work coordination by means of implementing general standards, rules and processes. The partners are constantly involved in the process of information exchange, take collective decisions and use both internal and external fixed and virtual assets. Researchers believe that external network effects are caused by "innovations being based on communication" and the fact that "stronger connections and integrity enhance growth indices" [15].

The attractiveness of integrated information structures is explained by the high economic indices, professionalism of the participants and effectiveness of the network organization. The interaction processes are conducted on the platform base.

The implementation of the platform model includes definite stages of the startup and activation plan:

- Development of a workable organizational structure;

- Implementation of the lean production and flexibility concepts;
- Elaboration of an adequate strategy of market placement.

Experts state that platforms perform better in both short- and long-term periods according to the key financial parameters. Companies only dealing with platforms or such that mostly do platform-based business have average income which is the multiple of 8.9 [14].

The network platform as a part of the technology and software connects all the participants of the partnership for the purpose of creating mutually beneficial possibilities. The practicability of the platform is proven by the network effect and intergroup external effects.

Platforms are multifaceted and their development may take unexpected turns. Their key function is to play an organizing role in creating multidimensional values by completely integrating the abilities and needs of the participants as well as by building up a powerful governance of the whole system. The marginal utility the end consumer gets on the platform is affected by the increase in the number of members in another group of end consumers (e.g., customers) on the platform. Eventually, a platform works as a multiplicator for its network.

Successful platforms provide for more effective exchange by reducing transaction costs. However, not all the network projects are successful. Some platform networks fail to reach the scale or never bring profit and disappear; in other cases, should the right business strategy have been selected, a platform can become successful at a later stage of development [4]. Due to this fact, each separate integration is created to be unique and special. The organizational principle is adopted through modelling a new network and is tested, as a rule, by carrying out an experiment.

According to some researchers, the organizational structure of the company affects the way the tasks are completed and the problems are solved. Using an experimental platform for structuring a company can help reveal the problems caused by manipulating the network structure for the sake of increase in performance [21]. With greater experience and working knowledge of the benefits of network structures, as well as an understanding of what outcomes can be expected, decision makers may be more prepared to make changes [11].

The greater is the diversification of the cooperation, the greater impact has the formation of multidimensional platforms responsible for the production and implementation processes. Scientists have to cope with structural issues, such as characterizing the topology of a complex wiring architecture, revealing the unifying principles that are at the basis of real networks, and developing models to mimic the growth of a network and reproduce its structural properties [3].

In the digital economy, the cross-sectoral interaction of structures is based on the digital platforms development [20]. Due to digital platforms, companies reach another scale in terms of almost unlimited numbers of customers, artificial intelligence technologies and other tools providing for high quality. In some situations, platforms may take advantage of their big user database to attract even larger number of users due to the integration of separate extra functions. There are well-known

Table 1 Network organizations with a complex of service offerings for different segments

Country	Company and services
China	WeChat: financial, domestic and government services
Indonesia	Gojek: food delivery, taxi, courier service, financial services
Japan	Line Corporation: logistics for restaurants, food delivery, payment system
Russia	Yandex Go: taxi, carsharing, public transport, shipping services, food delivery and delivery from restaurants
Singapore	Grab: taxi, food and parcel delivery, bike and scooter rentals, credit arrangement, payment system, online healthcare, insurance
USA	Uber: taxi, carsharing, payment system, food and goods delivery

examples of successful network organizations which managed to establish multilateral relations and develop a complex of service offerings for different segments (see Table 1).

The scale of use is one of the main features of any big active platform offering their service to different kinds of end customers. The global survey revealed that there are 176 platform companies around the world whose market value is over 4.3 trillion US dollars [5]. In the OECD countries, the COVID-19 pandemic caused a surge in the use of online platforms; in the segments that do not require personal presence the increase in traffic amounted to 20%. In the countries with better developed digital infrastructure and higher level of digital literacy there was an even steeper increase in the indices. This may serve as evidence that investments in such opportunities can be a way towards developing better resistance to economic upheavals in the future [16].

At the present time, general statistics does not give a clear-cut and full answer to the key questions regarding the role, nature and size of platforms. Defining the economic capacity of the organization of the network structures engaged in platform interactions is a complex task due to the scale of cross-sectoral and transborder potentials and their fast and dynamic development.

In McKinsey's opinion, the influence of platforms will only accelerate [13]. When estimating the prospects related to platforms, companies have to analyze the key properties of networks that they are going to use and consider the ways to enhance the network effects.

Therefore, the results of the experiments that have been performed allow outlining specific advantages of network structures in governance and detecting the weak spots of the network companies when building up a new platform organization.

5 Discussion

The challenges arising from studying the forms of networking in the platform development of ecosystems are explained by the dominance of the platformization processes in the economic relations. "The new systemic approach" is marked by certain permanent systemic transformations in the system structure; thus, judging by the inherent properties of the methodologies applied in the hierarchical and networking topology of the systems, we may conclude that the conventional principles of the system theory are subject to deep-rooted changes related to the antecedence of the functions and the subordination of the structure. Therefore, the traditional approach to the generation of the economic value of benefits in the economics has been radically changed as it is based on the development of network effects. It is essential to take into account the principles of the 'new' systemic approach in the process of ecosystem activity regulation and their sustainable independent performance over a long period of time from the perspective of designing new network structures in governance.

The above scientific challenge originates from the need to find solutions to the growing social and economic problems related to the systems losing their stability, increasing intellectualization and dematerialization of technologies in the digital environment. The unprecedented development of digital technologies results in the dramatic changes in the concept of the society's sustainable development, makes a considerable impact on the structures of the economic systems, which, consequently, leads to the reinterpretation of the prospects of the economic growth as well as raw materials and energy resources consumption. The building-up discrepancies between the digital technological development and the economic systems losing their sustainability calls for the introduction of new platform-based business models and stimulation of the new network structures development in governance based on breakthrough information technologies, which will allow creating new workplaces. Thus, the relevance of the research lies in the theoretical and methodological rationalization of the digital economy development according to the principles of the 'new' systematic approach and transformation of the network structures in governance.

6 Conclusions and Future Research

The research in the field of networking in the platform development of ecosystems allowed to determine the experimental nature of the transformations happening in the network structures in governance based on the principle of the new systemic approach. The platform base of the network structures development in governance has been methodologically rationalized and exemplified by such kinds of networks as distribution, franchise and outsourcing networks. The network structures are characterized by low-cost performance and integration benefits for the participants, which has led to their expansion and popularity. Digitalization opens up new opportunities for companies as it encourages use of innovative forms of production, consumption, cooperation and exchange via digital cooperation. New digital structure overcome cross-sectoral barriers and contribute to the development of cross-functional goods and services. As in the course of the research dedicated to the networking in the platform development of ecosystems the experimental nature of the network structures transformation in governance has been confirmed, it enables further methodological elaborations in the systemic analysis applicable to the development of economic ecosystems.

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Digital Ecosystems in Industry: Conceptualization and Strategic Aspects of Development

Anastasia Nikitaeva and Roman Serdyukov

Abstract The economic, social, and technological processes accompanying Industry 4.0 and leading to revolutionary changes in society have led to a sharp decrease in the effectiveness of organizational forms of the previous decades. New conditions and the operating environment of enterprises in the industrial segment of the economy, coupled with new technological capabilities, initiate the emergence of new forms of organizations. Methods of scientometric and content analysis were used in the paper to prove that digital ecosystems occupy an important place among such forms. The paper presents a comparative analysis of three core approaches to conceptualizing the category "digital ecosystem". An analysis of the thematic literature was carried out based on the study of the "Web of Science" database. As a result, it was revealed that most of the research is devoted to the technological component of digital ecosystems. At the same time, the establishment of effective digital ecosystems requires the disclosure of their economic and organizational aspects. The paper defines the main criteria and areas of activity for building a digital ecosystem of an industrial enterprise. It enabled us to give examples of measures of supporting and stimulating industrial digitalization through the transition to digital ecosystems.

Keywords Digital ecosystems · Industry 4.0 · Digitalization of industry · Ecosystem model of industrial development · New forms of economic organization

1 Introduction

The fourth industrial revolution (Industry 4.0) is revealed throw various technological, social, economic processes. It is supported by the various strategies of new industrial development. It leads to the formation of new conditions, factors, challenges,

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and opportunities for economic development. On the one hand, the old forms of organization of activities are becoming ineffective, and inadequate to the new economic conditions. On the other hand, cutting-edge digital technologies and the digital transformations associated with their use open up new opportunities for organizing the activities of economic players.

The increased role of information technologies and awareness of the benefits of their use makes them the main driver of organizational transformations. It covers not only industrial enterprises, but also the economy as a whole. However, for the industry, digitalization is a critical tool for increasing production efficiency. The significant expansion of digital technology capabilities and the risks associated with their emergence and spread, have led to an increase in the complexity of business, the formation of a new environment for its functioning, the emergence of fundamentally new business models, as well as new ways of organizing the value creation process [3]. Digital transformation actually changes the DNA of manufacturing structures [7]. Based on this, one of the main issues of economics is the search for new forms of economic organization and ways to transition to them. To remain competitive and continue to develop, enterprises need to evolve and adapt their activities to the conditions of the new operating environment. The response to the presented changes was the formation of a new ecosystem model for the development of economic actors. This is due to a change in the nature of the relationships between market entities to a more flexible one; transformation of the value chain, when traditional linear value chains are replaced by distributed digital value chains; blurring the boundaries between the real and virtual world, as well as the formation of cyber-physical and intelligent systems [27].

The establishment of digital ecosystems is becoming a response to these challenges. At the same time, the balance of digital ecosystem research is currently shifting to the technological dimension. This occurs while it is already understood that an organizational and economic strategy for the transition to digital ecosystems is required. At the same time, the conceptualization of digital ecosystems in industry and the theoretical design of methods and mechanisms for their formation are necessary. This paper is aimed at these research objectives.

2 Literature Review

The Fourth Industrial Revolution and the large-scale transformations of society associated with it in the last decade have been researched by many scientists. Industry 4.0 or the fourth Industrial Revolution is a new approach to production and a new stage of maturity of manufacturing companies, characterized by the mass introduction of advanced technologies that form new cyber-physical systems that connect all processes and subsystems of the company with each other, ensuring the integration of business and industrial manufacturing [4].

Industry 4.0 affects all spheres of human life, having a significant impact on its economic, environmental, and social aspects [11]. The highest degree of digitalization, automation, virtualization and decentralization is predicted for industry [11].

During the study of Industry 4.0, the subject/object focus of its conceptualization has been shifted. If in early studies the definitions of Industry 4.0 were focused on manufacturing processes (digitalization of production), then in later scientific research, attention is paid more to the paradigm shift towards the digital transformation of value chains in industry [11]. Following this logic, Industry 4.0 is nothing more than digitalization of the processes of creating and delivering value at all levels [11]. It is actually about the formation of "a hyper-connected system of smart materials, components, equipment, focal factories, suppliers, distribution channels, and even customers" [11]. This hyperconnected system is the basis of a new ecosystem model of the organization of the economy, forming a digital ecosystem of the enterprise.

Digital ecosystems have recently become the subject of research in the economic sphere. At the same time, the very concept of "ecosystem" has been studied for a long period of time in global scientific literature. An analysis of a wide range of studies and publications indicates that there is no single approach to the definition of the concept of "ecosystem". The variety of definitions of the term "ecosystem" is due to different approaches to its study and modeling.

The ecosystem model of interaction comes from the evolutionary theory in biology [17]. The term "ecosystem" was first introduced in 1935 by the British ecologist Arthur Tensley and meant any combination of interacting organisms and their environment [32]. Much later, the term ecosystem was borrowed by the social sciences.

G. Kleiner understands the socio-economic ecosystem as "a localized complex of organizations, business processes, innovative projects and infrastructure entities capable of long-term independent functioning due to the circulation of resources, products and systems" [18].

In the context of Industry 4.0, ecosystems acquire a new dimension associated with the digital transformation of the economy. The category "digital ecosystem" is emerging.

As with the diversity of ecosystem definitions, there is also a diversity of definitions of the term digital ecosystem. Digital ecosystems have become widespread in various fields of economics, simultaneously being an interdisciplinary value, as evidenced by a wide range of scientific papers from different fields of knowledge, such as biology, economics, IT, sociology, and philosophy.

The analysis of studies devoted to the study of digital ecosystems in the economy allows us to identify three main approaches to their definition.

The first approach is a digital ecosystem as a digital analogue of biological ecosystems. The use of the concept of "ecosystem" has been used both to describe biological systems and socio-economic systems, which is explained by a number of similar characteristics, such as: structure, functions, principles of functioning, conditions for interaction and exchange of resources with the external environment. However, in economic systems, unlike biological ones, the relationship between the elements is characterized by great mobility and flexibility. In economics, the term "ecosystem" became widespread in 1993 after it was applied to business ecosystems in James Moore's work "Predators and Victims: The new ecology of competition" [22]. According to James Moore, the business ecosystem is "dynamic and co-developing communities consisting of diverse actors who create and receive new content in the process of both interaction and competition" [24]. Moore includes the business community, which consists of a company, its consumers, suppliers, market agents, channels of movement of goods, owners and other interested parties, public and private organizations, competitors, as part of the elements of the ecosystem [23]. Drawing an analogy with biological systems, the scientist argued that the interests of consumers, as well as the growth of capital and investment, underlie the birth and functioning of business ecosystems. The continuity of some properties of biological ecosystems by economic (business, digital) ecosystems, namely: reliability, self-organization, and self-management, scalability, the ability to provide complex solutions to complex and dynamic tasks, as well as the automatic composition of these complex solutions is reflected in the works of Gerard Briscoe, Simon Levin [6, 20]. Subsequently, Moore's interpretation of the ecosystem was supplemented and expanded by Ron Adner.

He highlighted conditions that make an ecosystem economic. According to the scientist, an ecosystem is a "multilateral set of partners who must interact to realize the main value proposition" [1], and the conditions for the formation of an economic ecosystem are the presence of economic relationships, competition between enterprises, and the presence of stakeholders directly or indirectly interested in the development of the economic ecosystem [1]. The idea of biological continuity is also reflected in the works of Janine Benyus. In her opinion, a huge amount of experience and solutions to many project tasks have been accumulated in nature [5]. It can also be applied to digital ecosystems.

The second approach is related to the consideration of digital ecosystems as the new (more mature) evolutionary form of business ecosystems. In the context of new realities and widespread digitalization, an increasing part of the business is moving into the digital space, digitizing the concept of business ecosystems. As a result, digital business ecosystems combine both digital and business ecosystems.

Business ecosystems have been extensively studied by scientists from different research perspectives (including strategy, competitiveness, supply chains and other stakeholders, platform management, new enterprises, etc.) [13].

Ron Adner and Rahul Kapoor define a business ecosystem as an interdependent and complementary space that includes a dominant firm and suppliers, customers, competitors, and complementary companies from various industries [2]. Paul, Reeves, Schussler specify that within the framework of such interaction, products or services are created that together make up a common solution [30].

Marco Iansiti and Roy Levien define business ecosystems as "free networks of suppliers, distributors, outsourcing companies, manufacturers of related products and services, technology providers and many other organizations that influence the creation and implementation of the company's own proposals" [15]. Graza and Camarinha-Matos define business ecosystems as joint network organizations united by long-term strategic intentions and including virtual elements [12]. The digital nature of business ecosystems is evident in the definition of Jacobides M. The scientist points out that ecosystem partners "are digitally networked, have modular architecture, and are not controlled by hierarchical structures" [16].

Based on the analysis of the aforementioned definitions, it can be concluded that each participant of the digital business ecosystem is involved in the process of creating value, and the value itself is mutually created for all participants of the ecosystem. Consequently, each ecosystem participant benefits from such interaction and is motivated to continue functioning within the ecosystem. Thus, the process of value creation goes beyond the firm, its transformation takes place as a result of which, it acquires a distributed and digital character.

The third approach is related to the consideration of digital ecosystems from the perspective of a platform approach. According to this approach, the digital platform is the core around which a digital ecosystem is formed, linking its participants and internal subsystems of enterprises. In a broad sense, digital platforms are a core building block of the ecosystem, which is a virtual infrastructure that greatly simplifies the interaction between its users and the implementation of transactions between them, providing access to resources and their exchange, to create value for all participants. Gawer and Cusumano understand digital platforms as "products, services, and technologies organized into a common structure through which a company can create derivative products, services, and technologies", the scientists also note that digital platforms require the development of appropriate competencies in the field of information technology, but this is not the main competence for the industry [9, 10]. A feature of digital platforms is the strengthening of the effect of network externalities, which consists in increasing the cost of products/services and the value of the ecosystem as a whole, as the number of platform participants increases [8].

Parida, Burstrom, Visnjic, Wincent define an ecosystem based on a digital platform as a network in which the orchestrator (the owner of the digital platform) encourages/stimulates ecosystem participants to develop complementary innovations, and as a result, the network of firms shows significant interdependence [29].

Helfat, Raubitschek and Nambisan, Baron point out that an ecosystem based on a platform can be considered a digital ecosystem when it is mainly based on Internet or data-based technologies [14, 25].

Despite the high interest and a large number of studies on digital ecosystems, most of the articles is devoted to the technological component of digital ecosystems, their modeling and architecture, rather than their content and establishment as forms of economic activity organization, as well as strategies for transition to them.

3 Material and Methods

The study was conducted from the standpoint of systemic and ecosystem approaches. The methodology of this study is based on a combination of quantitative and qualitative analysis.

Based on the research of the essence of ecosystems in the socio-economic dimension, keywords were previously formed to frame the subject area. With the help of the formulation of key-words queries in scientific database, an empirical massive of data on the subject of the study was formed. The Web of Science system was chosen as an information search platform. It was determined by three main factors. First, the inclusion of a significant number of scientific publications in the database is based on strict selection. Second, the coverage in the database of publications on natural, technical, social sciences, humanities, and art (this is important because of the interdisciplinary nature of digital ecosystems). Third, the presence of built-in scientometric tools in the Web of Science. Then the generated data array was analyzed using scientometric tools. In addition to the quantitative analysis, a content analysis was performed to conceptualize the category of the digital ecosystem of an industrial enterprise.

The methodology adopted in this study is illustrated in Fig. 1.

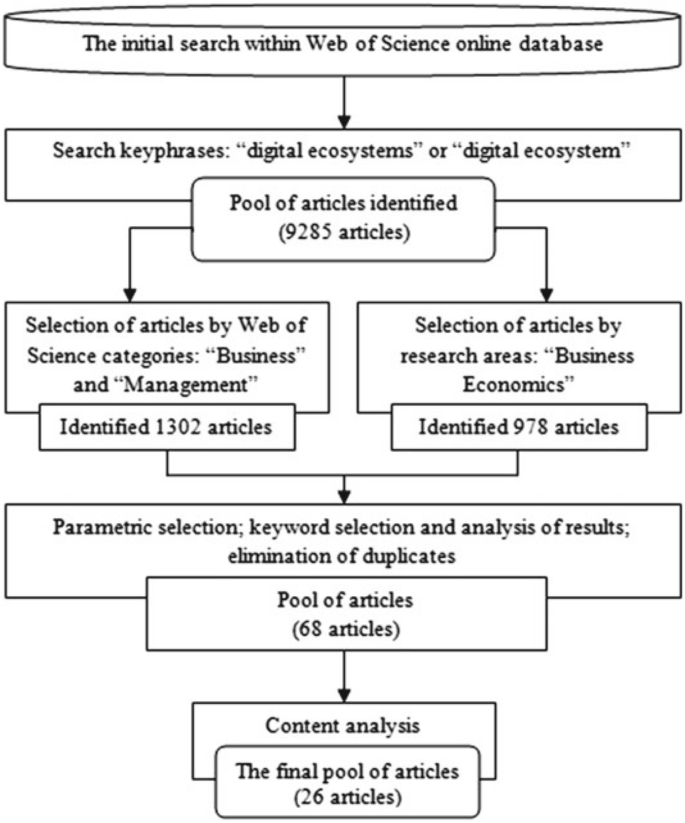

Fig. 1 Methodology overview

The use of content analysis, comparative methods, and grouping allowed us to solve several research problems. On the one hand, to identify the main approaches to the definition of digital ecosystems. On the other hand, to define the core components of digital ecosystems. It further made it possible to localize the transformation zones of industrial enterprises for the formation of digital ecosystems.

4 Results

According to the Web of Science database, there are 9285 scientific papers on the request of "digital ecosystem OR digital ecosystems", and more than half of them fall on the period 2016–2020. The analysis shows a positive trend in the number of studies (Fig. 2). If 278 papers were published in 2009, then in 2020 their number was 1273.

The interest in digital ecosystems is also confirmed by the steady increase in the citation of publications (Fig. 3). The h-index for the Web of Science metric is 131, which indicates the demand for scientific research on this topic.

Research on digital ecosystems is divided into Web of Science categories as follows (Fig. 4). The results obtained confirm the fact that more attention is paid in the literature to the technological component of digital ecosystems than to their organizational or economic component. This is also confirmed by the distribution of scientific papers by research areas, where Computer Science (2348 papers) takes the first place, Environmental Sciences Ecology (2151 papers) takes the second place, Engineering (1441 papers) and Remote Sensing (1070 papers) take the third and fourth places accordingly, and only in fifth place is Business Economics (978 papers).

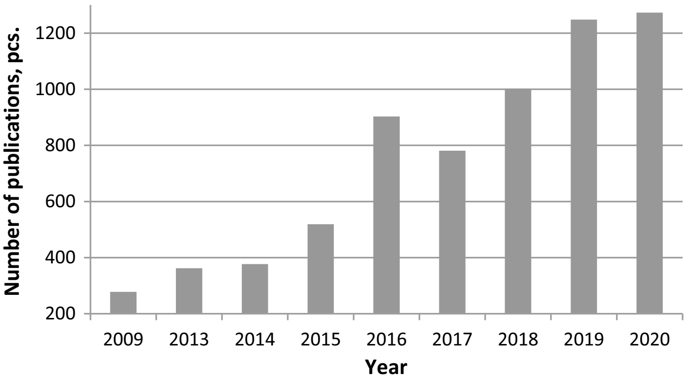

Fig. 2 Dynamics of studies in the subject area "digital ecosystem"

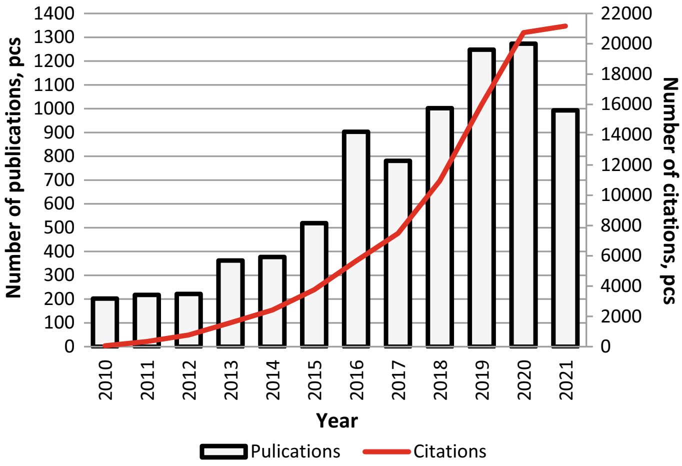

Fig. 3 Dynamics of studies and citation in the subject area "digital ecosystem"

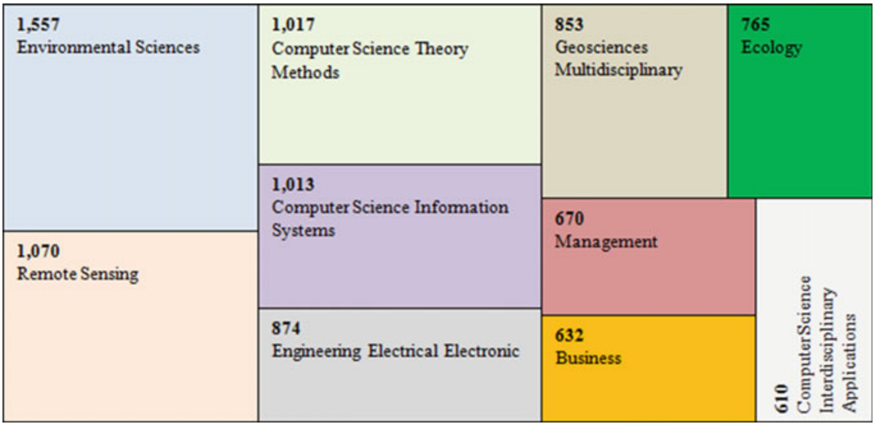

Fig. 4 Distribution of scientific papers devoted to digital ecosystems by Web of Science categories

Among these publishers are Elsevier (1459 publications), IEEE (1246 publications), and Springer Nature (1170 publications). The results obtained indicate the attention of the world's leading publications to this field of research.

According to the authors, it is impossible to strictly adhere to one of the approaches in determining the digital ecosystem, since each of them has its disadvantages and limitations. The first approach considering economic digital ecosystems as a digital analog of biological ecosystems has some limitations related to the fact that economic digital ecosystems have much greater flexibility and mobility between its elements, and also have their unique elements, which causes them to differ from biological ecosystems and the features of their functioning. The third approach, which focuses on digital platforms around which the digital ecosystem is built, is mainly technological in nature, paying attention to the architecture of platforms and the specifics of their modeling and functioning. In this case, the digital ecosystem is considered an infrastructure that ensures the interaction of parties. However, this is a rather narrow vision and understanding of the digital ecosystem, because the digital ecosystem is not a tool, but primarily a new way of organizing activities that can help adapt to the new realities of the digital economy. According to the author's opinion, not just the way of interaction between the participants changes, but the nature of interaction and the essence of the relationship between them, as well as the boundaries of organizations and the value chain. In our opinion, the second approach most fully reflects the essence of digital ecosystems. However, a more meaningful and complete definition of the digital ecosystem is possible due to the convergence of all three approaches. Only then is it possible to fully determine the content of the concept of "digital ecosystem" as an interdisciplinary value.

Based on the convergence of the three approaches, the authors define digital ecosystems as a meta-organizational form supported and interacting with the external environment and depending on its conditions, represented by a set of interacting, complementary, and interdependent participants (enterprises, suppliers, competitors, consumers). At its core is a digital platform providing technological infrastructure for their integration into the ecosystem, cooperation, and coordination, in order to implement strategic intentions, create and receive value.

Despite the high scientific interest and an adequate degree of knowledge of digital ecosystems, there is still a lack of understanding of what is necessary for the transition to digital ecosystems and how to implement it. An empirical study on the example of industrial enterprises in the South of Russia (more than 75 industrial enterprises participated in the survey) revealed an insignificant number of digital ecosystems and a low level of readiness for their implementation [28]. Digital transformation and the transition to digital ecosystems requires the organization not only to digitize their resources and activities, but also to comprehensively rethink and change its strategies, ways of interacting with stakeholders and reengineering the main processes [21]. However, it is important to understand that the strategies of the transition to digital ecosystems as the level of resource expenditure will be different for its participants. Conventionally, we can distinguish the orchestrator of the digital ecosystem, i.e. the dominant firm /owner of the digital platform around which the ecosystem is built, and ecosystem partners (suppliers, manufacturers, competitors). In our opinion, it is a priority to consider the issue of the formation of the digital ecosystem from the orchestrator's side, since the viability of the digital ecosystem and its properties depend on him.

In addition to certain actions that form a digital ecosystem, the orchestrator needs competencies and some criteria. Firstly, he must understand his target audience and their needs, and understand what can and cannot be done. Secondly, the dominant company must have an adequate level of technological and human resources. Moreover, human resources are given the main role in the digital ecosystem, since this is a perfect another personnel group with the necessary digital competencies, as they make it possible to design and build digital platforms, transition to digital ecosystems, as well as maintain its infrastructure and interactions within it. Thirdly, due to the high variability of the external environment, the orchestrator must be able to adapt quickly to its changes, as well as be prepared for risks. Fourth, since digital ecosystems contribute to the development of innovations, the orchestrator must be open and ready for them.

The strategy of transition to digital ecosystems is based on several actions:

1. Improvement of business processes and their automation
2. Digitization of enterprise resources, increasing the share of digital assets.
3. Formation of a new "digital" corporate culture and development of digital competences among staff.
4. Introduction of industry 4.0 technologies (industrial Internet of Things, artificial intelligence systems, cloud computing, and big data processing systems, expert systems, virtual and augmented reality technologies, etc.)
5. Creation of data protection systems, cyber defense.

It is also important to note that external conditions, largely emanating from government authorities, have a significant impact on the pace of digitalization of industry and the transition to digital ecosystems, for example, the approval of uniform standards, support programs, specifics, and strategies, as well as roadmaps. It will greatly contribute to reducing uncertainties when building their ecosystems, as well as facilitate access to the necessary resources. For example, in Russia, in July 2021, a strategy for the digital transformation of manufacturing industries was presented to achieve their "digital maturity" [31]. The strategy proposes an integrated approach to digital transformation based on 5 directions/projects: the Smart Manufacturing project, the Digital Engineering project, the Products of the Future project—customization of industrial products and repair according to condition, the New Employment Model project, and the transition to digital public administration project [31]. Another example is the approval of the national standard of the Russian Federation on "Computer models and modeling. Digital doubles of products. General provisions", defining the general provisions of their development and application, as well as standardizing several concepts [26].

5 Conclusion

The conducted research allowed us to draw several conclusions. First of all, in the new conditions of Industry 4.0, industrial companies need to look for new forms of organizing their activities to maintain competitiveness [19]. One of the most important forms of this type, is ecosystems that acquire a strong digital component. The conducted scientometric analysis revealed an increase in the number of studies of digital ecosystems. The research conducted using quantitative (scientometric) and qualitative (comparative, content) analysis methods revealed three main approaches to the definition of digital ecosystems of industrial enterprises: a digital ecosystem as an analogue of a biological ecosystem; a digital ecosystem as the advanced evolutionary form of a business ecosystem; a digital ecosystem as a platform. The authors justified, that digital ecosystems go beyond the technological infrastructure of industrial enterprises and practically determine their functioning and interaction with the external environment. When forming ecosystems, it is necessary not only to create a digital platform as a technological core. It is also important to build relationships with value creation participants in a new format. With this in mind, it is necessary to identify strategies and mechanisms for the establishment of the digital ecosystems of industrial enterprises. At the same time, the strategies for the formation of digital ecosystems should strictly correspond with the overall development strategy of the enterprise, changing it in the new circumstances of Industry 4.0. Moreover, the orchestrators of digital ecosystems play a particularly significant role here. The study allows us to conclude that, in practice, the formation of the digital ecosystem of an industrial enterprise should cover a set of solutions. We are talking about the reengineering and digitalization of business processes, the transition to distributed rational use of resources, the creation of digital corporate culture, the introduction of cutting-edge technologies of the digital economy, and the improvement of cyber security. We can talk about changing the entire business model of an enterprise through the implementation of an ecosystem approach to the organization of its activities. The search for drivers, tools, and enables for the transition to digital ecosystems, taking into account the specifics of territories, industries, and enterprises themselves, should be identified as future research areas.

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Digital Platform for Regional Industry: Prerequisites and Functionality

Victoria Akberdina and Anna Barybina

Abstract The paper briefly reveals the theoretical background of digital platforms in industry, identifies the types of platforms and their features. Challenging the dominant mode of digital platform studies that presume a global example, this paper purposely situates the platforms in regional terms. It confirmed the architecture and functionality of the digital platform in an industrial region. The Urals, the largest industrial territory of Russia, was studied as a research polygon. The purpose of the study was to prove the necessity of creating such a regional digital platform. The authors identified the prerequisites for the platform—geographical proximity of producers and buyers, a significant share of intra-regional trade, common institutional conditions. The paper presents the results of a strategic session with key stakeholders—regional authorities, industrial enterprises, R&D and investors. The authors systematized the stakeholders' requests in order to offer the functionality of the digital platform. Currently, the project of the Urals' industry digital platform (UIDP) is in the stage of public discussion.

Keywords Digital platforms · Regional industry · Regional digital platforms · Digital transformation in industries

1 Introduction

Digital platforms are a unique phenomenon in the existing world [1]. They radically transform not only the manufacturing processes, but also change the principles of industrial organization. While traditional industrial enterprises create value within

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the company structure or supply chain, digital platforms deal with an ecosystem of independent agents, jointly created value and multiplicatively increased effects.

Digital industrial platforms are the next stage of digital transformation in industry. In Europe, the USA and China, large industrial companies are creating digital platforms that are considered not only as a market place, but also as a new digital business model [9, 14]. A few years ago, the digital platform in the industry was considered exclusively as a trading platform for placing orders for raw materials, semi-finished products and goods. But today, a *significant part of production is concentrated on the digital platforms of contract manufacturers specialized in specific product niches.* This means custom-made production using equipment from an independent manufacturer that provides full control of the production and technological cycle, as well as compliance with the required quality level according to customer requirements. Technologically, being a set of algorithms, industrial digital platforms organize R&D, production, operation, predictive and after-sale maintenance, disposal, etc. Such a model greatly reduces transaction costs in production chains.

At the same time, *the regionalization of digital platforms should be understood as a tendency to create digital relationships between producers and consumers in territorial proximity*, as a process that is autonomous from the globalization forces. Unlike globalization, which is characterized by the loss of territorial identity, digital regionalization emphasizes the importance of geography. Regional models of digital platforms differ from global platforms and bring to the fore a territorial inquiry about where producers and consumers are located [21]. For regional industries, it becomes an element of the local positioning strategy, the regional authorities consider it as an opportunity for industrial growth and maintaining employment [2].

In Russia, the process of digital transformation has been started up—institutional conditions are being formed, national projects, federal and regional programs are being implemented, national priorities in terms of end-to-end digital technologies have been determined. But most Russian industrial enterprises are slow to change business models and introduce radical digital innovations. Therefore, the digital platforming in Russia is still reduced to state information platforms. Any digital platform is started up as a pilot project on a narrow segment in order to determine scaling vectors. In Russia the process of initiating pilot projects of digital platforms has begun.

In this regard, the *purpose of this paper is to justify the concept of a regional digital platform for the industrial region taking into account the opinions of key regional stakeholders.* The authors hypothesize the relevance of regional digital platforms as opportunities for deep use of the territories' potential to ensure industrial growth. On the one hand, the rational spatial concentration of industry is one of the leading factors of economic growth. On the other hand, network relations make no sense in the immediate proximity of manufacturing enterprises, and, accordingly, the industrial "saturation" of some territories. This paper is an extension of the research presented by the authors earlier [3].

2 Background

The study of academic literature, the experience of global corporations, and the opinions of leading expert communities led to the justification of the special role of digital platforms in the industry. Already today we say that Industry 4.0 will lead to the creation of vertically and horizontally interconnected industrial value creation networks [4, 8, 15], which, in turn, will change not only industry markets, but also the structure of value chains. The technological and economic effects of Industry 4.0 will transform industries into industrial digital platforms.

The transformation of industries into digital platforms will create economic value creation ecosystems, expanding value chains and involving consumers in innovative processes [8, 17]. Due to the accumulation of big data, algorithmization of their processing and intelligent data management, interaction takes place on the digital platform customers, suppliers and partners, taking into account the interests of all interested parties [15].

The "physical" industrial complex includes network-connected productions [3], industrial and consumer markets, engineering and science infrastructure. A digital industrial platform is essentially a virtual model of physical objects that have their own digital twins. It includes all the same industrial enterprises, consumers, service infrastructure and other elements, but the basis of their relationship is digital transactions.

We will use the widespread well-established concept of a digital platform [7, 11, 15, 16] as a developed ecosystem based on the relationships of industry elements (manufacturing enterprises, suppliers, dealers, research centers, universities, associations, etc.) carried out in a digital environment, ensuring a reduction in transaction costs due to effective specialization and division of labor. We emphasize the following well-established approaches to digital platforms:

- *a process approach* based on the logic of value creation in industrial production [6, 13, 15, 17]. This approach makes it possible to implement in a digital environment the process of value creation from R&D to production, sale and operation;
- *a technological approach* involving the study of clusters of digital technologies that ensure the qualitative transformation of the industrial complex [5, 11];
- *a sectoral approach* based on the identification of existing and promising industrial markets involved in digital transformation [8, 9, 11, 14].

At the same time, the latest conceptual papers on digital platforms demonstrate the development of the research paradigm [12, 18]. So far, digital platforms have mainly been analyzed from separate paradigms, such as economics, engineering, business and humanities. The *interdisciplinary ecosystem approach to the new digital platform paradigm* relies heavily on autonomous agents who contribute to the value proposition of the digital platform [10, 12]. This basic principle emphasizes the need for digital platforms to provide and coordinate an ecosystem of interacted and interdependent actors [18, 19]. It is this concept that fully corresponds to the goal of our research—to offer a digital industrial platform for the ecosystem of the region.

We will consider the digital platform from the position of key stakeholders in the regional ecosystem.

3 Methodology

3.1 Research Design

To study the cases of digital platforms, a *content analysis method* and *a functional approach* were used. Following common research practice, a qualitative empirical research approach based on *inductively analyzed in-depth expert interviews* was applied.

The study was conducted during *a strategic session*, which was attended by key stakeholders—regional authorities, industrial enterprises, R&D centers and investors. The strategic session was held to study the existing and expected needs of the platform participants in information (datasets), information services and the communication and financial environment. The work of the participants of the strategic session was organized into sections representing the interests of groups: Government, Science, Industry, Investor. The participants formulated proposals (requests) for other groups, which were jointly discussed and analyzed. Further work with the participants of the strategic session was proposed. The list of requests from different groups of participants was clarified and detailed, and a roadmap of actions was defined. This ensured that the needs of all potential participants of the digital platform were taken into account as fully as possible.

The assessment of the prerequisites for a regional digital platform in a particular region was carried out on the basis of *regional commodity exchange, considered in dynamics*.

3.2 Data Sample

The Urals, the largest industrial territory of Russia, was studied as a research polygon. The starting point was the task of developing interregional cooperation within the Urals macroregion in order to make greater use of its scientific and industrial potential. The prospects for the development of the economy of the Urals are connected by the fuel and energy complex, which provides up to 50% of the exports of the Russian Federation, the development of electric power, oil and gas processing and petrochemistry; as well as the manufacturing industry and the military-industrial complex.

To assess the prerequisites for the creation of a digital industrial platform in this macro-region, data on *intra-regional commodity exchange for the period 2016–2020* were used. We analyzed an export to other regions of Russia and imports from other regions, and the balance of intraregional trade exchange. The strategic session was held in October 2020 in Yekaterinburg (Russia), the capital of the Urals macroregion. The strategic session was attended by *62 experts from stakeholder groups*—government, industry, science and investors. We studied the functionality of 36 industrial platforms and ecosystems of 16 regional share-based platforms to highlight the key functions required for a regional digital industrial platform.

4 Results

4.1 Relevant Functionality of Digital Platforms

To understand the functionality of the future digital platform, we needed to understand what types of platforms there are in the industry, as well as what types of regional digital platforms exist. After analyzing 36 digital platforms in the industry (USA, China, Germany, Italy), we came to the conclusion that there are two fundamentally different types of digital platforms.

A Digital industrial platform Type 1 (DIP-1) is a digital ecosystem focused on creating value in industrial production through direct interaction between the buyer and supplier, as well as the implementation of digital transactions between them. This type includes two subtypes of platforms:

- *information and communication platform*, both providing information exchange and operational communication between participants of the industrial market (examples of this type of platforms are electronic catalogs of industrial products, catalogs of production capabilities of enterprises, etc.);
- *a transactional platform* that provides communication, financial and legal support for transactions (examples of this type of platforms are procurement platforms for public needs and the needs of private companies).

A digital industrial platform Type 2 (DIP-2) is a complex of interconnected digital technologies that provides a digital product lifecycle based on the industrial Internet of Things and the modeling of digital twins. This type of platform is by the essence of the digital business model of the product and corresponds to digital life cycle of products based on the industrial Internet of things and modeling of digital twins [12]. Thus, the basis of such a platform is the product and its digital counterpart, around which all participants "gather"—the segment of development and design, the segment of the main production itself, assemblers, suppliers, as well as the segment of consumers [5, 6, 20]. Moreover, it is the manufacturer of the final product that determines the standards of interaction.

On the other hand, along with the platforms comes a form of regionalization, localization in a certain environment, country or region, through the "soft" deliberate exclusion of other regions for the purpose of import substitution and the development of domestic production. Such platforms are regional entities, and we should pay attention to how platforms “build” regions and, indeed, often assume regions. A case study of 16 regional platforms (China, Sweden, Italy) showed that the term “regional digital platform” can mean two things: (1) a subnational or local context denoting a country’s region (for example, the Ural macroregion of Russia); and (2) grouping several countries into geocultural regions (for example, the Asian region). Such dimension of the regional platform as the mobilization of its quasi-monopoly power seemed extremely important.

We consider that a regional digital industrial platform should be Type 1. This type of platforms is the first evolutionary step in creating more complex platform models. And its creation does not require much money at the first stage and can be created in the PPP-format (public–private partnership).

4.2 Prerequisites for a Digital Platform in the Ural Macroregion (Russia)

The Ural macroregion (Federal District) includes 4 regions—Sverdlovsk Region, Chelyabinsk Region, Kurgan Region and Tyumen Region (with autonomous territories). Each region is unique in its own way.

In general, the Ural Federal District is characterized by a high level of interregional relations between the regions that are part of it. The share of the district’s products in the volume of imports of the Ural regions ranges from 9% in the Kurgan region to 40% in the Tyumen region. Also, the Chelyabinsk region is a large region in terms of the volume of imports of products from other regions of the Ural Federal District.

The Sverdlovsk Region has a significant positive balance of export and import of products to the territory of the Ural Federal District. The region occupies 54% of the export and 13% of the import. The main import trading partner is the Tyumen Region, which accounts for 63.2% of the import. The products of the Sverdlovsk Region are exported mainly to the Chelyabinsk (52.3%) and Tyumen (46.5%) regions (Fig. 1).

In the Chelyabinsk region, the import and export within the Ural Federal District region are approximately the same with a small positive balance. The main import of products from the Ural Federal District to the territory of the Chelyabinsk region is provided by the Tyumen region (74.6%). The main consumer of products of the Chelyabinsk region in the Ural Federal District region is the Sverdlovsk region, which accounts for 67.8% of all shipments of the Chelyabinsk region to the territory of the District. About a third of the supplies get on the Tyumen region.

The absolute volume of interregional commodity exchange in the *Kurgan region* is small, however, there are also structural features here. Kurgan region has a slight negative balance of interregional import and export. The main Ural suppliers of products to the Kurgan region are Sverdlovsk (53.4%) and Chelyabinsk (41.1%) regions. The directions of export of products of the Kurgan region are relatively balanced—about 40% falls on the Chelyabinsk region, and about 30% each on the Sverdlovsk and Tyumen regions.

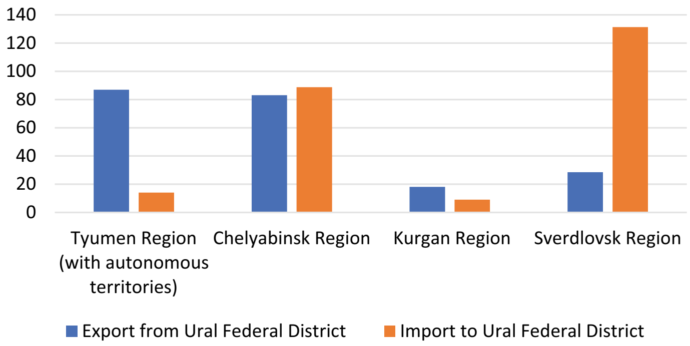
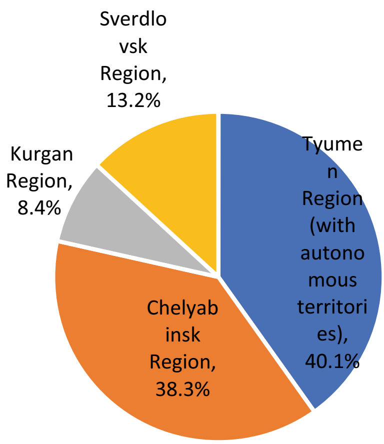


Fig. 1 Volumes of interregional import and export of industrial and consumer products to the regions of the Ural Federal District, billion rubles [22–25]

Fig. 2 Structure of interregional import of industrial and consumer products to the regions of the Ural Federal District [22–25]



The main partner of *the Tyumen region* in interregional commodity exchange is the Sverdlovsk region—69.6% in the volume of imports and 79.9% in the volume of exports.

The regions of the Ural Federal District have been integrated into the processes of interregional cooperation for a long time and quite successfully. It opens up opportunities for creating a regional digital industrial platform (Figs. 2 and 3).

4.3 Requests from Key Stakeholders

Following the results of the strategic session with key stakeholders interested in creating a regional digital industrial platform, the main requests for the functionality

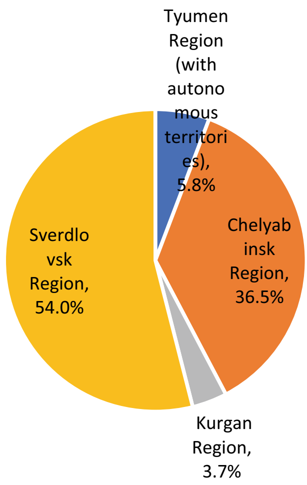


Fig. 3 Structure of interregional export of industrial and consumer products to the regions of the Ural Federal District [22–25]

of the platform were identified. Thus, *industrial enterprises* highly value the opportunity to receive orders from state corporations and monopolies, protected transactions and technical requirements (Table 1). Rather, the low significance of interaction with science through the platform turned out to be ambiguous. Industrial enterprises interacting with the digital platform get an additional opportunity: (a) monitoring, analysis

Table 1 Requests of the "Industry" stakeholder to the digital platform's functionality

Request for the digital platform's functionality	Frequency[a] (%)
The needs of state corporations and monopolies	90.2
Protected transactions	87.6
Technical regulations	78.4
Competencies: technologies, products, equipment	75.1
Investment	74.9
Innovative projects (products, technologies)	72.6
Criteria for selecting projects for investment	70.3
Statistical data by industry	54.9
Territorial development plans, infrastructure projects	34.1
Plans for innovative development of industries	32.4
Interaction of science and industrial enterprises	12.7
Expertise	10.6

[a]Multiple answers possible

Table 2 Requests of the "Science" stakeholder to the digital platform's functionality

Request for the digital platform's functionality	Frequency[a] (%)
Demand for R&D	91.5
R&D financing	90.2
Participation of enterprises in the initial stages of TRL	88.6
Plans for innovative development of industries	71.3
Interaction of science and industrial enterprises	56.2
Protected transactions	52.6
R&D expertise	48.7

[a]Multiple answers possible

and forecasting of the development of sales markets and production technologies; (b) to attract investors for the development of production, to use state support measures; (c) to introduce scientific and technical developments and innovative products; (d) to create cooperative chains; (e) to create clusters; (f) to lobby interests.

R&D centers (the "Science" stakeholder) are interested in such functions of the digital platform as identifying the demand for R&D, financing R&D and participation of enterprises in the initial stages of TRL (Table 2). R&D centers carry out through the digital platform a request for state support measures, for the industrial partners in scientific, technical and innovative activities; R&D expertise, analysis of financial and resource support for R&D are available through interaction on the digital platform.

The investors are interested in the state protection of investments and private property, the protected transactions and the information about the regional development priorities (Table 3). An investor on a digital platform should be able to assess the effectiveness, to create innovative products and to form an investment portfolio.

Table 3 Requests of the "Investors" stakeholder to the digital platform's functionality

Request for the digital platform's functionality	Frequency[a] (%)
Investment protection	98.2
Protected transactions	92.4
Regional development priorities	81.6
Professionally prepared projects	70.5
Territorial development plans, infrastructure projects	69.4
Plans for innovative development of industries	65.4
The need for production assets	52.1

[a]Multiple answers possible

Table 4 Requests of the "Government" stakeholder to the digital platform's functionality

Request for the digital platform's functionality	Frequency[a] (%)
Industry analytics	95.2
Demand for R&D	85.6
Demand for investment	84.1
Proposals for industrial policy measures	70.3
Information on personnel needs	63.9
Information about competencies	52.7

[a]Multiple answers possible

Regional authorities demonstrate such requests to the digital platform's functionality as an industry analytics, the demand for R&D and the investment (Table 4). The provision of this information makes it possible: (1) to monitor, analyze and forecast the markets of industrial products and production technologies; (2) to support industries and regions (territories).

The study of the stakeholders' needs allowed us to determine the preliminary functionality of the regional digital industrial platform.

Thus, we have determined the following. The *main functionality of the Urals' industry digital platform (UIDP)* will include the main features: search for partners; search for resources; search for investors; marketing data; search for needs; assessment of potential and efficiency; the protected transactions.

5 Conclusion

We conducted an in-depth analysis of digital platforms in the industry, identified the types of platforms, as well as the specifics of their regionalization. The study of intraregional commodity exchange in the Ural Federal District allowed us to justify a significant number of transactions on a regional digital platform. The strategic session with key stakeholders gave us the opportunity to understand the needs and wishes for the digital platform's functionality.

We assume that the platform belongs to the MaaS-type (Manufacturing as a Service) [12, 13, 15]. Firstly, the platform makes it possible to use the assets of regional enterprises more efficiently. Secondly, the platform increases the transparency of pricing. The platform becomes a prototype of a trading exchange. This will create conditions for market competition, ensure greater transaction speed and efficiency. Thirdly, the platform will be associated with effective localization. Geographical proximity of the platform participants means faster delivery speed and lower transportation costs.

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Towards Digital Twins for the Development of Territories

Arina Suvorova

Abstract Management of territorial development is a complex and extremely important process that requires advanced technological solutions and efficient methods of regulating socio-economic systems. The digital twin technology holds enormous potential in this respect although some of its possibilities still remain unexplored and unexploited. This study aims to identify and describe the characteristics of the digital twin of a territory. To this end, the research literature on this problem is analyzed and systematized. A special emphasis is made on the theoretical foundations underlying the concept of digital twin and its main interpretations. The study also discusses the use of digital twins for territorial (urban) development and the features that distinguish city digital twins from their industrial counterparts. The idea of a digital twin of a territory, like digital twins in other spheres, is based on representing a real object (system) in a virtual environment. This virtual replica is created and constantly updated through automated collection and processing of massive amounts of data. Importantly, there should be a two-way flow of data between the real and virtual space. In the case of city projects, however, changes in the virtual environment do not provoke direct responses from its real-life counterpart. Some adjustments in the physical object may, occur, however, if local governments take into account the results of digital twin simulations in their decision-making. Digital twins of territories are sophisticated constructions, elaborated within the interdisciplinary frameworks, and open to the public. These projects are usually highly dependent on socio-economic processes and the degree of civic engagement.

Keywords Digital twin · Territorial development · Theoretical analysis · Smart city

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1 Introduction

Digital twins (DTs)—the concept which has attracted a lot of scholarly interest in recent years—can be created for a wide range of applications as their capabilities and sophistication grow. While initially, the idea of creating virtual copies of real objects and using them for simulations to test different scenarios took root in the industrial sphere, today virtual copies are used in architecture [16], economics [45, 60], ecology [39, 45, 60], and medicine [14]. Moreover, in addition to physical objects, modeling can be employed for complex social and economic systems.

As the concept and application of DTs are evolving rapidly, researchers, analysists and administrators working with them have to deal with the growing number of challenges. Among the questions most widely discussed in research literature are the differences between digital twins and other automation components and tools [1, 10]; the choice of the most efficient methods of modeling and virtualization of physical objects [32, 63]; ways to assure data security and confidentiality [28]; and possibilities of digital twin integration [50]. These questions are reconsidered and reinterpreted as more scholarly attention is given to social relations, economic processes and other factors that have diverse impacts on socio-economic objects. Moreover, as DTs start to be applied at the level of cities or regions, new challenges arise, for example, ethical issues [5, 38] or risks involved in civic engagement [61]. The task of building an accurate DT becomes extremely complicated if the physical object to be copied is a large territorial system (e.g., a district, city or region) involved in multiple interactions with the external environment and comprising many elements connected through non-linear and constantly changing relationships. On the other hand, the explosive growth of digital technologies (systems for big data collection and processing, self-learning systems, blockchain, cloud technologies, etc.) can make the problem of creating digital twins of territorial systems solvable, although it will still remain a complex, time-intensive task. This article focuses on the aspects that need to be considered to adopt the digital twin technology for territorial development.

To this end, it is necessary to investigate the theoretical foundations of the digital twin concept, especially the criteria that distinguish it from other forms of virtualization and simulation. Some of the existing practices of DT application for regional development will be analyzed to determine to what extent these cases correspond to the theoretical criteria. In addition, the key characteristics of DTs of territories will be identified and described.

2 Methodology

The digital twin concept is underpinned by a comprehensive interdisciplinary methodological approach that encompasses many principles related to modelling and digitalization. The focus of this study is the development of theoretical and methodological aspects of "cloning" territorial systems in virtual space. This focus determines the choice of the systematic approach [53], which allows me to consider large amounts of heterogeneous data while concentrating on a set of key questions (specified in this study's targets). The study draws from the analysis of the corpus of publications in high-impact journals. The publications were selected in October 2021 from the Scopus database by using search terms "digital twin", "digital shadow", and "city digital twin". Moreover, the study relies on the evidence of DTs application for territorial development and management, mostly as part of the smart city projects in different countries.

3 Results

3.1 Digital Twin Concept: Theoretical Foundations

A digital twin is commonly understood as a digital representation of a unique product or unique system that comprises its selected characteristics, properties, conditions, and behaviors by means of models, information, and data [51]. It is a widely recognized fact [3, 18, 19] that the term "digital twin" was coined by Dr. Michael Grieves from the Florida Institute of Technology. In his work "Virtually Perfect: Driving Innovative and Lean Products Through Product Lifecycle Management" [24], he put forward the idea that for every physical product, with the help of digitized data, there may be constructed a virtual counterpart that can perfectly mimic the physical attributes and dynamic performance of its physical twin. It should be noted that initially, M. Grieves used other terms—mirrored space model [22] and information mirror model [23]—but it was the term "digital twin" that eventually entered common use in research literature and the manufacturing sector. Since the concept of the digital twin appeared, there have been tremendous changes not only in the terminology but also in the tools used to create virtual models as well as in the amount and quality of information needed for this purpose. While initially the data were limited, they were collected manually and stored on paper, with time the explosive growth of digital technologies has created opportunities for automated data collection, processing and storage, thus making the information more suitable for creating precise virtual copies of physical objects [25]. Therefore, in today's understanding of a digital twin it is not simply a representation of a physical object in the virtual environment, but a representation obtained through artificial intelligence, machine learning, and advanced analytics. The massive big data are continuously generated and collected via sensors, UAVs and other tools for data capture [12]. Other advanced technologies that are vital for digital twinning include Radio Frequency Identification (RFID) [64], the Internet of Things (IoT) [33, 46], the Industrial Internet of Things (IIoT) [9], Ethernet [62, 65], cloud technologies [4] and so on.

The aerospace industry has proved to be a trailblazer in the use of DTs [7, 54], turning this technology into a major trend in many other spheres. The increasing search for new DT applications in the real economy has engendered multiple, sometimes dramatically different interpretations of the concept, its characteristics, and possibilities of use [29].

Nevertheless, the key aspects of the original concept developed by M. Grieves have retained their significance. The core of a DT is constituted by the bidirectional flows of data and information that tie the virtual and real space together. The virtual space, in its turn, consists of virtual subspaces, which can be used to perform multiple operations such as data aggregation, modelling of different situations, optimization of the object's performance, and so on [25]. In order to transform physical objects and their virtual copies, a constant exchange of data between the two is necessary. Thus, DTs can be adjusted for use on different stages of a system's lifecycle: for instance, in manufacturing, the process involves the creation of a Digital Twin Prototype, the Digital Twin Instances or their combinations—Digital Twin Aggregates (for more on this, see [26]).

Thus, apart from manufacturing, the idea underpinning the concept of digital twins is quite universal and has a vast scope of potential uses. Nevertheless, most of the evidence concerning successful practices of digital twinning has been accumulated in the industrial sphere [44, 52]. Other application areas for the DT technology include smart construction, smart infrastructure, smart cities and regions.

3.2 Application of Digital Twins to Address Problems of Urban and Regional Development

Digital twins of territories are most widely discussed in relation to cities, although there is sufficient evidence showing the possibilities of DT use for modeling city districts [42] and regions [55]. In fact, the DT concept fits well into the current research agenda of urban studies, especially smart city development [40], sustainable urban development [21], and the creative city [49]. For a smart (creative, sustainable) transformation, a cutting-edge toolkit is needed to process large volumes of data, to automate and digitize the processes running or those that will be running within the territory. According to MarketsandMarkets, the global digital twin market size is expected to grow at a CAGR of 58% and by 2023 to reach $15.7 billion [11].

As the term starts to be used more and more frequently by urban scholars and public officials, its meaning is becoming fuzzier and it risks turning into another "buzz word". Therefore, claims that DTs are created for certain cities or regions should be viewed with a certain degree of skepticism.

City DTs are quite often understood as virtual models of cities (for instance, 3D models [20, 36]) based on large amounts of data [34, 35] and used to visualize processes in cities, to model various situations, to build forecasts and to make evidence-based decisions [31, 58]. Many popular applied solutions presented as examples of city digital twins follow this principle. Quite illustrative in this respect is the cloud-based service Bentley's OpenCities Planner [41], which was applied in Stockholm, Helsinki, Göteborg, etc. OpenCities Planner can be used to integrate data repositories to create comprehensive models reflecting the real-life territorial systems, to visualize these systems with the help of special software, and, based on data analysis, build different what-if scenarios (including scenarios involving human behaviour in environments). Another interesting example is the project Antwerp Smart Zone realized by Interuniversity Microelectronics Centre (*imec*), an international R&D organization, as part of the City of Things program [2]. The City of Things looks for answers to the complex urban problems or needs in the world of high technologies and the project in Antwerp is associated primarily with the creation of the city's digital twin, which accumulates the data on traffic, air quality, and noise. Some of the tools used to create DTs are used in Boston's 3D GIS City Model, which enables the government to modify 3D cityscapes to reflect new buildings [6]. Another example is the platform Virtual Singapore, which can be used by city planners to conduct virtual experiments, run simulations and develop analytical applications [56].

Even though these projects are of significant practical interest, it would be incorrect to describe them as digital twins of territories. On the other hand, such models share a number of features with DTs: they are virtual replicas of the real object (complex system) and are formed (and constantly updated) with the help of high-tech systems of data collection and processing. These models enable prompt responses of local authorities to emergencies and provide a feasible solution to many problems of territorial development. They, however, lack one important feature that DTs have—the two-way flows of data between the real and virtual space. The data on everyday urban processes and systems are used to adjust the parameters of the virtual model, but the changes in the virtual model (e.g., the choice of the optimal scenario) do not necessarily lead to corresponding changes in the real environment. Thus, such models are not digital twins in the true sense of the word, a more appropriate term would be "digital shadows"—simplified copies lacking a feedback connection [15, 47, 48]. Some adjustments of the real environment may occur, however, in response to the changes in its virtual equivalent if local governments and other regulatory bodies take into account the results of DT simulations in their decision-making [43].

The creation of relatively simple digital copies of territorial complexes or their individual elements is an important step towards incorporating DTs into the practices of urban and in the future regional development [13]. This process requires further elaboration of the territorial DT concept, which, in its turn, implies thorough analysis of the physical object's characteristics as well as a more in-depth understanding of the differences between this type of DTs and their counterparts in the industrial sphere.

3.3 Characteristics of Digital Twins of Territories

The term "digital twin of a city (or a region)" may seem quite ambiguous: for instance, there is uncertainty surrounding the object to be copied. The impression that may be formed is that DTs replicate socio-economic systems (or their elements) located

Table 1 Comparison of DTs of territories and industrial DTs

Indicators	DT in manufacturing	DT of a territory
Level of complexity	Cyber-physical system	Cyber-physical system-of-systems
Determinants of the model's key parameters	Production processes	Socio-economic processes
Co-creation and co-implementation of DTs with citizens	No public engagement	Active public engagement
Degree of openness	Rather closed than open	Rather open than closed
Sphere of creation/application of DTs	Industrial system	Interdisciplinary sphere

within a given territory—these systems comprise physical objects as well as local inhabitants, businesses and so on. It is, however, quite obvious that at this stage, the creation of a DT of a whole territorial community is a rather far-fetched prospect. It is possible to build a digital model of such community and use it to estimate future outcomes of certain processes or to forecast the changes in the population distribution patterns [57] or in economic relationships [37] for evidence-informed decision making. Therefore, it would be more reasonable to focus on the environment where the community lives and works, in other words, the object that will be copied by the DT should be a large-scale system of assets (buildings, infrastructure, amenities) located and arranged within the given space. The DT may replicate individual elements of this system (e.g., its energy supply system [17] or logistics hub [27]).

In this case, it may appear that the only difference between a DT of a territory and a DT of a particular element is the scale and complexity of the original object. The differences, however, go beyond that and relate to at least five extra criteria that can be used to compare different types of DTs (see Table 1).

The digitized data can cover a diversity of relationships and processes. To build a DT of a territory, it is necessary to take into account the interactions between people and their environment. On the one hand, it is the inhabitants of the territory that shape the ways in which the key objects in their territory operate: the inhabitants' activities are thus a key factor in the transformations of the territory. On the other hand, inhabitants of the territory constitute the main stakeholder in territorial development, who determines the priorities and directions of transformations, sets the parameters of optimality and thus helps public administrators to choose the best option from a range of possibilities. All of the above determines the importance of civic participation in territorial projects involving the DT technology [8, 30, 59]. If the local community is not engaged, such projects lose much of their meaning. The format of such engagement can be different: participation in public discussions about transformations of the territory via online communication platforms; automated alert messaging via special services, etc. Openness is another important factor that determines public engagement in the creation and implementation of a DT of a territory: virtual models (or their parts) can be made accessible to everyone (or to specific categories of stakeholders), have an easy to use, intuitive and attractive interface. Importantly, the development of urban and regional environment always involves multiple transformations of different spheres, which means that DTs of territories should be interdisciplinary and based on the integration of various data from different sources and efforts of many specialists from different domains—not only IT and modelling, but also engineering, architecture, social studies, economics, and so on.

4 Discussion

The idea of the construction and use of DTs to address problems of territorial development is gaining popularity: the number of publications on this topic in high-impact journals is growing as is the number of cities with virtual copies of their own, which can be later "reborn" as full-fledged digital twins. It is, however, obvious that this area of knowledge is at its early stage of development. A theoretically valid and methodologically sound foundation for digitalization in manufacturing can greatly contribute to solving certain questions, which are important for increasing industrial research potential, such as the questions about assessing DTs' role among simpler systems. However, the extant studies laying down the foundation have to be updated and expanded.

This study explores the idea and possibilities of using DTs to tackle problems of territorial development. Since the main focus of this study was made on the conceptual framework underpinning the DT technology and on the differences between DTs of territories and industrial DTs, the publications on digitalization and modeling in other spheres were excluded from the scope of the study. Nevertheless, it should be noted that research on the use of DTs in medicine, natural sciences and other vibrant fields could contribute to a better understanding of the yet unknown aspects of DT use for territorial development. Other topics of special interest in this sphere are the limitations of the idea of digital twinning, the most promising big data tools which can be used to create the most accurate virtual copies of complex systems, and ways of data transmission from the virtual to the real environment.

5 Conclusion

A digital twin is a universal tool to work with large and complex systems, for example, cities or regions: it can be used to analyze the development of these systems, to conduct virtual experiments, to make forecasts and to take evidence-based decisions. It is, therefore, necessary to explore the potential that DTs hold for such demanding task as management of territories from the theoretical and applied perspectives.

In this study, the classic understanding of the term "digital twin" was compared with the use of this term in the context of regional and urban development and in the industrial context. The analysis has shown that the term "digital twin" fails to accurately describe the majority of the current virtual city models. A set of unique characteristics of DTs of territories has also been identified.

These findings point to avenues of further inquiry on digitalization of territorial complexes.

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Digitalisation of the Economy and Regional Development

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Abstract The digitalisation of industry is an urgent aspect to develop regional economic systems, which involves introducing state-of-the art information and communication technologies into the activities of enterprises. Digital transformation is accompanied by a corresponding transformation of the structure of interregional interactions, influencing the depth and degree of regional differentiation, as well as the competitiveness of individual constituent entities of the Russian Federation. In this article, the authors assess the impact of digitalisation on the development of regions of the Russian Federation by determining the depth of digital transformation and the unevenness of digitalisation processes among the constituent entities of the Russian Federation. The purpose of the research is to study the digital transformation processes in a territorial context taking into account its impact on territorial differentiation and the cyclical nature of economic development. As a result of the research, the authors determined that in most constituent entities of the Russian Federation, the second stage of digital transformation is being implemented, while the country's territory is highly differentiated in terms of digitalisation performance. The authors have proposed several possible scenarios for the implementation of digital transformation processes in Russian regions.

Keywords Industry 4.0 · Regional development · Digital transformation · Spatial differentiation

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1 Introduction

The current stage of development of the world economic system can be characterised by a high degree of variation and dynamism, as reflected in the state of individual subsystems and processes. Technological innovation is a key driving force behind these sweeping changes. In the context of accelerating socio-economic processes, a prerequisite for the competitiveness of both individual enterprises and regional economic systems is the synchronous transformation of production processes in line with new technological requirements [24]. Currently, digitalisation is an integral part of such a transformation. Companies that were the first to make their way through digital transformation significantly outperform competitors due to higher productivity of both labour and equipment, lower costs, and increased safety of production processes, which is accompanied by significant changes in the activities of enterprises and business model adjustments. A typical feature of the early twenty-first century is the transition to the so-called Industry 4.0, within which digitalisation encompasses both all the most important processes of the production chain and the organisation of inter-firm interactions [14].

In Russia, the foundations of digital transformation were laid in the Strategy for the Development of the Information Society in the Russian Federation in 2017–2030, as well as in the Programme "Digital Economy of the Russian Federation", which provides for incentives to digitise all the key sectors of the Russian economy. The most important condition for successful digitalisation in Russia is to provide stakeholders in economic processes with access to modern network technologies, programmes, new digital equipment, and ICT technologies based on access to the Internet and other modern data transmission channels [6].

The digitalisation of industry goes along with the introduction of new types of equipment based on robotics, resource-saving and waste-free technologies, as well as production automation. Contemporary information systems ensure prompt decision-making and productivity growth of all factors of production, increased competitiveness, development of new technological solutions, and introduction of them into production.

These processes claim special attention at the regional level. Russia is characterised by high differentiation of territorial development, when the spread between the conditions and indicators of individual regions can reach high values. In this context, digital transformation can become a powerful driver of territorial development, serve as a mechanism to overcome the lag of individual regions, and improve their competitiveness by contributing to the balanced development of the entire country. In this work, the authors set the goal to study the digital transformation processes in a territorial context taking into account its impact on territorial differentiation and the cyclical nature of economic development.

2 Literature Review

The digital transformation of both the socio-economic system as a whole and individual subsystems, including industry, is a major focus of interest of the research in the modern scientific community [23]. A statistical analysis of the impact of the degree of digitalisation on the level of economic development, investment, and employment is carried out [6, 9, 13, 15, 18, 22]. Some researchers emphasise a stable positive relationship between the development of contemporary information infrastructure (including the Internet speed) and the economic growth rate [3, 21].

Separately, researchers consider the features of digitalisation processes in various countries and regions including developed ones [5] in the Asia–Pacific Region [11], Africa [8, 17, 20], Arab countries [25] and Russia [12, 19, 27].

Special mention should be made of the works that reveal the theoretical and methodological features of digital transformation processes. In the study by Vertakova et al. [26], the structure of transformation processes in the economic system is analysed; the following levels of digital transformation of industry are distinguished: the level of existence (change in objects and subjects of social consciousness), the level of manifestation (change in conditions, values), and the level of implementation (implemented changes).

Some researchers focus on the digitalisation of industrial enterprises. Kovalchuk and Stepnov [10] introduce the "new digital space" concept, which includes enterprise production processes implemented in the digital environment. Behrendt [4] distinguishes business processes, primarily transferred to the digital environment. Maltseva and Bragina [13] explore the possibilities of increasing labour productivity through digital transformation.

Glezman et al. [7] highlight the basic properties of digital technologies (innovation, integrability, criteria, flexibility, minimality, and functionality), as well as key stages of digitalisation, such as computerisation of industry, provision of network exchange, application of innovative software, production of digital devices and components, production of robotics, implementation of digital management models, creation and implementation of cyber-physical models. In the monograph edited by Lavrikova, Doctor of Economics Andreeva [1] considers the prerequisites for the digital transformation of the Russian industry and provides a methodology for assessing digitalisation.

Some authors consider the digital transformation processes in the context of individual regions [2, 7].

However, there is a shortage of works that consider the digital transformation processes in the context of the interregional differentiation processes considering the impact of the ICT integration into the economic system on the regional development processes.

3 Material and Methods

The informational background of the research was made up of digital society development indicators in the regions of the Russian Federation published on the official website of the Federal State Statistics Service (https://rosstat.gov.ru/). For the analysis, the following indicators of the constituent entities of the Russian Federation were selected: the proportion of entities that used personal computers, the entities' costs associated with the deployment and use of digital technologies, the number of professionals in information and communication technologies, the proportion of entities that analysed big data (in % of the total number of entities), the share of entities by the area of using IoT technologies (in % of the total number of entities) in the energy consumption optimisation and automation of production processes, management of logistics and product movement, the volume of gross regional product, the volume of shipped goods of its own production, works and services performed on their own by economic activity. The analysis used the most recent data published at the time of writing, for 2020 or 2019, as well as the trend data over the past 10 years, if available.

A variation factor was used as the main indicator of territorial differentiation; the maximum, minimum and average values were also determined. In addition, according to individual indicators, ranking was carried out, as well as leaders and those lagging behind among the regions were determined.

For the Tyumen and Arkhangelsk Regions, data without taking into account the autonomous areas in order to avoid duplication of information (the Khanty-Mansiysk, Yamalo-Nenets and Nenets autonomous area were analysed separately) were used.

A correlation analysis with the Pearson coefficient was carried out; control calculations of the Kendall and Spearman Tau-b coefficients were also carried out. For calculations and analysis, the SPSS statistical package tools were used.

When classifying the stages of digitalisation, as well as the criteria and indicators used for each stage, the authors used the previous research results including the monograph edited by Lavrikova and Andreeva [26, pp. 184–188], where the stages of digital transformation of industry are distinguished as follows: (1) primary information and communication digitalisation; (2) electronic data sharing with external network partners; (3) use of custom software; (4) production of information and communication technologies and equipment; (5) production and use of robots and sensors (industrial Internet).

A feature of this research, which determines the scientific novelty, is the study of the stages of digital transformation of the economy in the context of the uneven social and economic development of Russian territories. The authors assumed that digital transformation can become a tool to reduce disproportions in territorial development, as well as enhance the stability of regional social and economic systems against the consequences of unfavourable macroeconomic environment.

4 Results

At the moment, Russia consists of 85 constituent entities of the Federation including 22 republics, 46 regions, 9 territories, 3 cities of federal significance, 4 autonomous districts and 1 autonomous region. The constituent entities of the Russian Federation can be characterised by a high degree of heterogeneity of social and economic development; for example, Moscow accounts for 21% of the gross regional product of all regions of the country, 20% of all economic funds, 15% of retail trade turnover, while Moscow is home to 8.6% of the population of Russia. For comparison, the share of the Sverdlovsk region, one of the regions advanced in industrial development, in which 2.9% of the country's population live (and the region includes a city with over a million people), accounts for only 2.7% of the gross regional product in the Russian Federation.

Historically, Russian industry has been a territorial development driver by strengthening the internal and external ties of regions, determining the employment pattern and increasing the competitiveness of individual territories. However, the third and fourth industrial revolutions significantly change the role of legacy industries by presenting new demands and providing new opportunities. Currently, a quarter of the Russian GDP is accounted for by industrial products but the consequences of global transformation processes are increasingly affecting the activities of Russian enterprises in most Russian regions, the share of the industrial sector is steadily decreasing each and every year. Digital transformation in industry is a necessary response to the challenges of a new stage in the development of the world's economic system, and it is carried out in stages [1]. At the first stage of digital transformation, industrial enterprises are computerised; in most Russian regions, this stage should be recognised as completed (see Fig. 1). The transition to the second stage means high integration of information technologies into the external and internal relations of an enterprise. Document flow, accounting, HR recordkeeping, and some other processes begin to be carried out with the features provided by the contemporary IT environment.

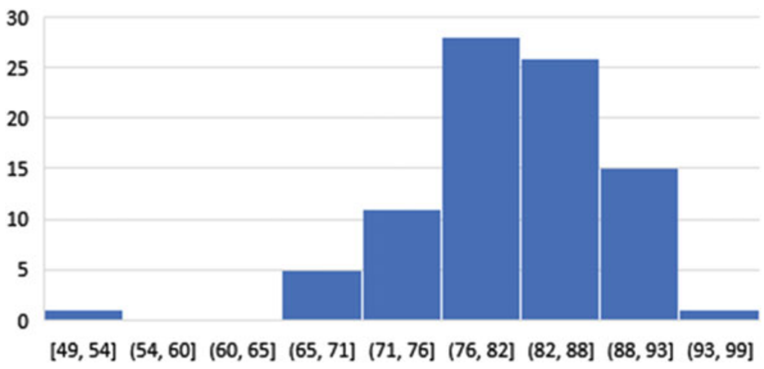

Fig. 1 Distribution of constituent entities of the Russian Federation by the share of entities that used personal computers (2020, %)

At the third stage, the IT environment tools are used to enhance the efficiency of management activities, research and development, procurement, and sales management. A significant part of the processes in entities is carried out through corporate automation tools represented by CRM, ERP, and SCM systems. At the moment, many regions are going through this stage, the distribution of the constituent entities of the Russian Federation by the number of entities with CRM, ERP, and SCM systems is extremely uneven (see Fig. 2).

The fourth stage of digitalisation goes along with the development of its own information products and technologies. Among the most important trends at this stage are the Internet of Things, the use of electronic twins, the widespread use of big data analysis in management decision-making collected through the contemporary information environment tools.

According to the 2020 data, in most of the Russian regions, the proportion of entities, that use big data analysis, does not exceed 3–5% (Fig. 3); in Moscow, which is the digitalisation leader among the constituent entities of the Russian Federation, the proportion of such entities is 8%, and the Internet of Things integrated into

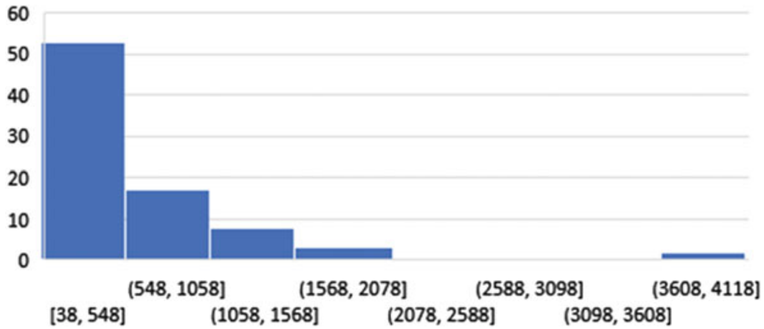

Fig. 2 Distribution of constituent entities of the Russian Federation by the number of entities that had CRM, ERP, and SCM systems (2019, %)

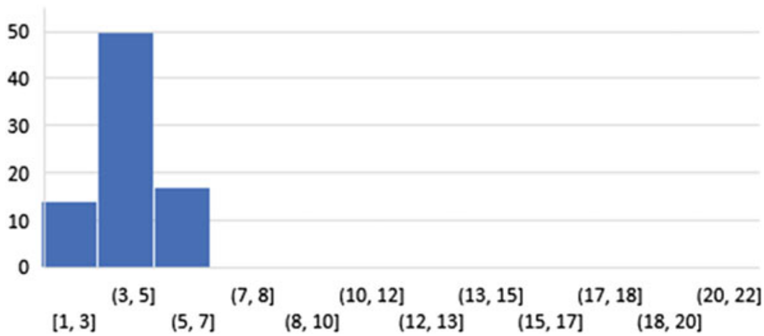

Fig. 3 Distribution of constituent entities of the Russian Federation by the share of entities that use Big Data (2020, %)

activities of 10%, on average in Russian regions, only 3–4% of entities use the Internet of Things.

To assess territorial differentiation according to the degree of digitalisation of regional economic systems, the variation factor was used, and also, as additional indicators, the ratio of the minimum and maximum values of indicators among the constituent entities of the Russian Federation with the average was calculated. In addition to special indicators of the information economy, general economic indicators were also considered, such as GRP and the volume of products shipped, in order to compare the differentiation in the field of digitalisation and the level of interregional differentiation in the country as a whole. For the calculations, the 2020 data were used, except for two indicators, since at the time of preparing the material, the data had not yet been published. The calculation results are presented in Table 1.

As can be seen from the data presented, the degree of differentiation in terms of the economy digitalisation parameters differs significantly depending on the specific

Table 1 Differentiation of constituent entities of the Russian Federation by certain economic indicators

Indicator	Min/mean	Max/mean	Coefficient of variation
Costs of entities associated with the implementation and use of digital technologies, 2020	0.02	51.16	1.36
Number of information and communication technology professionals, 2020	0.04	20.84	0.93
Number of entities that had CRM, ERP, and SCM systems, 2019	0.06	6.09	0.68
Proportion of entities that analysed big data (as a percentage of the total number of surveyed entities), 2020	0.33	4.87	0.24
Proportion of entities by areas of use of IoT technologies (as a percentage of the total number of surveyed entities), 2020			
Optimisation of energy consumption (electrical, heat) in the territory of the entity	0.33	3.04	0.32
Automation of the production flows, management of logistics, and product movement	0.23	3.04	0.36
GDP, 2019	0.05	17.26	0.89
Volume of the shipped goods of own production, works, and services performed on their own, 2020			
Mining operations	0.001	14.89	1.32
Manufacturing	0.001	13.19	0.92

indicator. The largest gap between the constituent entities of the Russian Federation is recorded in terms of the entity's costs for the use of ICT, and the maximum value differs from the average by more than 50 times. For this indicator, the ranking result is quite expected; the cities of Moscow and St. Petersburg, as well as the Moscow, Samara, and Astrakhan Regions, are in the top five. The Chukotka Autonomous Region, the Altai Republic, the Tyva Republic, the Karachay-Cherkess Republic, and the Jewish Autonomous Region are at the bottom of the list. In terms of the number of ICT specialists, interregional disparities are also significant, although less pronounced than in terms of the volume of ICT expenditures, the variation factor was 0.93, and the best indicator was 20 times higher than the average. Moscow, St. Petersburg, and the Moscow Region are also in the lead here but the Sverdlovsk Region and Tatarstan rank 4th and 5th. As far as the rest of the digitalisation indicators are concerned, the gap between the territories is significantly lower. In terms of the number of entities with the CRM, ERP, and SCM systems, the variation reaches 0.68, the leader (Moscow Region) is only six times higher than the average. Differentiation by the share of entities analysing big data and using the Internet of Things is not high. It should be noted that the territorial asymmetry in terms of digitalisation parameters is quite comparable with the asymmetry in relation to general economic indicators.

In terms of dynamics, it is of interest to consider changes in the interregional differentiation parameters in terms of the volume of goods shipped (in general and in relation to innovative products) (see Fig. 4).

As can be seen from the above calculations, the general economic differentiation between territories is very stable, although it has tended to increase over the past 10 years (the variation factor increased from 0.91 to 0.95). However, the differences in the volume of production of innovative products over the period under review changed significantly and clearly showed two periods, from 2010 to 2013 and from

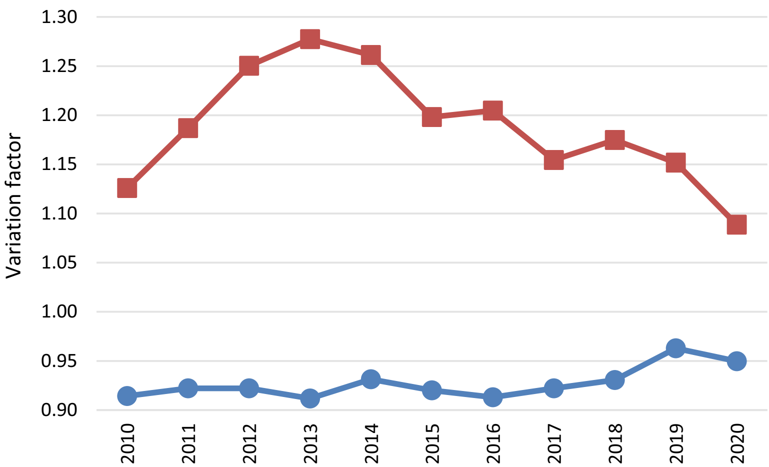

Fig. 4 Differentiation of the constituent entities of the Russian Federation by shipped goods of their own production, works and services performed on their own (variation factor)

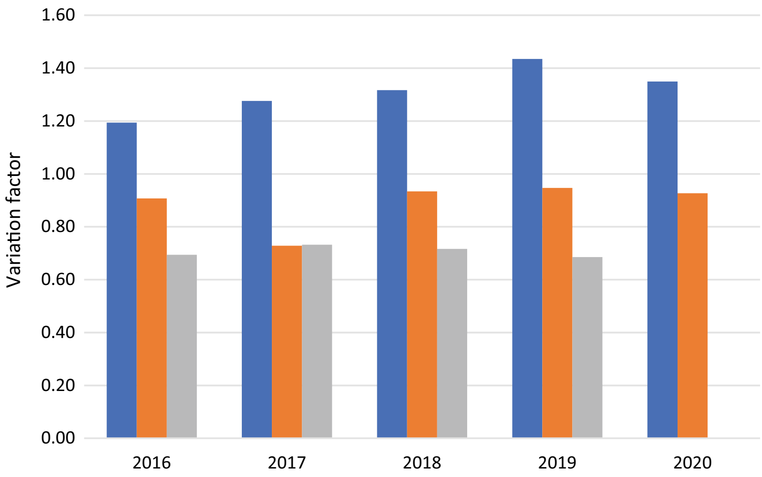

Fig. 5 Differentiation of subjects of the Russian Federation by economy digitalisation indicators (variation factor)

2013 to 2020. During the first period, interregional differentiation increased rapidly, from 1.13 to 1.28; in subsequent years, on the contrary, there was a decrease to 1.09; the influence of macroeconomic dynamics is very likely here since the period of 2014–2015 can be characterised by a decrease in economic growth in Russia, a sharp collapse of the national currency and a deterioration in some other indicators. Therefore, the leading regions during this period slow down innovation activities allowing other territories to narrow the gap.

Unfortunately, it is not possible to trace the information transformation trend data at the territorial level over 10 years for most indicators; based on the available data, the analytic horizon is limited to a period of 4–5 years (even then, not in all areas of analysis). Figure 5 shows the interregional differentiation trend data in the ICT costs of entities, the number of ICT staff, and the number of entities that use high-tech information systems (including CRM). According to the considered indicators, the inter-territorial differentiation in the country is quite large but its changes are not always linear. The gap between regions in ICT spending widened from 2016 to 2019 along with the relatively stable macroeconomic parameters of the country as a whole; but in 2020, the differentiation is decreasing amid economic problems associated with the pandemic. A similar pattern has already been noted for the innovative goods shipped. Differentiation in terms of the number of ICT specialists and the number of entities with CRM systems changes without a clear trend; it increases in some years while decreasing in others, and the reason is most likely in the nature of the considered indicators which measure the presence of a certain phenomenon but not the efficiency of economic activities; it is preferable to increase the volume of cost indicators reflecting the digitalisation results; unfortunately, most indicators in this area currently officially published in Russia, are not that kind but record only the quantitative and not qualitative side of the introduction of digital technologies.

Table 2 Calculation of the correlation matrix in relation to the industrial production index for the constituent entities of the Russian Federation and some economy digitalisation data (unloading from the SPSS information complex)

Indicator	ICT costs	ICT staff	CRM	Bigdata	Internet of Things, production	Internet of Things, power sector
Pearson correlation	−0.136	−0.130	−0.060	−0.048	−0.058	−0.074
Value (double-sided)	0.214	0.236	0.580	0.662	0.595	0.500
N	85	85	85	85	85	85

To conclude the analysis, it is required to test the hypothesis about the stabilising role of digital transformation processes for regional development; they enhance the economic system resilience in dealing with adverse environmental factors. There are studies stating a positive relationship between the development of the ICT sector and economic growth in the regions [16] but they did not consider the impact of digitalisation on the dynamics of economic growth during the crisis period.

The traditional arsenal of correlation analysis is quite suitable for measuring the presence of a relationship between ICT development and the sustainable development of regions. Since 2020 is the most recent crisis year in the country's development in the historical perspective, it was decided to use the industrial production index for April 2020 as an indicator of a region's macroeconomic stability, when there was a significant deterioration in economic dynamics. In relation to this indicator, a comparison with the regional digitalisation indicators used earlier to analyse territorial differentiation was made (Table 2).

For the calculations shown in Table 2, the Pearson correlation as the most popular toolkit was used; however, similar calculations with the Kendall and Spearman Tau-b coefficients were carried out, which, however, did not provide any significant differences in the results obtained. The assumption that digitalisation development reduces the vulnerability of a region is not confirmed. For all five investigated digitalisation parameters, no significant correlation between the variables was found. Therefore, in April 2020, the economic dynamics in the regions deteriorated regardless of the development of the ICT sector, although the global trend indicates that it was the IT sector companies that proved to be the most resilient to the crisis consequences, also due to the increase in remote forms of communication between market entities and the increased use of IT infrastructure. It is possible that a higher degree of digital transformation is required to manifest such an effect than is currently in the Russian regions. According to the authors, this issue is still relevant and requires further study with broader statistics.

5 Discussion

Differentiation of territorial development is a fairly typical phenomenon, especially for spatially extended countries. The determining factors of inter-territorial disparities can be various climatic and geographic conditions, uneven natural resource base, uneven distribution of production facilities and the existing settlement system, development of transport infrastructure, etc. A major factor determining the importance of individual regions in the inter-territorial ties is economic growth and its determinants including technical progress. In the context of the transition to another technical and economic setup determined by the parameters of Industry 4.0, it seems very timely to assess the consequences of the new technological revolution for spatial and regional development, since there is an opportunity to direct and adjust the spatial projection of digital transformation at the initial stage of technological changes.

Previous studies have proven the significant impact of digitalisation on regional development. There are positive effects of digital transformation on the growth of labour and capital productivity, and the rate of economic growth. In particular, using regression analysis tools, the direct impact of the labour and capital digitalisation on regional growth has been proven; it is measured through the number of people employed in the ICT sector and the ICT costs of entities [16].

However, the impact of digitalisation is not always limited to any positive effects. In particular, a possible variant of a destructive digital transformation is considered, which can be characterised by rapid and radical changes in enterprises; it results in impairing the ability to compete and undermining the financial potential of firms [24].

Three scenarios of digital transformation can be considered in the context of the impact on the regional development processes (see Table 3).

Among the above options, the third scenario is undoubtedly the best, although the implementation should be accompanied by the improved implementation of industrial policy measures and an increase in the transparency of mechanisms for distributing financial assistance between regions. In the current situation, the second scenario is more likely, which can be partially confirmed by the research results. Implementation of the first scenario should be recognised as the most negative option, while the technological inferiority of certain territories will not be preserved, but there will be a significant loss of the competitive edge by the national economy as a whole.

6 Conclusion

Based on the research conducted, the main conclusions can be formulated as follows.

At first, the digital transformation process in Russia as a whole and in the regions of the Russian Federation can be considered to have begun; in recent years, investments in the ICT sector have grown significantly, employment in this area has increased, and government support measures have increased.

Table 3 Scenarios of the effects of digital transformation on the territorial development in Russia

Scenarios	Rate of digital enablement	Spatial coverage	Digital investment performance	Implications for territorial differentiation
Scenario 1	Slow	Narrow, first of all—the largest urban agglomerations—Moscow and St. Petersburg, to a lesser extent—other million-plus cities, as well as regions with a priority order of financial support	Low, part of the funds, including those allocated with the state support, were invested in unpromising projects or outdated technological solutions that do not allow providing enterprises with a competitive edge	Insignificant, due to weak economic effects
Scenario 2	Average	Narrow, primarily covers regions with a high concentration of labour and capital resources, in addition to large cities—regions with a high resource and industrial potential	Average, part of new digitalization projects turn out to be highly effective, providing an opportunity to reduce the cost of current production or increase production of fundamentally new products	Strengthening territorial differentiation, the leaders of past years consolidate their position, backward and depressed territories lag even further in the socio-economic development
Scenario 3	Above average, approaching the pace of digital transformation in leading overseas countries	Substantial spatial coverage—from 30 to 60% of the constituent entities of the Russian Federation (over time), also through ensuring competitive access to financial support with equalizing coefficients by area	Above average, including due to wide spatial coverage and general agglomeration effect on the country's economy	Smoothing differentiation by strengthening economic growth and increasing the investment attractiveness of areas presenting a problem in the past

Secondly, it can be stated that the first stage of digital transformation is complete, and it is accompanied by large-scale computerisation of the economy. At present, the second stage is well in progress, and the transition to the third stage is being carried out, but this process is accompanied by extreme territorial unevenness, so far, signs of the fourth stage can be recorded only in an insignificant number of regions not exceeding 10% of the constituent entities of the Russian Federation on average.

Third, the differentiation of regions according to individual digitalisation indicators in general coincides with the average values of general economic differentiation, which is also typical of the past periods of the country's development. The accuracy of current analytics is hampered by the scarcity of the information base on digital transformation processes provided by official Russian statistics.

Fourthly, unfortunately, the scale of digital transformation does not yet make it possible to significantly reduce the impact of crisis factors on regional development; perhaps further integration of digital technologies will make it possible to increase the stability of regional socio-economic systems, as the experience of foreign countries shows.

Fifthly, at the moment, one can state the provided "window of opportunity" for the implementation of one of the three key scenarios for the impact of digital transformation on regional development in the Russian Federation; the transition to the third most favourable scenario requires increased attention to the effectiveness of industrial policy measures and increased transparency and competitiveness in the distribution of the federal aid for large state projects and programs to stimulate scientific and technological developments.

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Structural Effects of the Introduction of Cross-Industrial Advanced Manufacturing Technologies: Experience of the European Union

Olga Smirnova and Alena Ponomareva

Abstract The economic and industrial transformation is currently determined by the success of scientific and technological progress in such knowledge fields as information technology, biotechnology, nano- and microelectronics, robotics, etc. It is worth noting that technology does not develop in isolation. The convergence of technologies leads to a mutual reinforcement of their effectiveness and expands their scope of application. The formation of cross-links between industries and the use of advanced technology by enterprises impacts the industry's structure and the entire economic system. The article deals with cross-industrial innovation as one of the drivers of economic development and a factor in transforming the economic structure. The article deals with the technological transformation of national EU economies in the context of growing global trends of digitalization and green economy. A review of the technological transformation of developed countries' economies seems appropriate in terms of the continuity of best practices of technological modernization of the economy. Trends in the use of advanced technologies in various economic sectors are analyzed, using the example of EU countries, which can be adapted to emerging markets. The dynamics and structure of using such advanced technologies as new materials, robots, micro-and nanoelectronics, and industrial biotechnology were analyzed. As a result of the study, it is shown that today's competitive technology is the product of a non-linear innovation process. It is concluded that the effective cross-industrial relations of EU enterprises are formed under the development of the cluster form of interaction.

Keywords Cross-industrialization · Advanced technologies · Technological innovations · Structural analysis · Digitalization

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1 Introduction

In the present dominant knowledge economy, technology is becoming a major factor in competitive and sustainable development. The issues of technological transformation, especially the digital industry transformation, are increasingly discussed by economists [14, 22, 23, 25]. The increasing pace of digitalization of the economy is affecting all areas of economic systems. For the competitive development of industry, the most important factor is access to modern technological solutions providing production with greater resource efficiency, the lowest cost, and reduced environmental damage.

The EU countries are world leaders in socio-economic development and the competitiveness level of industrial production [5]. In 2020, the EU introduced a new industrial policy with the main priority of the dual transition to green and digital technologies. The objective of the declared industrial strategy is, above all, to increase the global EU competitiveness and strengthen the technological Europe autonomy. According to this strategy, the environmental friendliness of industries and commitment to the use of circular economy technologies are significant conditions for their competitiveness. Also, a strategic direction for Europe is to increase investment in research and technology implementation in areas such as artificial intelligence, 5G, data and metadata analysis. In 2018, 10% of European companies used Big Data technology, and 25 companies used cloud computing services in their operations [6].

The technological industry transformation in the EU is based on the formation of a single space of scientific research with free movement of scientists, knowledge, and technology, in transparent and open competitiveness [8, 21]. The new EU industrial policy is based on open science. New forms of partnership between industrial enterprises, state funds, and society are being formed.

The article aims to consider the experience of using advanced cross-industrial technologies in EU countries. Analysis of the dynamics and structure of diffusion in various sectors of the economy is carried out by assessing the effects of "spillover" of the introduction of technology and the cross-industrial effects of the impact of advanced production technologies on the economy.

2 Literature Review

Increasingly, the process of innovation emergence, including technological innovation, is non-linear. A derivative of the open innovation model is based on the interactions of different fields of knowledge, the so-called cross-industrial innovation model [3]. The effectiveness of cross-industrial innovation in unrelated industries is increasingly discussed in scientific publications (Huang and Ji [10], Mahnken and Moehrle [16], Lyng and Brun [15], etc.).

The industry transformation is a permanently dynamic process, during which the current technological modes in the industrial sector change [24]. This process includes a whole system of mutually correlated processes, the result of which is a change in the set of technologies prevailing in production. Certainly, the main factor in changing technological modes today is the global trend of digital economy development. A single digital space contributes to the development of network interactions and transforms relationships between participants in the value chain.

Studies by the World Economic Forum show that soon there will be no economic and social sectors not transformed by digital technology [20]. The research concludes that the greatest effect from the use of digital technology will have an economy in which "not only traditional industries and services will be well developed from the standpoint of digitalization, but, above all, cooperative links between them will be formed" [12, 20].

However, the basis of the fourth industrial revolution is not just digital transformation. Technological convergence and the formation of hybrid technologies are currently of particular importance when changing technological patterns. Convergence refers not only to mutual influence but also to the interpenetration of technologies. In this process, the boundaries between individual industrial technologies are blurred, and at the interdisciplinary level, their greatest effectiveness emerges. The appearance of cross-industrial open industrial-service ecosystems, including many different information systems for managing enterprises and devices, is taking place [20].

The cross-industrial transformation of industry is understood as the technological inter-industrial interaction of the industrial complex and its cross-contracting with other economic sectors. The innovation of industrial technology can be used, in addition to common linear models, in industries not directly related to each other [1]. Unlike closed innovations, which occur within a single organization (from development to market launch), the cross-industrial model will produce multiplicative effects in different economic sectors. This model involves active cooperation of institutions both within the triple helix (science, business, society) and horizontal integration of the company to strengthen the effects of scientific and production cooperation. A breakthrough in scientific and technological development is impossible without increasing the innovative activity of industrial companies and their effective cooperation.

Changes in obtaining and transferring knowledge and technology have their trends and features (Fig. 1). One is the multidisciplinary nature of technology, the introduction of traditional technologies into new markets with altered functions. Also, with the development of new forms of innovation, ethical and social problems, such as the impact of technology on privacy and the environment, are increasing [3]. The dynamic trend of multidisciplinarity and the globalization of technology reinforces the importance of the cross-industrial model of innovation.

There are many examples in the history of worldwide technological development where technologies have been more effectively applied in sectors other than those in which they originally appeared [3, 9]. For example, there are three types of cross-industrial uses of space technology. The first is direct use. The technologies were not originally designed for production outside space conditions but later successfully adapted to terrestrial conditions (materials, coatings, electronic sensors, computer

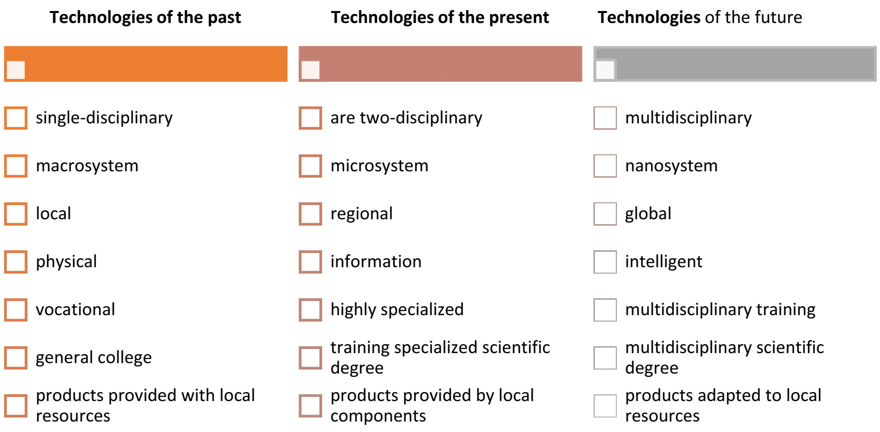

Fig. 1 Changes in requirements and technology trends [3, 4]

programs, etc.). Some technologies are also dual-use, developed in parallel—for use in space and on Earth. There is also an indirect emergence of technology; its creation took place outside the space industry but was based on its development. For example, medical equipment for deep tissue cooling is based on using cryogenic fluids [3].

The essence of the open and cross-industrial innovation model is to change the internal processes of innovation management. These processes must become more open; there is a technology diffusion process through the joint action of universities, laboratories, start-up companies, suppliers, consumers, and manufacturers. Under such conditions, the place of internal competition of industrial enterprises must prioritize the need for their interaction and cooperation to obtain new technologies and knowledge, allowing them to enter the international market with high added value products. This trend necessitates the emergence of new business models that enable effective collaboration to generate innovation while maintaining competition. Innovations created in one industry affect others: there is a so-called "knowledge spillover" between fields of knowledge. This process has been termed "spillover effects" (secondary effects). This spillover effect can be the impetus for developing new processes, products, and services in related industries [13].

To facilitate cross-industry innovation processes, a structural approach is needed to change innovation processes at the company level. Currently, Russian companies are facing the issue of their production and organizational business processes being unprepared for technological transformation and digitalization trends. The issue of the lack of necessary skills and competencies is also relevant. The success of creating and implementing cross-innovations largely depends on the network interactions of companies and the closeness of their scientific and production relations [2]. One of the effective organizational forms of such interactions for implementing the model of cross-industrial innovations is cross-industry innovation clusters, which have become a relatively new direction of cluster development [17].

The creation of innovative clusters with the participation of high-tech industry occupies a special place among industrial policy tools both in Russia and other countries [8, 11]. This form of interaction is effective for developing the innovative potential of local economies (at the regional level) and is used in many countries with developed economies (USA, Italy, Germany, France, etc.). In a general sense, a cluster is understood as an integrated structure with many links and interdependencies. The basis for the creation and successful functioning of modern clusters is infrastructure and technology [11].

Cross-industry innovation clusters use a system of knowledge and technology dissemination based on cross-links. In a cluster, participants have a competitive advantage in the form of specialization, which allows minimizing the cost of implementing innovations [3] and reducing the risks of inefficient or unclaimed technological innovation.

The literature review has concluded that there is a growing trend of knowledge interdisciplinarity, the non-linear nature of the creation and dissemination of technology. Cross-industrial introduction of technologies can help reduce the risks of technologies not being in demand, increase the economic effects of their implementation, and change the economic structure. In particular, this is influenced by the use of military and space technologies in the civil sector and advanced manufacturing technologies in the social, service, and management spheres. In the following article, using the EU example, a study of advanced production technologies in various sectors of the EU economy is conducted.

3 Material and Methods

The rapid rise of advanced technologies is transforming businesses, industries and the society and it is profoundly changing the future competitiveness and employment dynamics of nations. Traditionally, the source industries for cross-industry technologies are advanced high-tech industries, such as space engineering, chemistry, and biopharmaceuticals. New industries that have successfully applied cross-industry innovation technologies are packaging materials and waste recycling.

The starting point of this analysis has been 16 advanced technologies that are a priority for European industrial policy, which enable process, product and service innovation throughout the economy and hence foster industrial modernisation. The advanced technologies within the focus of this report include advanced materials, advanced manufacturing, artificial intelligence, augmented and virtual reality, big data, blockchain, cloud technologies, connectivity, industrial biotechnology, Internet of Things, micro- and nanoelectronics, mobility, nanotechnology, photonics, robotics, and security.

The level of uptake of advanced technologies has been measured based on a variety of sources such as the business survey, production indicators, text-mining of company websites and available Eurostat indicators.

Technology generation and exploitation have been captured through patenting activity and production and trade of technology-based components in the EU countries. The patent indicators measure the ability to produce new technological knowledge relevant to industrial application. Production indicators measure the relevance and dynamics of the production and absorption of advanced technology based components.

Using the example of EU countries, the study analyzes the effects of cross-industrialization, that is, the use of advanced technologies in various sectors of the economy. The analysis includes a study of the dynamics and structure of the introduction of advanced production technologies in the manufacturing, service, agriculture, finance, and management sectors. The application of such advanced technologies, which have traditionally been implemented to a greater extent in the manufacturing sector, is considered. This is the use of modern materials, robotics, micro- and nanoelectronics, industrial biotechnology.

The study is based on patent data collected by the European Commission [7]. The patents have been localized based on the location of the legal owner of the patent application, and therefore the analysis reflects the owner/applicant of the technology. The advanced manufacturing technology use rates considered reflect the proportion of businesses that have incorporated advanced technology into their company's operations or production in the overall sample obtained from the ATI survey. This survey was conducted in 2019 and 2020. The 2020 study included 1500 companies from France, Germany, Italy, Spain, Denmark, Sweden, and Poland. The 2019 survey is based on a sample of 900 firms from 11 countries. This survey covers enterprises of different levels, from small and medium-sized to large companies [7]. The study does not take into account the impact factor of the COVID-19 pandemic.

4 Results and Discussion

Advanced manufacturing technologies use technological and organizational innovations to improve products or manufacturing processes. They are based on technologies based on robotics, automation technology, or computer-integrated manufacturing. Future technologies developed in the Industry 4.0 concept include the introduction of networking between machinery, equipment, buildings, and information systems, the ability to monitor and analyze the environment, the production process and own state in real-time, the transfer of control and decision-making functions to intelligent systems, etc. Advanced technologies such as Big Data, Blockchain, Cloud Computing, artificial intelligence, augmented, virtual reality technologies, and other advanced areas of modern science underlie economic growth, competitiveness, and digitalization of production. The new generation of technology enables economic benefits from analyzing and using data, improving and accelerating production processes, reducing the number of transactions, and a host of other new opportunities. These technologies are used in the industrial sector and are already widespread in all sectors of the economy (Fig. 2).

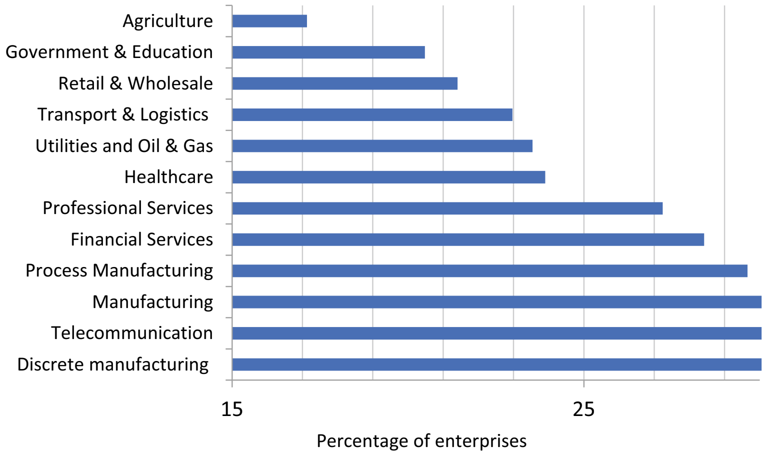

Fig. 2 The use of advanced technologies in various sectors of the EU economy, 2020 [7]

According to the 2020 survey, advanced technology is generally mostly used in the manufacturing and telecommunications sectors. About a third of all manufacturing EU companies use advanced technology in their business activities. The agriculture sector is the least involved (17.13%).

Technologies for creating new modern materials allow for new properties of products and services and reduce their cost. As a result, the use of new materials provides new quality goods and services in manufacturing and the aerospace industry, transportation, construction, health care, and others. The use of new materials, including recycled materials, in addition to the economic effects, can reduce energy use and, as a consequence, carbon dioxide emissions into the environment. Also, technologies for developing new materials allow obtaining the equivalent of scarce materials.

Figure 3 shows that in 2020, compared to 2019, new materials technology is increasingly used in non-manufacturing enterprises. Among the industries with the sharpest growth in the use of these technologies, one can note the education and management sector (8.38%), the agricultural sector 4%, the financial sector and telecommunications (more than 10%), more than 16% of service sector companies use the technology of new materials.

Robotization, both in manufacturing and services, has not stopped at its fast-growing pace. Robotics encompasses the design, construction, implementation, and operation of robots. Robotics technology currently allows obtaining robots of various categories. These are specific robots designed to perform a specific task, they can be stationary or mobile, but their functionality is limited. Multi-purpose robots are designed to perform several functions, and here is an opportunity to personalize their functions for the company's tasks. The new generation of cognitive robots can make decisions and reasoning, allowing them to work in complex environments. It is important to note that they are capable of learning and making decisions.

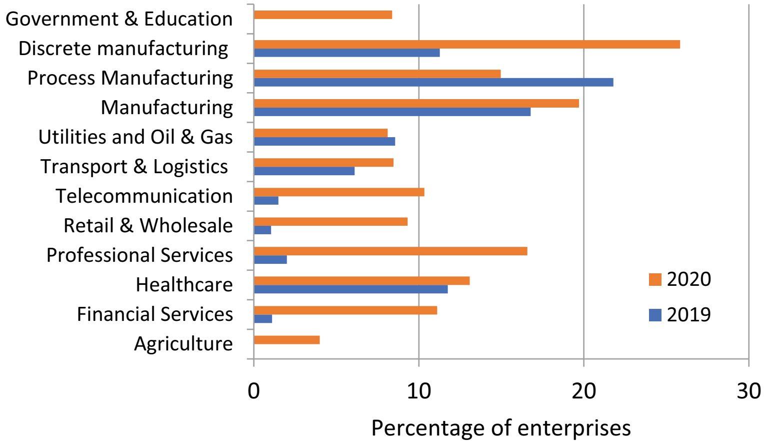

Fig. 3 The use of modern materials in various sectors of the EU economy [7]

In continuous manufacturing, the share of EU enterprises using robots in 2019 was 1/3, and in 2020 it is already half of all surveyed enterprises (Fig. 4). The functionality and complexity of the work performed by industrial robots continue to gain momentum. A large increase is noted in telecommunications, from 3 to 20%. In the financial sector, about 25% of companies surveyed in 2020 use robotics technology. In 2019, fewer than 10% of organizations in the sector were using robots in their operations.

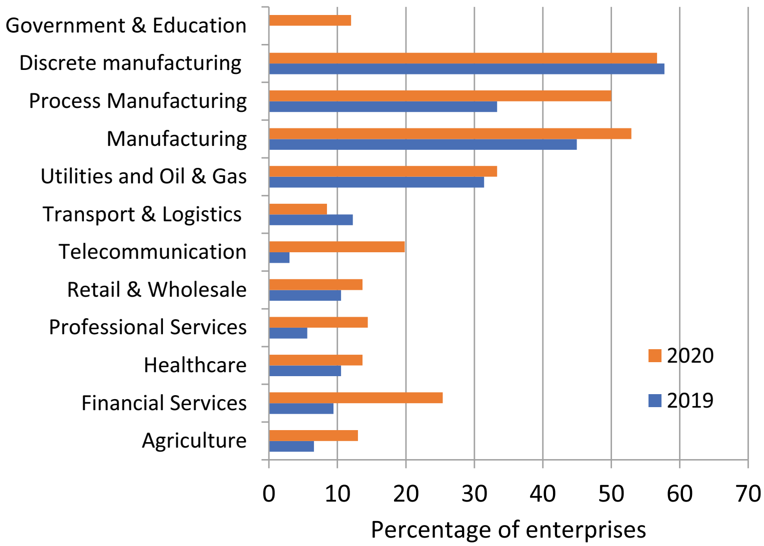

Fig. 4 The use of robots in various sectors of the EU economy [7]

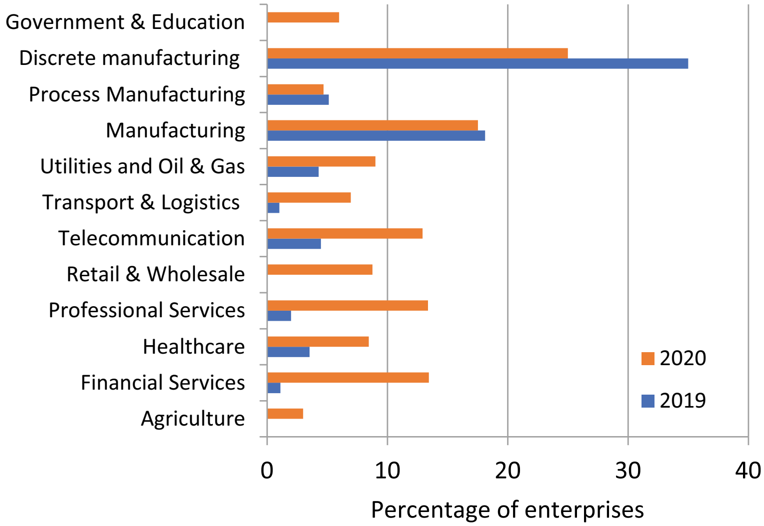

Fig. 5 The use of micro-and nanotechnology in various sectors of the EU economy [7]

Nanoelectronics is an interdisciplinary science and combines different areas of electronics. The laws of interaction of electrons, other charged particles, and quasi-particles with electromagnetic fields in various media, and the use of this interaction to create electronic devices by nanotechnology, are studied. The advances in modern microelectronics amaze with their boldness of technical solutions and their wide range of applications. The use of nanotechnology leads to the development of intelligent nano- and micro-devices and systems, which entails enormous changes in vital areas such as health care, energy, the environment, and manufacturing. Figure 5 shows that micro and nanotechnologies are penetrating all sectors of the EU economy. It is important to note the large increase compared to 2019 in the discrete manufacturing industry. It is also noticeable in non-manufacturing industries such as telecommunications, the financial sector, sales, and services.

An analysis of the use of industrial biotechnology is of particular importance for assessing cross-industry effects (Fig. 6). Industrial biotechnology integrates knowledge from such sciences as biochemistry, microbiology, molecular biology, and applied sciences. Biotechnological processes involve the use of microorganisms, cell and tissue cultures. The application of biotechnology has become more common in the industrial processing and production of chemicals, materials, and fuels. Microorganisms, or components of microorganisms, are used to produce products and allow for economic effects in the form of reduced energy consumption or reduced by-products. More and more technologies and products based on biology are appearing in the market. In the early stages, biotechnology was associated with enzymes used in the food, agricultural industry. On the other hand, modern technologies include the production of biochemical products and biopolymers from agricultural or forestry waste.

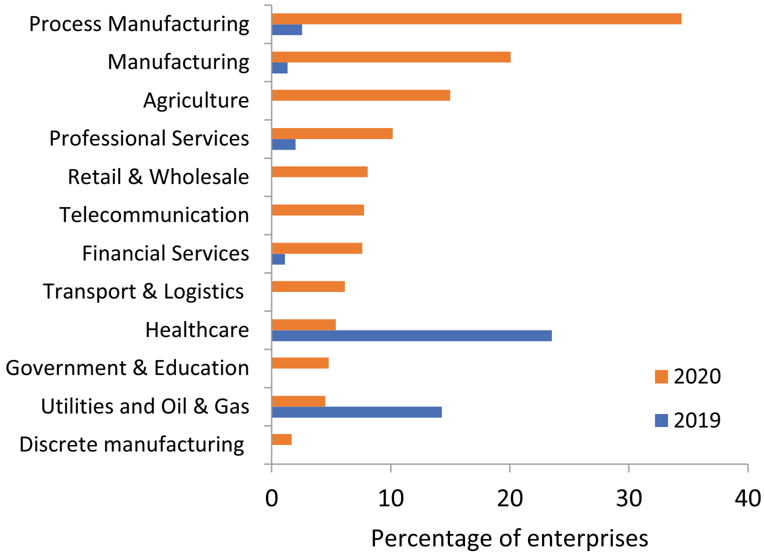

Fig. 6 The use of industrial biotechnology in various sectors of the EU economy [7]

In 2019, these technologies were most prevalent in health care, utilities, and energy in the EU. However, in 2020, one can see widespread adoption of biotechnology in industries. According to the 2020 survey, more than 34% of European continuous production plants use them. They are also becoming widespread in agriculture, telecommunications, and trade. Such trends point to the increasing cross-industrial effects of technological and organizational innovations and their increasing multidisciplinarity.

The analysis shows an increasing spread of technologies developed on an interdisciplinary basis, as well as the presence of spillover effects—technologies initially used in some sectors are spreading with great speed to other areas of economic activity. The presence of such effects, in the authors' opinion, is associated with a large number of cross-connections of European enterprises, the spread of interaction in the form of inter-regional and inter-industry clusters.

The effects of technology spillovers between industries in the long term inevitably change the sectoral structure of the national economy. The cross-industrial application of advanced production technologies will allow the formation of a more balanced structure of the economy, which will increase its resistance to various external shocks [18].

The development and application of cross-industrial innovation in clusters have many advantages. First of all, these are competitive advantages—the development of radical innovation leads to the creation of new industries, which also changes the industry structure and increases the competitiveness of the national economy. Cross-industry interactions also reduce the risks of not using innovation, and the experience of using the technology in other industries helps reduce the cost of additional research.

5 Conclusions

The global mainstream of today's competitive development for the industrial economy is its digitalization and focus on the green economy principles. This trend must, to some extent, affect all areas of the economy, industry, and the social sphere. The study shows that the spread of advanced production technologies leads to the transformation of the industrial sector and, in the long term, changes the sectoral structure of the economy. Trends of digitalization and green economy change approach to the implementation of industrial policy [6, 19]. It is important to note that industrial policy is understood in a broad sense and interpreted as structural in European countries. Cross-industrial technology is becoming a factor in creating a balanced economic structure.

The technologies in demand today are the product of a non-linear process of innovation. The economy's competitiveness can be ensured by advanced technologies derived from the intersection of different knowledge fields. Interdisciplinary research, the involvement of business in the creation of new technologies, and active inter-industry cooperation are of great importance when reducing the technological dependence of national economies' industries on the global technology market. The practice of using advanced technologies in the EU countries shows that in addition to the space industry, cross-industrial technologies are being developed in chemistry and new materials, medicine, biology, information and communication, mechanical engineering, and electronics. The cross-industrial use of technology represents a significant potential for economic growth in a networked environment due to synergies and spillover effects.

The study shows the increasing spread of production technologies in the non-production sphere, which will lead to changes in the sectoral structure of the economy in the long term. Also, this cross-industry spread of advanced technologies shows the balanced structure of the EU economy.

Advanced technology on an interdisciplinary basis is a basic condition for an early transition to a cycle economy. In the context of digitalization, more demands are placed on business. This cannot but affect the organization of business processes; there are new forms of interaction in clusters, business networks, virtual structures. New forms of interaction will allow enterprises to respond more flexibly to technological challenges. The proper support for the spread of such new forms of organization as inter-industry clusters by the state will maximize the cross-industrial effects in the economy as a whole.

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Best Regional Practices for Digital Transformation in Industry: The Case of the Industry 4.0 Program in Portugal

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Abstract The Portuguese government, through its program for Industry 4.0, Portugal I4.0, has been supporting projects aimed at the digital transformation of the economy by mobilizing European funds and governmental subsidies from the Portugal 2020 Program. The objective of this study is to analyze the best regional practices for digital transformation in the industry 4.0 in this context. The following research questions arise: which are the best practices for digital transformation in Portugal under this Program and what was the impact on the competitiveness of Portuguese industries after the implementation of these technologies through the Incentive Value from 2017 to 2019? The methodological approach is correlational, and it establishes a relationship between the I4.0 Incentive Value and Competitiveness in order to identify the best regional practices for digital trans-formation in the Portuguese industry. The hypothesis of this study is accepted for the period 2017–2019, since the factors that make up the industry 4.0—European Fund—Incentive Value dimension are associated to the degree of competitive-ness, which was measured by a set of related variables. Further studies are necessary for longer periods and with a broader scope, the result shows the relevance of the Program.

Keywords Digital transformation · Regional practices · Industry 4.0

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1 Introduction

According to market logic, the convergence between manufacturing and the basic technologies of Industry 4.0 (I4.0) makes it increasingly essential for companies to formulate innovation strategies to strengthen their technological capabilities. Also, digital transformation changes industrial processes and procedures, as well as changes the relative positions of key actors in the value chain and intellectual property regimes. In this shifting landscape, [1, 9, 38, 40, 41] agree on the distinction of three sectors in which industry 4.0 stands: (1) core technologies (hardware, software, connectivity); (2) basic technologies (analytical, security, artificial intelligence, electrical, 3D systems); and (3) application technologies (home, personal, company, manufacturing industry, infrastructure, vehicles, etc.). In view of this distinction, it should be noted that Industry 4.0 is a peculiar concept to the Fourth Industrial Revolution (4IR), which accompanies digital transformation, automation and data exchange in technologies including the internet of things (IoT); big data; 3D printing (additive manufacturing); cloud computing; autonomous robots; augmented virtual reality; industrial internet of things (IIoT); cyber-physical systems; block-chain; artificial intelligence; intelligent sensors; smart logistics; drones; simulation and digital twins; smart factory; nano-technology; biotechnology, among others [2, 4, 6, 10, 14, 17, 18, 24, 26, 27].

Since the technological evolution leads to the convergence between the components and the knowledge of new technologies [29, 30], the I4.0 allows the management of industries that manufacture products with greater complexity, but also with flexibility. Thus, the 4IR, through the digitalization and interconnection of all objects (projects, parts, machines, devices, etc.) implies a significant improvement in the manufacturing systems. In contrast with previous industrial revolutions, I4.0 is based on the creation of networks and interconnectivity between existing assets and technologies, therefore not limiting itself to the replacement of existing assets and technologies, and mainly using Information and Communication Technologies (ICT). After the implementation of the I4.0 concept in Germany, other countries have also progressed in the use of their inherent technologies, and in this context patent rights must be emphasized insofar they are crucial for companies because of their exclusive nature, corresponding to rights of their owner To address the above-mentioned challenges, this paper puts forward the following research objective: to analyze the best regional practices for digital transformation focusing on the case of Industry 4.0 Program in Portugal, from where two research questions arise: which are the best regional practices for digital transformation in the Industry 4.0 Program of Portugal, and what was the impact on the competitiveness of Portuguese industries after the implementation of the industry 4.0 technology-enabling projects through the Incentive Value from 2017 to 2019.

Therefore, based on the Portuguese case, and starting from the questions that were just raised, this research contributes to deepen the study of I4.0 in the domain of the best regional practices for digital transformation in a theoretical, methodological and empirical way. From the theoretical point of view, there is an analysis that allows inserting the digital transformation in the context of the industrial structure. From a methodological point of view, the study contributes applying a comparative analysis to the literature on the relationship between digital transformation and the technological conditions from the I4.0 perspective. In empirical terms, the study focuses on how the digital transformation in industry can configure a prerequisite for the competitiveness of industries in the country. These results are the first step to create a digital platform that delivers a comprehensive assessment of digital transformation over time.

The structure of the article is organized as follows. Section 1 covers a brief introduction to the core issues. Section 2 presents the conceptual framework and develops the analytical structure of our approach. In Sect. 3 the methodology that was followed is described. Section 4 shows the results that were obtained in the empirical research. In Sect. 5 the main results are discussed. The paper closes stating the main conclusions, the study limitations, and offering clues for further research.

2 Background

2.1 Industry 4.0

The literature has investigated many aspects of 4IR, both in the field of applications and in the academy [18, 33, 34]. The I4.0 has been considered a new industrial stage in which several emerging technologies converge to provide digital solutions. For the purpose of this paper, it must be considered that the inventions of 4IR can be classified in three big categories, each of which is subdivided into several technological domains: (i) Main technologies (hardware, software and connectivity) that allow transforming any object into an intelligent device connected through the Internet; (ii) Enabling technologies (big data, artificial intelligence, 3D systems, human–machine interaction) that are used in combination with linked objects; (iii) Application technologies (home, personal, company, transformation industry, infrastructure, vehicles) in which the potential of linked objects can be explored [35, 36].

Under this approach, [38, 39] use a more restricted definition, where I4.0 is connected to intelligent manufactures in which new and distinct technologies change the organization of value chains. The scope is the "digitalization" of production that integrates with the new ICT. This conception of I4.0 has reflected a strong will by national governments to promote reindustrialization, being smart industry its central element [38, 40]. Naturally, smart industry requires wide availability and integration of the factory with the entire product life cycle and production chain activities [7, 16], including changes in the way people work. In fact, the smart industry depends on the adoption of digital technologies to collect real-time data and analyze it, providing useful information to the manufacturing system [42].

2.2 Governmental Subsidies

Moreover, the literature often suggests that I4.0 will expand the opportunities for many regions, create new regional leaders combined with the potential to shift the geography of knowledge production in various directions. This is, in any case, one of the aspects to be analyzed in the present study. On the one hand, there is a focus on management among the different research advances referring to I4.0 [5, 8]. In addition, research is progressing on specific technologies and industry-focused issues [12]. However, little emphasis has been placed on the role of governmental subsidies when executing I4.0 projects and the impact of these technologies on business performance [16].

On the other hand, several empirical studies have described the issue of subsidies to innovation activities mainly using financing, tax incentives, special loans and similar policies. Among these studies, [3, 11, 15] evaluate the impact of an innovation program in Italy, noting that the subsidy increased the number of patent applications submitted by beneficiary companies. Other studies [15, 19, 20] concluded that subsidies are one of the most widely used international instruments because they reduce the costs associated with R&D and innovation. More recently, it has been observed that public interventions are primarily aimed at reducing the effective cost of R&D, promoting cost sharing and encouraging companies to invest in research and thus improving the efficiency of innovation activities [25, 28].

In this context, governmental subsidies can reduce the cost of R&D activities for companies and generate more innovation by motivating additional private R&D spending [28]. Government R&D funding also changes the behavior of recipient companies and affects the innovation pattern [21, 23]. Direct subsidies used in isolation or with tax incentives strengthen the R&D orientation of small and medium-sized enterprises (SMEs) [15]. As such, governmental R&D subsidies play a positive role in innovation. It is also important to note that credit promotion policies, with public guarantee, can also provide incentives for existing low-cost access to financial capital to promote innovation efficiency [8].

Another important aspect pointed out by Sung [11, 28, 29] indicates a positive two-way causal relationship between company innovations and variables like R&D subsidies, availability of internal innovation resources and industry competition. Also, [58] conclude that subsidies can promote technological competition, but they can also limit innovation when there is an oversupply of subsidies. In addition to this issue, the study by [41] stated that special loans and tax credits positively affect a firm's innovation performance, while direct allocations sometimes have negative effects. From this perspective, a preferential tax policy was found to have a significant positive impact on R&D efficiency, but not on the market conversion efficiency. Also, [11] found that financial support from the government has a significant negative impact on R&D innovation efficiency, but government tax support has a significant positive effect on R&D innovation efficiency. And finally, [40] noted that direct financial support from the government has no impact on improving the efficiency of technological innovation in high-tech industry. Regarding governmental R&D

subsidies, this section highlighted that they are used as a tool to foster technological development or support in general, innovation, start-ups, etc. The conclusions of this section indicate that subsidies and their use can be a strategy to differentiate and generate results for organizations as sources of competitive advantages; the results can however be diverse.

3 Material and Methods

In this first moment, the study carried out was of an applied nature, being designed from documental research through the use of secondary data.

In a second moment, the study can be categorized as a causal study with the objective of testing the relationships between variables. The aim was to establish relationships between two or more concepts or the degree of relationship between these concepts, considering that the formulation of hypotheses in studies of a correlational nature validates the association between variables and not the causality of a phenomenon. As such, the effects of the incentive value of the European Union (EU) Funds on the competitiveness of Portuguese industrial companies were analyzed through projects focused on I4.0 technologies in two dependent samples of the periods 2017–2018 and 2017–2019. Thus, the study evaluates companies enrolled for the receipt of EU Funds, which had implemented I4.0 projects in the same period, arising from the Partnership Agreement between Portugal and the European Commission, called Portugal 2020, under the scope of the Operational Program of Competitiveness and Internationalization—COMPETE 2020.

In this sense, the COMPETE database was used, consisting of the set of projects that were approved between 2016 and June 2020. It should be noted that only companies receiving subsidies for projects with an initial project execution date of January 2017 were considered, with those companies being analyzed that appeared in the indicator base from 2017 to 2018 and from 2017 to 2019, i.e., a period of 1 or 2 years. Companies with projects executed after 2018 were not considered. At first, in the selection of the two samples, the definition of specific I4.0 measures was not identified in the COMPETE base, but projects in different measures were included, such as R&TD—Copromotion, R&TD—Individuals, R&TD—Mobilizing Programs, SIAC, Innovation—Productive, Innovation—RCI, IQ SME—Individuals, IQ SME—Sets, IQ SME—Vouchers. Therefore, a first search was made with keywords related to the subjects and description of the projects supported by these measures. Specifically, keywords related to I4.0 were applied: I4.0, Industry 4.0, Artificial Intelligence (AI), Internet of Things, Robotics, Cloud Computing, Machine Learning, Additive Manufacturing and Simulation.

After searching for keywords with the terms in Portuguese, English and acronyms, a second criterion was applied regarding the year the project started. This returned 123 companies with projects implemented in I4.0 enabling technologies. Next, teaching and research institutions were discarded, leaving 91 companies. After a new analysis of the companies, there were companies with projects executed after 2017, resulting in the exclusion of about 44 companies and leaving about 36 (thirty-six) industries for analysis with projects implemented between 2016 to 2018.

Subsequently, a research model was developed that allowed for the proposal of the relationship between variables: the dependent variable was Industry Competitiveness (Operating Revenue, Number of Employees, Total Factor Productivity (TFP), Gross Value Added, EBITDA and Net Profit) and the independent variable was Industry 4.0 Incentive Value (EU Financing).

The following precepts explain the choice for the model with its dimensions and factors. The traditional ex-post competitiveness indicators (performance, market-share and profitability, the so-called revealed competitiveness), as well as the ex-ante indicators (efficiency), provide the means, within the new productive paradigm, to determine the factors that generate competitiveness. As competitive performance is a variable summarizing all the conditions that influence competition over a given period of time, there is a way to derive causes or interconnections between the variables that determine competitiveness in the industry.

For the set of companies with subsidized projects that were filtered from the COMPETE base, the economic-financial database Orbis Europe was accessed, which contains detailed financial information on 120 million European companies. The database has 10 years of detailed financial information and analysis and modeling of the financial indicators, including the variables used in the research model.

The data obtained through the research were analyzed with statistical techniques that allowed us to decide on the acceptance or rejection of the established associations. Non-parametric statistics were chosen because of the small number in the samples and the suspicion that the data were not normally distributed. The number of companies was 36 (thirty-six), thus constituting a small group of information for analysis according to non-parametric statistical techniques (Siegel, 1975). In order to test some associations in the SPSS software, the group was divided into two samples, one considering the time frame 2017–2018 and the other the time frame 2017–2019, which were also considered of a higher degree and a lower degree, both in terms of dimensions and factors, allowing for the application of difference tests. A level of 5% was established as significant for the hypothesis test. This is the standard level applied in social sciences and appropriate for samples with a size close to 50, which is the specific case of this study.

The following tests were used in the analysis [38]:

A. Kendall rank correlation coefficient tests are applied when several variables are studied simultaneously to determine how they are interrelated. The more the given index approaches a certain level, the higher the correlation.

$$S = \sum_{i<j} (sign(x[j] - x[i])) * (sign(y[j] - y[i])) \tag{1}$$

The following equation is used to test the significance of the Kendall coefficient:

$$c2 = k(N - 1)W \tag{2}$$

B. The Wilcoxon signed-rank test is used to compare whether the rank measurements of two samples is equal when the samples are dependent.

$$\left\{\left(X^1, Y^1\right) \ldots \left(X^n, Y^n\right)\right\}. \tag{3}$$

Thus, Di = Xi – Yi, for i = 1, 2, …, n. Therefore, the sample D1, D2, …, Dn is obtained, resulting from the differences between the values of each pair.

Hypotheses are established to perform the Wilcoxon Test:

$$\begin{aligned} H0 = \sum pi(+) = \sum pi(-) \qquad \sum pi(+) > \sum pi(-) \\ H1 = \sum pi(+) \neq \sum pi(-) \qquad \sum pi(+) < \sum pi(-) \end{aligned} \tag{4}$$

H0: There is significant correlation between the variables (Operating Revenue, Number of Employees, Total Factor Productivity (TFP), Gross Value Added, EBITDA and Net Profit) when they are correlated with the EU Fund variable (Industry 4.0 Incentive Value).

H1: There is no significant correlation between the variables (Operating Revenue, Number of Employees, Total Factor Productivity (TFP), Gross Value Added, EBITDA and Net Profit) when these are correlated with the EU Fund variable (Industry 4.0 Incentive Value).

4 Results

4.1 Best Regional Practices for Digital Transformation in Industry 4.0 in Portugal

The industry 4.0 Program in Portugal is part of the National Strategy for the Digitalization of the Economy developed by the Ministry of Economy and the Digital Transition Strategy to be deployed through a set of measures based on three axes of action: (1) Accelerate the adoption of I4.0 in the structure of Portuguese businesses; (2) Promote Portuguese technological suppliers as I4.0 players; and (3) Turn Portugal into an attractive pole for investment in I4.0.

The industry 4.0 Program is currently in Phase II. Phase II of the program was launched with the objective of fulfilling a decade of sustained convergence with the European Union, described in the National Strategy for the 2030 Horizon. This phase was developed with contributions from over 50 entities and is characterized as transformative in relation to Phase I, which was mainly demonstrative and mobilizing in nature. In this new phase, it is estimated that 600 million euros in public and private investments will be mobilized in the next two years. The various initiatives should involve 20.000 companies, train more than 200.000 workers and finance more than 350 transformation projects.

The government has set up COTEC to supervise the implementation of I4.0 in the country. COTEC Portugal is responsible for industrial transformation solutions and the mobilization of decision makers and entrepreneurs within that purpose. This context created a collaborative platform (PI4.0) co-financed by public funds, involving business groups and state agencies like the Strategic Committee [16].

According to data from, the strategy is based on above-mentioned three action axes. The process was designed from the bottom up, with contributions from hundreds of stakeholders from various key sectors and the definition of over 60 measures. Since 2016 (when the first phase began) the organization has been based on six priority directions: human resources training, technological cooperation, creation of I4.0 startups, funding, investment support, internationalization and legal and regulatory adaptation. Four working groups were also created for priority sectors where digitalization has more impact (tourism, clothing, agri-food and automotive). Later, sectors such as construction (in particular with the diffusion of Building Information Modeling, or BIM), and connected healthcare were added.

Through the various initiatives carried out inside and outside the country - national meetings, innovation conferences, technical visits to manufacturing facilities and missions at international industrial trade shows such as Hannover Messe—the organization promoted reflection on such topics as the transformation of professions and jobs, the role of collaboration in innovation, the relationship between humans and machines and business training. The importance of the circular economy, the imperative of cyber-security and the distinction of excellence in industry were also highlighted.

The measures include the sharing of knowledge, experiences and benefits as a way to stimulate the massive transition to I4.0. To this end, it uses such tools as Shif 4.0, which allows companies to make a self-diagnosis about their digital maturity. The new phase of the industry 4.0 Program also provides for a set of measures to promote, facilitate and finance the access of companies to experimentation with I4.0 methods and technologies, as well as to support their scale-up and digital transition, employing tailored credit solutions. New support tools for Productive Innovation will be launched and, among other measures, technology-industry collaboration platforms and cyber-security training will be promoted.

In this context, IAPMEI, which is the public institution for the support of SMEs, is the partner of firms in the promotion of the available Incentive Systems that are distributed according to three types of action: R&D, Productive Innovation and the Digital Economy for R&D projects in cyber-physical systems; Virtualization and Simulation; Artificial Intelligence; Digitalization; Augmented Reality and Wearables; Nanotechnology and Advanced Materials; Energy. According to, the following incentives are in place for the R&D action:

- SI R&D to support projects comprising industrial research and experimental development activities leading to the creation of new products, processes or systems, or to significant improvements in demanding products, processes or systems. The beneficiaries of this measure are companies of any nature and legal form, and the following subsidies are part of the action: Non-Refundable Incentive (INR) up to 1 M euros per beneficiary (after 1 M euros: 75% Non-Refundable and 25% Refundable); Base Rate 25% up to (Limit (ESB)):—Industrial Research Projects: 80%—Experimental Development Projects: 60%.

- SI R&D Centers that support projects seeking to create or reinforce the internal competencies and capabilities of the companies through the creation of structures dedicated to the implementation of R&D and the necessary certification of research, development and innovation management systems through the NP 4457 standard, contemplating direct costs (expenses with technical personnel dedicated to streamlining the R&D centers; HR training; technical, scientific and consulting assistance required to structure the centers; scientific and technical instruments and equipment, software for the project, among others) and indirect costs. The beneficiaries of this measure are SMEs of any nature and legal form. In the case of co-promotion projects, non-business entities of I&I system are also beneficiaries through the Non-Refundable Incentive (INR)—50% for SMEs and 15% for Non-SMEs (only in co-promotion).

For Productive Innovation projects, the focus is on connectivity actions, intelligent production processes, additive manufacturing, intelligent machines, advanced materials, modular operations, 3D printing, and autonomous robots. The incentives vary between 15 and 75%, with 50% of the total amount provided through a non-refundable subsidy, to be granted under SI Innovation; 50% of the total amount is provided through a bank loan without interest, associated to a financial instrument funded by strategic program of Portugal 2020.

Industry 4.0 vouchers seek to promote the definition of an own technological strategy in order to improve the competitiveness of the company, aligned with the I4.0 principles [58]. This measure is meant to achieve digital transformation through the adoption of technologies that allow for disruptive change in the SME business models (acquisition of consulting services in order to identify a strategy conducive to the adoption of technologies and processes associated with I4.0, particularly in the strategy design and implementation areas applied to digital channels for the management of markets, channels, products or customer segments; design, implementation, optimization of Web Content Management (WCM) platforms, Campaign Management, Customer Relationship Management and E-Commerce, etc.). These vouchers have a unit value of 7.500 euros and are meant to support more than 1.500 companies, representing a public investment of 12 million euros.

The SI Individual Project Qualification aims to strengthen the business training of SMEs through organizational innovation, applying new methods and processes and increasing flexibility and responsiveness in the global market by using intangible investments in the area of competitiveness (organizational innovation and management, digital economy, brand creation and design, product, service and process development and engineering, protection of industrial property, quality, knowledge transfer, distribution & logistics, eco-innovation, professional training, HR hiring).

The strategic plan for phase I of Portugal i4.0 was composed of 60 public and private measures and private measures grouped into six major axes of priority action: Capacity Building of Human Resources; Cooperation Ecosystem; StartUp i4; Financing and support to investment; Internationalization; Legal and Normative Adaptation.

Among the various existing public instruments in the Phase I (Table 1) that support investment in the transition to a more digital economy, two stand out: the Vale Industry 4.0 and the Incentive System for Productive Innovation i4.0.

It also connects those best regional practices for digital transformation in industry to the eleven initiatives identified in COTEC's Industry 4.0 Phase II report (Table 2). In order to fill the identified gaps and leverage a generalized transition to Industry 4.0, phase II of Portugal i4.0 considers it necessary to act in three strategic lines: Generalize i4.0, Empower i4.0, Assimilate i4.0, and strategic lines: Generalize i4.0, Empower i4.0, Assimilate i4.0 [22].

4.2 Analysis of the Non-parametric Tests

As explained above, Kendall's correlation was used to assess whether variables were correlated or not when interconnected (Table 3).

As can be seen, the variable Industry 4.0 Incentive Value has no correlation with the variables Productivity and Employees. However, a high correlation can be observed between Operating Revenue (0.958) and the Ind. 4.0 incentive value, followed by a high correlation between EBITDA (0.776) and the Ind. 4.0 incentive value. This is important to confirm the fact that they are dependent variables and belong to the same order group.

Subsequently, the normal distribution of both samples was verified, adopting the Wilcoxon signed-rank test with the defined hypotheses (HA, HB, HC, HD, HE, HF) in order to assess whether there were statistically significant differences between the *ex ante* and *ex post* periods for the receipt of the Industry 4.0 Incentive Value. Revenue volume is a performance indicator par excellence. The analysis of performance was carried out through the Operating Revenue variable, which is defined as sales and services rendered during the financial year, excluding value added taxes and other directly related taxes.

In turn, the efficiency analysis was carried out first through the employment variable. The efficiency indicator translates a company's capacity to generate products at efficiency levels equal to or higher than those observed in other companies, mainly with regard to prices, quality, services, price-quality ratio, technology, wages and productivity. Indeed, the qualification indicators consider the incorporation of technical progress in products as well as business organization and the cooperation between firms and public and private investments.

In general, competitiveness depends on adjusting the strategies of companies to the current competition standard. It is important to highlight that the success of companies ultimately depends on the reproduction of these factors in the internal

Table 1 Policy measures phase I [13]

Measure	Description	Benefits	Execution
Framework program horizon 2020	It sets out the framework for EU support for R&I activities, strengthening Europe's scientific and technological base and promotes the benefits for society as well as better exploitation of the economic and industrial potential of innovation and R&TD policies	It contributes to creating a society and economy based on knowledge and innovationby exerting a leverage effect that mobilizes additional funding for research development and innovation, in order to achieve the R&D targets and the 3% GDP target forresearch and innovation across the EU by 2020	Implemented
Portugal 2020—Vale I Industry 4.0	Supports projects in the scope of Portugal 2020 that aimed at acquiring consultancy services in R&TD activities and technology transfer services, aiming to intensify the national intensify the national effort in R&I and create new knowledge to increase the competitiveness of companies	The support is aimed at companies, under any legal nature and form, being considered as eligible as eligible investments the acquisition of consultancy services in R&TD activities and acquisition of technology transfer services through non-refundable incentives. reimbursable incentives	In implementation Applications open periodically
SIFIDE II SI R&D	The Entrepreneurial Research and Development Tax Incentives System, in force during the period from 2013 to 2020, aims to support R&D activities. It has the goal of continuing to increase the competitiveness of companies by supporting their efforts in R&D	The support is aimed at the creation or improvement of a product, a process, a program or an equipment or equipment, which present a substantial a improvement and which do not result of a simple use of the current state of the art. of existing techniques	Implemented

Table 2 Policy Measures Phase II [13]

Measure
Evaluation of digital maturity
Industry 4.0 experience
Innovation stimulus
sectorial and digital training and development
Learning factories
Experimentation and apprenticeships
Digital connectivity
Industry 4.0 coaching
Innovation risk management
Access to finance
Financing and transformation

Table 3 Kendall correlation

	Gross added value	EBITDA	Net profit	Productivity	Employees	Operational revenue	Ind. 4.0 incentive value
Gross added value	1	0.032	0.023	0.239	−0.003	0.098	0.545
EBITDA	0.076	1	0.276	0.176	−0.009	−0.007	0.776
Net profit	1	0.454	1	0.041	0.189	0.085	0.486
Productivity	0.041	−0.029	0.087	1	0.183	0.038	−0.034
Employees	0.189	−0.056	0.075	0.183	1	−0.057	−0.032
Operational revenue	0.085	0.176	0.006	0.038	−0.057	1	0.958
Ind. 4.0 Incentive value	0.086	0.005	−0.008	0.045	−0.032	0.958	1

plan and in the market performance of the organization. One of the conditions for the implementation of I4.0 is the impact on industrial productivity. In this work, total factor productivity (TFP) was used as the amount of product obtained with a weighted unit of all production factors [1]. $TFP = Y/aK + bL)$, where: Y is the product; K is the capital factor; L is the labor factor; a and b are the weights of the respective factors.

Gross Value Added (GVA) is another variable related to competitiveness and production efficiency. It is the final result of the productive activity over a given period. GVA is the difference between the value of production and the value of intermediate consumption, leading to surpluses.

EBITDA is an indicator of a company's financial profitability and efficiency year by year. It shows a business' potential to generate cash, because it indicates how much money is generated by operating assets. EBITDA means Earnings Before Interest, Taxes, Depreciation and Amortization. By also eliminating the effects of depreciation and amortization of the company's assets, EBITDA brings the result closer to the cash potential of the business.

Finally, net profit makes it possible to analyze the competitiveness and efficiency of the company, especially through the comparison of different years and its competitors.

The situation was analyzed based on the mean difference test of the scores obtained for the dimension Ind. 4.0 incentive value and the factors Operating Revenue, Number of Employees, Total Factor Productivity (TFP), Gross Value Added, EBITA and Net Profit (Table 4).

The evaluation of the results of the hypothesis tests reveals that of the six variables in the first sample with the 2017/2018 variations, only Operating Revenue had a statistically significant difference between the results of the companies before and after the execution of the projects. Indeed, between the two periods of time and considering the application of the incentive value, only one variable showed an increase or upgrading of competitiveness based on the execution of the projects.

However, the evaluation of the results of the hypothesis tests reveals that in the second sample with the 2017/2019 variation—that is, a longer period of maturity of the competitiveness variables—the six variables had a statistically significant difference between the results of the companies before and after the execution of the projects considering the application of the incentive value (Table 5).

A general result of the indicators analyzed to verify the differences in significance by performing two tests (Kendall Correlation and Wilcoxon test) is that the application of the model to the research problem seems to be reasonable. As such, there is evidence that the stimulated value component (EU funds) could have an association with the degree of competitiveness over a longer period of analysis, i.e., sample 2017–2019.

Table 4 Wilcoxon signed-rank test of samples related to the 2017/2018 variation

2017/2018 variation	Significance	Hypothesis test related samples
Ind. 4.0 Incentive value × Operating revenue	0.162	Retain the null hypothesis
Ind. 4.0 Incentive value × Employees	0.004	Reject the null hypothesis
Ind. 4.0 Incentive value × Productivity	0.002	Reject the null hypothesis
Ind. 4.0 Incentive value × Net profit	0.001	Reject the null hypothesis
Ind. 4.0 Incentive value × EBITDA	0.002	Reject the null hypothesis
Ind. 4.0 Incentive value × Gross added value	0.003	Reject the null hypothesis

Table 5 Wilcoxon signed-rank test of samples related to the 2017/2019 variation

2017/2019 Variation	Significance	Hypothesis test related samples
Ind. 4.0 Incentive value × Operating revenue	0.807	Retain the null hypothesis
Ind. 4.0 Incentive value × Employees	0.278	Retain the null hypothesis
Ind. 4.0 Incentive value × Productivity	0.278	Retain the null hypothesis
Ind. 4.0 Incentive value × Net Profit	0.196	Retain the null hypothesis
Ind. 4.0 Incentive value × EBITDA	0.972	Retain the null hypothesis
Ind. 4.0 Incentive value × Gross added value	0.151	Retain the null hypothesis

5 Discussion

In this section, the research hypotheses are analyzed and the results are discussed, considering the validity of the proposed model and the statistical significance of the coefficients. According to the presented results, the hypothesis is rejected for 2017–2018 and accepted for 2017–2019. The central hypothesis of this study is accepted, since the factors that make up the industry 4.0—EU Fund—Incentive Value dimension have an association with the degree of competitiveness (Operating Revenue, Number of Employees, Total Factor Productivity (TFP), Gross Value Added, EBITDA and Net Profit) in the 2017–2019 period. Although the same did not happen in the 2017–2018 period, that result leads us to conclude that it is important to analyze longer periods for a more consistent evaluation of the process, even when it comes to new and rapidly developing technologies. Moreover, the Wilcoxon Test confirmed the association between the Ind. 4.0 Incentive Value and the degree of competitiveness. In addition, it should be noted that when companies are separated into two samples—one for a longer and the other for a shorter period—the revenue factor has different mean scores in these two groups, discriminating the most competitive ones. This means that operating revenue would be the only variable that would have an implication for increased competitiveness in the smaller time period of 2017–2018.

In this analysis, we highlight that:

H0—There is significant correlation between the variables (Operating Revenue, Number of Employees, Total Factor Productivity (TFP), Gross Value Added, EBITA and Net Profit) when they are correlated with the European Fund variable (Industry 4.0 Incentive Value) in the 2017–2018 period. This hypothesis was rejected. Only Operating Revenue had a statistically significant difference between the results of the companies before and after the execution of the projects.

H0—There is significant correlation between the variables (Operating Revenue, Number of Employees, Total Factor Productivity (TFP), Gross Value Added, EBITA and Net Profit) when they are correlated with the European Fund variable

(Industry 4.0 Incentive Value) in the 2017–2019 period. This hypothesis was accepted for six variables through the Wilcoxon test.

In the Kendall Coefficient test, the variable Ind. 4.0 Incentive Value has no correlation with the variables Productivity and Employees. However, a high correlation can be observed between Operating Revenue (0.958) and the Ind. 4.0 incentive value, followed by a high correlation between EBITDA (0.776) and the Ind. 4.0 Incentive Value.

The results suggest, therefore, that there are different intensities of the effects of the governmental subsidies of the industry 4.0 Program on the competitive position of Portuguese industries in the two periods under analysis, pointing to a relevant role of industrial policy when the period of analysis is longer, directly identified, in the strategic direction of the firms. The analyses revealed that there were variations in the competitiveness of the industry when the longer 2017–2019 period was considered. As a result, we consider it important to monitor these processes throughout their evolution, including relatively short periods, in order to obtain more accurate and consistent results, as we suggested at the beginning for countries that are filling the progress gap, even if historical experience is scarce. It is important to note that no previous research has been identified addressing the relationships between the constructs that make up the research model, making it impossible to compare the results obtained with the results of other studies.

When measuring the competitiveness, we also found that the means for the period 2017–2018 were lower, but no statistically significant differences were identified with the 2017–2019 period. We also confirmed that the more adherent the project was to I4.0 technologies, the more favorable the competitive position of the industries in 2018 and in the following period. However, the subsidy does not influence the competitive position in relation to the type of company, whether or not it belongs to a group, or due to its location (for example, whether it is from the North, Center or South of Portugal, whose contexts present differences from this point of view). One aspect that deserves to be highlighted is the role of the size of the firm as measured by the number of employees and its direct effect on the competitive position. The results suggest effects of similar intensities of the size on the competitive position in both periods under analysis. In a way, the results point to a greater competitive capability of larger firms, although this is to be expected.

6 Conclusions

The study had peculiar characteristics since it analyzed the best regional practices for digital transformation to the industry 4.0 Program in Portugal and the role of European Union funds regarding the competitiveness perspectives of companies developing I4.0 projects with enabling technologies. Faced with this objective, the I4.0 determinants in Portugal and the role of government agents in promoting these enterprises were presented. As such, it should be stressed that the contextual analysis initially proposed as a general objective enabled an understanding of the industry 4.0 Program in Portugal and of how it consolidated the competitive positions in industry.

The study was developed through a methodological approach as a descriptive and a correlational nature, seeking to establish relationships between the Incentive Value and Competitiveness or the degree of relationship between these concepts, in order to identify, through quantitative arguments, the role of EU funds in the competitiveness of I4.0 in Portugal. For the purpose of the study model, the definition was assumed that the companies that were more oriented to receiving funds had a better competitive performance. Above all, it was assumed that the funds were a way to expand the base of the competitive dimensions. It would be also possible to claim that more dynamic and effective companies are also the ones more attracted to explore European funds. Therefore, the association would probably also happen due to other factors like new markets, more effective training, redesigned processes and so on.

The study relied on the use of non-parametric statistical techniques. Kendall's rank correlation coefficient and the Wilkinson Test were used to interpret the results. Based on this, the study's general results reveal that in the first sample, the incentive value is not fully correlated with competitiveness, since only the hy-pothesis that contained the Operating Revenue factor presented significant levels. According to the presented results, the central hypothesis of this study is accepted, since the factors that make up the industry 4.0—European Union Fund—Incentive Value dimension have an association with the degree of competitiveness (Operating Revenue, Number of Employees, Total Factor Productivity (TFP), Gross Value Added, EBITA and Net Profit) in the 2017–2019 period.

Although the same did not happen in the 2017–2018 period, that result leads us to conclude that it is important to analyze longer periods for a more consistent evaluation, even when it comes to new and rapidly developing technologies. In the field of industrial policy, the results of this study are also important from the perspective of decision makers. As the funds are disputed for various uses (Collie, 2005), even in the context of I4.0, and since their scrutiny is politically relevant, a thorough analysis of these investments, including short periods of a few years, can be a valuable tool to improve decision making and avoid waste.

Despite the methodological care applied in carrying out this study, some limitations should be noted for the adequate understanding of the results expressed here and the consequent consideration of their implications. The focus in a specific country is a study limitation. Within the other limitations of the present work, the restriction of choosing one model to measure the best regional practices for digital transformation in industry and fund receipt dimensions with a limited number of factors should be noted, since the research option was to evaluate only result measurement indicators.

It is clear that the case under study is only a small sample, but its extension or even generalization to other cases may improve the effectiveness of the "upgrade" process that the country wants to put into practice. Thus, comparative studies, both sectoral and cross-country, conducted according to quantitative or qualitative methodologies, may also bring significant added value to the research. Another necessary perspective would be to focus on the management of the funds deployment process in order to understand to what extent it influences the success of the subsidized companies when measured through competitiveness.

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Digital Transformation and Current Trends in the Technological Development of the Industrial Complex: Russian Experience

Olga Smirnova and **Lyudmila Chesnyukova**

Abstract Digital transformation (Industry 4.0) is characterized by the large-scale coupling of technologies in industrial production, high operating activities based on cyber-physical systems, and the introduction of digital technologies in business processes, which have already proven their effectiveness in world practice. The study aims to assess structural changes in the industrial complex of Russia in the digital economy. New technologies used in industry are identified as a result of the study based on the concept of Industry 4.0. The analysis of the introduction dynamics of digital technologies in the industrial complex of Russia, which involves the intensification of innovative long-term development, is carried out. The authors present a theoretical model of digitalization of the industrial complex, based on a set of interrelated components from the beginning of the digital design and modeling technology development to further production, through networks of industrial cooperation and subcontracting, including logistics, sales, and subsequent service of digital services, IT services, industrial things from the Internet.

Keywords Digital transformation · Industrial complex · Industry 4.0

1 Introduction

Currently, the development of the industrial complex in the context of digital transformation is determined by many technologies already available in the industrial market, such as cloud computing, advanced robotics, 3D printing, artificial intelligence, the Internet of Things (IoT), and big data analytics. All of these, in addition to the technological transformation in the industry, are giving way to new forms of value creation such as the "collaborative consumption economy" and new forms of

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networking such as inter-industry clusters, business networks, and virtual structures, which will emerge as these technologies come together, generating new products and services, new business models, new forms of labor activity. The widespread use of digital technologies, the development and implementation of new technologies, and technological innovations can positively impact the development of the industrial complex of Russia.

The Boston Consulting Group report defines the digital economy as all economic activity based on digital goods and services, whether new business models or transformed business models. The document discusses three dimensions of the digital economy: the impact on value creation of 9% direct impact, another 9% induced impact, and 1% additional externalities [9]. According to the Institute for Statistical Studies and Economics of Knowledge of the Higher School of Economics, the share of digital technology in the value-added of the business sector is 3.4%, while for OECD countries, it is 5.4% [17].

New joint research conducted by PwC and ABBYY shows that one of the threats faced by actors in the industrial complex in the implementation of digital technology is the lack of skills or resources to effectively manage modern technology [23]. These threats faced by industrial complex entities must be addressed through digital adaptation. Thus, in an increasingly flexible, connected, and technological marketplace, businesses will need to remain competitive and economically, socially, and environmentally sustainable.

The article aims to analyze the development of Russia's industrial complex under digital transformation, to highlight promising areas of industrial complex development from the perspective of modern technology based on the implementation of tools of Industry 4.0 in industrial production.

2 Literature Review

The modern development of the industrial complex is impossible to imagine without the widespread introduction and use of information and digital technologies. Studies on the adaptation and implementation of digital tools in the real economy confirm that in the global perspective, the future of the industrial complex depends on the implementation of advanced digital technologies in the business environment [13, 18]. New technological solutions provoke the transformation of existing business processes (inter-industry clusters, business networks, and virtual structures), society, and the economy, affecting value chains, production, and trade.

The issues of digital and technological transformation of the industrial complex are considered in the works by Romanova [2, 24], Pozmogov [22], Tolkachev [32] from the position of using digital technologies in the business environment to extract additional income and competitive advantages. The main trends of digital transformation in real economy organizations are reflected in the works by Alcácer [3], Bauernhansl [6], Cheng [10], Filippov [11], Landro [18], Morrar [21], Tapscott [31], who considered digitalization as an implementation of Industry 4.0 tools.

Economists Frank, Mendes, Ayala, Ghezzi consider the digital transformation (Industry 4.0) in terms of stimulating technology, considering the increase in the value of the production process and management systems in the production environment [12]. These approaches are considered complementary concepts. The scientific article by Sima, Gheorghe, Subić, Nancu aims to substantiate the relationship and the impact of Industry 4.0 on the development of human capital and consumer behavior [29]. A study by Androniceanu, Georgescu, Tvaronavičiene, Androniceanu identifies the impact of digitalization on labor productivity in many developed countries and industries [5]. Economists Gisario [14], Miśkiewicz and Wolniak [20] conclude that the introduction of digital technology in the industry leads to increased energy efficiency and is a competitive advantage. The articles by Glotko, Polyakova, Kuznetsova, et al. provide theoretical provisions, approaches, and principles of digitalization of state regulation in the field of industrial data and define the essence and forms of this regulation [15]. Guseva and Dmitrieva supplement these provisions by studying the relationship between digital technology and engineering solutions and justify the transition to new models based on information technology [16].

The research results presented in the works by Akberdina [1, 2], Bodrunov [7, 8], Gribanov [13], Sukharev [30] allowed the development of an applied toolkit for studying the digital transformation of Russia's industrial complex. The transition to digital platforms is a key tool for the digital transformation of the industrial complex; it forms a digital environment whose individual elements interact with each other.

3 Materials and Methods

Let us highlight the key technologies used in the industry based on Industry 4.0:—Artificial Intelligence (AI), the Internet of Things (IoT), blockchain (BC), and supply chain traceability. These technologies complement each other in industrial processes, playing specific roles in the industry digitalization (Industry 4.0): AI as a set of algorithms that improve business processes in industrial manufacturing; IoT allows the control and management of remote access, automated devices that improve efficiency in the industry; identification and electronic traceability system that allows greater data transparency from beginning to end in the supply chain and analyze the actions of IoT, improving efficiency in industrial manufacturing; the use of blockchain technology in industrial production, in the era of digital technology to function effectively in a business environment according to the criteria of multiple participants without the participation of third parties.

The use of the above technologies positively affects the efficiency of business models, production flexibility, and the level of service of the industrial complex. These digital technologies simultaneously create additional opportunities and threats associated with advanced information and digital technologies, providing outstripping industrial development.

The introduction of digital tools in industry will increase the efficiency of industrial production and increase the competitiveness and adaptability of business structures.

Fig. 1 The model of digitalization of the industrial complex of Russia

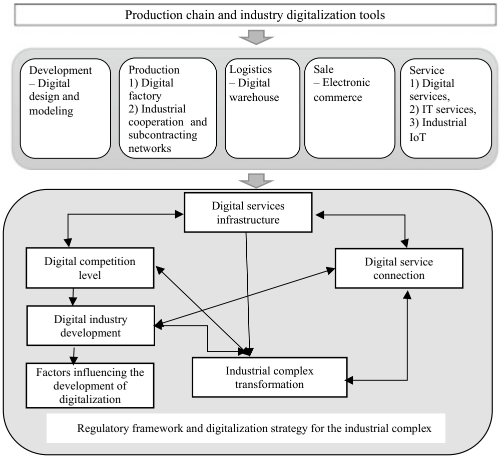

Figure 1 presents a theoretical model of digitalization of the industrial complex of Russia, including digital tools at various stages of the production chain. In addition, the model highlights the most relevant technological opportunities identified in the context of the transformation of the industrial complex in the transition to Industry 4.0.

The proposed model defines a systematic relationship between each chain component, placing it in a value network of suppliers and customers forming a digital ecosystem and digital platforms of the industrial complex providing a logistic architecture of production and product delivery industries of the industrial complex, and potentially brings a rapid adaptation of the company to market needs.

Analysis of the impact of digital technologies on the development of the industrial complex of Russia is an important strategic task. Currently, the Ministry of Digital Economy of Russia is developing the National Index of Digital Economy of Russia. The methodology for calculating the index is expected to be approved by the end of 2021. The index development is based on the world's leading practices and considers the country's peculiarities. The application of this methodology will make it possible to analyze the digitalization process of the industrial complex and create an appropriate assessment of the industries that form the Russian industrial complex [4].

A comprehensive methodology for technological development directions of the Russian industrial complex is based on primary Rosstat indicators for 2010–2020. The analysis includes the following indicators: (1) distribution of digital technologies in the industrial complex organizations that used personal computers, websites, local area networks, servers, and global information networks [1, 30]; (2) dynamics assessment of the use of new technologies and technological innovation in the industrial complex; (3) structure analysis of research and development costs for high-tech, medium-tech, and science-intensive types of economic activity. In addition, the structure of the industrial complex is assessed by indicators [1, 2, 30]: the share of mining and manufacturing in Russia's GDP; analysis of the growth rate of labor productivity; the degree of depreciation of fixed production assets in Russia.

The proposed methodology of comprehensive analysis allows assessing the degree of digitalization of the industrial complex and identifying development opportunities associated with the introduction of technology in the organization of the industrial complex. Note that developing a digital access infrastructure is critical to provide individuals and businesses with access to digital content and services and enable operators in the supply chain (e.g., application and content providers) to interact with each other without third-party involvement.

4 Results and Discussion

The industrial complex is the defining sector of economic activity in Russia. Let us analyze the structure of the manufacturing and extractive industries according to Rosstat indicators for 2010–2020 (Figs. 2, 3 and 4). Industry occupies a key position in the GDP structure and forms more than 25% of Russia's gross domestic product (GDP) [26].

From 2010 to 2020, in general, there was a slight increase in the industry share in GDP; extractive industry—0.45%, manufacturing—0.53%, and high-tech and knowledge-intensive industries—2.03% (Fig. 2).

Active transition to the development and implementation of new technologies and technological innovations in the industry will increase labor productivity, which is determined by the ratio between the indicator of production volume (GDP) and the resource use indicator (Fig. 3) [1]. In the Russian economy as a whole, according to Rosstat, from 2010 to 2020, there was a slight increase in labor productivity—1.3% [28]. Based on the average growth rate in projected 2020, labor productivity was 101.2%, indicating a slight decline. There was also a slight increase over the entire period in manufacturing (3.6%) and mining (0.9%). In the forecast 2020,

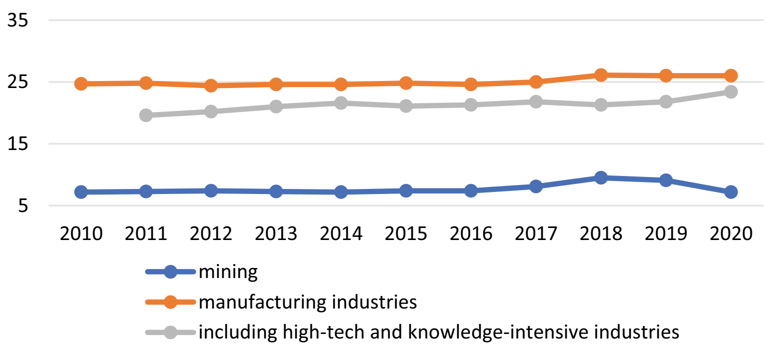

Fig. 2 The share of mining and manufacturing industries in Russia's GDP for 2010–2020 [26]

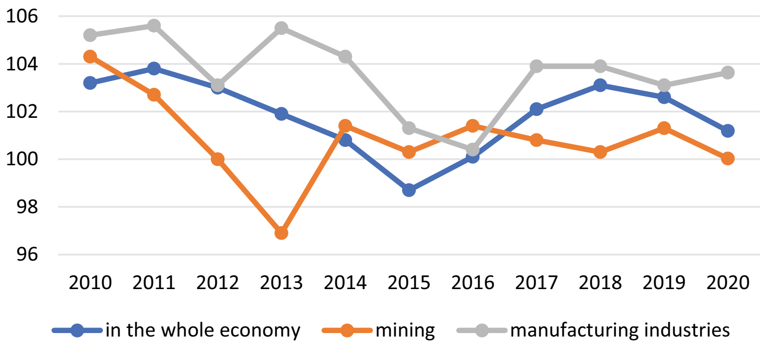

Fig. 3 Dynamics of labor productivity growth rates for 2010–2020, % [28]

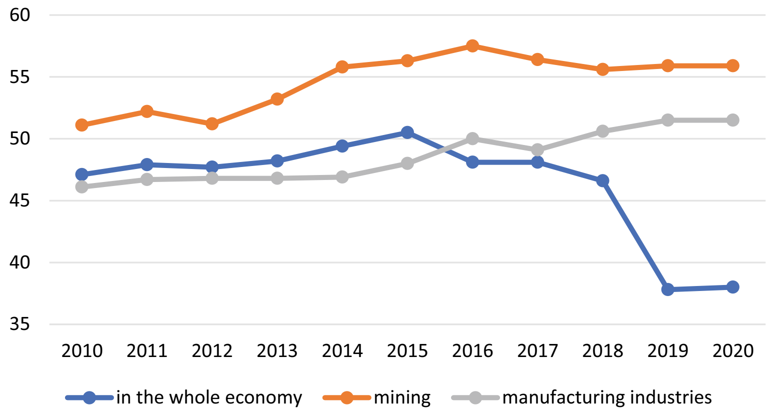

Fig. 4 Dynamics of the depreciation degree of fixed assets in Russia, % [28]

the growth rate of labor productivity in manufacturing was 3.6%, which indicates some positive dynamics. In turn, in the extractive industries, labor productivity, in general, will remain unchanged. This is due to the low level of manual labor and the predominance of mechanization and automation in industrial production.

Labor productivity in industry is influenced by various factors, including the degree of wear and tear of basic production assets of enterprises (Fig. 4).

For the analyzed period from 2010 to 2020, there is a decrease in the indicator by 1.9%, which indicates the renewal of equipment (Fig. 4) [28]. The wear of equipment is 1.1% and in the extractive industries 0.9%, which indicates a high degree of wear of equipment employed in the manufacturing and extractive industries for the whole period in the manufacturing industry. At the same time, industrial production is more capital-intensive than other sectors of the economy, and at present, the modernization and transformation of the industrial complex are proceeding at a slower pace.

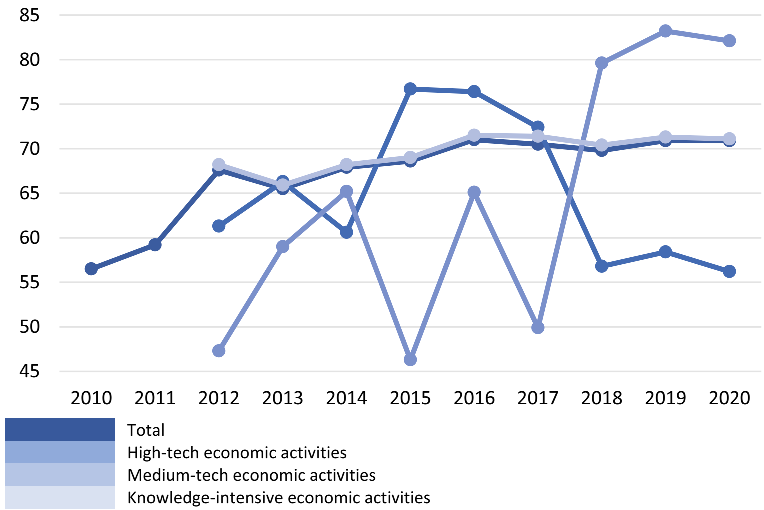

Fig. 5 Dynamics of the share of domestic expenditures on research and development in priority areas of science, technology, and engineering in the total volume of domestic expenditures on research and development in Russia, 2010–2020, % [27]

The development of digital technologies in industrial production involves the intensification of innovation. Let us consider the indicators of innovation activity (Fig. 5; Table 2). There is a slight increase in the volume indicator of innovative goods, works, and services by type of economic activity: mining—the growth was 2.60%; manufacturing—the growth was 1.46%, which indicates the positive dynamics [27].

Let us analyze the dynamics of the share of domestic expenditures on research and development in the priority directions of science, technology, and engineering development in 2010–2020; this indicator varies significantly depending on the type of economic activity (Fig. 5) [27]. In the knowledge-intensive types of economic activity for the entire analyzed period, there is a slight increase of 0.55%. In high-tech economic activities, there is a decrease of 0.25%. In medium-tech industries, which include manufacturing, an increase of 10.78% is noted.

As part of the study, let us highlight indicators of the use of digital technology in the industry in Russia, such as the use of organizations of local computing and global information networks of the industrial complex [1, 30], organizations' use of personal computers, servers, and websites. Let us assess the components of digital technology in the economy of Russia as a whole and highlight their impact on industrial development (Table 1).

According to Table 1, from 2010 to 2020, there was a decrease in the use of personal computers in the surveyed organizations for all types of activities by 1.4%. There is also a change for the worse in the extractive (−2.35%) and manufacturing (−1.52) industries. For the analysis of the share of organizations that used servers, a positive trend is noted in the economy as a whole; the increase is 12.15%. A pronounced positive trend is observed in manufacturing (13.75%). In the extractive

Table 1 Economic growth rates of indicators of the share of organizations that used personal computers, servers, websites, local computing, and global information networks, % [25, 27]

Type of activity	Indicator	2011/2010	2013/2012	2015/2014	2017/2016	2019/2018	2020/2019
Total	Personal computers	100.3	100.0	98.4	99.7	99.5	86.3
	Servers	108.2	104.2	179.3	99.6	100.7	86.2
	Organizations with a website	115.8	109.3	105.7	103.3	102.0	85.2
	Local area networks	104.2	102.4	94.5	98.1	99.4	86.1
	Global information networks	102.6	101.4	99.1	100.1	100.0	–
Mining	Personal computers	100.7	102.0	98.0	96.6	98.6	83.6
	Servers	94.6	96.8	185.4	96.1	99.5	78.7
	Organizations with a website	107.5	110.8	107.8	96.8	108.0	79.2
	Local area networks	103.5	101.9	96.1	93.3	99.6	81.4
	Global information networks	100.9	101.8	98.0	96.0	99.2	–
Manufacturing industries	Personal computers	100.3	100.2	99.6	98.5	100.0	87.8
	Servers	111.2	103.7	201.8	104.5	102.1	85.3
	Organizations with a website	104.9	102.5	102.9	102.4	102.6	83.1
	Local area networks	102.9	101.3	96.0	100.9	101.9	86.7
	Global information networks	100.9	100.3	99.9	98.4	100.3	–

Table 2 Economic growth rates of indicators of the use of new technologies and technological innovations in the extractive and manufacturing industries in 2012–2017, % [27]

Type of activity	Indicator	2013/2012	2015/2014	2017/2016
Mining	Growth rate of the share of organizations that carried out technological innovation, %	91.429	89.231	92.727
	Growth rate of the number of new technologies acquired by organizations, %	88.430	78.698	90.250
Manufacturing industries	Growth rate of the share of organizations that carried out technological innovation, %	99.167	99.180	116.102
	Growth rate of the number of new technologies acquired by organizations, %	82.896	87.484	110.680

industry, the growth rate was 7.70%. The intensity of the server use in the manufacturing industry compared to the mining industry is related to the specifics of production and the need to analyze and store big data. In general, the share of organizations that used websites has positive dynamics, but in the extractive industries, the growth rate of indicators is lower than in manufacturing. In terms of the share of organizations that used local computers and global information networks, there was a decrease for the entire analyzed period. This phenomenon is related to the fact that firms are beginning to use servers or outsource the management of their documentation [19, 25]. The extractive industries noted the largest decrease (−3.52%—local area networks; −10.57%—global information networks). In the manufacturing industries, the trend is similar to the changes in the economy as a whole: the decline in the use of local area networks was −2.26% in the manufacturing industry and −2.05% in the economy as a whole; the decline in the use of global information networks was −10.01% in the manufacturing industry and −9.01% in the economy as a whole. The decrease in these indicators is largely due to the cost of using Internet resources, and the location of enterprises and organizations of the mining and manufacturing industry since not all of Russia has high-speed Internet. The above indicators in the manufacturing industries show multidirectional dynamics for organizations using personal computers, local and global information networks, servers, and websites. In industries related to mining, the situation is somewhat different and is characterized by a decrease in the distribution of digital technologies in organizations.

Characterizing the dynamics of the use of new technologies and technological innovations in the industry, one can note that this process is continuous, refers to knowledge-intensive, and its implementation requires a long time (Table 2) [27].

In industrial production, the following key objectives are necessary to effectively implement technological innovation and new technologies: (1) encourage and facilitate companies' access to public funding for R&D, which allow industrial complex enterprises to implement R&D initiatives based on AI solutions and their use; (2) encourage private investment in R&D through access to various financing alternatives.

5 Conclusions

Structural and technological changes in the Russian industry in this study are considered from the perspective of Industry 4.0 tools, creating modern business models based on the introduction of digital tools that help improve industrial production efficiency. In addition, there is a transformation of the business model, which is defined in terms of the formation of new (digital) markets based on the value network model, which leads to interaction between all market player suppliers and customers.

The proposed theoretical model of digital transformation of the industrial complex involves adapting existing industrial production processes and introducing new technologies through digital design and information modeling. It is necessary to develop and implement modern industrial technologies and technological innovations in the business environment for the effective and competitive functioning of the industry in the global market in an uncertain environment. The introduction dynamics of digital technology in the Russian industrial complex were analyzed based on empirical data using official statistics and other information from open official sources. The analysis of structural changes in the industrial sector of the Russian economy has revealed that it is necessary to work on the transition of the industry to the digital space, involving the entire production chain in specific technological processes and exploiting various innovative technologies, with which decisions can be made to develop a more efficient, balanced and focused on the real needs of the market production chain. It is shown that the introduction of digital technology elements has a positive impact on the transformation of the industrial complex; the ongoing technological changes indicate an important factor in the transformation of the organization mode of economic activity of the industrial complex towards the servicization of the economy.

Thus, the analysis conducted allowed concluding that the development of the industrial complex under digital transformation continues to gain momentum and positively impacts the real sector of the Russian economy. The algorithm and methodology for analyzing the implementation of digital technologies presented in the article can become an instrumental basis for assessing structural changes in the industrial sector of Russia's economy. Further prospective studies will focus on the analysis of digital platforms, changes in the existing business models of the industrial complex in the direction of network structures.

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Knowledge Analysis on the Industry 4.0 Diffusion in Italian Manufacturing: Opportunities and Threats

Gionata Morelli, Fabio Musso, Federica Murmura, and Laura Bravi

Abstract The evolution of digital technologies places companies in front of an expected paradigm shift that allows manufacturing companies to achieve greater interconnection and cooperation between their resources and customers. The aim of this study is to quantify the diffusion of Industry 4.0 technologies in Italy and offering through the use of Strengths Weaknesses Opportunities Threats (SWOT) matrix an assessment of the Italian context in the 4.0 era. This study is based on the processing of data from a survey conducted by the Monitoring Economy Territory (MET). The survey took place between October 2017 and February 2018, and was aimed at quantifying the diffusion of the enabling technologies of Industry 4.0 in Italy. The sample consists of 23,700 companies. The introduction of systems whose implementation is the result of great technological innovations represents a huge opportunity for companies willing to adopt them, which accept to take the risks that being a precursor in this area entails. The costs associated with investments in new technologies are considerable but, if they were to be integrated intelligently, they would allow companies to obtain a huge competitive advantage over competitors who had to introduce the innovations in their production plant at a later time.

Keywords Enabling technologies · Manufacturing Industry · Industry 4.0

1 Introduction

In an increasingly hectic world, characterized by a market dynamism never achieved before, the adoption of technologies associated with Industry 4.0 is an essential lever in order to remain competitive [1–3].

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The innovations that have been shaping and transforming the production sector in recent years, causing profound changes in the internal processes of companies, are of such a magnitude that it can be spoken of a Fourth Industrial Revolution [4].

The evolution of digital technologies places companies in front of an expected paradigm shift that allows manufacturing companies to achieve greater interconnection and cooperation between their resources and customers [5]. It is a series of changes based on the ubiquitous presence of information technology (IT) tools, whose goal is to create a smart company, with high flexibility, low lead times, small batch production and advanced product customization, with the ultimate aim of offering superior value to the customer [5, 6].

The Industry 4.0 paradigm is presented by a growing number of analysts and stakeholders as a turning point of such magnitude as to justify the term of a new industrial revolution. This new concept has its roots in Germany, where starting from 2006 it has begun to think about the potential of integrating Information and Communications Technology (ICT) into manufacturing processes [7].

The expression "Industry 4.0" was used for the first time in 2011 in Germany at the Hannover Messe, the most important trade fair on industrial technologies. Subsequently, in October 2012 a working group dedicated to Industry 4.0 and chaired by Siegfried Dais of the engineering and electronics multinational Robert Bosch GmbH and Henning Kagermann of the German Academy of Sciences and Engineering (Acatech), presented to the federal German government a number of recommendations for its implementation. On April 8, 2013, at the annual Hannover Fair, the final report of the working group was released [8, 9].

Industry 4.0 or Intelligent Manufacturing is defined by Kang et al. [10] as the fourth industrial revolution that represents a new paradigm and consists of the convergence of cutting-edge ICT and manufacturing technologies. It provides a solid foundation for making effective and optimized decisions through faster and more accurate decision-making systems.

The peculiarity of this revolution arises from the interconnection and cooperation of workers and cyber-physical systems (CPS), in practice it involves integrating physical processes with digital technologies. The inclusion in manufacturing processes of intelligent machines connected to the internet will result in an increase in the quantity of goods produced, a reduction in errors and consequently in production costs and the ability to respond immediately to changes in production schemes [11–13].

The development towards Industry 4.0 has a substantial influence on the manufacturing industry [2]. It is based on the establishment of smart factories, smart products and smart services embedded in an Internet of Things and of services also called industrial internet [14]. The effects of these technologies could be summarized in greater efficiency and flexibility in business processes, associated with a radical change both at the aesthetic and operational level of factories [13].

Starting from the data collected from a report developed by the Monitoring Economy Territory (MET), the objective of this study is to quantify the diffusion of Industry 4.0 technologies in Italy and offering through the use of Strengths Weaknesses Opportunities Threats (SWOT) matrix an assessment of the Italian context in the 4.0 era, highlighting strengths and weaknesses, but also opportunities to be seized and threats/risks to be avoided.

2 Background

2.1 Characteristics and Implications of 4.0 in Manufacturing: A Digitized Manufacturing

The Industry 4.0 revolution brings with it an agglomeration of digital technologies that have come to maturity all together: Internet of things, the Cloud, new human–machine interfaces, collaborative robots easier to manage, the possibility of interfacing production resources in a much simpler way than before, machines with machines, machines with transport systems and with people. The technologies available today allow to have much more efficient and effective factories than those had until now [2].

The paradigms characterizing the industrial system have evolved over time and with them the role of the consumer has also changed, going from a model of craftsmanship characterized by the ability to create customizable products, to a model of mass manufacturing in which the customer assumes a passive role; then moving towards a mass customization model in which customers take an active role. Finally, the concept of "on-demand manufacturing" has been reached, where customized products and services are followed by a strengthening of the role of the consumer, that is no longer limited to being a simple active consumer, but is considered a prosumer, that is a consumer more than active in the process that involves the phases of creation, production, distribution and consumption of the product [15, 16]. The consumer now plays a decision-making role with respect to design, planning, configuration, order, production phases and can decide on parameter changes up to the moment of execution [17]. Figure 1 shows the evolution of the different types of manufacturing and its customers.

Decisions, which become more precise and faster, are made on the basis of very extensive information (big data) through the interaction between man-objects-machines, using resources in the most intelligent way possible and drastically reducing waste, with repercussions also in terms of energy efficiency [18].

The rigid separation, inside the factory, between the real part and the digital part disappears. This naturally impacts on professional skills, which change and may also require frequent updates, making use of interdisciplinary training models.

The possibility of having large amounts of information available will allow companies and consumers to communicate more intensely and easily with each other, bringing innovations to current business models. There is an increasingly stringent link between the simple sale of a product, assistance, predictive maintenance, and performance monitoring [19]. The symmetrical exchange of information and the real-time dialogue between the producer and the end user will make it possible to

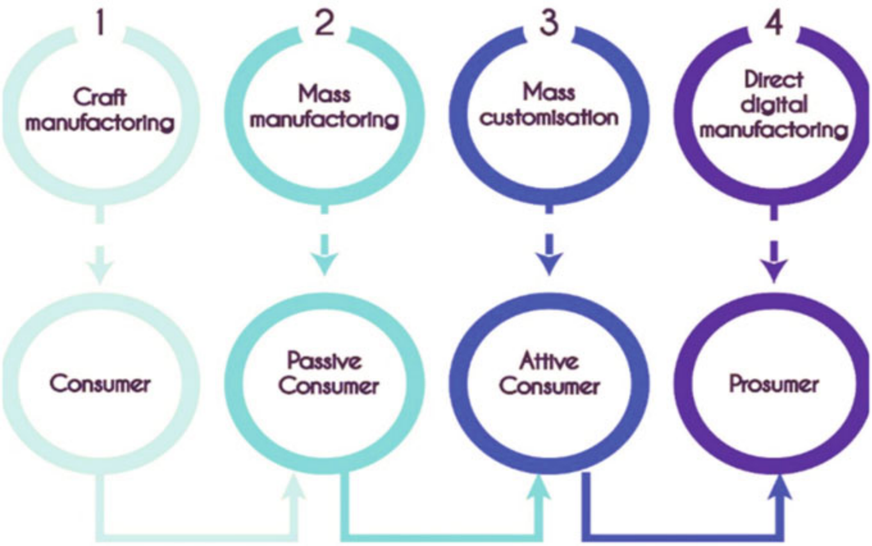

Fig. 1 Evolution of the different types of manufacturing and its customers

identify the wishes and needs of the consumer and therefore the trend in demand, but will also determine a change in the contractual relationship between the two subjects [20]. This opens up new business scenarios such as "servitization", ie the ability to generate profits from continuous services rather than from one-shot sales.

A servitization-centric approach offers benefits to both the customer and the manufacturer/distributor. First, it creates trust and increases the chances that the customer will continue to purchase new products, spare parts and upgrades of products already purchased from the manufacturer/distributor, creating a stream of sustainable profits and excellent growth prospects [21]. The boundaries between manufacturing and services will become increasingly blurred and the manufacturing sector will also increasingly produce services and will require the service sector to provide new services. The impact on production chains will be enormous: interconnection between companies will increase, revolutionizing global value chains. All companies, from the smallest to the largest, will be in a network according to the parameters dictated by Industry 4.0, which will involve every phase of the supply chain, from design to product creation, marketing and after-sales assistance. The integration of the various phases and therefore of the companies will be destined to increase [22].

2.2 The Different European Plans on Industry 4.0

The transition to the new paradigm has posed difficulties for European companies, as demonstrated by a study on the adoption of digital technologies in industry, carried out in 2016, according to which 41% of companies declare that they have not yet made investments for Industry 4.0. However, a more recent survey shows that 75% of the companies surveyed see digitization as an opportunity, while 64% of those that have made technological investments report good results (http://ec.europa.eu/). The rise in state awareness of the importance of having a state-of-the-art industry has meant that governments across Europe have taken steps to support the implementation of digital technologies and to strengthen their industries. Most of them are aimed at strengthening the industrial competitiveness of their countries and modernizing economies to make them more "fit" for the future or to ensure the sustainability of the manufacturing sector [23].

Table 1 Projects of the digitization policy

Country	Promoter	Budget (euro)	Financing approach	Recipients
France (2015)	Government, ministries, and regional governments	10 mlrd	Mixed	Industry, especially Small and Medium-sized Enterprises (SMEs) and mid-caps
Germany (2011)	Government (Ministry of Education and Research and Ministry of Economic Affairs and Energy)	200 mln	Mixed	The focus on SMEs is not particularly accentuated even if the state contribution to research is higher in % for SMEs
Spain (2016)	Government (Ministry of Industry and General Secretariat for Industry and SMEs)	97.5 mln	Public	Strong focus on SMEs and specific measures for SMEs both in economic terms and in terms of assistance and advice
UK (2012)	British government	164 mln	Mixed	Business, industry and research organizations
Italy (2012)	Government (Ministry of Economic Development)	45 mln	Public	Companies regardless of size, sector or location

Although they share the same intentions, the differences in the methods and objectives with which the various states have set up the digitization campaign are considerable. Table 1 shows information regarding launch dates, allocated budgets and funding approaches used in the digitization policies of the countries considered.

Germany was the first European country to adopt a strategic plan in 2011, called “Industrie 4.0”, aimed at connecting new digital technologies and the world of the Internet with manufacturing production. This initiative was promoted by the federal government, through the Ministry of Education and Research and the Ministry of Economic Affairs and Energy, inspired by the guidelines of the “High Technology Strategy 2020” published by the German government in 2010. While the ministries play a leadership role, the industry has taken a decisive role in the practical implementation. France is the nation that has invested the largest budget, 50 times that of Germany [24]. Italy, as it can be seen, is among the countries that have invested the least.

A further element of differentiation between the countries is inherent in the methods of financing, most have opted for a mixed approach in which both the public and the private sector contribute, while Italy and Spain are betting everything on public funding. As far as Italy is concerned, this is due to the focus that has been given to the search for innovative solutions, often at university level, for which a direct economic return for companies is not easily foreseeable, thus limiting investments by the private sector. With regard to this point, there have been significant changes since the Industry 4.0 Plan started in 2017, with a more intensive participation of the industrial world [25].

All these development policies focused on Industry 4.0 are part of general frameworks or broader strategies focused on innovation, research and industry.

The action plans of the Member States show similarities, especially as regards the objectives. Most nations aim to strengthen the country by intervening on the growth of competitiveness, through the modernization of the industry. Among the other objectives pursued there is the creation and propagation of new generation technologies, the development of new products and the efficiency of production processes [23]. From a technological point of view, the Internet of Things and Cyber Physical Systems are the technologies of greatest interest, however, only France and Germany have drawn up specific plans for their development.

2.3 The Macro-environment for the Development of the Industry 4.0 Phenomenon

In order to formulate a scenario analysis on the Italian manufacturing sector, it is useful to observe the general economic picture in a comparative key with the Euro area. Over the past 20 years, the European Union economy has grown at an average annual rate of around 1.4%, while Italy has recorded worse performance with 0.5%. The most explanatory element in Table 2 is the differential between Italy and the Euro

Table 2 Average annual GDP growth rates (Eurostat data processing; in per cent)

Region	1995–2015	1995–2007	2007–2009	2009–2015	2016–2019
Euro area (19)	1.4	2.3	−2.1	0.8	1.9
Italy	0.5	1.5	−3.3	−0.3	0.8
Differential Italy–Euro area	−1	−0.8	−1.3	−1.2	−1.1
Francia	1.5	2.3	−1.4	1	1.8
Germany	1.3	1.6	−2.3	1.9	1.8
Spain	2.1	3.8	−1.3	−0.1	2.6

Area. Even in a decade of substantial growth like the one that goes from 1995 to 2007, there are 0.8 points less growth that worsen with the progress of the 2008 economic crisis and its subsequent developments. Only in 2016 the average fell below 1%. At the same time, it should be noted that the economies of the three main continental countries, in addition to Italy, namely Spain, France and Germany, present values almost always in line with the Euro-19 average and, in some cases, even higher (https://ec.europa.eu/eurostat). The reasons linked to Italy's low annual growth rates are many and change depending on the angle from which the problem is tackled (see Table 2).

Italy is the second largest economy in Europe in terms of the incidence of the secondary sector on GDP even though in the last quarter of a century the weight of manufacturing has almost halved in Italy. Both in relation to added value: from 29.6% in 1976 to 16.6% in 2010. Both in terms of employment: from 28.1% in 1977 to 17.5% in 2018 (measured on work units). Similar, and even more pronounced, trends have been observed in the other major advanced nations.

These negative results are in particular due to the deindustrialization process that has hit the European industrial sector in favor of countries where labor costs are significantly lower, such as China, India and Brazil, which have instead recorded high growth and productivity rates in recent years.

However, evaluating the relevance of manufacturing by taking into consideration only the statistical data would be reductive and misleading. It is also important to vigorously emphasize the qualitative elements of manufacturing so that its real value is understood.

Undoubtedly, the economic and financial recession has undermined the efficiency and growth of the European manufacturing sector, highlighting its fragility and heterogeneity. The global economic recession has involved all the major advanced economies, with a particularly significant impact on countries, such as Italy, with a strong manufacturing vocation and a high propensity to export. However, the intensity of the recession and the speed of recovery were very uneven across countries [26]. Today, European industry continues to run at two different speeds: while the German and Eastern industrial sector is gaining market share and seeing productivity grow rapidly, other EU states are on the road to deindustrialization [27].

The trend towards deindustrialisation represents a real and constant threat that could greatly reduce not only the high-value activities of individual national industries, but the competitiveness of Europe as a whole [20].

If technologies are introduced that automate production processes in which man is inserted today, it is inevitable that productivity will increase, the ratio volume of production/labor input grows because the denominator decreases. It is evident that an increase in labor productivity, associated with the diffusion of these technologies in European countries, could determine a process of re-shoring by companies that bring back to their own country the productive activity that is today found in countries with cost of minor work [28, 29]. This is because the work will have in absolute value a lower incidence on total costs and therefore will be a less decisive factor in the choices related to the location of the productions. This would produce positive effects in terms of employment, but also in relation to transport costs and environmental impacts, since production sites and outlet markets will be closer [30].

3 Methodology

This study is based on the processing of data from a survey conducted by the Monitoring Economy Territory (MET), an independent research company founded in 1992, which is at national level, the only independent source that annually prepares a study on the support interventions for businesses carried out in the 20 Italian regions by both regional and national administrations (and also of European interventions). The study was commissioned by the Italian Ministry of Economic Development. The survey took place between October 2017 and February 2018, and was aimed at quantifying the diffusion of the enabling technologies of Industry 4.0 in Italy. The sample consists of 23,700 companies and is representative of the population of industry and of production services, of all size classes and all Italian regions and with registered offices throughout the country. Specifically, the universe considered is composed of companies operating in 38 sectors, defined in the third digit of the Italian Nace Code (see Table 3).

The questionnaire was administered at each individual company to a reference person, typically the administrator, a manager in charge or the entrepreneur, depending on the characteristics and size of the company. The contact person was identified by means of a first contact in the course of which the research initiative was presented. About 75% of the interviews were carried out in Computer Assisted Web Interviewing (CAWI) mode, by setting up appropriate links on the dedicated platform, while the remaining portion was carried out in Computer Assisted Telephone Interviewing (CATI) mode.

The survey is based on a stratified random sampling design, with the selection of companies in the strata with equal probability and without re-entry. The strata are defined by the aggregation of the following variables: region, registered office of the company, size expressed in terms of class of employees, sector of economic activity [31].

Table 3 Partition of the sector of economic activity

Industry sector	Italian Nace 2007 subsection
Food supply chain	DA
Clothing supply chain	DB–DC
Wood and furniture	DD–D36.1
Paper, printing and publishing	DE
Rubber, plastic and chemistry	DH–DG–DF
Metals	DJ
Manufacture of means of transport	DM
Mechanics	DK
Electric machines and electronic equipment	DL
Other manufacturing industries	E–C DI–DN (excluding 36.1)
Transport, post and communications	I–60–61–62–63–64
Other business services	K–71–72–73–74

4 Results

4.1 The Diffusion in Quantitative Terms of the 4.0 Phenomenon in Italy

The first element of importance emerged from the survey refers to the spread of “4.0 Enterprises” on the total population of industry in Italy. Based on the data collected, it emerged that 8.4% of companies use at least one of the technologies that characterize the new paradigm of Industry 4.0. To this percentage it is possible to add a further 4.7% of “traditional” companies that have planned 4.0 interventions.

The first evidence that emerges from the analysis is that the spread of the aforementioned technologies increases with the dimensional growth of companies. Only 6% of micro enterprises and 18.4% of small enterprises are 4.0, against 47.1% of large enterprises. According to Istat data, SME enterprises reaches 4.1 million units and represents 95.2% of active enterprises, therefore, it is understandable why the national data on the adoption of these technological levers ultimately stands on a worrying 8.4%. Micro SMEs have a considerable weight within the Italian economic system, both in terms of employment and in terms of creating added value, so it is evident that any action aimed at increasing the productivity of the Italian production system must be done considering these size classes of firms (Fig. 2).

Companies can therefore be divided into three categories, based on the level of adoption of Industry 4.0 technologies:

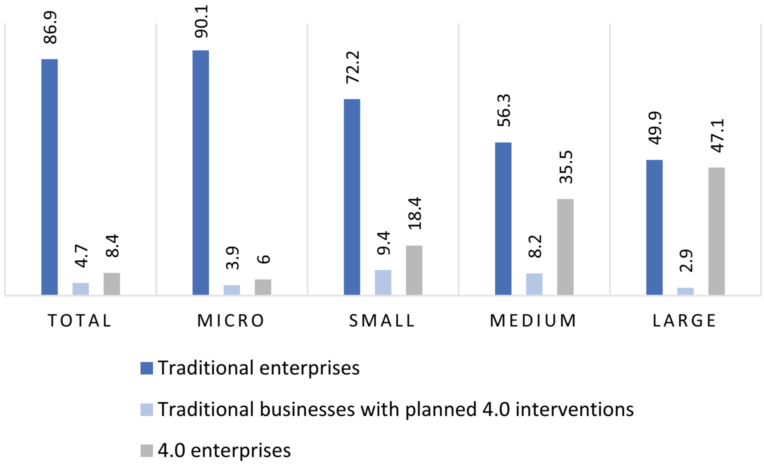

Fig. 2 Diffusion of 4.0 technologies, detail by dimensional class (percentage values)

1. *Adopters*, are companies that already have initiatives in place in the Industry 4.0 field;
2. *Future Adopters*, in this case it can refer to "traditional" companies that have planned 4.0 interventions;
3. *Non Adopters*, are companies that have no interest in implementing 4.0 initiatives.

As regards the diffusion of 4.0 technologies by geographic area, as it was desirable, the Center-North of Italy has a greater number of 4.0 companies (9.2%) compared to the South (6.1%). Leaving aside the total values that are systematically higher in the Center-North regions, what is striking in Fig. 3 are the difficulties encountered by companies of an intermediate size in the south of Italy, presenting significantly lower values than similar companies in the rest of the country.

Going into more detail of the individual technologies used, the analysis considers two macro-families:

- Technologies closely related to the production process, such as interconnected robots, additive manufacturing, simulations, augmented reality and intelligent materials;
- Technologies related to the intensive exploitation of information and data, such as horizontal or vertical integration of information, cloud, big data, analytics.

Taking into consideration only the companies that have already embarked on a path towards digitization, it emerges that they have invested more in technologies that involve the intensive exploitation of data and information (48.1% have invested only in data technologies), which means that they have well understood the value of collecting information.

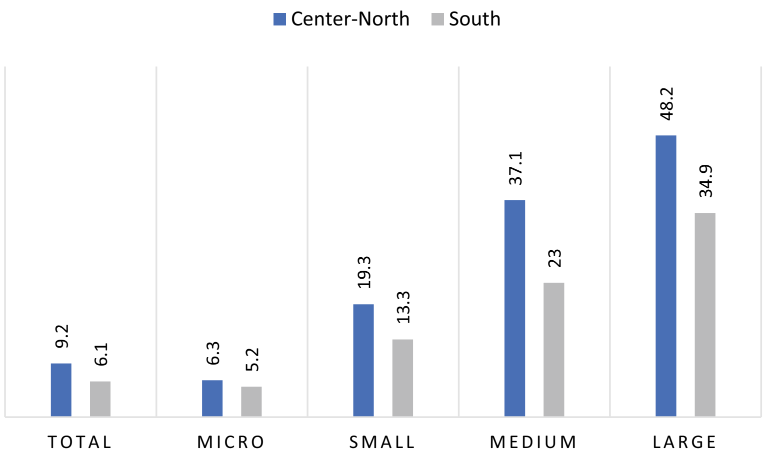

Fig. 3 Diffusion of 4.0 technologies by geographical area (percentage values)

In terms of technological orientation, it should be emphasized that cyber security, the horizontal integration of information and the Internet of things represent the most widespread environment for corporate investments, among medium and large companies. The use of collaborative robots, 3D printers and virtual simulations find a relatively appreciable diffusion only in the more structured companies, with percentages that exceed 20% among companies with over 250 employees.

The data collected show that when companies start investing, a virtuous circle is triggered, since, as it can be seen from Fig. 4, there is a positive correlation between the number of technologies currently held by companies and the number

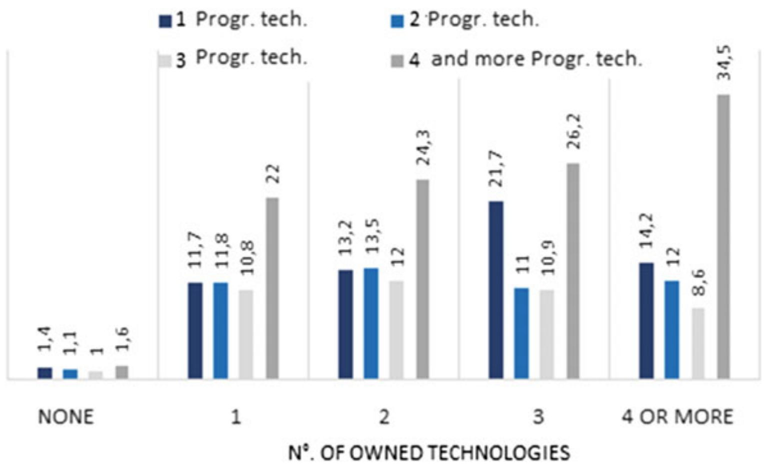

Fig. 4 Number of technologies planned for the next three years, details for the number of technologies currently used (percentage values)

of technologies in which the company intends to invest in the next three years. In fact, it appears that the corporate adopters intend to invest in further technologies in the near future and the number of these technologies increases with the increase of those already owned. The Mise-Met report said that "Traditional companies with very little probability will carry out 4.0 interventions in the next three years. On the contrary, companies that currently use 4.0 technologies have a high probability of expanding the set of 4.0 technologies used in the near future" [31].

After observing the degree of diffusion of 4.0 enterprises, it is useful to investigate some aspects related to the performance achieved by the adopting companies, both in economic terms, understood as growth in turnover, and employment.

As regards the first indicator, it is evident that in the adopter companies the improvement in turnover in the last three years is very marked, 42.7% of the companies reported an increase, while for those not adopters only 19.3% of this recorded growth. In addition, 29% of traditional companies reported a decrease in turnover, against a decrease in turnover in 18.2% of 4.0 enterprises.

With reference to the second indicator, 36.2% of 4.0 enterprises recorded an employment growth compared to 16.4% of traditional enterprises, although it should be emphasized that they present a slightly higher number, in the case of 4.0 enterprises compared to the others, even those that recorded a decline in employment (17.8%).

4.2 A SWOT Analysis of Italian Manufacturing in Relation to the 4.0 Phenomenon

After having defined the Industry 4.0 phenomenon, outlining its characteristics, implications both in the business and social fields and having described the specificities of the Italian economic system in which the new paradigm is being developed, assessment of the Italian manufacturing context in the 4.0 era has been defined, underlining strengths and weaknesses, but also opportunities to be seized and risks to avoid.

Trying to understand what are the real expected benefits and potential of Industry 4.0, taking into consideration the interpretations provided by various observers on the impact that 4.0 may have on Italian manufacturing, at the cost of some simplification, these interpretations can be divided into two groups.

On the one hand, those who argue that due to the peculiarities of the Italian economic system and the pervasiveness of micro and SMEs it is not possible to implement such a radical change. In this regard, there are several points that support this thesis.

Italian companies, and more specifically those purely family-run, have always shown a limited propensity for change and innovation, due both to their lack of aptitude for managerial management and to the problem of the chronic undercapitalization of the latter, i.e., the absence of an adequate level of risk capital for the proper conduct of business, with respect to debt to third parties. Undercapitalization affects not only the fiscal structure of companies, but above all there is another problem that characterizes Italian companies, namely the ability to find debt capital with credit institutions and other financial institutions. In the new paradigm there is no longer room for standardized products, but stable product differentiation strategies dominate since global demand, differentiated in culture and tastes, is willing to pay a premium price for variety, customization, reliability, design service content incorporated in the asset, that is, all the elements that concretize a high level of quality. Differentiation strategies require companies, to avoid obsolescence, constant investments in research and innovation (processes, products, organization, professionalism), but the scarce resources possessed by them affect the possibility of investing in these activities, which are considered crucial for guarantee the growth of skills and the possibility of gaining a competitive advantage over competitors.

Another weakness concerns the communication infrastructures whose development appears to be limited. Although the Government has drawn up a financing plan aimed at the construction of ultra-broadband infrastructures worth 6.3 billion euros, Italy still appears to be lagging behind with regard to ultra-fast broadband (100 Mbps and beyond), since this is just 22% compared to an EU average of 58% (http://ec.europa.eu).

One of the main factors that determine a weakness of the Italian manufacturing industry is the absence of large players operating globally and software vendors, such as Siemens and Bosch for Germany, capable of creating software suitable for mass markets or market niches.

Another slowdown in digitalization is the lack of e-competence. According to a recent analysis carried out by Modis, a company specializing in ICT and engineering consultancy, in three years in Italy approximately 135,000 positions in the ICT sector will remain uncovered, making our country one of the most in difficulty in the European scenario. The fault, in fact, is the still strong gap between the demand (by companies) for figures with high digital and technological skills and the supply of professionals with these skills. In the period 2013–2016, over 175 thousand job advertisements from web portals show an average annual growth of 26% in the demand for ICT professions. The comparison between estimated supply and demand for 2017 identifies as follows: in the conservative scenario, a deficit of 4400 ICT graduates compared to an excess of approximately 8400 ICT graduates, and in the expansive scenario a deficit of approximately 9500 ICT graduates and a surplus of ICT high school graduates of 5200. The mismatch between supply and demand for medium–high ICT skills is therefore of importance, a factor linked to the growing demand for more qualified ICT professionals by companies that are pursuing a decisive upskilling of the ICT workforce [32].

On the other hand, there are those who have emphasized the presence of a more articulated situation: alongside the weaknesses, the Italian economy, according to these authors, would also present aspects of dynamism and strength from which to start again and grasp the opportunities offered by the new digital revolution. Rullani [33] is one of the supporters of this theory: “Being different from the others … it could be our luck, if the difference we carry is emphasized, instead of being suffered as a sin of origin, a curse to be served".

As for the strengths of the Italian manufacturing, there are several points that include: flexible specialization and high technical know-how, which allow to adapt more quickly to the needs of the markets; the presence of a university system that provides quality resources; a high level of propensity for entrepreneurship which guarantees vitality to the industrial system; a strong industrial manufacturing system and great skills within the production chains; a culturally favorable and advanced approach on the part of the business system towards integration, a distinctive feature of industrial districts; good international reputation of Made in Italy products, which allow to achieve a high quantity of exports.

A review of the strengths and weaknesses of our manufacturing system is necessary to define an appropriate strategy for the introduction of the 4.0 paradigm and for the identification of opportunities, in particular for micro and SMEs. A strategy that should allow the transition to a digital economy, making it possible to recover the competitiveness gap with respect to competing countries. The opportunities offered by 4.0 allow companies in our industrial fabric to:

- increase productivity, this implies greater product competitiveness; companies will be able to combine the production of small batches and the extreme ability to respond to niche needs, thus bridging the competitiveness gap compared to other countries;
- enhance Big Data, thus giving value to the huge amount of data available to companies;
- adaptation of the production structure, given the opportunity to redefine the supply chain upstream and to invest in technology to take advantage of the availability of more efficient 4.0 inputs, thus improving the cost structure;
- revision of the market strategy, in a solution-based key through a better connection with downstream customers, through the customization possibilities offered by the new production paradigm, as well as the incorporation of increasing service shares (servitization) in the product sold, therefore increasing the turnover;
- redefinition of the internal organization, to maximize efficiency in interactions between man and machine, adapting tasks to new skills.

In a market-pull logic, the digitalization of manufacturing is creating a new production paradigm in which competition is played out on multiple aspects. Competition in the markets is no longer based solely on the product or the production process, competition now plays on aspects such as craftsmanship, design, personalization, authenticity and services [34].

To these, among the effects expected from the advent of Industry 4.0 on a global scale, it is added that of re-shoring, or the return of production lines within national borders. This is a phenomenon that is still limited in numbers, as shown by research carried out by the Uni-CLUB MoRe Back-re-shoring Research Group consortium, from 2000 to 2015 there were 120 cases of re-shoring, a number that positions Italy as the first European country and the second in the world for the return of companies to the national territory even if the phenomenon grew steadily until 2013 and then suffered a reduction in 2014 (https://reshoring.eurofound.europa.eu/).

The access of Italian companies to Industry 4.0 does not depend only on investments in enabling technologies, but it is therefore necessary to invest in the training dimension, since in this sense investments in advanced technologies require new skills. This requires the availability on the labor market of new relational and advanced technical skills, capable of interfacing with new technologies not only passively but also actively thanks to research work and the domain of technology. Technological skills and knowledge in this context appear as a prerequisite not only for the worker but for the company itself which intends to maintain, thanks to a constant process of innovation, a dominant position on the market.

A strengthening of the technological equipment would therefore also allow the Made in Italy manufacturing sector to create greater value and generate more resources in support of investments and competitiveness [3].

As with any new phenomenon that offers new opportunities, there are also new threats and problems. Living this fourth industrial revolution unconsciously entails serious risks for companies. First of all, that of being swept away from the market, to be replaced by companies that have managed to adequately incorporate new technologies into their business. In addition to this, among the most dangerous effects for the Italian industrial manufacturing sector there are the inability to "create a system", cyber-attacks, employment, the growth of inequality and the lack of risk management systems.

With regard to the first, the risk of failure is due to the inability of the national industrial structure to create a system, favoring a real cultural leap. Innovation must concern all production sectors, regardless of the sphere in which the company operates and the geographical area; rather than sectors, there should speak about innovative and non-innovative companies. The risk is high, and the lack of large national players that act as a driving force for other companies, as regards the activity of innovation, undermines the goal of creating a common vision based on a synergistic work between various actors, from the industrial world.

If on the one hand Industry 4.0 represents a great opportunity, on the other it is a sword of Damocles on the heads of entrepreneurs. For this reason, before investing in Industry 4.0, a SME must be capable and skilled in risk management. Risk management is the process by which the potential risk for a SME is measured or estimated and then strategies are developed to govern it. In addition to experience and suitable professional figures, today entrepreneurs can also rely on powerful and precise data analysis software, essential in helping companies make the most important choices or changes in progress. The important thing is to create rapid and continuous communication between the various players present in the new companies. A further critical issue concerns the scope of risks that can no longer be managed in relation to a single industrial plant or a single commercial unit. In fact, with Industry 4.0, industrial production becomes automated and interconnected, while the value chain becomes increasingly integrated. In this context, the "attack surface" increases and companies, supply chains and national production districts are more exposed to cyber-attacks. Attacks with which it is possible to obtain sensitive information

Table 4 SWOT analysis of Italian manufacturing in relation to the 4.0 era

Strengths	Weaknesses
• Excellent international perception of Made in Italy • High propensity for entrepreneurship • Business vitalism • University system that provides quality resources • Existence of a strong manufacturing system and a high technical know-how in the industrial sector • Flexible micro and SMEs able to respond more quickly to market needs	• Undercapitalization of companies • Difficulty in accessing credit • Low investment in innovative and R&D activities • Limited development of communication infrastructures • Poor propensity for managerial management • Poor basic digitization • Absence of large industrial players on a global level and of a software vendor • Poor digital skills
Opportunities	Threats
• Increased productivity and saving of energy resources • Improvement of the connection with downstream customers • Back re-shoring phenomenon • Growth of highly skilled workers • Possibility of modernizing the industrial system, with positive effects on the competitiveness of products • Redesign of production processes with the aim of improving efficiency	• Increase in inequality • Lack of a risk management system • Problems related to maintaining data secrecy (Cyber security) • Increase in unemployment (for those groups of workers with low skills) • Inability to make a "system" • Industrial decline • Inability to implement innovative systems adequately

or knowledge of company know-how, with destructive effects that can involve and damage the entire value-chain.

Among the threats deriving from Industry 4.0, the employment appears to be the most current in fact, if not managed, change and digitalization can be disruptive for work. Table 4 summarizes the results of the SWOT analysis presented above.

5 Conclusions

What is now called the fourth industrial revolution is the first of the revolutions to be studied in the full development of its course, exactly for this reason this is a situation that in some ways is unprecedented in history and consequently its effects turn out to be still very uncertain; the only certainty is the extent of the organizational changes to which companies are called.

The introduction of systems whose implementation is the result of great technological innovations represents a huge opportunity for companies willing to adopt them, which accept to take the risks that being a precursor in this area entails. The costs associated with investments in new technologies are considerable but, if they were to be integrated intelligently, they would allow companies to obtain a huge competitive advantage over competitors who had to introduce the innovations in their production plant at a later time.

In face of an increasingly dynamic market and an ever-greater variability of production, it becomes obvious how it is necessary to make company work flexible, so that workers will be less tied to specific tasks and routine tasks, with the consequent need to possess skills, through which to solve problems as they arise. For this, education has a fundamental role and the worker training process takes on a more continuous character, with the need to prepare training courses to prepare staff to fill the new positions that the Industry 4.0 revolution entails. The road to Industry 4.0 should therefore be framed in a process already underway. In particular, in light of the technology push approach that led to its birth and development, the market pull logic must be included in the debate. That is, wondering what are the different problems present in Italian companies that the introduction of Industry 4.0 can help solve and, consequently, what opportunities for the country system. Industry 4.0 can represent a great opportunity for Italian manufacturing, which more than others in Europe could benefit from. In fact, Italy has these main features:

- it excels for customized and high value-added productions, which require production dynamism and flexibility;
- in the long term, if open standards were established to support the interoperability between systems of different companies, the Italian industrial system characterized by the largest number of micro and small enterprises at European level could also benefit from new interconnection tools to create networks of extended enterprises even outside the country's borders, resulting in an increase in competitiveness even in the presence of small dimensions;
- Italy is the second largest manufacturer in Europe, with a recognized ability to integrate innovative technologies into products to provide value-added solutions.

To exploit these opportunities, however, it is necessary that the diffusion of Industry 4.0 should be strategically addressed through a clear industrial policy, in order to avoid the concrete risk of fragmentation due to the intrinsic multidisciplinarity of the topic and the large number and different types of stakeholders who have launched initiatives on this topic. The road to Industry 4.0 must therefore be framed in a process in which institutions must create the enabling conditions so that companies can work, experiment and develop through adequate industrial policies capable of enhancing those characteristics on which the game of competitiveness, innovation, internationalization, opening up to the capital market is being played today. This is especially important for a nation like Italy, where little is invested in Research & Development, where the productive fabric is fragmented and where often due to the large presence of family businesses there are cases of path dependence, in which companies are reluctant to change, as strongly rooted in the past and firmly certain that the strategies that guaranteed survival in the past can guarantee it in the future as well.

Today more than in the past, it is necessary for the Italian institutional system to take an active part with a clear vision and a consequent coordinated action plan between the world of research, the business world and the public apparatus, to create and seize the opportunities of this revolution. It is relevant to change the way a State is seen, from a passive and inert entity to an active entity and catalyst for new investments [35]. Industry 4.0 can be seen not only as a revolution, but as a great challenge that can only be tackled if all the players involved play their part. The main limitation of the study derives from the national focus on the Italian manufacturing system. For future studies it would be really important to compare different European realities, in order to define similarities and differences among countries, that would be very important to define a concrete European investment strategy on Industry 4.0 development among SMEs.

5.1 Managerial Implications

It is important to contextualize innovation with respect to the point at which the research in a given discipline has arrived and to direct research and innovation efforts to address in a focused manner the challenges still open in each technological area. Only in this way it will be possible to go beyond the individual local applications that characterize the adoption of 4.0 technologies today and implement real innovations of business models. In order to move to an Industry 4.0 framework, extremely important issues will have to be resolved and these challenges that involve private subjects, the production system and the country system as a whole will have to be addressed and overcome. It can be affirmed that although it is undoubted that today the Italian industrial model is showing its weaknesses with respect to productivity, scarce digital skills, the size and dynamism of advanced economies, the industrial system is facing an epochal technological-cultural change, certainly not easy and of immediate implementation, but which, it represents not only an opportunity to prevent Italian companies and in particular micro and SMEs from being blocked, but above all an opportunity to exploit the wealth of our markets and territories that are a resource of inestimable value.

New technologies make it possible to overcome the weaknesses of a system such as the Italian one, which is centered on small and medium-sized enterprises. In addition, the significant productivity gains allow the lowering of labor costs per unit of product which penalizes our production system compared to those of the other countries with which Italy is in competition. Italy could therefore be represented by the ability to orient Made in Italy from a 4.0 perspective, that is, the ability to rethink new digital production methods such as to ensure cost savings combined with craftsmanship and tradition.

5.2 Limitations and Future Research Directions

The main limitation of the study is linked to the fact that data collected is not fresh data and the survey has been done in 2018. Therefore, for future research it would be relevant to collect more recent data (up to 2021) of this issue and verify also the impact that Covid-19 pandemic could have had on the Industry 4.0 investments and diffusion, considering to make a comparison among different European realities.

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Development of the Digital Economy: A Case Study of 5G Technology

Yuchan Wang

Abstract Digital technology is widely used in related industries of the national economy and has become a new driving force for economic development. This paper takes 5G as an example to discuss the integration development of the digital economy. As a new type of communication technology, 5G is playing an increasingly important role in modern society. At present, more and more industry fields have developed and used 5G technology. The competition of 5G is not only competition in the communications field but also competition between industries and economies, between countries and regions. It is also a good opportunity to open up various industries and enter the information revolution. The 5G technology will completely change the current operating mode of many industries and bring greater convenience to people. Compared with traditional communication technology, 5G technology has outstanding features in all aspects, such as new network architecture, flexible spectrum sharing technology, fast transmission speed, strong transmission stability, and short delay.

Keywords Digital economy · Industrial development · 5G · Technological revolution

1 Introduction

With the rapid development of modern society, the development of science and technology also changes with each passing day. The technological change in communication technology is one of the fastest-growing technological changes today. In order

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to cope with the larger data flow and growth rate in the future and increase the development and use of new services, the fifth generation of mobile communication technology (referred to as 5G) came into being [21]. As the most cutting-edge communication technology, 5G mobile communication technology has received great attention all over the world. At present, there is a lot of research on 5G technology, and most scholars take the development status of 5G technology and 5G-related applications as the research objects [8, 20, 25]. Little attention is paid to the development history of 5G, and the application of 5G technology is also relatively general. It is necessary to understand the development history of 5G, highlight the advantages of 5G, and make better use of 5G technology to serve modern society.

5G communications and blockchain technology are both representatives of current emerging technologies and the frontiers of strategic emerging industries. As a communication infrastructure, 5G technology provides a guarantee for the transmission of massive amounts of data and information. Blockchains can assist 5G technology to solve the privacy, security, and trust issues [5]. Therefore, the integration of 5G and blockchains can not only improve network information security and optimize business models but also promote each other and coordinate development. In the 5G era, 5G and blockchain technology are in mutually empowering relationships. If the information network is like a transportation network, the connected device is the car, 5G technology is the highway, and the blockchain is the traffic rule, which can ensure that the data transmission on the highway is safer and more accurate. In other words, 5G can enable networked devices to transmit data faster, and the blockchain ensures the efficiency and safety of the transmission process. The integration and development of 5G and blockchain technology have a strong multiplier effect. The number of nodes in the network will increase geometrically, which will generate huge network value [29]. With the development of 5G, the Internet of everything is expected to be truly realized. Based on this, this paper focuses on the development and application of 5G technology.

2 Methods

This paper uses the literature research method, qualitative analysis method, and a combination of theoretical analysis and empirical analysis. First, based on related literature, the author summarizes the relevant research on the digital economy and 5G technology and constructs the research ideas and content of this article. Second, the paper provides a qualitative description of 5G technology and its development and application based on relevant theories of the information economy. Third, combining the current situation in the world affected by the COVID-19 epidemic, combined with actual cases, the study summarizes the convenience, accuracy, and efficiency of 5G technology. The way for the future development of 6G technology and its integration with blockchain is proposed.

3 The Development of 5G

5G stands for "Fifth Generation" Wireless Technology and it is the next evolution for mobile technology after 4G LTE. 5G will bring faster speeds and improved network capacity and efficiency. 5G enables operators to address the exponential growth in mobile and Internet of Things (IoT) connections. The performance goals of 5G are high data rates, reduced latency, energy savings, reduced costs, increased system capacity, and large-scale device connectivity. 5G aims to deliver a significant technological leap from LTE, delivering an exponential increase in peak and average speeds and capacity [17]. A significant increase in download and upload speeds could enhance many existing use cases including cloud-based storage, augmented reality, and artificial intelligence. 5G will also enable cell sites to communicate with a greater number of devices. Reduced latency could enable edge computing, making possible remote graphic rendering for enhanced gaming. Primarily a mobile technology, 5G will also allow mobile operators to deliver fiber-like wireless broadband service, which also makes it possible to increase speeds.

When the 5G wireless access network and the core network are connected, the basic network is the 5G bearer network. The bearer network is the foundation of the 5G network. Only by ensuring the flexibility, short delay, and high transmission of the basic network, can the 5G network be applied efficiently and quickly. The network architecture of the bearer network is shown in Fig. 1, which is mainly divided into four parts—network slicing, synchronous transmission, forwarding layer, and management layer [9, 14, 15]:

- Network slicing is to cut out different functional networks under the hardware conditions of the existing network and apply them to different scenarios, and they are independent of each other.
- The synchronous transmission method uses data blocks as the transmission unit. A special character or bit sequence must be appended to the head and tail of each data block in order to perform error control on the data block.

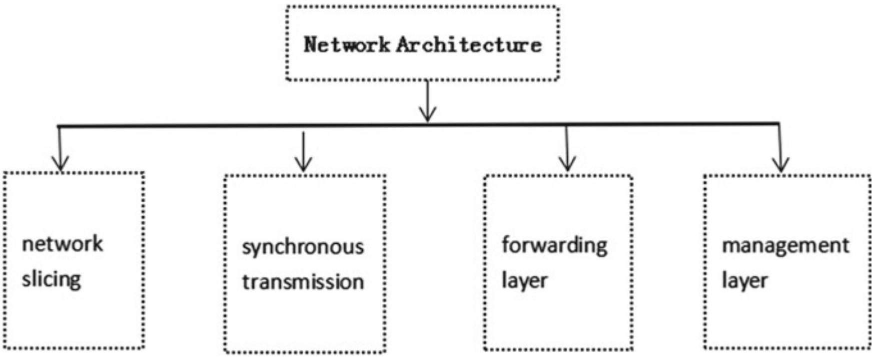

Fig. 1 The network architecture of a 5G bearer network

- The forwarding layer is the layer forward to the upper controller.
- The management layer is the layer that manages the feedback signal to the lower controller.

Since 1G technology began in 1984, it has been developed for more than 30 years. In 1979, the first-generation wireless communication technology standard (1G) was officially released in Tokyo, Japan. By 1984, the 1G wireless standard was promoted throughout Japan by Nippon Telegraph and Telephone. Building on analog technology, 1G was designed for voice only.

In 1991, 2G was put into commercial operation on the Finnish Global System for Mobile Communications (GSM) standard. The wireless standard it brought was far superior to any standard provided by the first generation. Compared with 1G, 2G provides data services for mobile devices for the first time, including SMS text messages and digital encrypted conversations, which not only significantly improves wireless connections, the quality of digital voice calls, but also reduces static noise and background noise. More importantly, text information, picture information, and multimedia information (MMS) have become possible, creating a new way of communication for people [12, 18].

3G technology debuted in May 2001. As with the emergence of 1G and 2G technologies, Japan took the lead in realizing 3G network services in October 2001. The United Kingdom also followed closely. In 2003, it launched its own 3G network service. However, because there were fewer mobile phones supporting 3G networks in the market at that time, the large-scale application of 3G was also delayed accordingly. Just as the performance of 2G technology far exceeds 1G, and the performance of 3G technology in data connection performance far exceeds 2G, 3G was designed to support integrated voice, as well as low-cost and low-data mobile Internet. The users can use new services such as location services, watching mobile TV, participating in video conferences, and watching online videos.

4G represents a major redesign of traditional technologies and aims to provide high capacity and data for large-scale mobile services. In 2009, the UK was the first to introduce 4G networks, and the country's telecommunications giant, EE, even covered 4G services in 11 major UK cities, including London and Birmingham. 4G network speed can reach up to 12 Mbps, which is 5 times faster than 3G network speed. However, because the 4G signal fails to cover the entire UK effectively, it has also been criticized by many British people. According to a survey conducted by the mobile data platform Ogury, British residents can log on to the 4G network only 53% of the time, making the UK the country with the worst 4G signal coverage in Europe, far behind Spain and Italy [7]. However, for those users connected to the 4G network, 4G provides a higher-speed mobile network, allowing them to play online games, watch high-resolution videos and TV programs, and hold higher-quality video conferences.

In 2008, some countries began to explore 5G. In 2012, 5G emerged, which was driven by completely new services and requirements. In 2013, Samsung announced the development of a 5G network. In 2016, Google planned to develop a 5G network, British Telecom and Huawei established a 5G research partnership. In 2017, the International Telecommunications Standards Organization 3GPP announced the official logo of 5G, the Ministry of Industry and Information Technology of China issued 5G related notices. In 2018, the 3GPP5GNR standard SA was released, and China Unicom announced the deployment of 5G. In 2019, South Korea started preparing for commercial use of 5G. In 2020, the British government allowed the use of Huawei equipment on 5G networks, and in 2020, Samsung launched its first 5G smartphone. In July 2020, 3GPP announced the completion of the second version of the 5G standard R16. It has realized the three aspects of expanding new capabilities, exploiting existing capabilities and reducing costs, and increasing efficiency from usable to easy to use, further enhancing the ability of 5G to better serve industry applications. In short, 5G technology has been developed on the basis of a combination of existing technology and revolutionary technology, aiming to meet extreme capacity and user needs. It will connect various applications with high social and economic value and lead human beings into a full-time connected society. It is expected that there will be billions of connected objects in 2020.

This development process is shown in Fig. 2.

5G technology is still in its infancy in the current social environment in China, very few people use 5G technology, and many users who purchase 5G packages are still using 4G mobile phones [5, 16, 24]. It was used in a unit or group. These conditions indicate that 5G technology has a limited level of practical application, and it is still in its infancy. This is mainly because 5G technology still has many unsolved difficulties, and the cost of full use is higher. From the perspective of technology R&D and innovation, there is a relatively high level of research and development on 5G

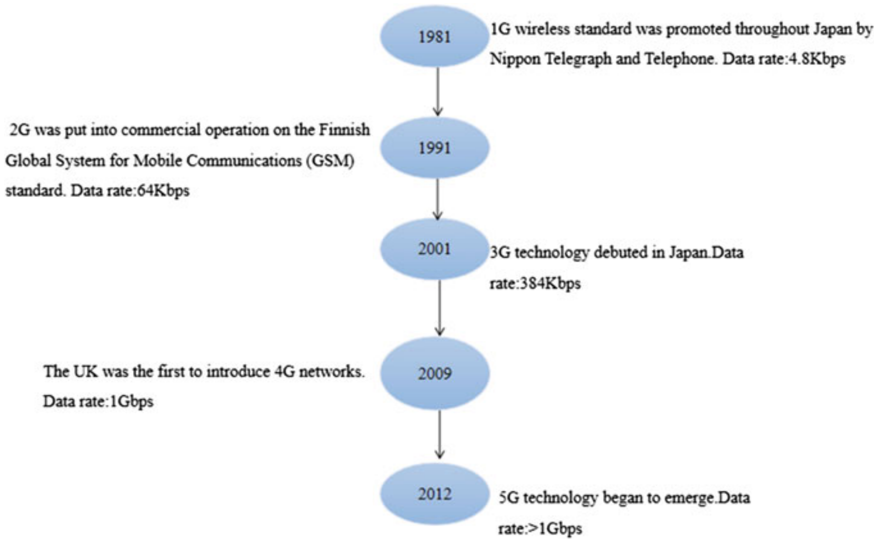

Fig. 2 The development path from 1G to 5G

Table 1 The advantages of 5G compared with 4G

Technical index	Peak rate	Traffic density	Delay	Connection number density
4G	1 Gbps	0.1 Tbps/km^2	10 ms	10^5/km^2
5G	10–20 Gbps	10 Tbps/km^2	1 ms	10^6/km^2
Promotion	10–20 times	100 times	10 times	10 times

technology, and it is currently in a leading position in the world. In particular, Huawei has been committed to the research of 5G technology during its years of development and has achieved many research results. In general, the research on 5G technology has achieved more results, and this technology has also begun to be actively used in the current social environment. However, the development and use of 5G technology is still in its infancy and requires active attention and in-depth exploration in the follow-up time to ensure that 5G technology achieves better development results.

4 Advantages of 5G

4G changes life, 5G changes society. Compared with 4G, the performance goals of 5G are high data rates, reduced latency, energy savings, reduced costs, increased system capacity, and large-scale device connectivity. As shown in the Table 1, compared with 4G, 5G has greatly improved in key indicators. The following table presents the advantages of 5G compared with 4G.

Compared with 4G, the first advantage of 5G is that the data transmission rate of 5G is 10–20 times that of 4G. The second advantage is lower network latency (faster response time). The delay is less than 1 ms of 5G end-to-end, while that of 4G is 30–70 ms [28]. Due to faster data transmission, 5G networks will not only provide services only for mobile phones, but will also become general home and office network providers, competing with cable network providers. The moment the mobile phone is connected to 5G, the network speed is directly full, and the download rate close to 1 Gbps makes people intuitively feel the great power of 5G, greatly saving the time required for downloading. Figure 3 shows the comparison in the speed test of 4G and 5G.

5 Application of 5G

At present, 5G technology has entered the application stage, including high-definition live broadcast, transportation, virtual reality, and other fields. By the end of July 2020, 99 network operators in 46 countries and regions around the world have indicated that they have begun to provide 5G services [30]. At present, 5G applications are continuously enriched in China, covering many fields such as industry, medical care,

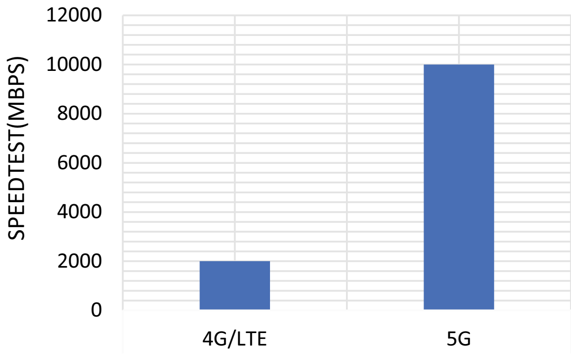

Fig. 3 The download speed of 5G

media, and transportation. Whether it is non-destructive testing of composite materials, remote control of brain surgery, and the first-line "cloud broadcast" of news sites, one can find the strong force of 5G.

VR technology is the crystallization of scientific interdisciplinary fields such as computer hardware technology, sensor technology, robotics, and artificial intelligence. With the rapid development of 5G, VR technology has entered a period of vigorous development. At the 33rd China·Qinhuai Lantern Festival in Nanjing, 5G + VR real-time lamp appreciation was realized, and many visitors experienced the VR lamp appreciation on the spot.

The most widely used are 5G + 4K live broadcasts. In 2019, the State Administration of Radio, Film and Television proposed to actively layout, it integrates the broadcasting and communication methods of radio and television with 5G technology to create conditions for the transformation of traditional radio and television networks [10]. The broadcast smart media equipped with a 5G network will spread local brand programs to all parts of the country. During China's highest level conference in 2019, 5G network coverage of the Great Hall of the People has been achieved, providing efficient news reporting services for media workers and the general audience. In Hefei, Xinqiao International Airport has realized the first 5G airport information construction in China [3, 4, 22]. With the support of 5G technology, it can realize real-time tracking of baggage, optimization of parking space resource allocation, intelligent video face recognition tracking, and early warning of security queues; Shanghai Hongqiao Business District has created the first 5G demonstration business district in China.

China is a country with the largest population in the world. With the improvement of people's quality of life, medical problems have gradually entered the public's field of vision. However, the two levels of medical resources are severely divided, problems such as lack of information in hospitals impede the development of a harmonious society. A smart hospital built with the help of 5G network technology will greatly improve these problems, reduce doctor-patient conflicts, and improve the quality of medical services [13]. In fact, smart science in 5G technology played a great role at the epicenter of the epidemic disease in 2020. An online remote diagnosis center equipped with 5G technology came into operation. The online platform allows senior medical experts with different specialties who work at major hospitals in cities such as Beijing, Shanghai, and Guangzhou, Guangdong province, to diagnose and treat critically ill coronavirus patients at hospitals in other cities. The images and other data can be transmitted between Wuhan and other major cities at high speed, which enables high-quality online discussions. New technologies allow minimizing patients' mortality rate and reducing the likelihood of the doctors and nurses contracting the virus. Robots are used in wards instead of humans to help safeguard medical staff members from infection. The robots are equipped with devices such as cameras, ultra red sensors, and radars so they can move in isolation areas while controlled remotely by doctors via mobile phones.

The application and development of 4G will eventually become a thing of the past, and 5G networks are developing in the direction of diversification, broadband, integration, and intelligence. With the popularization of various smart terminals, mobile data traffic will explode in and after 2020 [6, 26]. Autonomous vehicles, also known as self-driving automobiles, rely on artificial intelligence, visual computing, radar, monitoring devices, and global positioning systems to work together to allow computers to automatically and safely operate motor vehicles without any human active operation. Now, self-driving technology has been realized in many countries, but it has not been applied to real life on a large scale. With the development of 5G technology, self-driving technology will not only be realized on a large scale but also improve the safety of autonomous vehicles. The probability of automobile accidents will be greatly reduced, which is of great significance to society.

Besides this, the huge improvement brought by 5G will cause an unimaginable industrial revolution and cover all areas that are closely related to production and life. 5G technology will open up many new application areas, relying on massive Internet of Things connections. All smart devices such as mobile phones, houses, cars, work and public facilities will be connected to the 5G network at the same time and work together without the need for gateways and routing. For example, hydrometers can report data in real time to reflect the city's operating conditions, traffic lights can be intelligently adjusted according to real-time traffic flow, relying on high-reliability and low-latency communication. Real-time information can be guaranteed in massive data exchanges so that any remote instruction can arrive within a few centimeters. Roadside cameras can tell the car to brake urgently when it detects the danger of a blind spot. Even robots led by 5G technology will gradually replace humans in firefighting, aerial work, assembly line work, garbage disposal, and even as waiters. Online shopping will be more intelligent. The analysis of big data will suggest what products one should buy, when one should buy them, and which platform to choose. Big data will be automatically analyzed to avoid problems when buying something, to guarantee the most suitable price and the required quality. The work will become more intelligent, more flexible. It will be possible to change the work time, which used to be from 9 o'clock am to 5 o'clock pm. The system will automatically distribute the work according to employees' capabilities, which will improve work efficiency and save the company's costs, let everyone work more freely and earn a higher income. Environmental problems will be resolved; automatic monitoring through the "sky eye" will show pollution and garbage accumulation, according to regional division, and automatically send robots to clean. Even the probability of divorce can be reduced before the marriage through big data analysis making it possible to calculate the partners' current indicators [2, 19, 23, 27].

In short, 5G provides the possibility to build smart communities, smart transportation, and smart cities, smart park, smart manufacturing, and so on.

6 Conclusion

5G is like a football game. There are several teams on the field at a time, there are many nets, but there is only one goal worth scoring, to use the smallest capital expenditure and operating expenditure to obtain the greatest practical ability. It is expected that 5G will bring a really comfortable, convenient, intelligent, wireless world—the Wireless World Wide Web (WWWW) to support enormous data rates and huge numbers of user applications and services. However, there is a different focus on 5G technology in different countries [1, 11]. China is more focused on vertical applications and services. Japan currently favors extreme mobile broadband but supports vertical sectors as well. Korea is mainly focused now on extreme mobile broadband. The USA supports an approach similar to the European one, focusing on extreme mobile broadband, as well as extreme machine-type communication, including vehicle-to-X communication (V2X), where X stands for everything. So governments of all countries should attach importance to the development and application of 5G, increase the construction of 5G base stations, and achieve full coverage in the education, medical, transportation, power, telecommunications, and finance industries that are related to the national economy and people's livelihood, and give full play to the leading advantages of the digital economy.

At present, one can observe a critical period of vigorously developing 5G mobile communication technology in China. The rapid economic and social development and the improvement of informatization are inseparable from the 5G engine. At the same time, it is also facing the severe situation of various external technology blockades. In this era, it is necessary to strengthen the integration and development of 5G-related industries and promote deep cooperation of 5G-related enterprises. Although the 5G network is powerful, there are still many difficulties in network deployment, which are mainly reflected in physical site selection, property coordination, equipment compatibility, etc. Government agencies, communication design and construction units, equipment manufacturers, communication operators, and other units should work together to integrate 5G communications, mobile terminals, and big data technologies into a complete set of industries. Only in this way, one can improve the upgrade speed of software and hardware in the industry, meet people's demand for 5G technology, realize the mature development of 5G technology, and ensure the rapid and efficient full coverage of the 5G network. Besides, research on what comes after 5G will be started gradually, there will be some interesting topics in the discussion by academics and industry. A new 10-year generation of mobile communications is coming.

5G is a major change in mobile communication technology, and it will lead to a new wave of disruptive innovation. As the foundation of the entire technology industry, 5G will build the world's IT infrastructure together with technologies such as blockchain, artificial intelligence, cloud computing, and big data.

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Digital Transformation of a Public Lighting Infrastructure: A Sustainable Proposal

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Abstract One of the effects of the last Spanish real estate bubble is the combination of an expansive growth of urban areas with a reduction in their density. This has left the municipal corporations that own the public spaces, facilities and infrastructures, mainly green areas and roads, with a legacy that influences and limits their management capacity, due to their duty of conservation and their high operating cost. Given the current situation of the electricity market and the increasingly demanding environmental regulations, the tendency of public administrations is to find a solution to the high emissions of greenhouse gases (GHG) and light pollution, which in turn can reduce maintenance costs and electricity bills. Due to the great potential of LED technologies and electronic equipment for their regulating capacity, telemanagement and long lifespan, a digital transformation of the public lighting of a couple of urban areas in a small coastal city in southern Spain is performed. First, the implementation of measures to remotely manage them for decreasing energy consumption and pollution levels is analyzed. Then, the amortization of necessary investments is studied. Next, compliance with current legislation is justified. Finally, the feasibility and profitability of actions proposed is successfully assessed.

Keywords Public lighting · LED technology · Telemanagement · Sustainable city

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1 Introduction

The implementation of the 2030 Agenda for Sustainable Development Goals (SDGs) raises a series of challenges that must be faced by governments, civil and scientific society and private companies [1]. Among them, education, gender and inequality, health, well-being and demography, energy decarbonization and sustainable industry, sustainable food, land, water and oceans, sustainable cities and communities, and digital revolution for sustainable development must be highlighted. In order to be achieved, these objectives require a collaborative effort among the different stakeholders involved, whose relationships can be quantitatively assessed through smart indicators in terms of robustness, flexibility and efficiency [2]. In the context of this research, well-being and demography, energy decarbonization, sustainable cities and digital transformation issues will be considered by municipal corporations [3], regulatory agencies and legislators [4], as well as by neighbors, and local manufacturers.

Half of the world's population already lives in cities and the forecast is that by 2030 this will increase to 5 billion (exceeding 60%) [5]. However, to comprehensively address this problem, the concept of cities must be extended to that of urban areas. Furthermore, although these areas still represent only 3% of the planet, they already consume between 70 and 80% of total energy. Therefore, all efforts to reduce consumption will have a positive impact on global sustainability [6]. In the case of Europe, urban areas have been showing a considerable increase in size for just over 20 years [7]. In addition, population distribution within these increasingly growing urban areas is tending to become more dispersed [8]. It should be noted that, although the dispersed model has been considered less sustainable than the compact one [9], discrepancies in this regard continue to emerge [10], although both models must face these energy challenges.

In Spain, urban growth during the years of the last real estate bubble (1998–2007) produced a significant change in terms of building densities, dropping substantially to below 35 dwellings per hectare. In particular, the region of Andalusia accounted for almost 20% of all growth produced in Spain [11] during these years. In addition, 2 hectares per day were altered or even destroyed in the first 500 m of the Spanish coast [12] by the development of urbanizations and constructions (infrastructures and buildings). Among the 35 most destroyed municipalities, only 5 of the most affected are Andalusian (but 3 of them from Cadiz). In parallel to this urban development, energy consumption was growing too. The current trend in energy prices leads to measures aimed at optimizing demand and promoting energy savings and efficiency must be implemented. In this regard, municipal corporations are facing the challenge of ensuring energy management that allows them to address economic growth and achieve a consensual social welfare, while also contributing to the sustainability of non-renewable resources and the preservation of the natural environment.

In the field of public lighting [13, 14], digital transformation can support public lighting systems to help achieve the SDGs [15]. The synergy of these actions aligns actions aimed not only at achieving cost savings, but also at reducing GHG emissions and mitigating night sky light pollution [16]. To this end, solutions focused on automation [17] can be proposed for the transformation of the system into part of a smart city [18]. In addition to automating public systems, this allows integration with information systems [19], being compatible with other services aimed at achieving smarter cities [20]. Accordingly, this digitalization and automation is a critical point of those pursued by the 2030 Agenda [21], mainly affecting the SDGs that are related to the use of energy resources and the design of smart cities:

- Ensure access to affordable, reliable, sustainable and modern energy for all;
- Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation;
- Make cities and human settlements inclusive, safe, resilient and sustainable;
- Ensure sustainable consumption and production patterns.

In summary, the reduction of energy consumption and the mitigation of light pollution are the main challenges that public lighting must face. First, public lighting is a source of high energy consumption for municipal corporations, which in Andalusia can account for up to 60% of the energy consumed and 80% of their electricity bills [22]. In addition, these networks are systems with long periods of operation, so that improvements in their management can lead to large energy savings. Second, the brightness of the night sky (defined as a disturbing and intrusive light that can generate nervous disturbances), because of the current way of life [23], is increasingly affecting the urban ecosystem. In Andalusia, this issue is addressed by the Decree 357/2010 on the protection of the quality of the night sky [24]. In addition, an optimized public lighting provides greater confidence of circulation, takes care of reflections, and waste to sky, as well as preserves the natural cycles of flora and fauna and rationalizes energy consumption [25]. Therefore, this is a very attractive factor for public administrations, both economically and environmentally.

However, the lack of a common regulatory framework is one of the major obstacles for a wider adoption of disruptive practices related to public lighting infrastructures. It can be noted that commercial applications for the promotion of smart cities related to public lighting are not always providing the expected results [26]. For instance, one of the main challenges facing this industry is to design, develop and implement a common standard, despite competition among manufacturers. This can be done with open system architectures, which allow integration with existing infrastructures, thus achieving greater performance in management and maintenance. In this regard, there are individual initiatives and proposals using the European EN-15232 standard as a basis [27] which may mark the route to be followed. In this context, the work being conducted by the ISO/TC 268 Committee "Sustainable cities and communities" of the International Organization for Standardization (ISO) should be highlighted, representing the alignment between the best practices agreed upon and the SDGs.

With the purpose of identifying energy efficiency and saving measures that contribute to sustainable development in the municipal context, energy audits of public lighting may be undertaken, based on a situational analysis that makes it possible to know the mode of exploitation, operation and performance of the lighting systems, as well as state of their components, energy consumption and operating costs. In Spain, these audits must be based on the Protocol for Energy Audit of Public Lighting (PAEIAPE) [28] of the Spanish Institute for the Diversification and Saving of Energy (IDAE), which requires that the following activities should be performed:

- Make an inventory of the main elements included in the system: meter panels, control and protection panels and lighting points;
- Perform a technical evaluation of the operation and diagnosis of the main deficiencies, with observations regarding the corrective measures that should be adopted for a perfect exploitation of the system;
- Propose the main actions to achieve the maximum reduction of the energy consumption of the system, without affecting its quality and service parameters;
- Assess the technical feasibility and quantify the proposed actions in energy and economic terms.

2 Objectives

This research will propose a sustainable public lighting infrastructure. The owner requires to recover the investment by reducing energy consumption. This can be achieved by selecting light sources with a longer lifespan, more efficient and less polluting. First, the current state of existing public lighting in a couple of urban areas in Chipiona (an Andalusian coastal municipality of less than 20,000 inhabitants located in the province of Cadiz), will be audited. Then, a series of measures will be discussed with the municipal corporation to reduce the energy consumption and, therefore, the levels of GHG emissions and night sky pollution. Next, an economic study will be performed to assess the feasibility of undertaking the investments required to implement the improvements proposed and to analyze their amortization. Additionally, the inclusion of a grant within the framework of the Sustainable Construction Program of the Regional Government of Andalusia will be suggested. Finally, the replacement of luminaires will be proposed to obtain:

- Lower energy consumption (including lower light pollution);
- Lower maintenance (including longer service life);
- Higher energy performance (including higher color rendering);
- Direct current operation (suitable to be powered by renewable energies);
- Customization (on/off, power regulation, choice of color temperature);
- Telemanagement (remote modification of parameters);
- Promotion of circular economy (support by local manufacturers).

3 Methodology

This research presents two case studies located in Chipiona, a small city located in the north coast of Cadiz, between the Guadalquivir River estuary and the Rota Naval Station, as shown in Fig. 1. Case studies are a research method widely used by researchers [29]. They are particularly insightful when dealing with complex research objects (sustainable public lighting) in their real scenarios (urban developments) [30], especially when object and context are hard to separate [31]. In addition, their capability as a research method to refine theories in explanatory studies are of particular interest in the energy performance of urban areas [32–34]. In the dynamic scenarios in which energy sources move, case studies are also appropriate for understanding challenging phenomena affecting cities, including points of view of agents involved (as the owner of the urban areas, the municipal corporation) [35].

Fig. 1 Situation and location of urban developments to be audited

The purpose of this research consists of reducing the consumption of non-renewable energy, GHG emissions, level of light pollution and consumption of material resources. Therefore, the scope of this research includes replacing a series of public lighting luminaires with more energy-efficient ones, as well as adding control and measurement equipment to regulate the luminous flux of the infrastructures (by telemanagement). These interventions will be undertaken in a couple of urban developments, as shown in Fig. 1, whose use is mainly residential. The first zone is a suburb located in the southwest of the city and covers 60 ha. The second zone is a tourist development (second home of non-resident neighbors) located in the south of the city and covers 105 ha.

3.1 Regulatory Framework

With the entry into force of Royal Decree 1890/2008 [36] that approved the Energy Efficiency Regulation in Outdoor Lighting (REEIAE) and its Complementary Technical Instructions, the lighting levels, as well as the uniformities, illuminances and other parameters that guarantee an efficient lighting of a road were definitively regulated in Spain. As a design requirement imposed by the municipal corporation, existing columns, poles and arms are not modified (only lamps will be replaced in luminaires). Therefore, the layout of light points, interdistances, heights and type of roads are conserved, with the result that the only intervening variable, for compliance with the REEIAE, is the power and photometry of the lamps. According to the PAEIAPE by IDEA, reviewed in the Introduction section, the following information must be collected:

- Location (including name of the study area, location of the lighting panels using UTM coordinates, number of lamps and type of lamps);
- General data (including voltage, protection, ground resistance, ignition, dimming and control system);
- Energy data (including consumption, contracted power, contracted tariff).

Additionally, a grant is requested to the Andalusian Energy Agency, which is co-financed with the European Regional Development Fund (ERDF), called Incentive Program for the Sustainable Development of Andalusia 2020 (a+ program). The objective of these funds is to promote investments in energy saving and efficiency and the use of renewable energies in buildings for private or public use and infrastructures (located in the Region of Andalusia). This is intended to help society to improve the conditions in which energy is used, through renovation works for the reduction of energy demand in buildings and improvement in the efficiency of lighting systems, among others. The incentive, which is available for municipal services in Andalusian cities with less than 20,000 inhabitants, is 60% of the total cost of the project, provided if a series of technical requirements are met:

- Renewal of equipment that improves the energy efficiency of the current ones, without increasing the installed power;
- Reduction of annual consumption;
- Inclusion of energy management systems using ICTs exclusively for lighting, including control, connectivity and zoning, allowing remote management;
- Application of RD 1890/2008 (REEIAE);
- Pre and post certification of installations.

3.2 *Context Analysis*

The urban developments under study are residential zones very close to the coast, so they also include pedestrian areas. They are formed by different typologically similar roads, whose characteristics, in order to define the types of lighting according to their regulatory framework, are summarized in Table 1.

Based on the analysis of the current status of both public lighting infrastructures, a series of lighting studies (in short, energy audits) are carried out, selecting lamps that meet the lighting needs (uniformity, illuminance, color rendering index, etc.), using LED technologies, and adding new and more efficient equipment. Therefore, the luminous flux can be regulated, managing (controlling, scheduling, changing) the periods of operation and their intensities.

The two public lighting infrastructures under study were installed and commissioned during the Spanish real state bubble 1998–2007 (at the beginning and the end,

Table 1 Road characteristics for designing the public lighting

Parameter	Zone 1		Zone 2	
Typical speed (km/h)	30–60 (Medium)		5–30 (Slow)	
Users (motorized traffic, slow users, cyclists, pedestrians)	All		All	
Vehicle density	<7000/day		<7000/day	
Vehicle parking	Yes		Yes	
Traffic restrictions (elements)	Yes		Yes	
Face recognition	Yes		Yes	
Difficulty of navigation	Usual		High	
Cyclist and pedestrian density	Medium		High	
Field of view and visual complexity	Usual		High	
Conflictivity/criminality	Low		High	
Lighting class	S1	ME4b	S1/S2	CE2
Mean illuminance (lux)	15	20	15	20
Minimum illuminance (lux)	5	0.4	5	0.4
Regulatory compliance	RD 1890/2008, D 357/2010			

respectively). The most efficient technology to meet the public lighting needs, in that geographical, social, and economic context, was provided by lamps with High Pressure Sodium Vapor Discharge lamps (HPS). They were equipped with reflectors and diffusers to achieve uniformity in the road and distribute the luminous flux. Mercury Vapor (MH) lamps were also used, although their consumption was very high and could not be dimmed. High-intensity discharge (HID, both HPS and MH) lamps were massively used until LED technology lamps were introduced in the market, offering higher energy performance and luminous efficiency and less maintenance. This led many cities to consider replacing their public lighting systems, since the investments can be recovered, due to the great energy savings, long lifespan y low maintenance that the new ones offer [19, 37].

4 Results

The main results of the energy audits performed are presented below. First, the lighting results (including consumption and emissions) are presented. Next, the telemanagement system employed, which is provided by its digitalization, to remotely control the infrastructure is described. Finally, the economic results of the interventions are presented.

4.1 Lighting Results

First, field data are collected in an orderly, clear, and concise manner to assess the initial status of these facilities. Next, an identification of the facilities is designed, which are divided by the control and protection panels (CPPs). Each CPP (whose area of action is indicated by color in Fig. 2), in turn, is divided into subzones. Then, they are analyzed as a whole, frame by frame. Finally, a global study of the lighting in each urban development is performed.

As mentioned before, existing bodies must be preserved, so the same light points will be installed at the same height and with the same layout. Accordingly, only lamps will be replaced (but including the addition of new equipment for telemanaging them). All existing lamps are HID ones. Therefore, both HPS and MH lamps are equipped with capacitors. However, these will not be necessary if LED technology is selected. On the other hand, although the current lamps cannot be dimmed, the new lamps, thanks to remote management, can do it (becoming essential for mitigating the night sky pollution). In addition, in order to improve lighting maintenance, the photoelectric cells will be replaced by a system based on an astronomical clock.

Table 2 summarizes the main characteristics of lamps (replaced and new ones, including ingress protection (IP), light source, lamp power and equipment consumption). The interventions in both urban developments include the replacement of 515 HPS lamps (210 in Zone 1 and 305 in Zone 2) and 195 MH ones (75 in Zone 1 and

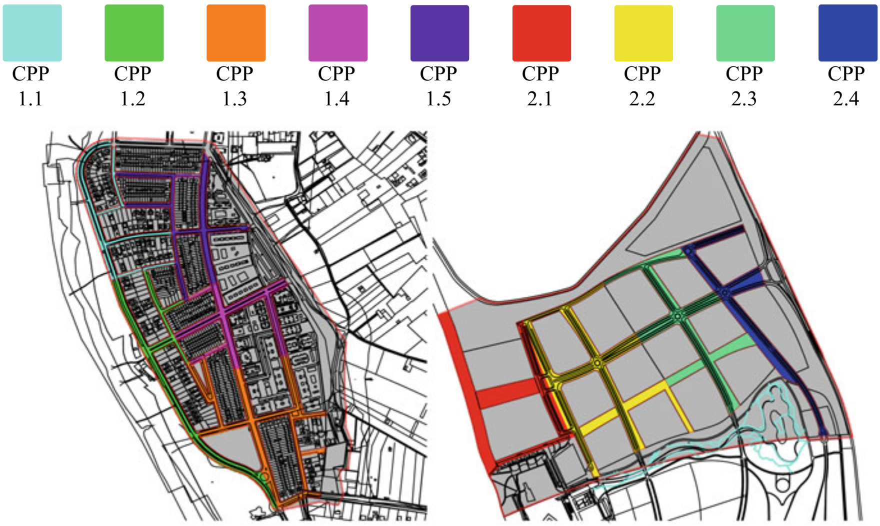

Fig. 2 Delimitation of CPPs by zone

Table 2 Lamp characteristics

Manufacturer	Models	IP	Light source	Lamp power (W)	Equipment consumption (W)
Indalux	752-OVX	55	HPS	150	21
	IQD			100–250	16–27
ATP	Villa		MH	125	14
Socelec	Ioana				
BJC	Delta				
LEC	L-T	67	LED	35–50	4
	V-T			15–30	
	S-MV			30–150	4–8
	LYD			25–80	4–8

120 in Zone 2). Furthermore, the annual operating hours that have been counted for the Energy Audit sum up to 4481 for HPS lamps, 2085 for MH ones and 4311 for the new LED lamps (once adjusted according to the REEIAE).

Energy Audits, which have been performed according to PAEIAPE by the IDAE classify data by:

- location (subzones, series, units, disposal, interdistance and support heights)
- general (road width, lighting classes, mean illuminances, and uniformities)
- energy (light sources, installed power, consumption, energy performance, energy efficiency index (EEI) GHG emissions, and EPC labels)

Table 3 compiles the main results of the intervention by CPP, establishing the previous status, the proposal and the reduction achieved. The proposal is presented in two steps: First, only with the replacement of lamps (LED) and second, including the equipment for digitalization and automatization (LED + D + A). In addition, Table 4 summarizes the entire installation in each of the urban developments. As can be checked in Tables 3 and 4, a reduction in energy consumption and GHG emissions of slightly more than half in Zone 1 and almost two thirds in Zone 2 is achieved. If telemanagement is implemented, then a decrease of almost three-quarters in Zone 1 and almost two-thirds in Zone 2 is obtained if the lamps are replaced as specified above and the remote management is installed as specified below.

4.2 Telemanagement Results

The lighting industry has evolved rapidly over the last years from conventional lighting (for example, with HID lamps) to LED technologies [38]. The benefits of this new technology are now widely accepted globally [39]. Among the advantages that its application provides, the great convergence between information and communication technologies and lighting ones must be highlighted. Lighting applications are moving beyond light management to other data-driven services [40]. In the public lighting segment, municipalities (as public space owners) are increasingly demanding connected lighting, which is fast becoming an ideal platform for the use of smart city applications [41]. Therefore, there is a real need to use an open system [42] to integrate these applications, creating, in turn, new opportunities for welfare and development.

Digitalization allows new luminaires to be remotely controlled by the technical office of the municipal corporation. In addition, automatization allows enables them to prepare the system against triggers. Among the multitude of remote management systems on the market, the city of Chipiona has opted for the technology offered Signify by Philips, based on the management of scenes through communication nodes integrated in each luminaire, connected to a server via GSM on a platform known as Interact City [43]. This scalable platform allows public lighting to be controlled centrally, managing all lighting assets individually or as a group, and creating multiple lighting scenes. These controls ensure that lighting levels are in the right place, at the right time, to improve citizen safety and security. This allows the operator to schedule different lighting calendars, as well as prepare the system for specific anomalies, which would be triggering activated. In addition, other functionalities can be implemented, such as environmental monitoring (pollution, noise, ice, etc.) or incident and accident detection, among others.

In order to implement point-to-point telemanagement, the following elements are necessary:

- Xitanium LED Xtreme driver sensor ready (luminaire power supply compatible for communication with DALI 2.0 protocol);

Table 3 Compilation of energy audits by CPP

CPP	Concepts	Previous status	Proposal (LED)	Proposal (LED + D + A)	Reduction (%)
1.1	Installed power capacity (kW)	8.2	2.2	2.2	73.6
	Energy consumption (MWh/year)	36.8	11.5	9.3	74.6
	GHG emissions (Tn/year)	5.6	1.7	1.4	74.7
1.2	Installed power capacity (kW)	9.8	2.7	2.7	72.4
	Energy consumption (MWh/year)	43.7	14.5	11.7	73.3
	GHG emissions (Tn/year)	6.7	3.6	2.9	55.9
1.3	Installed power capacity (kW)	13.1	3.6	3.6	73.0
	Energy consumption (MWh/year)	58.8	23.0	18.6	68.4
	GHG emissions (Tn/year)	8.9	2.8	2.3	74.0
1.4	Installed power capacity (kW)	9.2	2.5	2.5	73.1
	Energy consumption (MWh/year)	41.0	13.1	10.6	74.2
	GHG emissions (Tn/year)	6.3	2.0	1.6	74.2
1.5	Installed power capacity (kW)	10.3	2.7	2.7	73.5
	Energy consumption (MWh/year)	45.4	14.5	11.7	74.3

(continued)

Table 3 (continued)

CPP	Concepts	Previous status	Proposal (LED)	Proposal (LED + D + A)	Reduction (%)
	GHG emissions (Tn/year)	6.9	2.2	1.8	74.4
2.1	Installed power capacity (kW)	21.9	8.8	8.8	60.1
	Energy consumption (MWh/year)	98.4	46.8	37.8	61.6
	GHG emissions (Tn/year)	70.3	32.4	26.2	62.8
2.2	Installed power capacity (kW)	28.9	11.7	11.7	59.4
	Energy consumption (MWh/year)	129.6	62.6	50.6	61.0
	GHG emissions (Tn/year)	80.3	38.8	31.4	61.0
2.3	Installed power capacity (kW)	22.1	8.2	8.2	62.7
	Energy consumption (MWh/year)	99.0	38.5	31.1	68.6
	GHG emissions (Tn/year)	61.5	25.4	20.5	66.7
2.4	Installed power capacity (kW)	19.0	6.8	6.8	64.0
	Energy consumption (MWh/year)	85.1	36.7	29.7	65.1
	GHG emissions (Tn/year)	52.7	22.8	18.4	65.1

Table 4 Summary of energy audits by zone (urban development)

Zone	Concepts	Previous status	Proposal (LED)	Proposal (LED + D + A)	Reduction (%)
1	Installed power capacity (kW)	50.5	13.6	13.6	73.1
	Energy consumption (MWh/year)	225.7	76.5	61.8	72.6
	GHG emissions (Tn/year)	34.3	12.4	10.0	70.8
2	Installed power capacity (kW)	92.0	35.6	35.6	61.3
	Energy consumption (MWh/year)	412.1	184.6	149.2	63.8
	GHG emissions (Tn/year)	264.8	119.3	96.4	63.6
1 + 2	Installed power capacity (kW)	142.5	49.2	49.2	134.4
	Energy consumption (MWh/year)	637.8	261.1	211	136.4
	GHG emissions (Tn/year)	299.1	131.7	106.4	134.4

- Zhaga connector (standardized connector for interface specifications between LED luminaires and light sources);
- Connection node LLC7270/00 CityTouch OLC COM SR DG model (secure management platform with GSM card).

The Interact City platform allows the lighting management of the urbanization to be centralized, allowing the operator to program lighting schedules, and ensuring the correct lighting levels. However, regardless of the possibility of modifying scenes on specific days or by seasonality, an appropriate regulation curve must be established according to the needs of the urbanization to ensure a reduction in energy consumption during low-traffic hours.

Figure 3 shows the programmed behavior curve. First, the luminaire starts at sunset at 100% of its luminous flux until the third hour of operation, when it drops by 30%. Then, one hour later, it decreases again to 40% of the total luminous flux, and so on until after five night hours. At this point, the lighting again operates with

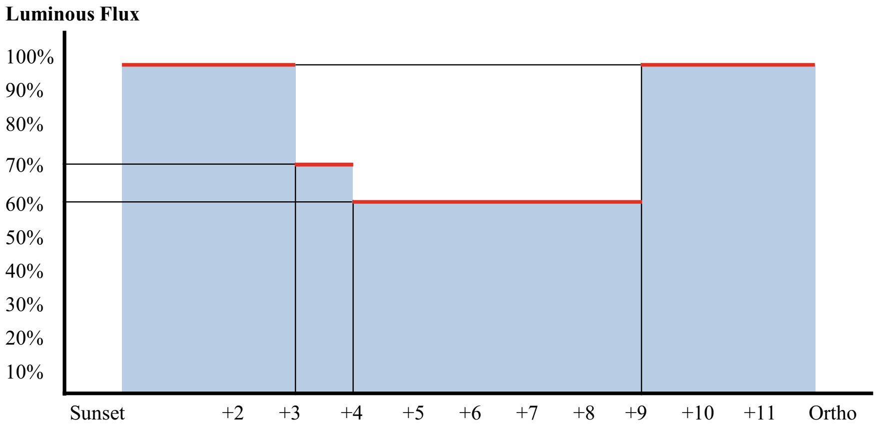

Fig. 3 Luminous flux as a function of operating hours

100% of the luminous flux to end the cycle by cutting off the lighting at the time marked by the astronomical clock (previously installed when replacing lamps), with the corresponding ortho.

Equation 1 shows the energy savings produced by the basal curve, being ϕ_i the nominal luminous flux. It can be noted that without this behavior curve, savings would be twenty percent lower than those obtained thanks to the automatization.

$$\text{Savings} = 0.3 \times \phi_i \times 1(\text{hour}) \times 365(\text{days}) + 0.4 \times \phi_i \times 5(\text{hours}) \times 365(\text{days}) \quad (1)$$

4.3 Economic Results

Finally, an economic balance of the interventions is made. The terms of costs, benefits, amortizations, annual interest rate and even the grant by the a+ program (which will be considered optional for studying the profitability without its concession in order to be extrapolated to other cities that are not eligible for its application) will be discussed.

In relation to the benefit, first of all, the annual energy saving is estimated, from the analysis of the billing by CPP, from the Royal Decree 1164/2001 [44]. Next, the terms of billing by power, of active energy (comparing the discriminatory modalities of 2 or 3 periods and saving systems by reduction of flow), and of reactive power are studied.

Finally, it is necessary to focus on the active energy term, and how it is achieved by means of the flow reduction that remote management allows, as explained before. Table 5 summarizes the annual electricity savings in both zones. The proposal is

Table 5 Savings on electricity bill by zone (urban development)

Area	Current bill	Proposal bill (LED)	Proposal bill (LED + D + A)	Annual savings
CPP 1.1	7,371.78€	1,390.09€	1,123.66€	6,248.12€
CPP 1.2	8,686.88€	1,676.31€	1,355.02€	7,331.86€
CPP 1.3	11,558.83€	2,239.68€	1,810.41€	9,748.42€
CPP 1.4	8,177.87€	1,547.41€	1,250.82€	6,927.05€
CPP 1.5	9,014.60€	1,678.42€	1,356.72€	7,657.88€
Zone 1	44,809.96€	8,531.91€	6,896.63€	37,913.33€
CPP 2.1	12,880.88€	5,224.28€	4,222.96€	8,657.92€
CPP 2.2	14,297.18€	5,344.32€	4,319.99€	9,977.19€
CPP 2.3	19,366.94€	5,798.80€	4,687.36€	14,679.58€
CPP 2.4	11,728.82€	4,269.66€	3,451.31€	8,277.51€
Zone 2	58,273.82€	20,637.06€	16,681.62€	41,592.20€
Zones 1+2	103,083.78€	29,168.97€	23,578.25€	79,505.53€

presented in two steps: First, the replacement of lamps (LED) and second, the inclusion of the equipment (LED + D + A).

Another savings that can be achieved come from maintenance. The usual maintenance costs for HID lamps consists of replacing burned-out lamps and equipment, whose useful life is 15,000 h of operation under proper conditions. However, as they are exposed to surges, a corrected useful life of 6000 h is estimated (which represents a reduction of more than fifty percent with respect to the useful life provided by the manufacturer, under ideal conditions). Both lamps and equipment are replaced every 2 years, so the replacement of luminaires saves maintenance costs of 69.50€ per HPS lamp and 42.60€ per MH one every two years, with an increase of 3% per year.

Another issue to be taken into account is the residual value of the luminaires in their current status, previous to the intervention in which they are replaced by other LED technology luminaires. Due to their years of use, the lamps in Zone 1 are considered to be depreciated. On the contrary, in Zone 2, considering a depreciation of 8% per year, it is estimated a residual value of the current installation of 20% on the price of the luminaires. This means a residual value of 532.00€ per HPS lamp and 326.00€ per MH one.

Regarding the cost, an initial investment of 240,770.80€ for lamps and 40,041.32€ for equipment (Zone 1), and 377,506.91€ for lamps and 59,710.74€ for equipment (Zone 2), respectively, must be faced. These costs include general expenses and industrial profit, in terms of material, machinery and labor. It is also necessary to include the maintenance of Wellight servers to enable remote management for each area, with an initial fee of 360.00€ and an annual increase of 6% (although the first year of service is included in the budget), and the cleaning of the luminaires every 4 years, at a rate of 5.15€ per luminaire (considering a municipal worker performance of 3 units per hour), with an update rate of 3% per year. It can

Table 6 Summary of economic and financial indicators

CPP/Zone	Zone 1 (LED)	Zone 1 (LED + D + A)	Zone 1 (with Grant)	Zone 2 (LED)	Zone 2 (LED + D + A)	Zone 2 (with Grant)
Net present value (NPV, 7%)	120,435.71€	145,096.71€	253,351.23€	93,480.23€	107,287.10€	275,836.76€
Internal rate of return (IRR) (%)	15.93	16.13	33.50	12.11	11.96	29.54
Profitability index (PI) (%)	50.02	51.67	90.22	24.76	24.54	63.09
Payback (PB)	6 years 9 months	6 years 8 months	3 years 8 months	7 years 10 months	7 years 10 months	4 years 1 month

be noted that although LED modules with stabilized voltage reach a useful life of up to 70,000 h (at 4311 h per year of operation would reach about 16 years), a linear amortization of 10 years is chosen, coinciding with the warranty on the luminaires by the manufacturer, so that replacement costs could be reduced (while ensuring the duration of the investment).

Additionally, from the regulatory bases for the granting of incentives for the sustainable energy development of Andalusia in the period 2017–2020, the action 31 includes adaptation works for the reduction of energy demand and energy efficient installations in buildings and infrastructures of the cities. The amount to be incentivized, given that both developments belong to a municipality with less than 20,000 inhabitants (according to the census of 31/12/2020), amounts to 60% of the total contract budget, 168,487,27€ (Zone 1) and 262,330.63€ (Zone 2), respectively. Table 6 summarizes main indicators that probe the feasibility of both interventions, including the first and second stages as well as the grant, which is considered as a possibility (not being required for the profitability of the investment).

5 Conclusions

The case study focuses on prioritizing the mitigation of energy consumption and removal of energy waste. This is done by the renewal of current lamps for more efficient ones. This proposal undertaken in a couple of different urban developments, replacing HID lamps with LED ones, is feasible, both from an energy and environmental point of view. Energy consumption and GHG emissions are drastically reduced (almost 2/3 in Zone 1 and 1/2 in Zone 2). In addition, the mean illuminance is increased, greatly improving the lighting uniformity.

It should also be noted that, thanks to the remote control and management of lighting schedules and flows provided by the inclusion of new digital equipment, the quality of service to citizens is improved and the promotion of smart cities is encouraged. This behavior curve is the basis of a point-point optimization, which can be programmed. Telemanagement automatically optimizes the system, achieving an additional improvement of almost one quarter in decreasing energy consumption and GHG emissions (reaching a total reduction of almost 3/4 in Zone 1 and 2/3 in Zone 2). In addition, light pollution is also mitigated by just over one-fifth, although this can be increased customizing each answer.

The economic results obtained by the replacement of the lamps (NPV of 213,915.94€, IRR of 13.71%, profitability index (PI) of 34.60%) are slightly improved if telemanagement is included (NPV of 252,383.81€, IRR of 13.73%, profitability index (PI) of 35.15%), and greatly increased if the grant is applied (NPV of 529,187.99€, IRR of 31.26%, profitability index (PI) of 73.70%). It should be noted that these results can be enhanced if the total service life of 16 years of the new lamps is considered instead of the 10 years of the commercial warranty provided by manufacturers. In summary, these indicators support the exportation of the model to other localities, especially those with less than 20,000 inhabitants located in the region of Andalusia which, with a relatively low density of housing, find themselves with urban infrastructures to maintain that considerably reduce their budgets. Finally, thanks to the choice of the manufacturer of the new luminaires, the local economy is promoted and the life cycle of the process is cleaned up.

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Additive Manufacturing as a Digital Design Technology in the Wood-Furniture Sector: Benefits and Barriers to Its Implementation

Laura Bravi, Federica Murmura, and Gilberto Santos

Abstract The research analyzes the potential sustainable benefits and barriers to the implementation of Additive Manufacturing in the wood-furniture industry, trying to identify the gaps in perception between "traditional" and "3D companies", and also to predict which are the main factors that could lead companies to its implementation. It has been administered a questionnaire in 2017, on a sample of 2035 Italian companies in the wood-furniture industry, using simple random sampling, obtaining 234 participants. The Analysis of Variance and binary regression were used to evaluate data collected. The research highlighted how Italian 3D companies are interested for new products and product features showing a propensity to innovation and putting design and made in Italy in the first place. The results underline that the main advantages of using 3D printing are the reduction in time to define technical specifications of products, in time for prototyping and production. For the successful implementation of AM technologies, the decision to adopt them has to be accompanied by a change in jobs and tasks, and thus a change in work practices and structure. The experimental techniques used is the added value of this study: no previous quantitative analysis has been realized on a large sample of furniture companies.

Keywords Additive manufacturing · Industry 4.0 · Innovation · 3D printing

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1 Introduction

Currently, the world economy is going through a period of transition and change in the manufacturing landscape and one of the most significant drivers of this change is the emergence of advanced manufacturing technologies that are enabling more cost- and resource-efficient small-scale production. The development of Additive Manufacturing (AM), commonly known as 3D printing, in addition to other societal trends such as servitization [1], personalization [2] and prosumption [3, 4], has led companies to rethink their manufacturing processes and activities.

At the same time, the quality of products must be improved [5, 6] taking into account environmental issues [7, 8], as well as, those related to safety at work [9] and social responsibility [10]. All this aiming for value creation [11, 12] and excellence in business [13, 14] with help of lean tools [15–17].

According to Mellor et al. [18], this technology evolved during the mid-1980s when computing and control systems progressed [19]; in its early years AM was mostly applied for the fabrication of conceptual and functional prototypes, also known as Rapid Prototyping (RP). These prototypes were most commonly used as communication and inspection tools, producing several physical models in short time directly from computer solid models that helped to shorten the production development steps [18].

Only recently 3D Printing has gained much attention, as the process has proven to be compatible with industrial manufacturing beyond prototyping [20–23] In the last decades, the production of end-use parts from Additive Manufacturing systems, the so-called Rapid Manufacturing (RM) has emerged even if its economic impact has remained modest [24].

Many of these technologies have been developed simultaneously but there are various similarities as well as distinct differences between each one [18, 25]. Therefore, 3D Printing can be applied to various manufacturing markets and it could affect the quality of their productions. Mellor et al., [18] highlighted that market and product characteristics must be the basis of the decision to invest in Additive Manufacturing technologies. Any technological investment has to be supported by a high utilization. The process must meet the manufacturing and business needs of other products if it will not be highly used on one product [26]. The product characteristics are generally: a degree of customization, an increased functionality through design optimization and a low volume [18, 27].

Considering that, following the lines of Murmura and Bravi [28], the research focuses on the Italian wood-furniture industry with the aim to understand if companies in this sector are investing in digital technologies and in particular in AM techniques, to remain competitive in their reference markets and how investing in this technology could affect the quality of these products. It has been decided to focus the research on this sector because the Italian furniture industry is one of the solid pillars of made in Italy, known and appreciated in all international markets. Its businesses have a great tradition and also have a strong ability to innovate, from an environmental and technological point of view. Wood-furniture companies have already begun the transition of their production systems from the paradigms of the linear economy to that one of the sustainable and circular economy, and are increasingly opening up to new production technologies [29, 30]. The study tries to investigate the potential sustainable benefits and barriers to the implementation of AM in this specific sector, identifying the gaps in perception between "traditional companies", which use traditional prototyping and production techniques, and "3D companies", which have implemented these new technologies yet. Moreover, the research tries to predict which are the main factors that could lead companies to AM implementation, considering the fact that this technology could impact in the quality of companies' production processes. Therefore, the research questions, which the paper investigates, are the following:

RQ1: *how much AM technologies are widespread among the Italian companies which operate in the wood-furniture industry and how much these companies are investing in it to remain competitive in their reference market?*

RQ2: *Which are the main environmental, quality and organizational changes that AM technologies had brought to "3D companies"?*

RQ3: *which are the main factors that lead companies to the adoption of AM technologies?*

At our knowledge, no previous studies consider the development of AM technologies in the wood-furniture industry and the aim is to cover this gap. The added value is the experimental techniques used, that is a quantitative analysis. There are many qualitative case studies developed analyzing AM, but no previous quantitative analysis has carried out on a large sample of companies focused on the furniture industry to deepen the diffusion and use of such technologies in this sector.

Data considered have been collected before this period of pandemic, but in this context, Additive Manufacturing (AM), has emerged as one remarkable fabrication process because of its accessibility and flexibility to quickly produce complex and monolithic parts or even mechanical systems [31]. Thanks to its ability to be a useful technology for its wide range of materials and techniques, AM can be used in a myriad of areas and applications, from rapid prototyping to medicine and aerospace end-use parts or furniture. During this pandemic, AM was the first responder: it demonstrated one of its strengths in this crisis due to its ability to deliver parts quickly and locally, because it needs no tooling along with shorter lead times. Therefore, the idea behind our study, even if data cannot be considered updated to this last period of crisis, will remain and in the post-Covid era the main logic of adoption will be restored again [32].

The paper is divided as follows: section two defines the theoretical framework on Additive Manufacturing, section three presents the research design and section four describes the main results obtained. Subsequently section five is used to discuss the theoretical contribution of the paper, the managerial implications derived from it and the conclusion, main limitations and future research directions.

2 Background

According to Ford and Despeisse [33], the adoption of AM and other advanced manufacturing technologies appears to herald a future in which value chains are shorter, smaller, more localised, more collaborative, and offer significant sustainability benefits [20].

Firstly, AM can cause changes in the supply chain of a company and on its flexibility [34]. Gebler et al., [20] underline that supply chains shift from physical goods to digital ideas/designs [27, 35]. This shift increases supply chain dynamics by reducing the "time-to-market" [36] and by inducing furthermore a relative decline in imports/exports [35, 37].

Furthermore, supply chains are expected to become less transport intensive. AM makes it possible the production of multiple parts simultaneously in the same build, getting an entire product [37]. According to Ford and Despeisse [33], while centralized AM has the potential to reduce inventory holding requirements because small numbers of parts could be produced on demand economically, decentralized AM could overcome inventory holding as well as conventional distribution problems.

Douglas and Stanley [38] highlight three different alternatives for AM, defining a fourth one. The first one is where an important proportion of consumers purchase AM systems or 3D printers and produce products for themselves [23]. The second is a copy shop scenario, where individuals submit their designs to a service provider that produces goods [39, 40]. The third scenario involves AM being adopted by the commercial manufacturing industry, changing the technology of design and production. They consider a fourth scenario: since AM can produce a final product in one build, there is limited exposure to hazardous conditions, and there is little hazardous waste [41]. For this reason, there is the potential to bring production closer to the consumer for some products [42, 43].

In relation to the economic, quality and environmental implications this technology may significantly reduce the need for large inventory, that is a relevant cost in manufacturing, where, in some cases, the determinants of financial reporting quality, which is a very complex issue in the manufacturing industry and a significant contributor to a company's finance were investigated [44]. Reducing inventory frees up capital and reduces expenses [38, 45, 46].

As a result of life cycle assessments, the adoption of Additive Manufacturing could lead to significant savings in the production of goods [20]. 3D printing reduces manufacturing-related resource inputs since it requires only the material which is needed to print the product without too many losses. Support materials can usually be reused [20, 23, 41]. Energy consumption is an important factor of sustainability to consider. Energy studies on 3D printing, however, tend to focus only on the energy used in material refining and by the AM system itself [47].

According to Gebler et al. [20], 3D printing determines also shifts in labour patterns, as the process is highly automated and only requires human workforce in pre- and post- processing [36]. Labour related implications reveal different patterns in developed and developing countries. The high degree of automation could be economically beneficial for developed countries with ageing societies, but destabilizes developing countries if the production and thereby the production volumes re-shift to consumer countries [35]. Open source-based applications of 3D printing could contribute to a sustainable development in rural areas with low economic profiles, as 3D printing bridges the spatial gap to the next market of spare parts, consumer products or tools [48].

What is more, an important impact is on company culture and how it has to change to accommodate [18, 49]. According to Murmura and Bravi [28], using AM processes as a manufacturing technology requires designers and engineers to re-think Design for Manufacturing (DFM), in fact AM requires users to match product with process and to understand new technology process capabilities. Therefore, the workforce experience and skill are also proposed to be a key factor in AM implementation.

Further, Ford and Despeisse [33] stated that the freedom of design given by 3D printing allows to redesign products and components. Using additive techniques, several parts made of various materials can be replaced by one integrated assembly, which will reduce or eliminate cost, time and quality problems resulting from assembling operations.

Furthermore, with geometric freedom, AM allows products to be produced using less material while maintaining the necessary performance. Materials used for AM are not necessarily greener than materials used in traditional manufacturing. The one exception may be the bio-polymer polylactic acid (PLA) [19]. As for materials, metal and plastic are the primary used for this technology. Currently, the cost of material for AM can be quite high when compared to traditional manufacturing but AM is expected to become more cost effective as larger production volumes become more economically feasible than at present [33, 50].

However, analysing organizational implications of this new manufacturing technology, to obtain a competitive advantage over competitors it would be relevant to link the benefits obtained by the use of the technology with the business strategy [18, 51]. Linked to size, the structure of an organization is the key factor to successfully implement manufacturing technology as suggested by previous studies [18, 52]. Indeed, companies that adopt without first re-designing organizational structures and processes could face high difficulties [52, 53]. Hence, Mellor et al. [18] suggested for the successful implementation of 3D printing that when the company decides to adopt the technology, this decision should be linked to an organizational change in jobs and tasks and in company structure.

However, no previous studies considered with a quantitative methodology to analyse what are the factors of a successful implementation of AM in the wood-furniture industry and what are the main barriers perceived. Therefore, this paper tries to cover this gap, by quantitatively investigating the differences in perception between “traditional companies”, which use traditional prototyping and production techniques, and “3D companies”, which have implemented these new technologies in the wood-furniture industry yet.

The novelty resides in the experimental technique used, investigating a large sample of companies, to evaluate the diffusion of AM in this sector, and the main limitations to its adoption.

3 Methodology

3.1 Sampling Design

To collect data, it has been administered a questionnaire on a sample of 2035 Italian companies in the wood-furniture industry. Companies have been contacted using simple random sampling and the questionnaire was administered, from January 26th, 2017 to February 28th, 2017, using the computer-assisted web interviewing (CAWI) methodology. The questionnaire has been sent by e-mail and it has been followed a two-step administration, that is, two weeks after the first submission, it has been sent again asking those who did not answer to it yet, the possibility to participate. Thanks to the double administration 234 companies participated to the survey (113 companies during the first submission and 121 after the second submission). It has been asked that the questionnaire would be answered by a figure in the technical/production department, or by the figure who is more knowledgeable with respect to Additive Manufacturing, prototyping and internal production techniques.

Data have been collected before this period of pandemic, but the improvements in this last period considered mainly the medical sector [54, 55], while changes did not consider the furniture sector, as can also be seen from the reference literature that it is not updated to the time of pandemic. Therefore, the idea behind our study remains valid since as also suggested by Arora et al. [32] in the post-Covid era the main logic of adoption will be restored.

The questionnaire design is the following. The first part analyses the respondents' profile, the factors of importance in developing their products, prototype production and their knowledge and use of 3D printers. The second part of the questionnaire was only for those companies that know and use 3D printing in their production process, and it was asked them to evaluate benefits and barriers of this technology. The third part was reserved to those companies which know 3D printing but have never used it (neither internally nor externally), evaluating their motivation of non-use. Finally, the last section considers the level of 3D printing adoption in the company supply chain, and the relevance they give in investing in digital technologies.

3.2 Data Analysis

The aim of the research was to develop an exploratory analysis [56], in order to analyse benefits associated with the use of 3D printings in wood-furniture companies, and problems that impede its successful implementation.

A descriptive analysis was developed to describe the profile of the wood-furniture companies that participated to the survey. The questionnaire items (companies' attitudes and behaviours and perceived benefits and barriers) have been evaluated using a five-point Likert scale. The items were built following what was already found in the available literature panorama reviewed in paragraphs 2.1 and 2.2 in this article and also considering the research questions developed. To test the reliability of the items Cronbach's alpha values were computed, taking into account only values greater than 0.60 as suggested by Nunnally and Bernstein [57]. The Analysis of Variance (ANOVA) was performed using F-tests to statistically test the equality of means [58] and analyse the different perception of benefits and barriers of Additive Manufacturing between those companies that use it and those that don't use it. The Fisher statistic (F-test) is a ratio of two variances, that are a measure of dispersion of the data from the mean; larger values represent greater dispersion. F-statistics are based on the ratio of mean squares. ANOVA uses the F-test to determine whether the variability between group means is larger than the variability of the observations within the groups. If that ratio is sufficiently large, you can conclude that not all the means are equal [59].

Finally, a binary regression [60] was used to assess whether companies' attitudes and behaviours and the perceived benefits contribute to determine the investment on AM technologies by firms. The binary regression equation used is the following

$$\begin{aligned}\Pr(\text{AM} = \text{yes}) = \; & \text{logit}\,(\beta 0 + \beta 1\ \text{PRICERANGE} + \beta 2\ \text{AT\_CUSTOMIZ} \\ & + \beta 3\ \text{AT\_DESIGN} + \beta 4\ \text{AT\_QUAL\_MADEIN} \\ & + \beta 5\ \text{AT\_ECOSUST} + \beta 6\ \text{AT\_QUALMATERIALS} \\ & + \beta 7\ \text{AT\_BRAND} + \beta 8\ \text{AT\_IMAGINE} + \beta 9\ \text{BTIMESPEC} \\ & + \beta 10\ \text{BTIMEPROTOT} + \beta 11\ \text{BTIMEPROD} \\ & + \beta 12\ \text{BTIMETOMARKET} + \beta 13\ \text{BCOSTMATERIAL} \\ & + \beta 14\ \text{BCOSTMAGAZ} + \beta 15\ \text{BCOSTTRANS} \\ & + \beta 16\ \text{BCOSTMANODOPERA} + \beta 17\ \text{BRISPENERG} \\ & + \beta 18\ \text{BGEOMEQUAL} + \beta 19\ \text{BMODBUSINESS} \\ & + \beta 20\ \text{BINTERNAZIONALIZZ} + \beta 21\ \text{BPUNTIVENDITA} \\ & + \beta 22\ \text{BPERSONALIZZ} + \beta 23\ \text{BECODESIGN} \\ & + \beta 24\ \text{BIMPAMBIENTALE} + \beta 25\ \text{BNICCHIE} + \epsilon)\end{aligned} \tag{1}$$

where:

- AM (Additive Manufacturing) is 1 if the company has used both internally or externally AM techniques.
- PRICERANGE is the range of products realized by the company assessed by the scale "low", "medium–low", "medium", "medium–high", "high".
- AT_CUSTOMIZ is the attention paid to the creation of customized products assessed by a Likert scale from 1 to 5.
- AT_DESIGN is the attention paid to the creation of modern and innovative products with high design assessed by a Likert scale from 1 to 5.
- AT_QUAL_MADEIN is the attention paid to the creation of quality products that meet the standards of the "Made in Italy" assessed by a Likert scale from 1 to 5.

- AT_ECOSUST is the attention paid to the creation of sustainable products assessed by a Likert scale from 1 to 5.
- AT_QUALMATERIALS is the attention paid to the quality of the materials used for the creation of products assessed by a Likert scale from 1 to 5.
- AT_BRAND is the attention paid to the enhancement of the brand to be competitive on the market assessed by a Likert scale from 1 to 5.
- AT_IMAGINE is the attention paid to the image of the company communicated to customers assessed by a Likert scale from 1 to 5.
- BTIMESPEC is the perceived benefit of reduction in time to define technical specifications of products assessed by a Likert scale from 1 to 5.
- BTIMEPROTOT is the perceived benefit of reduction in prototyping time assessed by a Likert scale from 1 to 5.
- BTIMEPROD is the perceived benefit of reduction in production time assessed by a Likert scale from 1 to 5.
- BTIMETOMARKET is the perceived benefit of reduction in time to market assessed by a Likert scale from 1 to 5.
- BCOSTMATERIAL is the perceived benefit of reduction in costs of materials assessed by a Likert scale from 1 to 5.
- BCOSTMAGAZ is the perceived benefit of reduction of inventory and unsold costs assessed by a Likert scale from 1 to 5.
- BCOSTTRANS is the perceived benefit of reduction in transport costs assessed by a Likert scale from 1 to 5.
- BCOSTMANODOPERA is the perceived benefit of reduction of labour costs assessed by a Likert scale from 1 to 5.
- BRISPENERG is the perceived benefit of energy saving assessed by a Likert scale from 1 to 5.
- BGEOMEQUAL is the perceived benefit of the creation of new products with complex geometries, increased performance and quality assessed by a Likert scale from 1 to 5.
- BMODBUSINESS is the perceived benefit of the creation of a new business model assessed by a Likert scale from 1 to 5.
- BINTERNAZIONALIZZ is the perceived benefit of a greater chance of internationalization assessed by a Likert scale from 1 to 5.
- BPUNTIVENDITA is the perceived benefit of the shift of production to retail outlets assessed by a Likert scale from 1 to 5.
- BPERSONALIZZ is the perceived benefit of product customization assessed by a Likert scale from 1 to 5.
- BECODESIGN is the perceived benefit of co-design with the customer assessed by a Likert scale from 1 to 5.
- BIMPAMBIENTALE is the perceived benefit of reduction in environmental impact assessed by a Likert scale from 1 to 5.
- BNICCHIE is the perceived benefit of having the ability to serve niche markets assessed by a Likert scale from 1 to 5.

In data processing, it has been used SPSS 23.0 program, Statistical Package for Social Science.

3.3 Non-response Bias

It has been verified that there were not significant differences among early and late respondents to detect if there was a non-response bias [61]. To assess this, it has been developed a set of tests that compared answers during the first and the second administration of the questionnaire. All t-test comparisons showed insignificant differences ($p < 0.1$ level).

4 Results

4.1 Profile of Respondent Companies

Among the 234 respondents, the study will consider the differences between “3D companies”, that is, those which are implementing internally or externally additive manufacturing technologies ($n = 76$) and those who know this digital technology but have never used it in their activities, called “Traditional companies” ($n = 158$).

Considering the whole sample, 19.3% of companies declared to use AM internally, 13.2% to use it externally, while Traditional companies are 67.5% of the entire sample.

Table 1 defines the profile of companies. 3D companies are in majority of a medium size (43.4%) with a higher turnover (between 11 and 50 Mln Euro), while Traditional ones are of a smaller size (49.4%) with a lower turnover. 3D and Traditional companies are mainly located in the north, but 3D companies work more with international markets and realize mainly products of an upper-middle range.

In the whole sample of companies that participated to the survey the majority of respondents work in the accessories sector (13.7%), followed by those producing office furnishing (12.0%), kitchen furnishing (11.1%) and bathroom ones (9.4%). 3D printing technologies are used mainly by those realizing accessories (18.4%) and those producing bathroom (13.2%) and office (13.2%) furnishings. This permits to state that it is not the design of the wooden furniture, but it is mainly the design of the components, accessories and furniture complements to be influenced by the use of AM technologies in the wood-furniture-industry. This could define the competitive design of firms in this sector since they know that consumers pay attention in details.

Table 1 Sample profile of respondent companies

Criterion	Index	3D companies		Traditional companies	
		n = 76 (32.5%)		n = 158 (67.5%)	
		N	%	n	%
Dimension	Micro	4	5.3	21	13.3
	Small	23	30.3	78	49.4
	Medium	33	43.4	46	29.1
	Large	16	21.1	13	8.2
Turnover (€)	Less than 2 Mln	4	5.3	37	23.4
	2–10 Mln	21	27.6	63	39.9
	11–50 Mln	34	44.7	43	27.2
	More than 50 Mln	17	22.4	15	9.5
Region	North	43	56.6	81	51.3
	Center	31	40.8	75	47.5
	South and Islands	2	2.6	2	1.3
Reference markets	Italy	3	3.9	11	7.0
	Italy and Europe	5	6.6	25	15.8
	International markets	68	89.5	122	77.2
Price range	Low	0	0.0	0	0.0
	Lower-middle	1	1.3	9	5.7
	Medium	9	11.8	39	24.7
	Upper-middle	50	65.8	91	57.6
	High	16	21.1	19	12.0

4.2 Attitudes and Behaviors of Wood-Furniture Businesses

Considering if wood-furniture companies of the sample realize prototypes, only 5.1% said not to realize them, while 80.8% said to realize them internally and 14.1% externally.

Considering the percentage of the total production of 3D companies made using additive manufacturing, the 72.4% of respondents declared to use it in only 10% of their total production; the 15.8% make from 11 to 50% of their production using 3D printing technologies and only 11.8% of them use these technologies in more than 50% of their production.

Analysing companies' attitudes and behaviours, considering the whole sample not reported in Table 2, they give much importance, when operating in their business, to their image (4.62), to the brand of Made in Italy (4.61), to quality of materials (4.60) design (4.56) and customization (4.53) of products. The analysis of variance (ANOVA) permits to discuss the differences of perception among the two groups of companies (traditional and 3D) for those items that have a statistically significant

Table 2 Attention paid to these factors in companies' corporate behaviour (α = 0.748)

	3D companies		Traditional companies		F	Sig
	n = 76 (32.5%)		n = 158 (67.5%)			
	Mean	SD	Mean	SD		
Creation of customized products	4.50	0.721	4.55	0.778	0.228	0.634
Creation of modern and innovative products with high design	4.79	0.442	4.46	0.737	13.287	0.000
Creation of quality products that meet the standards of the "Made in Italy"	4.70	0.542	4.56	0.718	2.080	0.151
Creation of sustainable products	4.18	0.725	3.81	0.945	9.270	0.003
The quality of the materials used for the creation of products	4.61	0.518	4.60	0.541	0.003	0.957
The enhancement of the brand to be competitive on the market	4.68	0.571	4.42	0.751	7.130	0.008
The image of the company communicated to customers	4.79	0.442	4.54	0.645	9.424	0.002

difference, while for those items that are not statistically significant, it means that there are no differences of perception among the 2 groups.

Considering the differences between 3D and Traditional companies shown in Table 2, companies that have begun to use AM techniques, in comparison to traditional companies, give more importance to the creation of modern and innovative products with high design (4.79), which meet the standards of "Made in Italy" (4.70) and pay high attention to the image they communicate to customers (4.79). Furthermore, the enhancement of the brand as a source of competitiveness on the market (4.68) and the creation of products that meet sustainability standards (4.18) is considered as very important.

4.3 Different Perceptions of Advantages and Disadvantages of AM

Subsequently the main benefits and barriers of using AM techniques have been investigated. As for the main advantages, it can be seen that the reduction in prototyping time (3.84), and the reduction in time to define technical specifications of products (3.50) are the most perceived ones by the whole sample. Table 3 shows differences in perception about the two groups of companies: 3D companies seem to perceive

Table 3 Benefits from 3D printing use, considering 3D and traditional companies (α = 0.948)

	3D companies		Traditional companies			Sig
	n = 76 (32.5%)		n = 158 (67.5%)		F	
	Mean	SD	Mean	SD		
Reduction in time to define technical specifications of products	4.09	0.786	3.22	1.313	28.877	0.000
Reduction in prototyping time	4.53	0.642	3.51	1.325	40.419	0.000
Reduction in production time	3.42	1.074	2.70	1.255	18.731	0.000
Reduction in time to market	3.82	0.795	3.01	1.184	28.718	0.000
Reduction in costs of materials	2.99	1.149	2.52	1.166	8.341	0.004
Reduction of inventory and unsold costs	2.21	1.123	3.22	1.141	0.501	0.480
Reduction in transport costs	2.16	1.132	2.11	1.092	0.106	0.745
Reduction of labor costs	2.75	1.297	2.53	1.224	1.662	0.199
Energy saving	2.64	1.116	2.50	1.144	0.834	0.362
Creation of new products with complex geometries, increased performance and quality	4.05	1.082	3.46	1.348	11.132	0.001
Creation of a new business model: offer of a virtual model	2.67	1.331	3.02	1.304	3.606	0.059
Greater chance of internationalization	2.53	1.238	2.65	1.199	0.551	0.459
Shift of production to retail outlets	1.93	1.075	2.11	1.098	1.297	0.256
Product customization	3.34	1.302	3.10	1.341	1.686	0.195
Ability to co-design with the customer	2.83	1.360	3.11	1.26	2.383	0.124
Reduction in environmental impact	2.74	1.300	2.69	1.117	0.081	0.776
Ability to serve niche markets	2.92	1.374	3.05	1.246	0.519	0.472

Table 4 Barriers from 3D printing use, considering 3D and traditional companies (α = 0.688)

	3D companies		Traditional companies		F	Sig
	n = 76 (32.5%)		n = 158 (67.5%)			
	Mean	SD	Mean	SD		
Technology is not suited to the wood-furniture sector	2.61	1.287	3.41	1.388	18.143	0.000
Lack of interest in the market	2.59	1.180	3.16	1.270	10.676	0.001
Lack of knowledge of potential benefits and problems	2.83	1.182	2.97	1.328	0.606	0.437
Lack of staff training	3.04	1.194	2.86	1.361	0.956	0.329
Excessively high investment	3.03	1.107	3.06	1.298	0.031	0.86

in a more relevant way the benefits related to the reduction in time to define technical specifications of products, in time for prototyping, for production and in the time-to-market of products. Moreover, it is relevant the possibility to create products with complex geometries, high performance and quality, to co-design products with the customer and in the same time to reduce the costs of materials used to realize products, as well as, also to reduce the manufacturing costs [62].

On the contrary Traditional companies think that 3D printing technologies allow the creation of a new business model, but this is less perceived by 3D ones. The other items are not statistically significant and it means that there are no differences of perception among the two groups of companies (traditional and 3D).

As for the main barriers in using 3D printings, these seem to be not relevant: the value related to the item that considers the technology not suited to the sector (3.15) and the investment considered excessively high slightly exceed the value of 3 (threshold of indifference) and are the two cited. Subsequently, Table 4 shows the differences among £d and Traditional companies: the latter think in a stronger way that there is a lack of interest for additive manufacturing in the wood-furniture industry and that this technology is not suited for this sector, assuming that this could be their motivation not for having approached it.

4.4 Binary Regression

The binary regression model tries to identify which are the main factors defining the probability of a company to use additive manufacturing technologies (Table 5). The dependent variable is a binary variable that takes the value 1 if the company is using 3D printing, otherwise zero. The logistic model allows to predict 3D printing use with a probability equal to 79.1% considering among the factors, companies' price

Table 5 Estimation of factors which defined the probability of 3D printing use

Observed			Predicted		
			Y_Possession of 3D Printing		Percentage Correct
			0.00	1.00	
Step 1	Y_Possession of 3D Printing	0.00	125	33	79,1
		1.00	16	60	78,9
	Overall percentage				79,1

a. The cut value is 0.340

range (see Table 1), their corporate behaviour (see Table 3) and the main perceived benefits of 3D printing use (see Table 4).

Evaluating the factors that influence the use of 3D printing among the respondent companies, price range is the most relevant, meaning that it is mainly companies that produce more high-end products that approach the use of these new digital technologies. Considering companies' corporate behaviour, it seems that the willingness to create products that are modern and innovative with a high design has been an incentive to approach to AM, while the attention paid to the creation of products that are customized and meet the standards of made in Italy would seem not so relevant in favouring the use of AM. Finally, among the perceived benefits, the model has estimated the reduction in prototyping time as the main driving factor, while the ability to serve niche markets seem to have a negative influence in the adoption of AM technologies (Table 6).

5 Discussion

This research was aimed at understanding the diffusion of 3D printing technologies among Italian wood-furniture companies. It has been decided to focus on this sector since it is one of the solid columns of made in Italy, and it is known and appreciated for its products in international markets. Data from Green Italy (2016) show that two of the three major European furniture producing regions are Italian (Veneto and Lombardy), and among the top 15, there are 5 (also Marche, Friuli Venezia Giulia, Tuscany), while it is second only to China for trade surplus in a world ranking, and it generates an added value of €4.9 billion, that is more than that of many countries naturally rich in woody raw materials (such as France, 2.3, Spain, 1.8, Sweden, 900 million €).

The research results show that the adoption of additive manufacturing is increasing and it is already quite widespread in Italy, with further potential of development as also stated by Rusconi [63]. A third of wood-furniture companies have already approached internally or externally 3D printing technologies and they are mainly the most structured companies with a higher turnover to have started investing in

Table 6 Factors influencing the adoption of 3D printing (Step 1a)

	B	S.E	Wald	df	Sig	Exp (B)
Price range	0.887	0.333	7.091	1	0.008	2.428
Creation of customized products	−0.704	0.308	5.209	1	0.022	0.495
Creation of modern and innovative products with high design	1.095	0.476	5.302	1	0.021	2.990
Creation of quality products that meet the standards of the "made in Italy"	−0.785	0.383	4.205	1	0.040	0.456
Creation of sustainable products	0.414	0.289	2.047	1	0.153	1.512
The quality of the materials used for the creation of products	−0.608	0.457	1.769	1	0.183	0.544
The enhancement of the brand to be competitive on the market	−0.474	0.417	1.295	1	0.255	0.622
The image of the company communicated to customers	0.908	0.502	3.274	1	0.070	2.478
Reduction in time to define technical specifications of products	0.022	0.280	0.006	1	0.936	1.023
Reduction in prototyping time	0.858	0.338	6.441	1	0.011	2.360
Reduction in production time	0.407	0.249	2.682	1	0.101	1.503
Reduction in time to market	0.198	0.292	0.457	1	0.499	1.219
Reduction in costs of materials	0.041	0.253	0.026	1	0.872	1.042
Reduction of inventory and unsold costs	−0.425	0.303	1.965	1	0.161	0.654
Reduction in transport costs	0.167	0.308	0.293	1	0.588	1.181
Reduction of labor costs	−0.095	0.238	0.160	1	0.689	0.909
Energy saving	0.169	0.295	0.327	1	0.567	1.184
Creation of new products with complex geometries. increased performance and quality	0.397	0.237	2.816	1	0.093	1.487
Creation of a new business model: offer of a virtual model	−0.452	0.280	2.618	1	0.106	0.636
Greater chance of internationalization	−0.010	0.315	0.001	1	0.975	0.990
Shift of production to retail outlets	0.088	0.290	0.092	1	0.762	1.092
Product customization	0.185	0.263	0.494	1	0.482	1.203
Ability to co-design with the customer	−0.248	0.226	1.200	1	0.273	0.780
Reduction in environmental impact	0.248	0.260	0.909	1	0.340	1.282
Ability to serve niche markets	−0.560	0.289	3.769	1	0.052	0.571
Constant	−7.803	2.556	9.319	1	0.002	0.000

Model summary: −2 Log Likelihood 188.307; Cox & Snell R Square 0.366; Nagelkerke R Square 0.511; Hosmer and Lemeshow Test: Chi-square = 6.452; Sig. 0.597

these new technologies. This is in line with the literature that found the size of an organization as a critical factor to the understanding of the process of implementation of new manufacturing technologies [64].

Linked to size, Mellor et al. [18] and Calabrese et al. [53] suggest that the structure of an organization is a key factor for the good implementation of a manufacturing technology, and that high difficulties can be encountered if the implementation is done without first re-designing organizational structures and processes [52].

Defining the profile of the companies which have started to use 3D printing, these give a relevant importance to aesthetic aspects of products they sell related to design and innovation and also to communicate a good image of themselves.

Among the benefits of using 3D printing, 3D companies perceive as relevant the reduction in time to define technical specifications of products, in time for prototyping and for production as also found in the research of Petrovic et al. [36] and Ford and Despeisse [33]. The adoption of AM mostly for reducing prototyping time is usual also in the automotive industry, where these technologies are used as a design and engineering validation tool [27]. 3D printers are used to make small parts and sub-assemblies for both visual analysis and quality control [65].

Other two important factors are the reduction in time to market and in production time; infact, as stated by Petrovic et al. [36], the use of 3D printing technologies will increase supply chain dynamics, creating a decline in imports/exports [60]. The work of Kotman and Faber [66] found that the reduction in logistical and production efforts thanks to the use of AM technologies is found as an important perceived benefit also in the construction industry.

As for the main barriers, these do not seem to be relevant and the main motivation of traditional companies for non-implementing 3D printing is the belief that this technology is not suited for this sector.

The study shows that the approach to the implementation of Additive Manufacturing techniques for a Small Medium Enterprise (SME) is likely to be different to that in a large multinational company as stated by Mellor et al. [18], and that to have success in implementing 3D printing technologies, their adoption should be accompanied by an organizational and structural change [52, 53]. However, made the necessary organizational changes, it has been shown that the technology can be implemented with success as demonstrated by the study. Baumers et al. [50] say that speculation that AM processes may intrinsically be at a disadvantage in high-volume industries appears premature. It is also imaginable that the elimination of tooling resulting from the adoption of AM removes significant front-end fixed costs associated with the introduction of new products, thereby promoting product innovation. Additive manufacturing provides opportunities for organizations to create product innovation, beating competitors on time, thanks to less time spent in defining technical specifications of products and in prototyping, dramatically reducing the time to market of the same [67]. 3D companies, which use AM techniques mostly for prototyping, can achieve to have these benefits and therefore reduce the final production time thanks to the use of a Computer Aided Design (CAD) software which gives a virtual representation of the object that has to be transmitted from a computer to the 3D printer [68]. In this way 3D companies can beat on time traditional ones, which do not use these techniques for prototyping, with the only limitation of material used, since 3D printers primarily use plastics, resins of metals. As stated by Mishra and Shah [69], new product development is a key source of competitive advantage for individual firms, and this is particularly true also for the furniture industry [70]. Moreover, the use of additive manufacturing could help developing strategies of sustainable production to be competitive in their own markets.

6 Conclusion

To implement a sustainable manufacturing strategy, an organization needs to focus on developing innovative products, create reconfigurable manufacturing systems, develop lean production system in order to have agile manufacturing, monitoring performance, and be a flexible organization. This study confirms that additive manufacturing can help to reach such sustainability objectives, thanks to product performance improvements, reduced materials use, and reduced logistics and transportation. The supply chain of businesses adopting 3D printing could become shorter, smaller, more localised and more collaborative.

The present study has its own limitations. Firstly, it has been taken into consideration only the wood-furniture industry, but it would be important to understand how companies of other Italian relevant industrial sectors, such as the textile, food and automotive are managing the investment on these technologies, to verify if the advantages and difficulties in implementing such technologies are similar to those encountered in the wood-furniture industry. Furthermore, the study specifically focused on the Italian reality of businesses, therefore, for future research it could be interesting to compare these realities with the other European ones.

Furthermore, the data is gathered using a structured questionnaire. For future research it could be interesting to develop an in-depth analysis using a Structural Equation Modelling for better understanding the relations among variables and therefore the factors which affects the adoption and non-adoption of Additive Manufacturing technologies in businesses.

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Strategy for Digital Transformation of Financial-Industrial Groups

Wang Can

Abstract In the era of Industry 4.0, the digital economy is reshaping at an unprecedented rate. Facing the historical opportunities and major challenges brought about by digitizing, industrial enterprises should actively adjust their strategic planning and prepare for corresponding management changes. The article uses the general scientific research methods, such as literature survey, analysis, and synthesis. Through the study of a large number of literature and the analysis of the existing typical cases, the components of the company's digital strategy are extracted, and the company's marketing and production are adjusted. Organization, R&D and other management models put forward a digital innovation strategy for the enterprise. Finally, based on the international environment of the world economy's digital transformation, the countermeasures of industrial enterprises are proposed in order to provide references for enterprises to realize technological transformation, management integration, business model reconstruction, and carry out digital strategic management innovation.

Keywords Digital strategy · Management model innovation · Constituent elements

1 Introduction

In the era of Industry 4.0, digital technology has been integrated into all aspects of people's lives, whether it is daily necessities, food, housing, transportation or enterprise management and production, all are affected by digitizing and change. The digital economy is reshaping at an unprecedented rate. It has become a new source of growth momentum for China's economy. According to statistics, the digital economy in China in 2002 totaled 1.2 trillion yuan, and by 2018, it grew to 1.3 trillion yuan at an average annual growth rate of 22.6%. The added value of China's digital economy industry in 2018 reached 14.5 trillion yuan. Figure 1 illustrates the development of China's digital economy in recent years.

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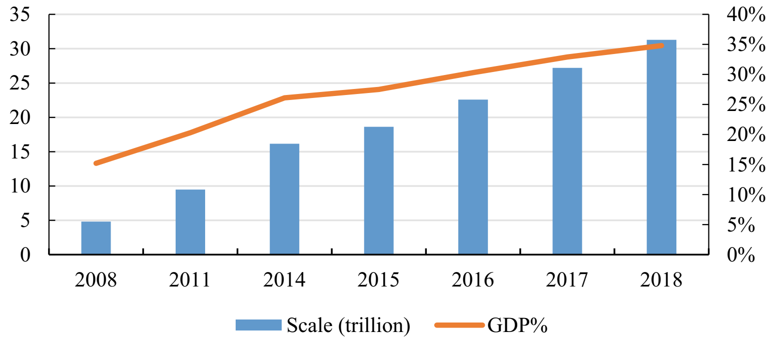

Fig. 1 The development of China's digital economy in recent years [1]

Driven by data, the digital value of industrial enterprises will be highlighted, realizing the reconstruction of the original business logic, and playing a certain role in promoting the digital transformation strategy of industrial enterprises.

Starting from the concept of digital transformation, this article summarizes the constituent elements of the digital transformation strategy of industrial enterprises by studying the literature and typical cases in the digital context, and adjusts the management modes of marketing, production, organization, and R&D to maintain the foundation of the enterprise. From the perspective of the management model, the innovation strategy for the digital transformation of industrial enterprises is proposed.

1.1 Problem Statement

Digital transformation is a dramatic (significant) and complete redefinition of an enterprise's business, not just IT, but also a redefinition of all aspects of organizational activities, processes, business models, and employee capabilities. According to the "2019 Chinese Enterprises Digital Transformation Index", the average score of Chinese enterprises' digital transformation is only 45 points, and only 9% of enterprises have achieved significant results. China is not the only country on the tortuous road of digital transformation. Some scholars pointed out that the practice of global enterprise digital transformation needs to be guided by a systematic theoretical framework with realistic insight and strategic orientation as a guide [2].

With the application of ABCD (Artificial Intelligence, Block chain, Cloud Computing, Big Data) and other underlying digital technologies, users have realized in-depth participation in the production. With the advent of the digital revolution, the competitive environment faced by companies has become more and more complicated. Under the current situation, how to adjust the management model of the company's marketing, production, organization, R&D to maintain the "eternal foundation" of the company? This paper combines the evidence of company management innovation and the characteristics of the times, explores the direction of management model innovation and change, plays a certain role in promoting companies to adapt to the operating rules of the digital economy, and helps companies to promote digital transformation strategies.

1.2 Research Questions

Research Questions:

1. How digitization affects industrial enterprise management reform and innovation?
2. Under the digital transformation strategy, how can industrial enterprises adjust their management models such as marketing, production, organization, and R&D to maintain their "eternal foundation"?
3. How to work out an innovation strategy for the digital transformation of industrial enterprises from the perspective of management models?

1.3 Research Significance

Conversion: Industrial companies have transformed from the numbers carried by traditional information technology to the numbers of new generation IT technology, realizing the upgrade of technology application.

Integration: Industrial companies transform from the process of physical state to the number in the information system, from the number in the physical form to the number in the virtual form, and open up the real-time flow and sharing of data in all directions, the whole process and the whole field, and realize the information technology and business management true integration.

Reconstruction: To adapt to the needs of the Internet age, and to accelerate the transformation and reconstruction of design, production, operation, and management under traditional business models based on the realization of accurate digital operations.

2 Literature Review

Digital transformation is a transformation and subversion of the way of thinking. In the past business model, consumers could only make choices within the range of products manufactured by industrial enterprises, but in the future it will become an industrial enterprise that produces and sells according to the needs of consumers, which imposes some requirements for industrial enterprises change.

Infor, the world's third-largest enterprise-level application software and service provider, proposed that the digital transformation of manufacturing companies mainly includes two aspects: achieving automated management and differentiating competition. This requires companies to restructure their businesses, create new data-driven models, as well as deliver better experiences, services and products, and further promote the realization of the goals of digital transformation—improving operational efficiency and increasing customer and employee engagement. The key digital methods include big data analysis, cloud computing, the Internet of Things, mobility and social network [3]. In its 2011 survey on digital transformation, IBM proposed that there are three main strategic ways for companies to achieve digitizing: (i) to reshape the customer experience and focus on value positioning; (ii) to reshape the operating model and focus on value delivery; (iii) to combine the first two approaches, while transforming customer value propositions and organizational delivery operations [4].

When studying the development of the digital economy, some scholars believe that the key is to implement a platform strategy that is suitable for the actual digital transformation of industrial enterprises, and rely on digital public service platforms to solve the difficulties, pain points and bottlenecks in the transformation and upgrading of industrial enterprises. Other Chinese scholars have put forward suggestions on the digital transformation strategy of industrial enterprises in terms of conceptual transformation, organizational structure adjustment, operating officer transformation, and external cooperation transformation. Schnand et al. [5] thought about how to realize the strategic transformation of industrial enterprises from five points: customer preference determines production trend, strategic adjustment flexibility, and operational transformation to improve efficiency, adjust organizational structure, and strengthen external cooperation. Hao et al. [6] provide directions for enterprises' strategic choices from the three levels of competition, operation, and organization. They use digital technology to create new capabilities and new businesses for industrial enterprises, and to achieve internal management of enterprises. Optimization enables enterprises to continuously improve their organizational efficiency, thereby providing customers with better products and services, and improving customer satisfaction and loyalty. Yongsheng and Yuanjie [7] emphasized the importance of top-level design when developing digital transformation paths for enterprises, and then innovating organizational models to improve corporate management; innovating business models to enhance corporate service capabilities; strengthening core capacity building. In addition, to support the sustainable operation of digital business models, companies also need to establish a digital culture. Digital enterprises need to form a digital corporate culture that adapts to changes faster, demonstrates a higher level of collaboration and cooperation, and has a stronger willingness to accept risks [8].

At present, there are still some shortcomings in the research on the digital transformation strategy of industrial enterprise. For example, there is no research on the management model. This article takes the management model of digital strategy as an entry point, and proposes an innovative model for the digital transformation strategy of industrial enterprises from the four aspects, such as marketing, production, organization, and R&D.

3 Material and Methods

3.1 Realization Path (Literature Analysis)

This paper uses general scientific research methods: literature survey, analysis and synthesis.

Under the current situation, most industrial enterprises are driven by "uncertainty" and try to innovate digital products and services in order to adapt to the changing environment. Driven by social motivations, digital capabilities on the consumer side are gradually being transmitted to the supply side. Cichosz [9] take companies as an example to study the changes in corporate business models in digital transformation and upgrading. It was found that many industrial companies used big data to build online platforms, electronic exchanges, and shared service platforms to connect partner resources and provide comprehensive service in order to accurately grasp the market and customer needs. Many Chinese and foreign companies are actively making digital transformation attempts. However, in the latest "2018 Chinese Enterprise Digital Transformation Index" report, the internationally renowned consulting company *Accenture* pointed out that although China has become the world's second largest digital economy, its total digital economy accounted for more than 30% of GDP, but only 7% of Chinese companies had significant digital transformation effects and could be called "transformation leaders". Even more companies still lack digital and intelligent transformation awareness and digital technology application methods [10].

3.2 Influence Elements (Case Analysis)

The digital economy is sweeping the world, and industrial companies are facing subversion by new competitors. Technology companies, start-ups, etc. are rapidly occupying business territory. JPMorgan Chase has achieved good results in dealing with the above-mentioned problems in digital transformation, and its successful experience is worthy of Chinese companies' reference.

In terms of technology promotion and team talent building: talent and technology are the key to corporate development and success of digital transformation. In recent years, JPMorgan Chase has invested heavily in this area. According to statistics, JPMorgan Chase invested 9 billion US dollars in digital technology in 2015, and has an innovative R&D team of 40,000 people around the world. In these digital technology budgets, 1/3 of the funds were applied to the development of new projects.

In terms of service model innovation: JP Morgan Chase introduced block chain technology and conducted its pilot promotion to improve the security of bank accounts. The project was carried out in parallel with the existing cross-border transfer system by the end of 2016, and finally completed the relevant tests. And Through the EEA, it aimed to extend cooperation with Intel, BP, Microsoft and other companies and jointly carry out technical research and development, so that more enterprises could benefit from the cooperation.

JPMorgan Chase's digital construction has achieved good results. According to the data in the customer satisfaction survey conducted by JPMorgan Chase in 2012–2017, the company's website became one of the most popular banking portals in the United States.

3.3 Elements of Digital Strategy

While summarizing the digital strategy of JPMorgan Chase, its constituent elements can be embodied in the following three aspects:

1. *Information processing system.* The level of information processing capability is critical to the development of enterprises, and has been regarded by many scholars and practitioners as an important indicator for judging the success of modern enterprises. The core elements of the digital strategy are the information processing systems and capabilities that represent the success of modern enterprises.
2. *Digital strategic partners.* Cooperation and common development are still the central topic for companies. In the new era, the development of industrial enterprises requires professional digital technical support and close cooperation with digital technical departments.
3. *Professional think tank.* The current digital transformation has become an inevitable requirement of the development of the times, and digital professional and technical personnel is expected to serve as an important resource in market competition. Companies can cooperate with universities, research institutes and other organizations. The relationship between the three elements is shown in Fig. 2.

With the information processing system as the foundation, companies can interact with digital strategic partners and establish a variety of cooperation frameworks and models. In the process of interaction between the company and the external environment, the former will share the intellectual advantages, brought by professional think tanks, with its digital strategic partners.

4 Results

The integration of ABCD and the real economy, based on the perspective of industrial upgrading, can make traditional industries more high-quality and more efficient. From the perspective of internationalization, the integration of ABCD and other technologies with the real economy can also help enterprises get on track. In a situation where enterprises fully use ABCD and other technologies, they will inevitably adjust

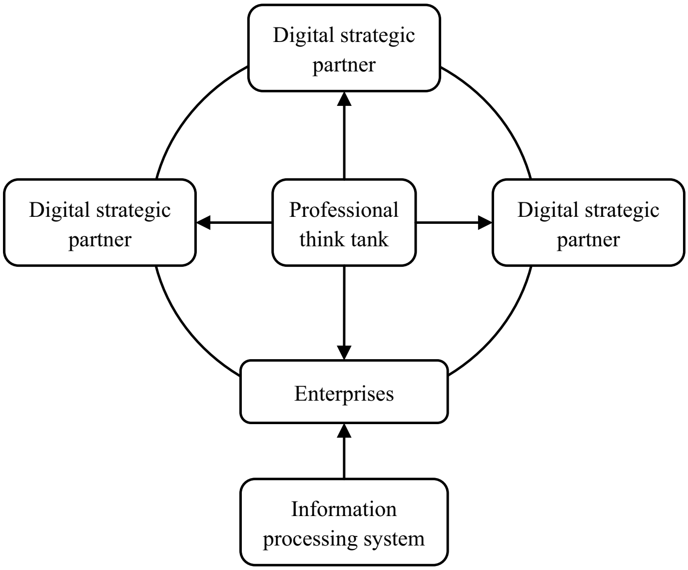

Fig. 2 Digital strategy elements and their connections [11]

their internal functional activities, and then, through the continuous improvement of value, enhance their efficient supply.

4.1 Marketing Model Innovation

The application of the ABCD technology has made the product supply more diversified and digital, but the increase in product types will lead to a rise in customer search costs. This method may not necessarily bring a good consumer experience [12]. With the continuous increase in information, users lack attention to specific products, and information overload makes the value that users obtain from products decline [13]. Focusing on the target market for precision marketing has become the foundation of the corporate marketing model in the context of the current era. The ABCD technology can help companies deeply understand the changes in user needs and create a unique and convenient user experience. Since there are certain differences between users and value-related user experience, companies should not ignore the diverse needs of users when designing experience scenarios [12]. It is the people-oriented operational thinking that enables companies to continue to tap new market opportunities from the perspective of demand.

Mastering users' consumption habits and intentions through big data is the basis for precision marketing. Therefore, it is particularly important to enhance the source of data. Analyzing the historical behavior of users can provide the company with effective market information and become the core basis for its marketing decisions. Omni-channel marketing is comprehensive digital marketing, which is the collection and sharing of various materials, people, finances, and information flows driven by data.

4.2 Production Model Innovation

The outstanding feature of digital technology such as ABCD is that it is better at capturing the ubiquitous power brought about by the popularization of digital information technology. The intelligent production line can switch varieties and batches at will, which can help companies control information replication, search and certification costs. Compared with traditional enterprise production, it improves production flexibility, production risk management, and control capabilities [14]. Based on real-time market information, enterprises can scientifically allocate production factors, make scientific arrangements for production plans, and flexibly release production capacity to enable rapid inventory turnover. In the situation of extensive online transactions, the computer can set up the best plan for the company through the analysis of user orders. The transportation cost of some products will increase, and product transportation will become more efficient.

The mode of production under digitalization has changed from traditional mass production to flexible production. The ABCD technology has further strengthened the control of the production stage, played a significant role in the continuous improvement of product quality, and opened the door for the company to participate in production activities. Among the factors affecting users' purchase intentions, product types have a profound impact, while price exerts a small impact [15]. Personalized products can bring higher value to users and better meet their needs. Compared with standardized products, users no longer passively accept products. They are eager to make choices among a large number of product attributes and follow their personal needs. Users are individuals (groups) who have the ability to develop, design, and innovate products with the company [16]. When users have a deep understanding of their own preferences and can better express them, they will be deeply involved in the product, thereby enhancing the value they obtain.

4.3 Organizational Model Innovation

The organizational structure of enterprises against the background of the industrialization era is hierarchical and pyramid-shaped, unable to adapt to changes in the external environment. With the rapid development of the digital economy, enterprises need to adjust the standards and content of their strategies. It also requires companies to innovate their organizational structure, re-coordination, evaluation and planning of the combination of people, finances and materials. In the context of the digital economy, the company's strategy should focus on "doing the right thing" and gain the greatest value by increasing cooperation with other companies.

The coordination between the different functional departments of the company is manifested in the vertical integration and horizontal entry of the business, and then the corresponding organizational structure is constructed. Among them, enterprises and users are independent nodes, and data transmission is the basic connection between them. The network organization with decentralized characteristics is based on nodes. In the distribution of resources, the position of physical space–time is gradually being replaced by the ever-expanding economic space–time. The circulation efficiency and effectiveness of elements should be further improved to create greater value. The dynamic ecosystem has such characteristics as a certain scale; participants can interact with each other at high frequency, trust each other, and can attract new participants [17]. Companies should continue to try to expand the scale of connections in order to efficiently propose value, and provide users with more additional value through cross-border business entry.

4.4 R&D Model Innovation

In the case of relatively limited information and consistent market demand, the original closed R&D model has significant competitiveness, but also it has certain defects in adapting to individual needs and controlling risks. It is difficult for any company to maintain a leading position in various fields in the era of digital economy. To achieve sustainable development and growth, new ideas should be continuously concentrated and presented. Therefore, innovation should not be limited to closed-door operations within the enterprise, but also require the cooperation of the entire ecosystem. In a constantly changing and risky market environment, the diversification of ecosystem participants provides more options for information exchange and problem solving, and makes the system more stable and able to better respond to risks [18]. Companies can also use the expertise provided by partners to reduce innovation costs, innovate quickly, improve the quality of innovation, and better keep pace with user needs [19].

5 Conclusion

Amid the digital revolution, the popularization and application of technologies such as ABCD has caused tremendous changes in the industrial structure and organization. Market competition has become increasingly fierce and complicated, and new challenges have continued to emerge. In the face of unprecedented changes in the global economy, digital transformation has become the only choice for industrial companies in the strategic direction.

Industrial enterprises should pay attention to the following aspects.

1. *Form a sense of digital transformation.* In the industrial age, enterprise production often only needs to focus on quantity and price. In the context of the current era, the company will closely follow the user management, and the product and service methods will focus on the creation and supply of value. Digitization not only improves efficiency through the application of technologies such as ABCD, but also enables corresponding changes in the nature of competition and innovates management thinking and paradigms. Only by keeping pace with the diverse needs of users and continuously increasing cooperation with ecological partners can companies seize digital opportunities and achieve their own development goals.
2. *Formulate and implement a digital transformation strategy.* Facing the current digital transformation trend, industrial companies urgently need to formulate a set of practical digital transformation strategies. Therefore, enterprises should establish the concept of system management, and their organizational design should fully consider digital transformation. At the same time, enterprises should make up for shortcomings in a timely manner based on the characteristics of "leading development and driving the whole". For the manufacturing industry, digital transformation should build a mature digital management control and decision-making system, and form a networked and flat organizational form. We need to pay attention to the operation of big data to provide guarantee for the precise implementation of marketing. We should use the digital main line and other technologies to manage the production process and play a certain role in promoting the flexibility of production activities. We also need to integrate customer relations, product design tools, and use methodologies to carry out lean entrepreneurship. It is necessary to choose open innovation platforms. Various open-source software encourages all kinds of "interest groups" to actively discover problems and provide solutions for achieving open and open-source R&D and innovation, as well as to grasp the economic development trend, rely on online platforms, change the original single employment mode, make it more flexible and change the value through effective focus on "fragments".
3. *Strengthen the attraction and cultivation of digital talents.* In the digital age, digital talent is a scarce resource for enterprises. In the process of digital transformation, the role of digital talent is particularly important. Cultivating and actively absorbing digital talents is the basic guarantee for the transformation and upgrading of enterprises. In order to cope with the current challenges of digital transformation and upgrading, some companies have also set up a Chief Digital Officer to coordinate platform construction and talent team management at the organizational level. At the same time, we should give full play to the advantages of external channels and recruit talents that meet our own needs from all over the world.
4. *Strengthen external cooperation.* In the era of Industry 4.0, the main activities of the industrial chain do not necessarily have to stay within the company.

> Take the software industry as an example: both Google and Apple support the developer community to continuously improve the quantity and quality of applications on their respective platforms. The travel portal site brings together airlines, hotels, car rentals, insurance companies, etc. in the industry chain, and users can easily develop a complete itinerary. Similarly, industrial enterprises also need to consider upstream suppliers as well as downstream suppliers and consumers, and pay attention to how each link of the industrial chain integrates into the new platform.

With the increase in enterprise digitization, the global economy is about to usher in a large-scale transformation. This transformation will promote economic growth and productivity, thereby promoting the improvement of people's living standards. The digital transformation of industrial enterprises may bring about disruptive changes, and those innovative enterprises that win in fierce competition will create immeasurable value.

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Theoretical Framework of Business Model Innovation Exploration for Sustainable Development

Yan Zhaoqiang

Abstract In modern times, increasingly prominent economic, social, and environmental issues threaten the sustainable development of human society while sustainable development has become the common vision and expectation of all humankind. If a company or enterprise wants to maintain its strong core competitiveness and achieve high-quality development, it should embed the mindset of sustainable development into all aspects of management and operation. Through summarizing and combining existing research results, this paper constructs a circular business model framework used to describe the sustainability of a company's existing business model. The proposed model is based on the integration of the principle of the sustainability triple bottom line and business model innovation so as to evaluate the sustainable development potential and level of the entire industry.

Keywords Sustainability · Business model innovation · Circular economy

1 Introduction

Although scientific technology is developing and changing rapidly with each passing day, the accompanying global economic slowdown, intensified social conflicts, excessive energy consumption, and serious ecological damage become more and more prominent. The sustainable development of human society is facing unprecedented threatens and challenges. As the main body of market and social activities, industrial companies take on great responsibility for these problems [11]. The strategy, direction, and trajectory of their development are crucial and the key issue is how to realize and maintain them.

Various sectors of society have conducted much active and meaningful research and exploration. In particular, the cross-study of sustainability and business models expanded on the basis of traditional business model research has become the latest hot spot in the current academic community. A series of preliminary research has

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been produced while a certain consensus has been reached that the economic value is no longer the unique, dominant, and decisive evaluation index for a successful business model. Regarding a company as a system architecture for the enterprise's value proposition, value creation and delivery, and value acquisition, it is not only necessary to integrate the strategic direction, the operating structure, and the profit logic, but also incorporate the environmental value and social value into the system for overall consideration.

At present, the research results on business models are very rich and mature, but there is not much research on the combination of sustainability and business models. It is still in the conceptual stage and has not yet reached a unified consensus. The formation mechanism, evaluation system, and realization path of sustainable business models are rarely involved and lack comprehensive analysis, in-depth exploration, and systematic construction.

2 Literature Review

2.1 General Overview of Sustainable Development and Business Models

The concept of "sustainable development" was first proposed in the report "Our Common Future" issued by the World Commission on Environment and Development (WCED) in 1987. Ten years later, Elkington [6] first defined the "triple bottom line" principle in the context of the micro-business environment. It is the minimum standard for enterprises to achieve sustainable development and requires enterprises to shift from a single pursuit of profit maximization to the maximization of overall economic, social, and environmental benefits, and strive to achieve a triple bottom line dynamic balance and coordinated development. This is a relatively widely recognized and applied theoretical model.

The research results on the definition, elements, and development tools of the business model have been relatively rich. Different scholars have drawn different conclusions from different perspectives. There is no widely recognized theory that is used for large-scale application. However, existing research generally agrees that the concept of "business model" is mainly supported by the concept of "value". For example, Teece and Richardson [14, 16] believe that the structure of the business model consists of value proposition, value creation and delivery, and value acquisition.

2.2 Research Status of Sustainable Business Models

In recent years, scholars and companies have tried to extend the concept of sustainable development to social and ecological aspects and realize the organic integration of sustainability and business models, which is currently a very new research field. Some scholars refer to the history and experience of traditional business model research to study the concepts, elements, development tools, and innovation mechanisms of sustainable business models, and have achieved preliminary results.

The current definitions of sustainable business models are based on the "integrated" solution on the traditional business model concept. The commonly used theories mainly include sustainable development theory [15], the triple bottom line principle [3, 4], value chain stakeholders [7], cultural strategy and organizational management perspectives [12, 14], etc. At present, the conclusions based on the triple bottom line are highly recognized, and a basic theoretical framework has been formed. It is believed that the sustainable business model establishes an ideal model that balances economic value, environmental value, and social value among stakeholders through a series of sustainable business behaviors or activities.

Along with studying business models, scholars have also conducted research on the development tools of sustainable business models, aiming at guiding the industry in the design and implementation of sustainable business models. At present, there are mainly the following six kinds of development tools that are more meaningful for reference: "Flourishing Business Canvas" [9]; "Value Mapping Tool" [2]; "Sustainability Innovation Pack" [5]; "Sustainable Business Canvas" [17]; "Triple Layer Business Model Canvas" [10]; "Business Model Canvas Extended for Infrastructure" [8].

Some scholars have also summarized specific types or paradigms of sustainable business models through case studies, literature analysis, and qualitative research. For example, Bocken established a classification of "sustainable business model prototypes" based on a large amount of existing literature and business practices, and finally sorted out eight sustainable business model prototypes [3]. Industrial companies can choose one or more combinations of these prototypes to reshape their own, which can help companies find new ways to create and deliver sustainable value and assist in the development of business model frameworks by discovering new business opportunities.

In addition, it should be pointed out that the sustainable business model is a dynamic operation model, which is in constant and sustainable change while it is not a fixed specific paradigm or a fixed logical operation. It needs to have a certain degree of flexibility, plasticity, and compatibility and presents a combination of a series of viable business models in many cases to cope with changes or challenges. Until now, several typical sustainable business models are concluded as follows: natural capitalism; product service system; new economic concepts (blue economy, green economy, sustainable economy, low-carbon economy, ecological economy); closed-loop business model; social business models; green business models and frugal business models, etc.

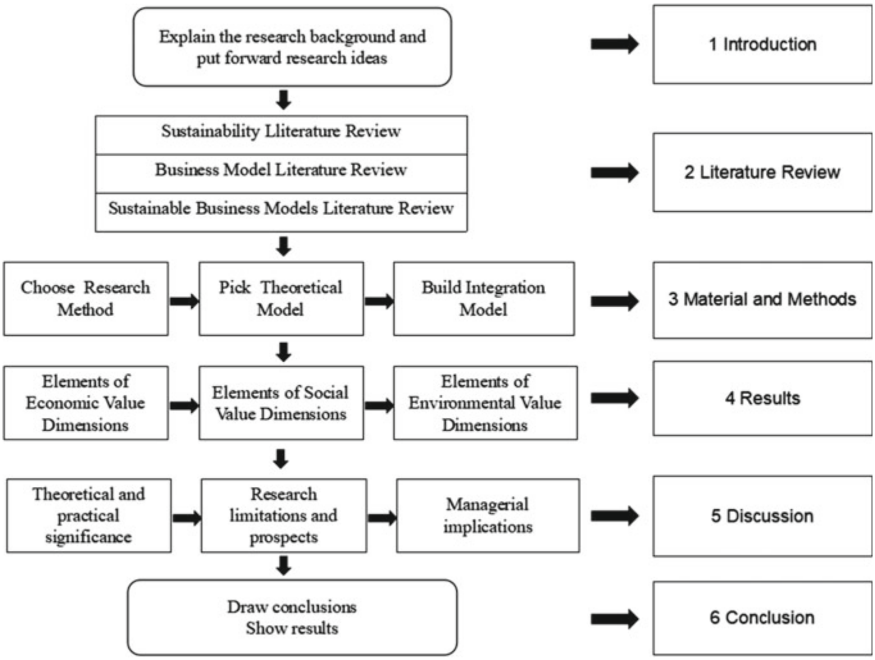

Fig. 1 Research method diagram

3 Material and Methods

3.1 Research Method

Through sorting out relevant literature dedicated to business models, sustainability, and their cross-study, a "circular business model framework" can be constructed and applied to specific industries and enterprises. This theoretical framework integrates relevant theories of sustainable development and business models while covering the mainstream research results in these two fields. The specific research method and route are shown in the figure below (Fig. 1).

3.2 Realization Path

In order to meet the standards and requirements of a circular business model, the traditional business model should undergo all-round and disruptive changes in its innovation concepts and realization paths.

Boons and Lüdeke-Freund [4] proposed three paths for sustainable business model innovation, including the in-depth development and wide application of new technologies, the implementation of a brand-new organizational paradigm, and creating new products and services. Based on this theory, this article believes that a circular business model can be realized in the following ways:

1. Revolutionary entrepreneurship, that is, the construction of a completely different organization or system, is often accompanied by business model innovation, which helps to achieve the sustainability of the business model. Specifically, high-level entrepreneurship can not only create, deliver, and obtain circular value for stakeholders but also pay more attention to the embedding of circular development concepts and the application of environmentally friendly technologies. This approach can also give birth to disruptive business models, makes it possible to discover and seize unknown and potential business opportunities, change the existing industry structure and business rules, create new types of occupations and jobs, effectively solve prominent social problems, as well as obtain outstanding social benefits.
2. In the industry 4.0 era, the wide application of various advanced technologies represented by digital technology has forced many industrial companies to explore new business models to adapt to these technologies. These new business models have more or less demonstrated certain sustainability characteristics or functions and also provide empirical analysis materials for the successful integration of sustainability and business models. A typical case is the "sharing economy" model based on mobile Internet technology. Without changing the ownership of products, the "sharing economy" model greatly improves the allocation efficiency of social idle resources through the transfer of use rights, fully embodies the circular consumption concept of coordination and cooperation, and contributes to resource conservation and environmental protection, which causes positive value creation effect for the economy and society.
3. The improvement of cognitive ability and the convergence of values can promote circular business model innovation from the root. Whether it is government policymakers or leaders of companies, and other social organizations, they all agree that the status of circular development is becoming more and more prominent, and the relevant attention, support, and investment are continuously increased. These factors give the organization a brand-new mission drive and operation logic, thereby reshaping the culture, structure, and practice, changing the business decision-making and practice methods, getting rid of the single economic benefit maximization orientation, and pursuing coordinated development of economic, social, and environmental benefits.

3.3 Theoretical Framework

In order to objectively and accurately analyze the business model that is in the process of transforming into a circular business model, this article tries to build a "theoretical framework of a circular business model", integrating relatively mature research theory of business models and the principle of the triple bottom line of sustainability.

The horizontal axis of this theoretical framework represents the sustainability orientation of the business model, namely economic value, environmental value, and social value. The vertical axis represents the key value links of the business model that consists of three parts: value proposition, value creation and delivery, and value acquisition, drawing upon the research by Teece [16] and Richardson [14]. Each sustainability includes a series of influence elements. Each cross-module contains several influencing factors.

4 Results

In terms of economic value, this article adopts the business model canvas theory proposed by Osterwalder [13], which is currently highly recognized and applied. This theory embeds the nine elements into the theoretical framework of a circular business model proposed in Sect. 3.3 according to their types and characteristics. The results obtained are shown in Table 1.

With reference to the ideas and methods of constructing elements of economic value, the following three questions need to be clarified in the aspect of the value proposition for social and environmental values: (1) Do the companies have the will and ability to realize social and environmental values? (2) What kind of social and environmental values can the company achieve? (3) For whom, with whom, and in what kind of relationship does the company realize social and environmental values?

In the value creation and delivery link, each business model element in this link also needs to reflect sustainability-oriented environmental and social values. The main topics include the following aspects: (1) How do the organizational structure and operating model create value to provide conditions for delivery? (2) Do the products or services produced by the company fully reflect the company's environmental and social values? (3) Which stakeholders at the environmental and social level are the

Table 1 Influence elements of economic value dimensions

	Economic value
Value proposition	1. Value proposition 2. Key partners 3. Customer segments
Value creation and delivery	1. Key activities 2. Customer relations 3. Key resources 4. Channels
Value acquisition	1. Revenue streams 2. Cost structure

Table 2 Influence elements of social value dimensions

	Social value
Value proposition	1. Type and scale 2. Target positioning 3. Stakeholder orientation
Value creation and delivery	1. Organizational structure 2. Production method 3. Operation model 4. Cooperation forms 5. Conduct code 6. Market structure
Value acquisition	1. Subjective experience 2. Objective comment

partners of the enterprise involved and what value they have created? (4) Could market rules and policy environment provide help and support to the enterprise?

In terms of value acquisition, subjective experience and objective indicators are used to evaluate the sustainability of environmental and social values. Subjective experience biases qualitative analysis, including resource integration, industry rectification, improvement of people's livelihood, environmental protection, etc. Objective indicators belong to quantitative analysis, composed of a scientific evaluation system containing a set of quantitative indicators that can determine the sustainability of a company's business model. At present, no unified standards have been adopted.

According to the description mentioned above, influence elements of social value (Table 2) and environmental value (Table 3) are preliminarily determined.

It can be seen from the results that the circular business model framework covers the main aspects and key links of the business model. At the same time, it better reflects the sustainability orientation of the economic, social, and environmental requirements, and also has certain theoretical and practical guiding significance.

Table 3 Influence elements of environmental value dimensions

	Environmental value
Value proposition	1. Type of industry 2. Cultural strategy 3. Policy guidance
Value creation and delivery	1. Brand project 2. Production link 3. Ecological network 4. Recyclable mechanism
Value acquisition	1. Subjective experience 2. Objective comment

5 Conclusion

Within the context of economic globalization and global integration, the company's production and operation are gradually transforming towards decentralization, transnationalization, and modularization. Industry integration is necessary and inevitable, and a sustainable product or service cannot be produced from the noncircular industry [1]. Therefore, a sustainable business model can no longer only seek the innovation of the company's internal business elements or the change of technology portfolio, nor is limited to the upgrade within the industry. Such a model should rely on the strong support of the entire sustainable industry or sustainable business ecosystem to fully exploit the sustainable value and characteristics of its own products or services [18].

5.1 Research Implications

The circular business model is a dynamic operation model, which is in constant and circular change and is not a fixed specific paradigm or a fixed logical operation. Therefore, the definition of a circular business model given in this article is the following: it can satisfy stakeholders' demands for circular creation, transmission, and acquisition of value, and achieve an organic combination and dynamic balance of economic benefits, social benefits, and environmental benefits.

The theoretical framework of the circular business model constructed in this paper is an effective integration of sustainability and business models, covering the results of existing research with reference significance, and enriching the research perspectives and research levels of business model theory. Companies can use this theoretical model to describe and analyze the sustainability of existing business models, determine strategic goals and operational strategies for sustainable development. Government and managers can evaluate the current status of sustainable development of the entire industry by comparing the differences between horizontal companies in order to promote the entire sustainable development of the industry.

5.2 Research Limitations

A sustainable business model is crucial for the long-term development of economic society and human beings. There are still many problems or difficulties that need to be resolved in terms of basic definitions, innovation factors, influence mechanisms, and performance evaluation. Many of the views and theories put forward in this article are not yet mature and comprehensive. Some are based on previous research results, and some are innovative results. In particular, the theoretical framework of a circular business model proposed in this article still needs to be further refined and improved. Its validity, applicability, and scientificity need to be further verified by empirical research.

Next, the author will try to apply the circular business model to different companies and industries, use questionnaire surveys and analytic hierarchy process to explore the relationship between the components of the sustainability-oriented business model, and try to establish a sustainability-oriented and quantitative evaluation system.

5.3 Managerial Implications

The sustainable business model has become an inevitable requirement and inevitable trend for companies to maintain their core competitiveness and long-term sustainable development. The theoretical framework designed in this paper can help companies better understand and evaluate the sustainability of their business models. To successfully realize the sustainable innovation of the business model, the following management suggestions are put forward:

First of all, companies must conform to the development trend. Against the background of sustainable development, companies must not deviate from the direction of sustainable development in the process of developing any products and promoting any cooperation.

Second, the realization of sustainable development is a long-term program and project, which cannot be achieved overnight or hastily. It is a process from quantitative change to qualitative change, which requires continuous attention, investment, and persistence.

Finally, companies need to strengthen cross-industry and cross-regional cooperation and exchange with an open, inclusive, and shared mindset. It is strongly recommended to learn from other companies and promote the sustainable development of the entire industry.

Combined with current research results and practical conditions, this article also suggests that in the current new economic and social development context, more profound sustainable business model innovation can be achieved through the following four paths: revolutionary entrepreneurship, technological upgrading, value recognition, and industry integration.

However, with the in-depth development of related research and practice, the comprehensive advantages and powerful effects of sustainable-oriented business models will become more and more prominent. At the same time, circular business models will surely become the focus and mainstream of future business model innovation and contribute to high-quality economic development, the overall progress of human society, and continuous improvement of the ecological environment.

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Open Innovation in Industry 4.0—A Risk Assessment Framework for SMEs

Vitor Anes, António Abreu, Ana Dias, Pedro Carmona, and Teresa Morgado

Abstract Small and medium-sized enterprises (SMEs) play a fundamental role in the economy of a society. About 90% of the world's economy is made up of small and medium enterprises, which employ about 60–70% of the workforce and generate 55% of the world's Gross Domestic Product (GDP). Despite the important role they play in society, they have been slow to adapt to new technologies and innovation strategies, and in some cases these strategies are even non-existent. This fact has had a negative impact on both economic growth and the performance of these companies. Currently, digitalization and open innovation are two essential strategies for the growth of companies. On the one hand, digitalization aims to increase productivity and efficiency, and on the other hand, open innovation aims to meet the needs of customers more efficiently. Despite the many benefits, these strategies have not been adopted at the desired pace and doubts remain about how they should be applied in SMEs. In this sense, this work aims to investigate the impact of digitalization and open innovation on SMEs' objectives and develop a model to evaluate the impact of their implementation and support decision making. To this end, a literature review was conducted to identify the strengths, weaknesses, opportunities and threats (SWOT) related to SMEs, digitalization and open innovation. A correlation was then made between SWOTs to identify risk factors that undermine the fundamental objectives of

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SMEs. This correlation was modeled to define a risk assessment and risk management framework that promotes the implementation of digitization and open innovation in SMEs.

Keywords SMEs · Industry 4.0 · Open innovation · Corporate risk

1 Introduction

SMEs are the backbone of the European economy and offer great potential for employment and economic growth. They have made a significant contribution to the European Union's GDP and are the main driving force behind the development of national economies and a common thread for entrepreneurship and economic development [1].

In this sense, supporting SMEs through incentives has been a priority for the European Union in recent years. Through this initiative, the EU aims to promote economic growth, job creation and economic and social cohesion, taking into account smart growth (based on digitalization), sustainability and inclusive policies.

According to the European Commission Recommendation 2003/361/EC of 6 May 2003, Article 2 defines SMEs as small and medium-sized enterprises. Accordingly, the definition of SMEs corresponds to enterprises "employing fewer than 250 persons and whose annual turnover does not exceed €50 million or whose annual balance sheet total does not exceed €43 million." This concept is applied in all countries of the European Union on the basis of three criteria: (1) number of employees, (2) annual turnover and (3) annual balance sheet.

SMEs are distinguished from large enterprises mainly by three characteristics: (1) uncertainty, (2) innovation, and (3) adaptability.

SMEs tend to be very vulnerable to fluctuations in the global economy, which leads to great uncertainty about their survival. Nowadays, although market penetration is easier and faster, it is also more volatile and vulnerable. SMEs not only contribute positively to economic growth and employment, but also are active in research and innovation. Although the economic crisis can affect SMEs all over the world, their adaptability/flexibility has served as a lever to combat adverse scenarios with the aim of surviving while generating economic growth and employment. SMEs help to improve competition, innovation, and overall productivity as they are the main vehicle for new entrepreneurs who provide the economy with continuous ideas for innovation and skills [2, 3].

SMEs have many positive attributes, such as: their growth strategy is customer-oriented and customer-focused; they are responsive to market needs; their organizational structure provides for highly visible top management; because of their size, they have low bureaucratic overhead; the work environment is usually informal, which promotes productivity and encourages innovation; they seize opportunities quickly and have high flexibility and adaptability [4].

Despite the socio-economic importance of SMEs, many of them have failed in important factors such as customer satisfaction, planning, monitoring, control and resource management.

This fact results from a number of weaknesses, some of which derive from some of the positive characteristics mentioned above. The best-known weaknesses of SMEs are lack of capital and/or poorer access to finance, inadequate or non-existent Research & Development (R&D), resource and market constraints, lack of skilled labor, lack of management skills, inadequate infrastructure (size, capacity, obsolete), lower job security, less strategic thinking, less standardization, limited application of new technologies, obsolete technologies, lack of integration of network systems and poor consumer/customer service.

In addition to these internal weaknesses, external threats include global competition, a flawed growth strategy, economic and political uncertainty, a challenging regulatory environment, environmental factors, consumer confidence (reliability, quality, brand image), internal staffing (information leaks), other new technologies, social security contributions, tax rates, and faulty communication [4, 5].

Despite these struggling challenges, SMEs also experience a set of opportunities such as partnerships and alliances; promotion of SMEs by governments and EU; test bed for new products and new markets, and test bed for new technologies.

1.1 Statement of Problem

In recent years, industry has adopted several strategies to meet the increasing difficulties posed by technological and social development. Indeed, societies are increasingly demanding and accustomed to being confronted with new technologies and new services at a very fast pace. Companies that cannot keep up with this pace fall behind, and those that do not adopt up-to-date growth strategies eventually have to admit defeat. In this context, two inevitable growth strategies are open innovation and digitalization. Innovation is one of the main arguments for the success of SMEs, but the current innovation models are not up to the current challenges. The most used innovation models in SMEs are the closed innovation models; an outdated innovation strategy that limits the potential of innovation initiatives.

The reason for this fact stems from the great uncertainty surrounding the intentions and actions of competing companies which may have access to sensitive information through open innovation activities and jeopardize the company's survival. Due to this uncertainty, open innovation has not been adopted leading to lost growth opportunities as well as increasing SMEs' exposure to negative impacts resulting from the global economy.

As aforementioned, digitization is also an unavoidable strategy for SMEs. In fact, the competitiveness of companies goes through digitization in its most varied forms. Real-time access to information and the use of artificial intelligence expands the horizons of opportunities. However, also in this strategy, SMEs encounter a set of uncertainties whose impacts can put the company at risk.

Therefore, it appears necessary to promote open innovation and digitization in SMEs through the modeling of inherent uncertainties.

According to the authors' knowledge, there are no frameworks in the literature that model this issue, taking into account the aggregate effect on SMEs resulting from uncertainties in open innovation together with digitalization.

1.2 Objectives

In this paper, we intend to model the aggregate uncertainties arising from the implementation of open innovation together with digitalization in SMEs.

The aim is to investigate how the implementation of these two strategies may affect goals, opportunities or even reinforce threats. It will also identify sources of negative impacts and develop a risk model to quantify them.

This framework will support decision-making in the areas of open innovation and digitalization and promote the implementation of these two strategies, in terms of economic growth and increasing the welfare of society.

2 Literature Review

2.1 Digitalization

Industry 4.0, also known as the fourth industrial revolution, is based on the technological development that has taken place in recent years. Advances in storage capacity, the increase in internet speed through 5G technology and the increase in computing capacity have encouraged the development of new areas of research and development with particular application in industry. Areas such as Big Data, Internet of Things, cloud computing, artificial intelligence and others are examples of the contribution of these advances, which have completely changed the paradigm of industrial management [6, 7].

The rapid storage of large amounts of digital information and its analysis in real time provides decision-support information that would otherwise be impossible to obtain. The level of precision and confidence is high, and the practical applications of this information are numerous.

For example, based on the stored information and its analysis, it is possible to analyze the past, the present and the future. The development of statistical and forecasting techniques makes it possible to predict future events and behaviors based on historical information. This type of information is very valuable as it allows estimating future scenarios, improving risk analysis and management, optimizing processes and making decision-making more precise. This information is stored in the cloud, i.e., on computer servers for data storage that can be accessed remotely over the Internet. The evaluation of the data is also done remotely and in real time.

The increase in Internet speed in recent years, as well as the increase in the reliability of Internet services, have been fundamental to the paradigm shift in the industry towards the adoption of so-called digitalization [8].

This has enabled the introduction of the concept of the Internet of Things, where devices interact with each other through sensors and the exchange of information, resulting in an integrated and intelligent dynamic network. Advances in artificial intelligence have played a key role in broadening the horizon of digitization development. Neural networks, fuzzy logic methods, data mining, Bayesian networks, among others, are examples of these advances that are currently being used in industry, and there are great expectations regarding the practical results that can be achieved with these methods in the near future. The digitalization of industry enables the optimization and consequent reduction of energy consumption in line with the sustainability strategy promoted in recent years, it also enables the minimization of waste and offers highly customizable products [9, 10].

Indeed, industrial digitalization brings innumerable benefits, such as: increased productivity, efficiency, competitiveness, improved turnovers; increase in highly skilled and well-paid jobs; improved customer satisfaction; increased product customization and variety; flexibility and control of production; effective monitoring and rapid response systems (safety of equipment and employees, higher quality control).

In addition to these benefits, a number of opportunities can be identified, namely: development of new lead markets for products and services; lower barriers to entry for participation in new markets; development of test environments for pilot projects and close relationships between companies and universities [11, 12].

On the other hand, the implementation of industrial digitalization is not without weaknesses, namely: development and implementation costs; possible loss of control over the company; dependence on the supply of workers with appropriate skills (lack of qualified personnel in general); high dependence on the resilience of technology and networks; dependence on investment and R&D; and lack of time to implement projects.

In addition, several threats can be identified, namely: high investment costs; technological immaturity; insufficient skills; cyber-attacks; unemployment; violation of privacy; cyber security (intellectual property, data protection); lack of knowledge about digital transformation at the top management level; lack of skills and resources for digitalization; brain drain and the risk of hybrid wars [13].

2.2 Open Innovation

In recent years, there has been a significant increase in corporate awareness of the need for modern innovation strategies in order to remain competitive and penetrate the market [14].

This paradigm shift is partly due to the increasing complexity of the innovation process, which has made companies' internal knowledge base scarce and insufficient. As a result, innovation activities have evolved into a global collaboration between numerous teams distributed across different geographical points and/or different companies [15].

The main objective is to enable the sharing of skills and knowledge provided by different companies and institutions, leading to the concept of open innovation. This concept has been extensively discussed and studied in the literature on innovation, being of particular importance in the field of innovation management [16].

Generally, open innovation is divided into three types, namely "outside-in", "inside-out" and "coupled". In the "coupled" form, two or more actors manage the flow of knowledge between their organizations to gain additional knowledge and bring ideas to market more effectively. Although the "coupled" form of open innovation is the most promising, it is also the one where uncertainty is greatest and where the negative effects of unsuccessful partnerships can threaten the survival of the partner firms [17].

This problem becomes even more critical for SMEs, which have withdrawn open innovation initiatives due to their small size and high vulnerability to negative impacts. On the other hand, larger companies, which are less exposed, have successfully tested this new way of innovation, proving that it is the right way to go [16, 18].

Based on successful examples, the same result can be expected for SMEs if exposure to negative impacts is done in a reduced and controlled way.

In this context, it is necessary to develop decision support tools that are appropriate to the paradigm of these partnerships and the respective ecosystems, in order to manage the interests of the partner companies in a "win–win" approach. However, the body of knowledge in this area is sparse in the literature. In particular, the available tools for the analysis and management of risks in open innovation between competing firms are very limited or non-existent.

Open innovation has several strengths that promote industrial growth, e.g., networking with competitors is a source of valuable information; co-creation with customers; enables the exchange of knowledge, ideas and technologies between firms; diversification of R&D investment and sharing; easier market entry; advantages in resource acquisition; increased speed of development; broader idea base; technological synergies; increased learning; use of intellectual non-property as a strategic tool.

These strengths promote various opportunities, such as, partnering directly with end customers (case of open innovation with customers); collaborating with external partners; using subcontractors to increase profits without hiring employees; experimenting to find new revenue streams; collaborating with universities and schools as a source of new employees.

On the other hand, this innovation approach has a number of weaknesses, namely more mistakes in routine processes; lack of legacy knowledge for additional tasks; heavy dependence on external knowledge; loss of overall control over the innovation process and intellectual property; loss of control over important knowledge; loss of flexibility; creativity and strategic power; use of consulting brokers leads to lower profit margins (costs may exceed benefits); power imbalance due to asymmetric partnerships and lack of partnership with end customers.

There are also a number of threats: the risk of disclosure of confidential information; loss of staff; unbalanced partnerships with advisory brokers; knowledge leakage to competitors and differences in technical standards and technologies [19, 20].

2.3 Risk Management in SMEs

Qualitative risk analysis and management models are most commonly used by SMEs because they allow characterization of risk scenarios in the absence of statistical data.

Open innovation partnerships are unique with unique scenarios, and it is not possible to obtain systematic and correlative information between scenarios. In this sense, quantitative models (with a statistical basis) are not directly applicable to this type of problem, which makes the challenge even greater.

The alternative solution is to use qualitative models. However, these models have a number of well-known limitations that are regularly discussed in the literature, such as the limitations of Failure Mode and Effects Analysis (FMEA).

FMEA is a risk assessment and risk management tool that aims to mitigate potential failures in systems, processes, projects, or services; it is used in a variety of industries and research centers.

Despite existing limitations, these models are still widely used due to their applicability and ease of interpretation. However, the results are sometimes ambiguous and require alternative measures with little scientific rigor.

The main criticisms are the fact that it is not possible to consider the relative importance between risk variables [21], to obtain the same risk index for scenarios with different risks, the difficulty to evaluate the risk variables by experts, the functions of non-injective and non-surjective risk prioritization with duplicate values and values that never appear in risk assessment, Scoring scales for risk variables with different paradigms that make it difficult to standardize the contribution of different risk variables, the impossibility of effectively measuring risk reduction after corrective actions, the impossibility of considering the interdependence between failure modes, and the impossibility of modeling the risk of complex scenarios because only three risk variables are considered in these models (severity, occurrence, and detectability), which is insufficient in these cases [22].

The models proposed in the literature to overcome these limitations are very complex and require a high level of prior knowledge, which questions their applicability to real cases in industry leads to a significant improvement in the results [23]. The limitations of qualitative models based on FMEA have a negative impact on their performance. However, when these limitations are overcome, these models are an asset, especially in the characterization of scenarios related to the analysis and risk management of innovations [24, 25].

However, the approach that is best suited to the analysis and management of risk in the context of open innovation is the hybrid approach, where qualitative models are used together with quantitative models.

3 Research Method

3.1 Proposed Approach

The research approach focuses on three dimensions, namely SMEs, open innovation, and digitalization. As a first step, the strengths, weaknesses, opportunities, and threats of each of these dimensions are identified in order to identify the main influencing factors. Based on the obtained results, a correlation between the influencing factors will be established to identify negative and positive impacts between the three dimensions, Fig. 1, and then evaluate the aggregate risk associated.

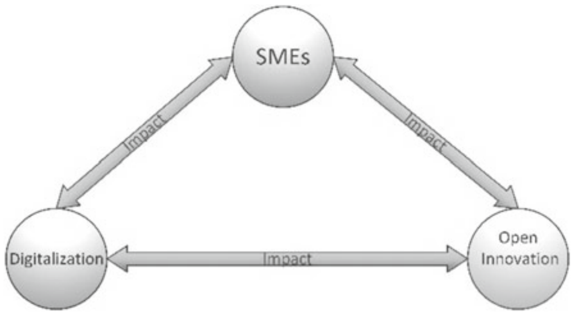
Next, the aggregated effect of the identified impacts in each dimension is evaluated, considering the four impact chains represented in Fig. 2.

These four scenarios describe the potential impact chains that SMEs may be exposed, if they decide to implement digitalization and open innovation.

3.2 Models' Design

Based on the concept described in the previous section, the total risk is calculated considering the four chains of effects (four risk scenarios) connected in series, because only one failure in one chain of effects is needed to experience the impact. In this sense, the overall risk can be calculated using Eq. (1),

Fig. 1 Correlation between the three dimensions, SMEs, open innovation and digitalization



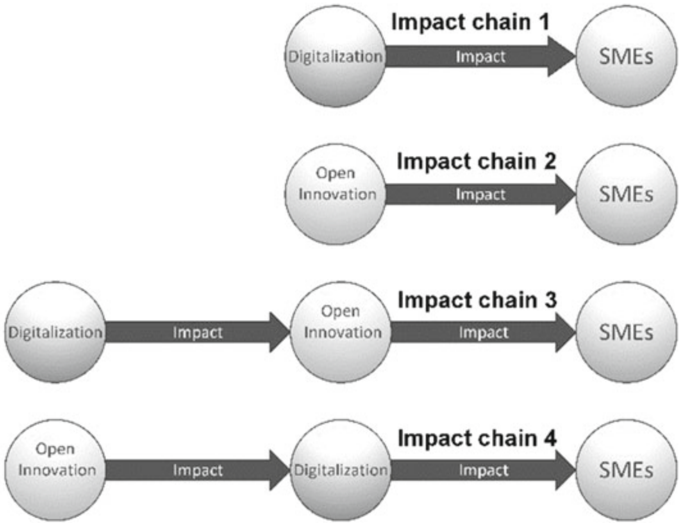


Fig. 2 Impact scenarios (IS) considered to evaluate aggregated risk

$$Risk_{aggregated} = \left(1 - \prod_{i=1}^{4} P_{f}\_ic_i\right) \cdot I_R \tag{1}$$

where $P_f\_ic_i$ represents the probability of the ith impact chain, and I_R represents the impact rating, i.e., a measure of the impact damage in the company's goals and expectations; this rating can be defined quantitatively or qualitatively depending on the company reality. At this point, it is necessary to evaluate the probability of failure of each chain of effects to determine the overall risk. According to Fig. 2, there are two different types of impact chains, namely those that have only one type of risk source (impact chain 1 and 2) and those that have two types of risk sources (impact chain 3 and 4), so the risk assessment in each type of impact chain will be different depending on the number of risk sources.

3.2.1 Risk Assessment of Impact Chains with One Risk Source

To properly evaluate a risk, one usually needs to consider the barriers to risk avoidance and the barriers to mitigation/recovery. The former aim to prevent the event from occurring, while the latter aim to avoid the impact if the event does occur. Figure 3 shows these barriers and how they are interconnected.

This graph can be updated for the risk scenarios considered for impact chain 1 and 2, as shown in Fig. 4.

The threats and weaknesses found for digitalization and open innovation are considered here as risk events. Therefore, the prevention barriers (left side) aim

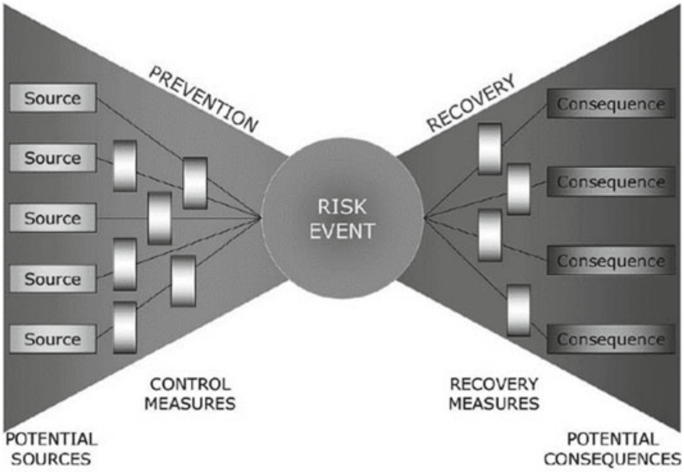


Fig. 3 Bow-Tie conceptual idea for a given event

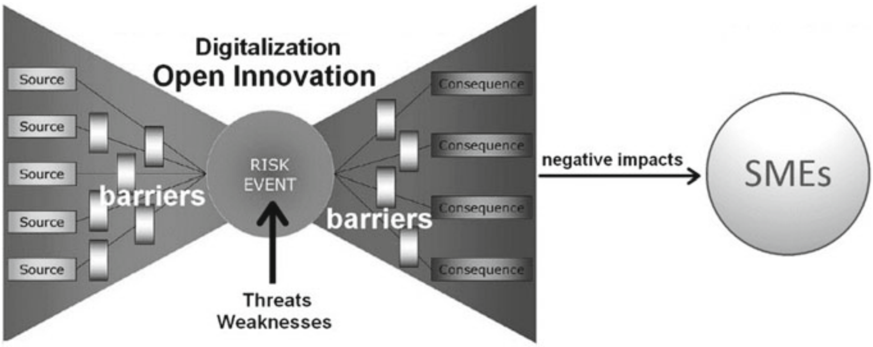


Fig. 4 Bow-Tie conceptual idea for impact chains 1 and 2

at avoiding the occurrence of a threat or a weakness that is promoted by a source or a set of sources. Then, if the threat or weakness does occur, the recovery barriers (right side) can minimize or even eliminate the potential impact.

To evaluate the overall risk of a bowtie it is necessary to evaluate the probability of failure of each barrier. For this purpose, the fault tree method is used for the barrier on the left and the event tree method for the barrier on the right.

Being P_ft the probability of failure of prevention barriers and P_et the probability of failure of recovery barriers, the aggregated risk can be calculated using reliability blocks theory, as shown in Eq. (2).

$$Risk\_ic\_1, 2 = \prod_{j=1}^{n} 1 - \left(1 - P\_ft_j\right) \cdot \left(1 - P\_et_j\right) \tag{2}$$

where j is the event number and n is the total number of threats along with the number of weaknesses.

3.2.2 Risk Assessment of Impact Chains with Two Risk Sources

Figures 5 and 6 show the conceptual idea for impact chain number 3 and number 4.

Figures 5 and 6 differ in the order in which the impact chains are considered. Impact chain 3 considers the consequences of digitalization as a source of threats and weaknesses to open innovation and impact chain 4 considers the opposite, i.e., the consequences of open innovation as a source of threats and weaknesses to digitalization. The risk of impact chain 3 and 4 can be assessed with Eq. (3), where D stands for digitalization and OI for open innovation.

$$Risk\_ic\_3,4 = 1 - \left(\prod_{j=1}^{n} 1 - \left(1 - P\_ft_j\right)\cdot\left(1 - P\_et_j\right)\right)_D \cdot \left(\prod_{j=1}^{n} 1 - \left(1 - P\_ft_j\right)\cdot\left(1 - P\_et_j\right)\right)_{OI} \quad (3)$$

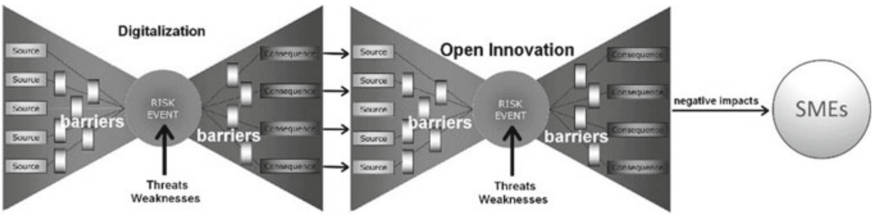


Fig. 5 Bow-Tie conceptual idea for impact chain number 3

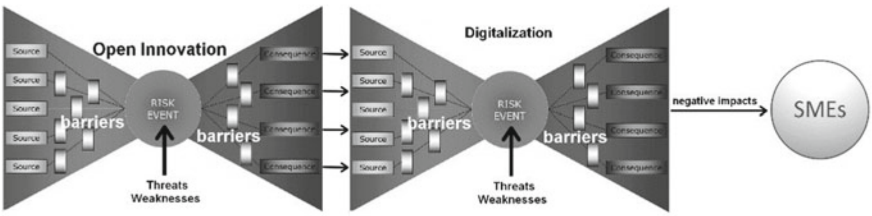


Fig. 6 Bow-Tie conceptual idea for impact chain number 4

4 Case Study

To illustrate the application of the proposed approach, consider the case study of a logistics company that intends to introduce Open Innovation together with digitalization.

According to the current status of the company, i.e., human resources, technology and services, a number of weaknesses and threats resulting from the implementation of digitalization and open innovation were identified, from which the impact chains shown in Fig. 7 were selected for analysis.

It is believed that there is a high probability that these weaknesses and threats will occur and that the resulting impact could negatively affect or even bankrupt the company, despite the many acknowledged benefits of open innovation and digitization.

For each impact chain (IC 1–4), the respective probability of occurrence is calculated according to the assumptions presented in the previous section.

First, according to the ability of the company to implement prevention and recovery barriers, and according to the configuration of the chain of effects, the probability of failure of the barriers is calculated using the methods of fault trees and event trees. Table 1 shows the results for the probability that the barriers fail to perform their function.

With the results shown in Table 1, the impact chain probability can be calculated depending on the configuration. Table 2 shows the results obtained with Eq. 2 (results

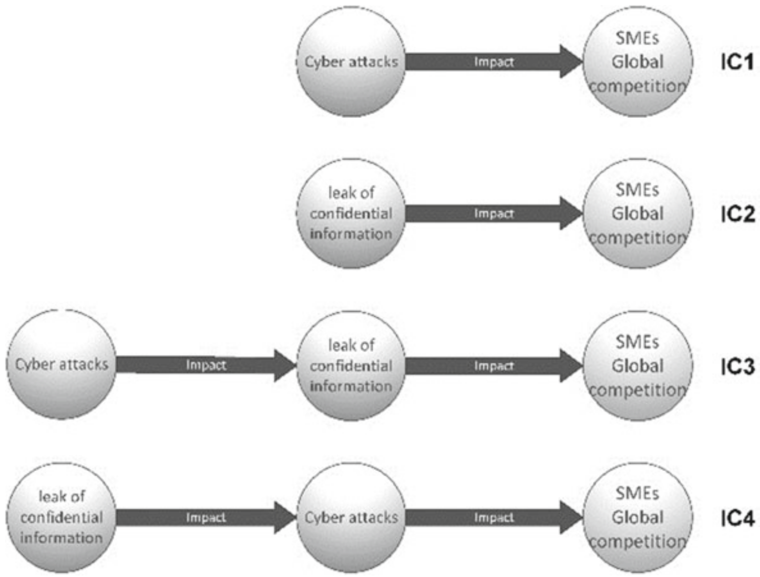


Fig. 7 Bow-Tie conceptual idea for impact chain number 4 applied to the case study

Table 1 Barriers 'probability of failure according to the impact chain configuration

IC	P_ft_D	P_et_D	P_ft_OI	P_et_OI
1	0.4	0.2	–	–
2	–	–	0.5	0.4
3	0.4	0.3	0.2	0.2
4	0.1	0.2	0.3	0.2

Table 2 Impact chain probabilities

IC	Impact chain probability
$Risk\_ic_1$	0.52
$Risk\_ic_2$	0.70
$Risk\_ic_3$	0.73
$Risk\_ic_4$	0.59

shown in rows 1 and 2) and 3 (results shown in rows 3 and 4) as a function of the type of impact chain.

At this point, Eq. 1 can be used to assess the aggregate risk of impact on global SME competition. Therefore, the aggregate probability can be calculated as follows,

$$P_{agregated} = 1 - 0.52 \times 0.7 \times 0.73 \times 0.59 = 0.84$$

and the aggregated risk for this scenario is:

$$Risk_{aggregated} = 0.89 \cdot I_R$$

As can be seen in this case study, the probability of failure of the barriers is too high, i.e., it is very likely that the company will feel the undesirable effects. It can also be concluded that the company is not ready to adopt digitalization and open innovation at this stage. This means that barriers need to be set or improved before the adoption of digitization and open innovation, which usually require investment. In this sense, a trade-off study is advisable to determine whether the returns justify the investments or not.

5 Conclusion

Digitalization and open innovation are two inevitable strategies of today's industry, but their implementation may have a negative impact on SMEs.

In this context, it is important to examine the extent to which a given company is able to avoid these negative effects through the resources available, be they material, technological or human. This knowledge can be important when deciding on the implementation of these strategies, as well as when assessing the investment required for their implementation.

In this work, a new methodology has been developed to support decision-making related to the implementation of digitalization together with open innovation in small and medium enterprises. The methodology establishes an aggregate risk analysis and management model that uses the assessment of strengths, weaknesses, opportunities and threats as a way to identify sources of risk.

To assess aggregate risk, the model considers the Bow-Tie approach and uses reliability theory to calculate the aggregate failure probability of the preventive and recovery barriers.

In the proposed model, and in addition to the aggregate probability, it is necessary to evaluate the impact of a particular event associated with the calculated aggregate probability, and the aggregate risk is then evaluated by multiplying the aggregate probability by the respective impact. The developed model was successfully applied to an illustrative case study and produced a result that met expectations.

The risk assessment and management model proposed in this work still lacks further validation studies as well as further developments to include impact chains originating from SMEs and targeting digitalization and open innovation. Adding this functionality to the model will close the impact cycle and improve the overall risk assessment and management capabilities.

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Digital Transformation of Russian Industry: The Specifics of Large, Medium and Small Enterprises

Elena Mezentseva

Abstract The digital transformation of industry is an objective trend in recent years and a necessary condition for the economic growth of the Russian economy in modern global conditions. However, enterprises of different industries and different sizes have their own characteristics that affect the speed of implementation of digital technologies. Also, this speed is influenced by measures of state policy to support digitalization, which should take into account these features. The aim of the work is to identify the features of digitalization processes at large, medium and small industrial enterprises and to analyze measures of state support for the digital transformation of industrial enterprises in Russia. The article highlights the features of digitalization of enterprises of various sizes, and the predominant types of digital technologies used in the practice of large, medium and small industrial enterprises in Russia and developed countries. We systematize state policy measures aimed at digitalizing the Russian industry, and highlight measures of small and medium-sized enterprises support. The study identifies the external and internal barriers to the digital transformation of industrial enterprises, and offers recommendations for improving measures to support the digital transformation of industry.

Keywords Digital transformation · Industry · Small and medium enterprises · Government support

1 Introduction

Digitalization has been the most striking global trend since 2010. The global pandemic has shown the importance of digitalization of production and business processes [33].

Empirical evidence suggests that digitalization has a direct positive impact on company performance [1]. According to the ISSEK of the Higher School

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of Economics, digital transformation will provide additional growth in labor productivity in the manufacturing industry by 20.2% until 2030 (cumulative) [11].

However, there is a large gap in the use of digital technologies between sectors of economy. The intensity of their implementation can be influenced by both transmission channels and government policy. Digitalization covers many industries, at the same time, not all of them are ready for digital transformation. The speed of implementation of digital technologies in industrial enterprises is influenced by both internal capabilities of the organization (human resources, technological level of production, etc.) and external one the level of competition in the industry, the availability of technologies and capital, as well as the development of legislation.

In this regard, it is relevant to study the issues of assessing the level of digitalization of industries and the effectiveness of government support measures aimed at its digitalization.

The aim of the work is to identify the features of digitalization processes at large, medium and small industrial enterprises and to analyze measures of state support for the digital transformation of industrial enterprises in Russia. To achieve this goal, we solve the following tasks: 1. to conduct a bibliographic analysis on the topic of industrial digitalization and the specifics for large and small and medium-sized enterprises; 2. to analyze the current situation in the Russian industry in terms of digital transformation, to study the existing indicators of industry digitalization, to determine the level of digital maturity of Russian industrial enterprises; 3. to identify the factors affecting the level of digitalization of enterprises of different industries and different sizes; barriers hindering the digitalization of small, medium and large enterprises; 4. to study the legal framework for the digitalization of industry and conduct an audit of government measures to support digital transformation, highlighting measures addressed to small industrial enterprises; 5. to make recommendations for improving the state policy of supporting the digitalization of the industry of the Russian Federation, taking into account the factors of differentiating the level of digital maturity of enterprises of different sizes.

2 Literature Review

In recent years, the economic analysis of industrial development has been carried out within the framework of the Industry 4.0 concept. The Industry 4.0 concept is based on the integration of information and communication technologies and advanced industrial technologies into the so-called cyber-physical systems aimed at creating a digital, intelligent and sustainable enterprise [13]. The main value of Industry 4.0 is in the connection of products, machines and people with the external environment and the integration of production, information technology and the Internet [12]. Industry 4.0 aims, on the one hand, to introduce highly efficient and automated production processes typical for mass production, and on the other hand, to create an industrial environment where individual and customer-specific products are produced in accordance with mass customization strategies [27].

Among the scientific works devoted to the digital economy and Industry 4.0, one can find studies concerning certain aspects of the digitalization of industry, such as innovative strategies for industrial modernization in the context of digitalization of the economy, the specifics of introducing the fourth industrial revolution principles [14], modeling of efficiency factors of production and technological processes [17], the role of production management in the conditions of Industry 4.0 [9, 10]. There are a number of studies which investigate more specific technologies associated with the digitalization of industrial enterprises: big data technologies [18], additive manufacturing [19], integrated data structures in enterprise resource planning (ERP) [34], digital competencies [29] and etc.

Successful implementation of Industry 4.0 is possible not only at large enterprises, but also at small and medium-sized enterprises [21]. A rather limited number of scientific works are devoted to the topic of digitalization of small enterprises in industry; they mainly consider general issues of how small enterprises can adapt the principles of Industry 4.0l [20, 32]. 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-sized enterprises. Matt et al. [21] make the earliest attempt to substantiate a methodological approach to how small and medium-sized enterprises can implement the principles of Industry 4.0. In Russia, there are practically no studies devoted to the digitalization of small industrial business. In our previous works [23], we identified the need for special studies for the implementation of Industry 4.0 technologies in small industrial enterprises, which will transform them into smart factories, and also highlighted the advantages and limitations for the implementation of Industry 4.0 technologies.

3 Materials and Methods

The digital transformation of industry is based on the concepts of the Fourth Industrial Revolution, Industry 4.0, and smart factories. The theoretical and methodological basis of the study is the scientific results set forth in publications in the field of the fourth industrial revolution, digitalization of industry, digital transformation of small and medium-sized enterprises.

The research methodology is based on network and institutional approaches. We applied methods of theoretical generalization, systemic, logical, structural, comparative analysis, and statistical methods. To solve the research problems related to identifying the specifics of digitalization of large, medium and small enterprises of Russian industry, the following research methods are used: analysis of scientific publications, a descriptive method for analyzing the dynamics of changes in the indicators of digitalization 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, a literature review on digitalization of industry, in particular on small and medium enterprises, in Russia, was done, where articles and conference papers published before November 2021 were analyzed. 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”.

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. We should notice that the topic “Industry 4.0 for SMEs” is gaining more and more importance for scientists engaged in engineering and industrial research. Among the publications in Russian, there are practically no scientific works on the topic of industrial small business in the context of Industry 4.0 and digitalization. The same applies to statistical data 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.

The paper analyzes the digital maturity of industrial enterprises of different sizes, the intensity of the use of digital technologies, the level of distribution of a number of digital technologies in enterprises of different industries and of different sizes. For this purpose, we analyze indicators that allow measuring the level of digitalization of individual sectors of the economy; we use international and Russian indices for assessing the development of the digital economy, in particular, the Digitalization Index for the main sectors of the Russian economy. The information base of the study was also made up of data from state statistics of Russia, regulatory information on government support for digitalization of industry, data from statistical bulletins of the Institute for Statistical Studies and Economics of Knowledge of the Higher School of Economics, expert opinions of heads of industrial enterprises and leaders of the IT-market.

4 Current Situation in the Digitalization of Industry in Russia

Industry plays a significant role in the Russian economy. The share of manufacturing industries in the gross value added in Russia was 15% in 2020 (14.2 trillion rubles) [5].

The availability of indicators that could measure the level of digitalization of certain sectors of the economy, in particular, industry, is an urgent issue. The work of

Koch explores the question of measuring methods of digital economy [15], as well as the possibilities and attempts to measure certain types of activities of the digitalized economy. Currently, the following indices for assessing the development of the digital economy are being calculated: the ICT Development Index, the Huawei Global Networking Index, the E-government Development Index, the Digital Economy and Society Index, the International Digital Economy and Society Index, the Boston Consulting Group's Economy Digitalization Index, the Global Digital Competitiveness Index, the Digital Evolution Index, Ivanov digital index. All these indices are global in nature, that is, they assess the position of the country as a whole in terms of the level of development of the digital economy. In 2019, the Institute for Statistical Studies and Economics of Knowledge of the Higher School of Economics calculated the Digitalization Index for the main sectors of the economy of Russia and a number of other countries, which characterizes the level of dissemination of key digital technologies. The value of the index (integral indicator) is calculated for each industry as the arithmetic mean of the share of organizations using each of the digital technologies [11].

Recent studies show that while digitalization is one of the main determinants of labor productivity in Russia, and that the most digitalized firms demonstrate higher growth, there is a large gap between and within sectors [35]. To a greater extent, digital technologies are used in services (finance and media), manufacturing is less digitalized [22].

The digital transformation of industries is currently uneven. The so-called "digital divide" in the level of digital technology assimilation exists both between industries and within each of them [4]. Among the main factors of differentiation of the rates and models of digital transformation of various industries, we note the following. 1. Development agenda, problems and challenges in the industry. 2. Business models and the place in the value chain. 3. Technological level and digital maturity. 4. The readiness of organizations to change. 5. Features of the formation and use of data. 6. Industry structure and economic situation. 7. Development of regulation.

Digital transformation requires the development of new technologies and the corresponding restructuring of business processes. Comparatively mature digital technologies, such as broadband Internet access, are quite widespread in Russia. So, in Russia 90.4% of industrial enterprises have it [11]. At the same time, the latest technologies are spreading in industries much more slowly. 27.6% of enterprises use cloud services, 29.6% use ERP systems, 19.6% use electronic sales and only 12% use RFID technologies. These indicators are included in the Digitalization Index, developed by the ISSEK of the Higher School of Economics, which just characterizes the level of distribution of these digital technologies in the sectors of the economy. The index of digitalization of industry is 36 points out of 100. According to the value of the index, the industry of Russia takes only 21st place among 27 countries for which the corresponding data are formed.

At the end of 2019, the cost of an introduction and using digital technologies in the manufacturing industry in Russia amounted to 158.2 billion rubles. The share of these costs in the industry's Gross Value Added is 1.2%. The leaders in investments in digitalization were enterprises of the machine-building and metallurgical complexes with costs of 82.2 and 49.1 billion rubles, respectively.

A few words about the technological basis for the digital transformation of industry. The digital transformation of industry takes place on the principles of the Industry 4.0 concept, including the transition to smart factories. At the same time, there is a digitalization of the entire life cycle of products (from concept ideas, design, production, operation, service and up to disposal), the use of digital models (twins) of both new designed products and production processes, as well as the proliferation of digital platforms [30]. This transition is based on the following main advanced technologies: artificial intelligence, big data, cloud computing, virtual modeling, the Internet of things, additive manufacturing, robotics, predictive analytics, etc.

The digital transformation of the industry is leading to the creation of a flexible and highly efficient distributed network production based on digital platforms that unite all participants in the value chain into a single ecosystem.

The digital transformation of the industry not only leads to a reduction in costs and an increase in labor productivity, product quality, but also allows reducing the time to market for products, provide mass customization and flexible (quickly adaptable to external changes) production.

Compared to traditional approaches involving the manufacture of a physical prototype and carrying out field tests, the development of products based on the digital twin technology helps to reduce the number of design errors and can reduce the time, financial and other resource costs up to 10 times or more [36]. Digital modeling and digital twins also make it possible to incorporate the characteristics of global competitiveness and high consumer requirements into products, and 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 regulations" to "on-condition repair").

5 Features of Digitalization of Enterprises of Different Sizes

As noted above, there is a differentiation in the pace of digital transformation of enterprises in different industries. These differentiation factors also affect enterprises of different sizes and determine the level of their digitalization.

In Russia, as well as in the leading developed countries, large companies are the leaders in digitalization [11]. Small and medium-sized enterprises are lagging behind in terms of the pace of new digital solutions adoption. In general, highly concentrated industries dominated by large businesses with access to significant investment resources are showing greater progress in digitalization.

In various industries, the introduction of digital technologies requires different investments, e.g. in terms of the volume and timing of implementation. In those industries where, along with large enterprises, a large number of small and medium-sized companies operate, the creation of various electronic services and platforms often doesn't require large investments, which opens up opportunities for a wide range of enterprises to introduce new business models of interaction with consumers. At the same time, in highly concentrated sectors of the economy, digital transformation is associated with quite high costs. All this speaks of the different possibilities of large and small companies.

Researchers from the Higher School of Economics [6] showed that there is a statistically significant relationship between firm size, age, export orientation, and adoption of digitalization and automation, namely, that larger, younger, and heavily exporting firms tend to use digital technologies. In addition, while older large firms maintain links with Russian research institutions, and such links work intensively as transmission channels for the introduction of digital technologies, small and medium-sized enterprises mainly benefit from increased intra-industry competition with foreign firms and are watching the changes in the demand models of their customers.

Researchers from France and Canada [28] 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 underutilized 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 enable deep business transformation (CPS, Machine-to-Machine, Big data, robots) are still neglected by small and medium enterprises" [28].

According to Russian practitioners in the implementation of digital technologies [2], digitalization of the manufacturing industry is currently proceeding extremely unevenly. For example, in high-tech processing areas, the level of maturity of "end-to-end automation" and "sales of industrial goods over the Internet" is extremely high, and technologies of robotization and the Internet of things are just beginning to be actively used. In the oil, gas and chemical industries, digitalization has embraced most of the major players. However, it is too early to talk about a full-fledged digitalization of the industry. Even driver companies are still focused on improving the efficiency of basic production processes, and only a few are using the achievements of digitalization to create new business models. All this concerns large enterprises, to a greater extent. That is, small businesses are in the lower stages of digital adoption.

The main barriers to the introduction of Industry 4.0 technologies and digital transformation are the lack of financial resources of enterprises and the high cost of projects in this area. In addition, among the constraining factors: insufficient digital maturity of current processes, low level of automation, lack of competencies and low level of IT literacy of employees; insufficient level of development of automated control systems for technological processes; low level of development of practices for working with data. These circumstances put small industrial enterprises in unequal conditions on the way to digitalization, in comparison with large ones.

6 Measures of State Support for Digital Transformation of Industry

State regulation of industrial digitalization processes and priorities in this area are spelled out in a number of documents at both federal and regional levels. The main documents are: the National Program "Digital Economy of the Russian Federation", the federal projects "Normative regulation of the digital environment" and "Digital technologies", the departmental project of the Ministry of Industry and Trade "Digital Industry", the Action Plan ("road map") "Technet 4.0" (advanced production technologies) of the National Technology Initiative, he Strategy for the Digital Transformation of Manufacturing Industries until 2030, recently adopted by the Ministry of Industry and Trade of the Russian Federation [26].

Currently, Russia has a system of measures to support the digitalization of the industry. These measures are provided by the Ministry of Industry and Trade of Russian Federation. The elements of this system are as follows:

- the project "Digital Industry" provides for the development of the regulatory environment, the capabilities of the GISP (State Industry Information System) platform [25];
- in accordance with the program of the Industrial Development Fund "Digitalization of Industry", loan financing of specific projects is provided in the amount of 20–500 million rubles at a preferential rate of 1–3% [7];
- subsidizing the reimbursement of part of the cost of developing digital platforms and software products for manufacturing enterprises [8], for which it is planned to allocate 2 billion rubles per year.

Taking into account non-budgetary sources, the aggregate financing of the implemented and currently being implemented specialized projects for the digitalization of industry is about 430 billion rubles (of which: about 57 billion rubles—funds from budgets of various levels, about 374 billion rubles—funds of enterprises and about 11 billion rubles—borrowed funds) [25].

The Russian government plans to increase funding for the most effective industrial support measures. They are aimed, in particular, at increasing the competitiveness of the products of Russian enterprises through the transition to digital. As a result of the Industry Digitalization Strategy, the costs of developing and launching high-tech products are expected to be halved. For the next 3 years, the budget, in particular, includes 25 billion rubles to compensate businesses the part of the costs of scientific research, 5.5 billion rubles—for subsidies for the development of digital platforms and software products, 5 billion rubles—to reimburse up to 50% of costs for creation of pilot batches of production means [16].

In addition, the Ministry of Economic Development of the Russian Federation creates a digital ecosystem within the framework of the national project "Labor Productivity" [5]. It provides access to digital services that are aimed at increasing the level of digital maturity and the maturity of business processes through remote diagnostics, providing analytical data about markets, training, and stimulating cooperation.

The National Technology Initiative plays an important role in the digital transformation of Russian industry and the creation of factories of the future [31]. As part of the Technet roadmap, work is underway to form test beds (TestBeds), experimental digital certification centers, information systems for planning and dispatching production, an open cloud software design platform, a predictive analytics platform for the industrial Internet of Things, etc.

A few words about the Strategy for Digital Transformation of Manufacturing Industries until 2030. It includes five areas of transformation, or projects. Thus, the "Smart Manufacturing" project involves the formation of an effective infrastructure and support system for the implementation of domestic software and hardware and software systems. The "Digital Engineering" project implies the creation of a national standardization and certification system based on virtual testing technologies. It means the development of universal marketplaces with resources for creating and selling products, as well as the formation of common data formats (libraries). The "Products of the Future" project speaks of the transition to customized industrial products and condition-based repairs. Namely, about the transition to a model of flexible conveyor production, the introduction of predictive analytics technology for the transition from "repair according to the regulations" to "on-condition repair". The "New Employment Model" project involves the creation of a competence exchange and services which increase labor productivity.

Also, the Strategy proposes a transition to digital public administration. That is, to the provision of state support services using the infrastructure of digital platforms, as well as the creation of cross-industry data models (data sets for enterprises and IT companies) [2]. As one of the results of the implementation of the strategy measures, by January 1, 2022, the Ministry of Industry and Trade will have generated at least 550 digital passports of backbone industrial enterprises, by the end of 2024—at least 9 thousand.

It should be noted that the Strategy is not limited to financial instruments only. Their application in isolation from institutional conditions will not bring positive results. Successful implementation of the Strategy's activities requires interaction between authorities and market participants, as well as improvements in some basic economic institutions (tax and arbitration systems, the investment climate in general, as well as the export situation).

Most of the measures to support the digitalization of industry are focused on large (medium) enterprises. Currently, a number of measures take into account the interests of small enterprises, although most of them are not aimed specifically at industrial small enterprises. In 2021, the Ministry of Digital Development, Communications and Mass Media of the Russian Federation launched a new mechanism to support small businesses, which allows them to purchase software at half the price by compensating manufacturers for 50% of the license cost. The support measure is implemented by Russian Fund for the Development of Information Technologies within the framework of the federal project "Digital Technologies" of the national program "Digital Economy of the Russian Federation" [3].

Also, we should mention the Federal project "Creation of a Digital Platform with a mechanism for targeted selection and the possibility of remote receipt of support measures and special services for small and medium-sized businesses and self-employed citizens" [24]. It implies the creation of a unified digital ecosystem containing comprehensive up-to-date information on all measures and institutions for supporting SMEs and allowing an entrepreneur to choose and receive support measures that he needs remotely.

As noted above, there is a differentiation in the rates and patterns of digital transformation of industrial enterprises of various industries and sizes. Accordingly, this requires differentiated approaches to government support for the digital transformation of various industries, as well as large, medium and small enterprises.

When forming a support policy, it is necessary to take into account a number of important circumstances: the digital transformation of enterprises and industries occurs through the sequential passage of the necessary stages of the introduction of digital technologies on the way to their full-fledged "digital maturity"; many interconnected digital technologies must be implemented simultaneously; to embed a complex of new technologies in the industry, it is necessary to create adapted infrastructure conditions. Thus, it is necessary to develop "local" digitalization (implementation and practical optimization of digital technologies in all basic production processes of each specific enterprise); elimination of the problems of acyclic digitalization (project assistance to enterprises in eliminating the gaps in the introduction of digital technologies in their production and supporting cycles).

7 Conclusion

The speed of implementation of digital technologies in industrial enterprises is influenced by both internal factors (human resources, technological level of production, etc.) and external factors—the level of competition in the industry, the availability of technologies and capital, and the development of legislation. These factors determine the level of differentiation in the pace of digital transformation of enterprises of different sizes. It was revealed that small businesses, due to existing barriers and restrictions, are at a lower level of digitalization of their activities. Small businesses are adopting the least expensive and least disruptive digital technologies.

We substantiated the need for further research in order to develop specific strategies, methods and tools for the effective digitalization of SMEs in industry. The limitation of this study was the fact that in Russia there are practically no scientific works devoted to the digitalization of small industrial business. Data on the real digitalization of industrial enterprises is very limited, often it is the results of surveys or case studies. Moreover, there are no statistics on the level of digitalization of small enterprises, especially for small manufacturing enterprises.

Currently, Russian legislative authorities have developed an extensive regulatory framework that determines the policy in the field of supporting the digitalization of industry. However, most of the support measures are targeted at large industrial enterprises. The existing measures do not take into account the specifics of industrial small enterprises.

It is necessary to practice a differentiated approach to enterprises of various sizes and formulate a state policy to support the digitalization of industry, taking into account the specifics of the industry, the size and digital maturity of enterprises, based on reliable statistics. We recommend the following measures to the state authorities: training digital personnel for industry, promoting the development of digital service companies; building an infrastructure for digital interaction of all subjects of industrial production at the intra- and inter-sectoral level, including small and medium-sized enterprises. An urgent direction for further research is the assessment of the effectiveness of the measures taken by the state support for the digitalization of the industry.

Manufacturing enterprises have significant potential for digitalization, however, its implementation requires systemic measures that will combine the efforts of both enterprises and the state, and take into account the specifics of large, medium and small enterprises.

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Business Model Innovation for the Internet of Things

Carsten Deckert, Jannik Kalefeld, and Martin Kutz

Abstract The increasing networking of machines and systems in the course of the Internet of Things is changing products, companies, and competitive boundaries. The commoditization of hardware is forcing traditionally product-driven companies to develop digital services and software solutions in order to continue to secure unique selling propositions and competitive advantages. Although many companies have successfully advanced the digitalization of their product portfolios, very few market players also manage to integrate the new solutions profitably and competitively into their business models. New types of performance and services can no longer be forced into the classic business model of pure product sales but require dedicated business models. To help companies break out of their comfort zone, this article deals with the development of a structured procedure for working out business model innovations. For this purpose, business model patterns, which account for 90% of all business model innovations, are taken as a basis and methodically selected. In so doing, a structural approach to business model innovation is developed.

Keywords Business model innovation · Business model patterns · Internet of things

1 Introduction

In the industrial sector, digital transformation is typically described by the term "industry 4.0"—the fourth industrial revolution. The Internet of Things (IoT) is one key technology of industry 4.0 [7]. Specifically, the Industrial Internet of Things

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(IIoT) is seen as one of the key technological innovation drivers of industry 4.0 by the German Federal Ministry for Economic Affairs and Energy ("Bundesministerium für Wirtschaft und Energie") [4].

The Internet of Things makes it possible for any person or object, at any place, at any time, to network with other objects that have a virtual personality. This creates smart products that monitor their own state, generate product-related data and share this data with other smart products [8]. In terms of the manufacturing industry, the Internet of Things has a two-sided effect. On the one hand, it enables manufacturing companies to offer digital services and software solutions that create increased plant availability and thus the basis for a more efficient production process [20]. On the other hand, however, dangers arise for the business models of traditionally product-driven companies, which have sometimes focused primarily on the development of product hardware and neglected to update their business model correspondingly, e.g. data-driven services. Customer requirements are also evolving with the Internet of Things and can therefore no longer be met by purely product-driven companies [16]. Instead of continuing to stick to tried-and-true business models, product-driven companies need to break out of their comfort zone to capture emerging business potential and remain competitive [13].

In general, a business model describes the basic principle by which an organization creates, communicates and captures value [18]. While most companies focus on the development of new products and services when redesigning their business model, only a few companies also manage to successfully innovate the business model as such [10]. A study by the Boston Consulting Group found that business model innovators are five times more profitable than pure product innovators three years after implementation [17].

Although not every company consciously engages in actively shaping its business model, every organization has a business model [5]. Within entrepreneurial practice, it has been shown that actively shaping one's own business model is a successful approach to responding to changes in the environment in times of high market volatility [23]. Therefore, it is important for product-driven companies to adapt their business model to the Internet of Things, as a "better business model will often beat a better idea or technology" [5].

In the next section, the term "business model" is defined and business model patterns are described, especially business model patterns promoted by the IoT. After that, the methodology for the selection of suitable business models is described followed by a demonstration of the method at the company Atlas Copco. In the final section, the findings are discussed and further research possibilities are elaborated.

2 Business Model Patterns

Digital Transformation requires a company to develop and implement a digital strategy which in turn requires the digital transformation of the company's business models [22]. In a comparison of 13 definitions of the term "business model", Schallmo [21] finds that most definitions include the combination of different core business components to create a value in the form of products or services. In conclusion, he defines a business model as "the core logic of a company that describes which value is created for customers and partners in which way" [21], own translation]. In a similar fashion, one of the main business books of business model design by Osterwalder and Pigneur [18] describes a business model as "the rationale of how an organization creates, delivers, and captures value".

To gain inspiration and a starting point for redesigning their own business model, companies can draw on so-called business model patterns, regardless of size and industry [10]. These patterns define the generic operating principle of business models that have already been successfully applied in practice. One of the best-known business model patterns is referred to as Razor and Blade and aims to distribute a heavily discounted entry-level product to as many customers as possible in order to facilitate the subsequent sale of high-priced consumables. According to Gassmann et al. [10], 90% of all business model innovations can be traced back to recombinations of 55 existing patterns. In order to build a successful business model themselves, companies can creatively imitate these proven patterns in order to apply them in their own industry [10]. Fleisch et al. [9] examined the 55 business model patterns of Gassmann et al. [10] for their suitability for the Internet of Things and identified 20 of the 55 patterns that have a positive relationship to the expected developments in the industrial environment (see Table 1).

However, the authors leave the question unanswered how companies can evaluate and select the patterns most suitable for them. The implementation of different patterns requires different technological prerequisites and resources. Companies are usually not able to implement or even check all possible recombinations of the 55 or 20 business model patterns in practice. Furthermore, companies must evaluate which patterns promise the supposedly highest competitiveness and profitability.

In principle, each business model pattern describes a unique operating principle that is clearly distinct from other patterns. Nevertheless, there are commonalities between certain business model patterns which, under certain circumstances, make a combination of business model patterns appear reasonable. The "Razor and Blade" pattern is aimed at selling high-priced consumables after an entry-level product has been heavily discounted and distributed to as many customers as possible. To prevent outside companies from offering the same consumables at lower prices, compatibility between the entry-level product and the consumables is often granted only to the original manufacturer through specially developed interfaces. This operating principle in turn represents a separate business model pattern known as Lock-In, which is for instance applied by the LEGO company [11].

Table 1 Business model patterns promoted by the IoT [9]

BM pattern	Possible manifestation in the IoT
Add-on	Remote sale of additional options and features for products during the usage period
Affiliation	Sales commissions for internet transactions are connected to the sales area locations in the real world
Crowdsourcing	Crowds of sensors generate data with refinement potential for data processing services
Customer loyalty	Incentive-based programs for repetitive purchasing can reward customers. Also, measuring the products' condition through sensors enables rewarding customers for using a product in a certain way
Direct selling	Objects purchase required spare parts for maintenance autonomously without intermediaries
Flat rate	Genuine usage and consumption can be measured to reduce the risks of traditional flat rate models
Fractionalized ownership	Monitoring capabilities allow to keep track of the genuine product usage when occasionally required products are shared amongst different owners
Freemium	Providing minor digital services or a basic product for free and offering premium services or full product performance for a surcharge
From push to pull	IoT technology fosters the implementation of decentralized organizational entities to enhance flexibility to customer needs
Guaranteed availability	Increasingly more equipped sensors and communication technology facilitate monitoring the actual availability of a product or service
Hidden revenue	Third parties generate the actual revenue by paying for making advertisements. IoT technology fosters location-specific advertising
Leverage customer data	Product-related data is constantly transmitted to the manufacturer and can be utilized for product updates and developing improved successor products
Lock-in	Digital handshakes and authentication mechanism are established to prevent compatibility with competitor systems
Pay per use	Only the genuine usage of a product is charged. Due to higher availability of IoT technology, this pattern becomes applicable for lower-priced products, too
Performance-based contracting	Instead of selling or renting a product, customers only pay for its genuine output. Reliable measuring technology supports realizing this pattern
Razor and blade	Instead of using patent protection to ensure seclusion, consumables for the "razor" can be authenticated via digital mechanisms

(continued)

Table 1 (continued)

BM pattern	Possible manifestation in the IoT
Self-service	Objects schedule maintenance intervals autonomously by scheduling appointments with service technicians
Solution provider	Refinement potential of product generated data can be utilized to broaden the portfolio by introducing data processing services
Subscription	Subscription periods could not only refer to accessing a service, but as well to using specific product functions for a limited time
Two-sided market	Platforms and clouds bring together data generators and data analysts

3 Methodology for the Selection of Business Model Patterns

A methodology for the selection of business model patterns was developed on the basis of a literature research on product capabilities with regard to the IoT as well as business model visualization and evaluation. Additionally methods from multivariate statistics have been analyzed with regard to their capability to show similarities between business models. The four-stage methodology developed evaluates the technical feasibility and economic attractiveness of business model patterns for companies from the manufacturing industry (see Fig. 1). The business model patterns for the Internet of Things shown in Table 1 serve as the input variable for this method. With each step, the number of patterns in question is narrowed down further. At the same time, the methodology provides a guideline for business model development so that, after its execution, an elaborated business model remains in the company for implementation.

The investigation of the technical feasibility of a business model pattern for a company under consideration is based on two classification mechanisms. In order to create a transparent classification for the capabilities of products in the Internet of

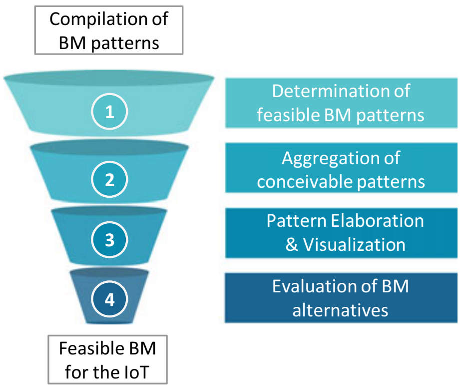

Fig. 1 Four-step methodology for selecting and elaborating business model patterns

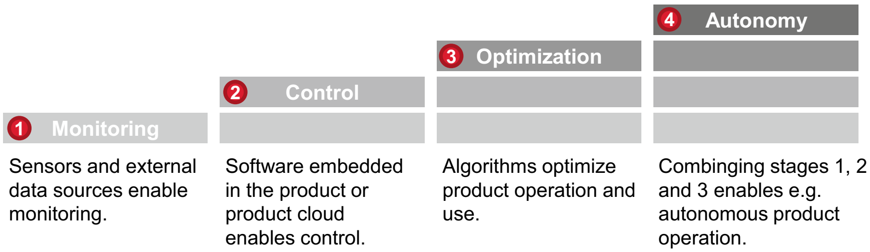

Fig. 2 Product capability stages in the internet of things, adapted from [20]

Things, Porter and Heppelmann [20] determine the four successive levels of monitoring, control, optimization and autonomy. Depending on its characteristics and capabilities, a product can be classified into one of four levels (see Fig. 2). The model was chosen specifically for its simplicity making it easy to understand and use, as companies would have to apply it in their business model innovation procedures.

In addition to connected products, the Internet of Things enables new digital services based on product-generated data [16]. For example, predictive diagnostics are services that index maintenance actions in a timely manner based on real product usage before damage occurs in the product. If companies offer these services for their products, the service share in their portfolio increases. In order to categorize companies on the basis of this service share, Tukker [23] distinguishes between three archetypes of product service systems. The service spectrum of a company can therefore be either product-oriented, use-oriented, or result-oriented. While services play only a secondary role in product-oriented companies and are offered primarily to promote sales of the actual product, functional performance plays the essential role in results-oriented companies. Between these two orientations is the use orientation, which gives equal weighting to products and services.

For each use case, the business model patterns and the product portfolio are both classified with the help of the two models described. The task here is to assess from a representative target group which product capability level or archetype would be required to implement the business model pattern under consideration. Similarly, the classification is carried out for the use case and thus determines which levels and archetypes can be achieved with the resources and product portfolio currently available in the company.

The second step is to combine similar patterns in order to narrow down the number of cases. As described above, there are business model patterns that draw on common principles and therefore have a high degree of similarity to each other, which is why they are often applied in combination. In order to methodically investigate factual connections, multivariate analysis methods can be used, which allow a quantitative description and simultaneous consideration of a large number of variables [1]. To investigate the similarity of n objects, multidimensional scaling according to Kruskal [14] is suitable. Using this methodology, objects are geographically arranged in a two-dimensional representation according to perceived similarity. The closer two

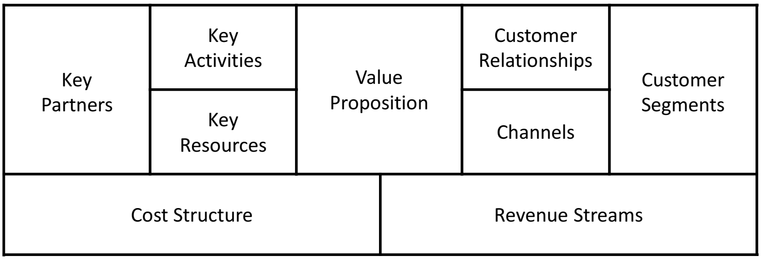

Fig. 3 Business model canvas [18]

objects are to each other, the higher their similarity. For the practical implementation of multidimensional scaling, the approach of Backhaus et al. [2] is followed. Users of the methodology build a similarity matrix for pairs of values of the feasible business model patterns. With the help of multidimensional scaling, the perceived similarities can be represented graphically and thus form clusters that group similar patterns together.

The next step is the development and visualization of the business model. For the visualization of a business model, the scientific literature offers a wide variety of approaches. The most widely used approach according to [16] is the Business Model Canvas by Osterwalder and Pigneur [18]. This divides a business model into nine building blocks and visualizes it clearly (see Fig. 3). At the center of the Business Model Canvas is the value proposition, which reflects the package of products and services that creates value for a particular customer segment [18]. The building blocks to the right of the value proposition form the central element of the customer including the customer segments (different types of core customer groups), customer relationships (relation to each core customer segment) and channels (communication with and distribution to each core customer segment). The building blocks to the left of the value proposition represent the infrastructure for value creation, which contain the key partnerships, activities and resources meaning the most important suppliers and partners, processes and assets to make the business model work [18]. All of the aforementioned building blocks are supported by the cost structure and revenue streams, which in combination represent the financial viability of a business model. Thus, dependencies of the building blocks among each other can be identified from the canvas. This results in business model alternatives which are evaluated in the following step.

The final step is the evaluation of the business model alternatives visualized in the previous step. The potential success of a business model can be evaluated on the basis of various criteria. Proven evaluation criteria are strategy conformity, the development of unique selling propositions, market attractiveness and profitability [6]. Furthermore, a business model must be robust to future changes in the market [15]. Koester [12] has investigated the suitability of assessment dimensions for business models and recommends strategy conformity, competitiveness, and future robustness as three generically applicable assessment criteria that can be adapted to specific companies. Strategy conformity refers to the ability of a company's internal environment to implement the considered business model. Competitiveness, on the other hand, describes the sustainable ability to capture and profitably expand a market share. Future robustness, as the third criterion, describes the suitability of a business model in view of potential developments in the corporate environment. The results of the evaluation can be presented in a business model evaluation matrix.

4 Demonstration of the Methodology Using the Example of Atlas Copco

In order to evaluate the practical suitability of the developed methodology, it is applied in a concrete use case. For this purpose, a company is to be considered to which the effects of the Internet of Things described at the beginning apply and for which a redesign of the existing business model is therefore conceivable.

Atlas Copco is a globally active Swedish industrial group divided into the Compressor Technology, Vacuum Technology, Power Engineering and Industrial Technology divisions, with a total of 34,000 employees. The Industrial Technology division's portfolio primarily comprises electric screwdriving tools used in industrial assembly. While the customer focus was originally on the torque-accurate assembly of joints using pneumatic tools, today's electric tightening tools feature a wide range of sensors. This makes it possible to monitor a wide variety of parameters in a screwdriving process and evaluate the data obtained for the purpose of increasing productivity. Along with higher customer demand for power tools, parameterization and analytics software and the associated consulting intensity have also become more important. Due to the Internet of Things, there are also new opportunities and business potential for evaluating the generated production data in real time for predictive maintenance purposes. Wireless control through more powerful network technologies also offers new potential in the area of monitoring and locating tools as well as a reduction in interfaces when integrating them into the production system.

Looking at this transformation at Atlas Copco, the company represents a typical example of an originally product-driven company that has electrified its products over the years and discovered new business potentials by adding software to its portfolio. By transforming the service division into an independent business unit in 2005, a dedicated focus was placed on product-related services according to the model of Tukker [23]. At the same time, the first attempts were already being made to redesign the company's own business model by testing use-oriented pricing for certain focus customers, but these were not pursued in the long term. However, since the value propositions for the customer are now increasingly derived from the areas of software and services, Atlas Copco can seize further market potential by redesigning its own business model and avoid the increasing devaluation of hardware, referred to as commoditization.

Table 2 Assessment of the feasibility of business model patterns for Atlas Copco

Pattern	Product capability level		PSS archetypes		Realizable
	Required	Reached	Required	Reached	
Add-on	(2) Control	(3) Monitoring	(2) Use-oriented	(2) Use-oriented	Yes
Razor and Blade	(1) Monitoring	(3) Monitoring	(1) Product-oriented	(2) Use-oriented	Yes
Self-Service	(4) Autonomy	(3) Monitoring	(2) Use-oriented	(2) Use-oriented	No
…	…	…	…	…	…

As specified in the developed methodology, the technical feasibility of the 20 business model patterns for the Internet of Things is first investigated by means of the product capability levels as well as the product-service-system archetypes for the Atlas Copco use case (see Table 2). The sensing and computing power integrated into the assembly tool enables customization of the user experience in terms of function. In addition, analytics software enables predictive maintenance intervals, increasing product performance and availability. Since autonomous tool coordination with adjacent systems and functions such as autonomous spare parts procurement are currently still in the development stage at Atlas Copco, but not fully ready for the market, product capability level (3), optimization, is achieved according to [20].

With increasing possibilities of analysis methods for product optimization, the benefit value in the portfolio shifts from a pure product orientation to a benefit orientation. Nevertheless, the mechanical process of the actual bolting remains in the foreground of all optimization initiatives, which is why the tool as such continues to represent the core benefit for the customer. Therefore, archetype (2), use-orientation is achieved. After checking the technical feasibility, the number of possible business model patterns for the Atlas Copco use case is thus decimated from 20 to twelve.

The remaining patterns are arranged geographically in a two-dimensional space according to their perceived similarity using multidimensional scaling. For this purpose, the patterns are compared with each other by the project team using pairwise comparison. The similarity matrix generated in this way serves as the input variable for the multidimensional scaling algorithm [2]. The result of this evaluation is shown in Fig. 4.

The geographical proximity of different patterns to each other makes it possible to form five clusters that summarize similar business model patterns. How the individual clusters would manifest themselves in the form of a business model in practical implementation for Atlas Copco is elaborated and visualized by the users of the methodology using the Business Model Canvas [18]. Five business model alternatives thus emerge.

The developed business model alternatives are examined by a representative target group from the internal and external corporate environment for competitiveness, strategy conformity and future robustness. According to the evaluation carried out, the attractiveness of the business model alternatives is illustrated in Fig. 5 in a business model evaluation matrix according to Koester [12].

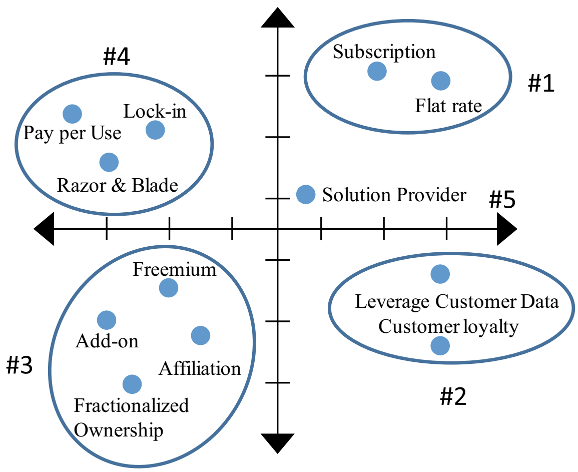

Fig. 4 Multidimensional scaling (Atlas Copco application)

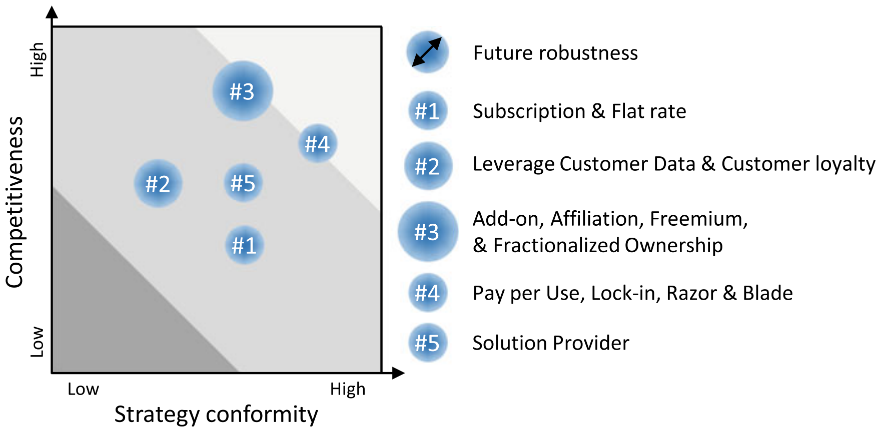

Fig. 5 Business model evaluation matrix (Atlas Copco application)

The evaluation matrix illustrates that Alternatives #3 and #4 show the highest attractiveness. Looking at the evaluation criteria of strategy conformity and competitiveness in isolation, Alternative #4 achieves the highest attractiveness. Alternative #3, on the other hand, scores slightly lower on these evaluation criteria, but has better future robustness. Consequently, the evaluation matrix does not provide a clear result recommending a business model alternative for practical implementation for Atlas Copco. Moving forward, users of the methodology will need to re-evaluate Alternatives #3 and #4 for their potential success. Additionally, Fig. 4 illustrates that there is some proximity in content between Alternatives #3 and #4. Thus, a potential combination of the two alternatives can also be explored to combine the benefits of the two alternatives into one business model. Since this evaluation is highly dependent on the use case, it should be customized and implemented individually for the considered company. Thus, the output of the developed methodology is a recommendation of business model alternatives, but not a clearly defined selection for practical implementation. Based on technical feasibility, content similarity of different patterns, recombination and evaluation of potential business success, two business model alternatives for Atlas Copco are recommended for further implementation. The developed selection methodology is therefore considered valid for the practical use case as it enables companies to select only individually feasible business model patterns, combine them, elaborate on them and provide a recommendation for implementation.

5 Conclusion and Outlook

In the context of this article, a methodology was described that enables traditionally product-driven companies to break out of their comfort zone and elaborate business model alternatives by means of a structured approach. By exploring a general compilation of business model patterns using appropriate classification mechanisms for a considered use case, a business model innovation can also be generated with a company's existing resources. Similarities in content between business model patterns are revealed by means of multidimensional scaling. This enables the methodical recombination of business model patterns, which according to Gassmann, Frankenberger and Csik [10] accounts for 90% of all business model innovations. The visualization and elaboration by means of the Business Model Canvas ensures the transparency and comprehensibility of the business model. Finally, the classification of different business model alternatives in an evaluation matrix allows to circumvent rigid decision patterns and to make case-based adjustments for recommended alternatives.

The practical application of the selection methodology was demonstrated using Atlas Copco as an example. With regards to the implementation of the recommended business model alternatives, further reviews and preparatory activities for the rollout are currently taking place. As Atlas Copco serves an extremely heterogeneous range of customers, segment-specific business models for the respective requirements of the different target groups are being implemented as a first step towards the elaborated patterns. By doing so, a rather gradual transition towards the elaborated business model alternatives is ensured, which comes along with a risk reduction and the possibility of gaining more insights for streamlining the business model before the official rollout [22].

Although the applicability of the selection methodology could be demonstrated using the example of Atlas Copco, it is subject to some limitations. In the context of investigating the technical feasibility of business model patterns, it is assumed that a company does not fulfill both classification mechanisms [20, 23] to the fullest extent. Thus, the number of eligible patterns can be reduced and the further procedure of the methodology can be facilitated. However, if a company with correspondingly high product capability levels according to [20] and service share in the portfolio according to [23] is considered, the number of patterns cannot be limited, resulting in an increased evaluation effort for subsequent steps. Furthermore, only the actual state of a company is evaluated in this step. This ensures that only technically feasible patterns are recommended for implementation. However, this leaves open the question of whether a pattern that is not yet currently feasible would promise greater business success. Building on this insight, a company could thus make more targeted investment decisions to enable the feasibility of potentially more successful business model patterns.

The combination of business model patterns with similar content is based on the thesis that 90% of all business model innovation results from recombinations of existing patterns [10]. However, it remains unanswered where the remaining 10% result from. Inevitably, the developed selection methodology can only produce recombined business model innovations. In order to also accommodate the remaining 10% in a methodical approach, creative approaches, such as creativity techniques, must be integrated into the methodical structure for further business model innovations.

Finally, constant change within the industry must be taken into account [3] which will require a constant adaptation of business models [19]. The Internet of Things will continue to change products and companies in the future. Thus, the methods and classification mechanisms used in the selection methodology also require constant adaptation to changing market and technology conditions in order to remain suitable for practical application.

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Analysis of Visual Modeling Tools Development for Complex Production Systems

Andrey Vlasov and Alexander Naumenko

Abstract The paper reviews the software tools for visual system analysis of complex production systems in the context of digital industry transformation. The main trends in the visual modeling development of complex systems and the problems of their implementation are outlined. The groups of tools for visual system analysis of complex systems are heterogeneous. There are diagrammatic, iconic, and parametric visual models. The analyzed tools differ in the depth of coverage of the studied processes, their detailing, and the integration of blocks of different levels of expertise into one model. Based on the results of a comparative analysis of individual classes of visual modeling tools, recommendations for their use are given. The market analysis of visual instruments is based on the Interest Index. According to the data, in Russia, there is a growing interest in solutions that focus on the modeling of active systems and opportunities to integrate the modeling of business processes with the modeling of information system components. One of the major trends in the development and implementation of modern visual business process modeling solutions is the use of simulation modeling as an integral component. Based on this, it is concluded that the visual model of the business process in digital transformation should be considered a digital twin. The analysis of the dynamics of the Interest Index allows stating the prevalence of ARIS-based tool solutions in the market. UML-based solutions in demand increased their share, but not significantly, indicating the conservatism and a certain constancy of the potential group of its users.

Keywords Visual modeling tools · Production systems · Business process · Industry 4.0

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1 Introduction

The Fourth Industrial Revolution ("Industry 4.0") affects all areas of life through digital integration and intelligent engineering. This transformation forms a new level of socio-productive relations based on the Internet of Things (IoT) elements, where machines adapt to perform certain functions [1, 18]. Industry 4.0 components, by their nature, are complex systems, i.e., systems whose model does not contain enough information for its effective management [2]. It can be stated that a sign of simplicity of a system is the sufficiency of information for its control; if the result of control, obtained with the help of a model, will be unexpected, then such a system is referred to as complex [15]. The formal representation of complex systems is a sophisticated task requiring the methods used to be broadly functional, conceptual, and interpretable [22]. Recently, various visual modeling methods have been increasingly used as such methods [4, 8, 10, 18–21, 24].

Visual methods of systems analysis, such as IDEF, RUP (UML), BPMN, EPC, are already known and widely used in various applications [10, 24]. They are referred to as the Big Four visual tools. Recently, new, promising paradigms of visual analysis have been emerging. Some of the previously known get new features. For example, the BABOK professional guide to business analysis determines that multiple modeling notations should be used for a comprehensive system representation since no single viewpoint can autonomously define the entire architecture of a complex object. Therefore, the *work* aims to systematize the tools for visual analysis of complex systems and assess trends in their development in the context of the digital transformation of industry.

2 Analysis of Trends in the Development of Visual Modeling Tools

Visual tools for modeling complex systems can be divided into three large classes: diagrammatic (focus on different levels of diagrams (graphic notation), almost without textual notation with a characteristic description of the model and impossibility of its further automated analysis by integral and differential criteria), iconic (verbal and pictorial components are linked at the substantive, content-compositional, and content-language level in the form of a single graphic metaphor—a conventional graphic notation) and parametric (attributive, combining the capabilities of graphic and textual notations with the capabilities of optimization and/or simulation modeling).

With the development of graphic computing capabilities, visual modeling tools have become increasingly common in various fields. The 1997 Gartner Group ranking [9], shown in Fig. 1, reflected the position of individual visual analysis tools in terms of their completeness and functionality. The market for computer tools for visual analysis was just emerging at the time.

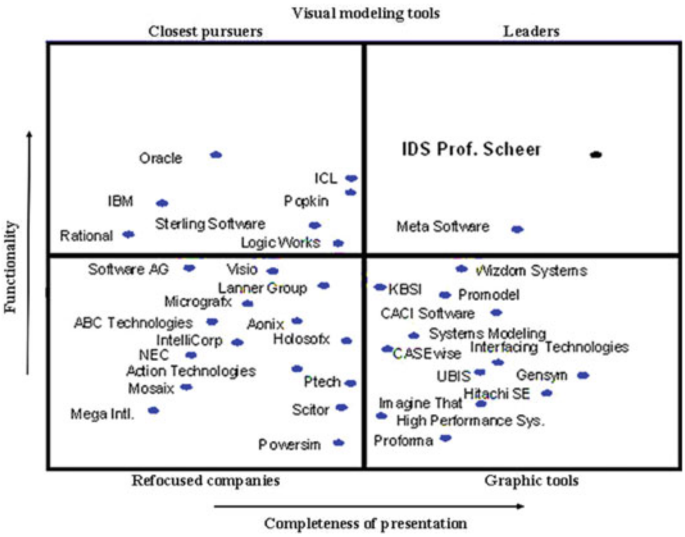

Fig. 1 Gartner Group visual modeling tools rating 1997 [9]

Let us trace the development dynamics of visual modeling tools. One can note the predominance of diagrammatic over parametric solutions (the lower quarters of the matrix are most filled). Among the diagrammatic tools presented in Fig. 1 are Microsoft Visio, Micrografx FlowCharter, Mosaix, etc.

Iconic solutions have their specifics. The dynamics of their development are largely determined by the movement of trends in interface design, which is largely associated with logo design. Iconic models include Flat Design, Skeuomorphism, Realism, Material Design, 3DDesign, etc. The analysis of trends in iconic graphics is the subject of a separate study.

Parametric (attributive) models combine elements of graphical and textual notation. Solutions implementing parametric models include Logic Works, Rational, IDS, L-SIM Server, ANS Technologies, Aonix, IntelliCorp, Bizagi Modeler, Holosofx, Megaint, etc.

The tools of each class have their pros and cons. The choice of a particular tool depends on the nature of the task at hand. In this case, the complexity of the tool should not take precedence over the complexity of the model being created. Let us analyze the individual tools of each of the classes presented in Fig. 1.

Figure 1 is dominated by the solution (IDS, ARIS) [3, 17], which represents a class of parametric (attribute-based) visual modeling systems. It is based on an extensive methodology that incorporates features of different modeling methods, reflecting different views of the studied system. The same model can be developed using several methods, which allow users with different training and customize it to work with specific systems. A wide range of software modules included in the ARIS family allows it to be used as a powerful analytical tool.

One of the common solutions supporting IDEF techniques was the BpWin/ErWin package [13]. The first version of BpWin was released in 1995 along with another CASE tool, ERwin (1993), designed for data modeling. Parallax Capital Partners acquired and consolidated the Erwin package as a separate solution from 2016 (Erwin, Inc.). In 2017, Erwin released Data ModelerNoSQL.

The most common of the diagramming tools is Microsoft Visio [11]. According to Gartner experts, Microsoft Visio is one of the best tools for companies just starting to model and analyze their business processes and focus primarily on their visualization. However, during the implementation of the business processes analysis, this solution is usually replaced by a more functional tool that contains graphics and extensive textual notation, allowing generating the resulting full-text documents and even elements of the program code future information system.

Another representative of the class of diagrammatic solutions is the Micrografx FlowCharter package [23]. It is possible to build a hierarchical decomposition of diagrams, the use of tools for statistical analysis, graphing, especially service elements. The package allows creating process maps/Swimlane diagrams/block charts, BPMN diagrams, schematics, cause and effect diagrams, Ishikawa diagrams, FMEA tables, SIPOC diagrams, etc.

IntelliCorp marketed a Knowledge Engineering Environment (KEE) for developing and deploying knowledge systems in Lisp. The company offered a LiveModel object-oriented technology solution for commercial development environments.

Holosofx worked in business process management. The first Holosofx software product was a modeling tool originally called BPR, later renamed WF-BPR and finally BPMWorkbench [7]. In 1997, Holosofx expanded its portfolio with its BPM Monitor product. In 2002, the company was acquired by IBM.

Another example of parametric solutions is the L-SIM Server solution [25]. This solution is compatible with BPMN 2.0 for use in third-party business process solutions (LannerGroup, L-Sim 2.0). The first version of the BPMN 1.0 notation was released in 2004. The current 2021 version is a development of Lanner's original L-SIM embedded modeling product. It makes it possible to easily create BPMN models and get fast and accurate statistical results without extensive integration.

The BizagiModeler solution also implements BPMN technology [5]. A business simulation model can describe several aspects of a company and consider both physical and social (active) factors; analyze a variety of "what-if" scenarios and obtain a better vision of the company's future. Implementable models allow simulating different strategies before they are applied and seeing problems before they occur.

The Powersim Studio solution [14] makes it possible to develop and explore future scenarios.

Among the solutions included in the review, it is worth noting the tools from Rational. The company has developed the Rational Unified Process (RUP) software development methodology. This methodology covers all stages of the life cycle of software systems. The creation of software systems was constantly becoming more and more complex. In 1994, a group of Rational Software employees (Grady Butch, James Rambo) began to create a special language of object-oriented modeling (UML). The project was based on Object-ModelingTechnique (OMT) and Booch modeling methods. In 1995, a preliminary version of the 0.8 Unified Method was released. Object-Oriented Software Engineering (OOSE) was integrated into the unified method, which provided excellent capabilities for business process specification and requirements analysis using application cases [6].

Briefly reviewing the solutions presented in Fig. 1, it should be noted that at the turn of the twenty-first century, many different companies in the market tried to offer their methods of visual modeling. Consortiums were formed to promote the most successful solutions. The problem of standardizing visual techniques became urgent. Let us analyze the trends of the modern market of visual modeling tools.

3 Comparative Analysis of Diagrammatic and Parametric Visual Tools

The structure of the visual modeling tools market has undergone significant changes since the early 2000s. Currently, many large companies prefer to use more complex parametric models than sets of individual static diagrams from diagrammatic models. However, diagrammatic solutions are still used when it is necessary to provide a given graphical functionality of the model while minimizing time costs (Table 1). However, such tools have almost no syntax control capabilities, depending on the developer

Table 1 Comparative characteristics of individual diagrammatic visual tools

Name	Advantages	Disadvantages
Visio	• Included in the extended MS Office package • Allows building business process diagrams in different notations • Allows prototyping interfaces • Ease of making changes • Ease of interpretation • A large database of built-in templates, stencils, macros, etc. • Ability to create BPMN schemes and their export for later use	• Static graphics, no possibility to form semantically related text content of the model • Lack of hierarchical decomposition of the model (single-screen model); • Inability to generate a summary report (text + graphics) on the model
Micrografx (Micrografx Graphics Suite)	• Advanced tools for technical illustrations; • Easy to learn; • A wide range of different raster filters	• Static graphics, no possibility to form semantically related text content of the model; • Lack of hierarchical decomposition of the model (single-screen model); • Editing multi-layer models is difficult

qualifications, do not have a clear attribute component, and their interpretation can be difficult.

Let us consider the diagrammatic solutions. The Visio visual model includes one or more diagrams on one screen. Each model includes a set of symbols (corresponding to model objects) and interfaces (corresponding to relationships). An important feature is the adaptability of the element language to the tasks of the developer; it is possible to add the author's symbols to the library model. There are no system restrictions on the rules and possibilities to create interfaces between objects. The advantages of the environment should include a comprehensive library of diagram templates for various applications. The template library, like the tool library, can be expanded by the user. The main disadvantages of the environment include the difficulties in creating large system models in conditions of constantly changing processes; the lack of integration tools requires a considerable cost to support a large set of models.

Micrografx solution makes many typical graphics jobs easy to handle with its simple interface. The environment includes a library of templates that allow users to create different types of diagrams. Among the main differences of the environment is the LivingFlowCharts technology [23]. It allows developers to implement "executable" flowcharts. Such blocks are dynamic elements; they can be used interactively. Another advantage is the ability to expand dynamic capabilities by developing own software plug-ins in Microsoft Visual Basic.

However, for a comprehensive solution to the problems of visual modeling, it is necessary to have an effective graphical editor and an integrated parametric analysis environment that implements a comprehensive design methodology and visual representation with parametric attribution of model elements.

Modern comprehensive visual modeling tools combine graphical, textual notation with system analysis, simulation, and optimization tools. In some cases, there is a tendency to integrate elements of diagrammatic models in the artifacts of parametric visual models. In the general case (although this violates the restrictions imposed by specific notations), it helps to simplify the interpretation of the model, as long as it does not overload it.

Parametric models are characterized by strict restrictions on the topology of models, their syntax and are built according to certain rules (Table 2). They have effective means of analyzing the correctness of model diagram syntax, which makes them less dependent on developer error. For parametric models, a significant problem is a semantic control associated with the analysis of textual attributes and the problem of semantic discontinuity—when it is necessary to combine different models into a single whole ("load mismatch" in systems analysis).

The L-Sim environment (Lannergroup) implements predictive modeling of processes under BPMN 2.0 [25]. It provides support for the BPSIM standard for modeling data exchange for BPMN. It is designed to be deployed directly in BPM packages or as a cloud service.

The tools supporting BPMN are now actively developing. This is mainly determined by the fact that the model emphasizes the process description of the specific role in the production process (considering the activities of the active system

Table 2 Comparative characteristics of individual parametric visual tools

Name	Advantages	Disadvantages
LannerGroup (L-Sim)	• Supports BPMN 2.0 notation • Built-in simulation tools • Process modeling procedures on real data • Integration with Java and Microsoft-based solutions • BPSIM standard support for data exchange	• Weak link to the reflection of the datasets being processed • Weak focus on further code generation • Initial conceptual diagram usually requires many iterations • Relatively complex semantics of the BPMN specification • Complex interprocess communication in terms of information flows • Not all BPMN semantics are supported in simulation modeling • Representation of the various roles is not straightforward • Not effective for schematization of decision flows
Holosofx (IBM)	• Allows modeling software systems in UML • Allows mapping UML models to BPM process models; • Allows transforming common elements between UML models and business process models • Provides error minimization	• Relatively complex semantics of the BPMN specification • Trained personnel required • Focus on large companies, large projects, and integration with other IBM solutions

elements). Using BPMN to solve design problems in complex systems with deep hierarchical decomposition is less appropriate. A list of some companies implementing BPMN solutions is shown in Fig. 2.

Several tools should be noted. The models in ARIS are graphical diagrams that display the relevant aspects of the system. This also determines which of the four

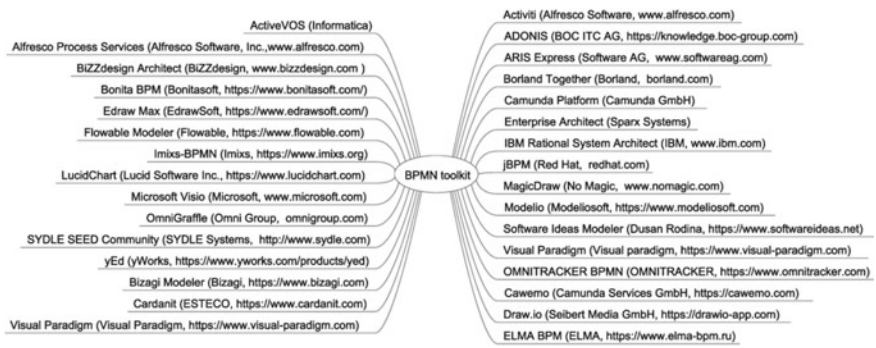

Fig. 2 Major companies implementing BPMN solutions

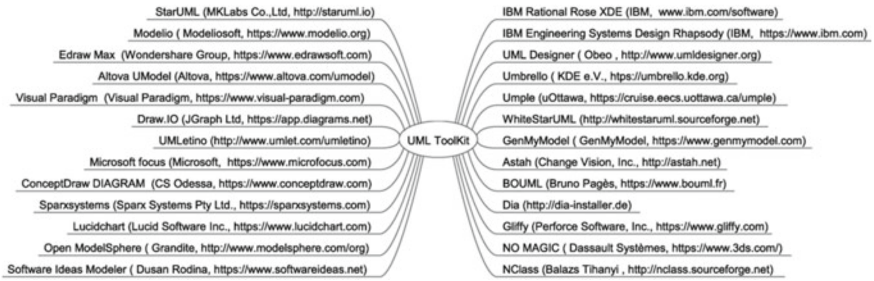

Fig. 3 The main companies that implement visual modeling tools with support for UML

aspects of the ARIS architecture (organizational structure, functional component, information component, and process component) will be reflected in the final model set. For a comprehensive description of the system, it is necessary to build models that reflect all of these aspects, but for some projects, a complete set may be redundant and require a study of one or two aspects. For example, organizational and process [3].

The wide range of ARIS features is also its main drawback. Its use is quite complicated, requires skilled personnel, and is usually used in large projects. With the help of this software, product models of the object are built, reflecting its vital activity from different sides.

Figure 3 shows some companies implementing visual modeling tools based on UML.

UML is positioned as a general-purpose modeling environment; it is more applicable in object-oriented programming. Due to the high standardization and efforts of the OMG consortium, UML has become widespread and is being dynamically developed as an open standard.

4 Discussion

At the initial stage of development, solutions developed and promoted by individual companies dominated, where the author's methods and diagrammatic solutions were implemented. Most parametric modeling systems were closed systems, often promoted as part of individual corporate projects. The most successful solutions on the market were absorbed by major vendors and subsequently promoted as part of their closed corporate systems.

Another class of solutions went the way of international standardization and openness. This approach has created a large pool of qualified users, which has predetermined the widespread use of standardized methods in the market.

A review of software tools for visual system analysis of complex systems has indicated a trend toward integrating solutions that analyze the business process and design information systems. The most successful modern solutions face the need to solve one of the system analysis problems—load mismatch. This problem illustrates the inability of the input of one system to perceive the output of another, which is evident in the integration of conceptual-abstract, structural, and object models within a single design environment. The problem of the "semantic gap" of visual models formed in this way can be solved by using knowledge-based approaches to form a unified presentation format of visual parametric models [8, 21].

Diagrammatic tools remain in demand in the market of static business process analysis projects. Although they do not allow creating full-dimensional visual models with the possibility of further analysis and optimization, they allow solving the problem of operational illustration. Trends toward minimalism and reduced time for non-production costs within the extreme design and similar methods make diagrammatic methods quite in demand.

Analyzing the market for visual tools, it should be noted about specific methods rather than proprietary solutions. In this regard, value indicators (the number of licenses sold and contracts signed) are not an objective measure of the success of a particular visual method. One can offer the "Interest Index" as one of the possible indicators for evaluation. It reflects the percentage of publications during the period under review in the periodical press and scientific and technical literature devoted to a particular instrumental solution.

By the example of the Russian market (according to the analysis of publication activity on the site of the Russian Scientific Electronic Library Elibrary, the total volume of a sample of 37,500 thousand records), recently there has been an increase in interest in solutions focused on active system modeling, and integration of business process modeling with modeling of information system components.

Figure 4 shows the dynamics of the Interest Index for ARIS, IDEF, UML, BPMN methods in the Russian publication segment.

The analysis of the dynamics of the Interest Index allows stating the prevalence of ARIS-based tool solutions in the market. Despite the relatively high complexity of the methodology, due to the extensive functionality, well-developed tools, and

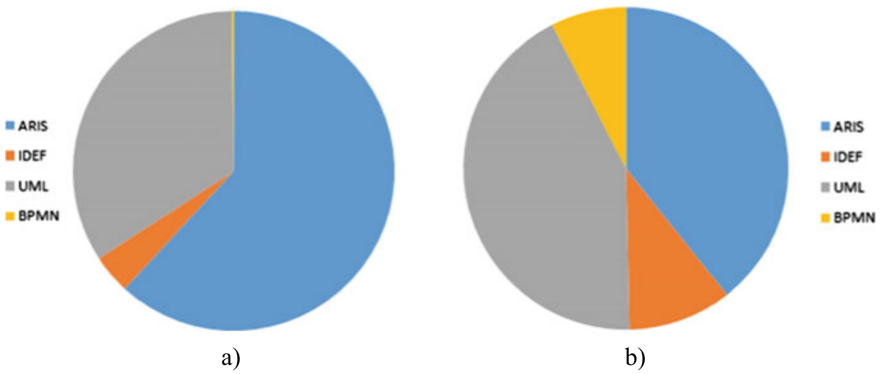

Fig. 4 "Interest index" in visual analysis methods in the Russian market **a** at the end of 2000, **b** for 2001–2021

integration of the solution into enterprise systems (e.g., companies such as SAP, Oracle, etc.), it causes the greatest interest in the market. At the same time, there is a tendency to simplify the models. There is an emphasis on the active model component (taking into account the human factor). This explains the growing interest in IDEF and BPMN structural methods. UML-based solutions in demand increased their share, but not significantly, indicating the conservatism and a certain constancy of the potential group of its users.

5 Conclusion

The study examined software tools for visual system analysis of complex systems. The main task of visual models is to provide transparency and manageability of the business process. The transition to the use of complex, parametric models must be justified in advance. Different technologies should be used at different stages of company maturity. The business process model must respond flexibly and quickly to change. For large companies, it becomes economically feasible to implement visual models of business processes in the concept of digital twins [12, 16]. At this level, the company is ready to manage end-to-end business processes; it vitally needs flexibility and scalability. One can state that the visual model of a business process in the conditions of digital transformation should be considered as its digital twin.

Parametric environments of visual modeling should apply various optimization methods and dynamic, flexible modification in real-time. One of the main trends in the development and implementation of modern solutions for visual modeling of business processes is the use of simulation modeling as an integral component. It is generally accepted that simulation modeling should accompany business processes from the initial stage of their formation, development, and implementation [18].

Modern visual modeling systems must meet high quality and efficiency requirements. They should provide the ability to formally represent the studied business process at all levels of expertise: conceptual-abstract, structural–functional, and object-oriented. They must have a uniform model description format. Implemented visual models and software tools must provide repeatability, predictability, multi-functionality, and completeness of models.

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Impact of Digital Technology on Supply Chain Efficiency in Manufacturing Industry

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Abstract With the advancement of digital technologies, supply chain management is changing dramatically. However, the practice and application of digital supply chains are complex and challenging. Some studies claim that technology is the core element, while others believe that efficient configuration and collaboration of technical functions assure successful applications. To address this gap, this research conducts a systematic literature review to analyze how digital technologies particularly the Internet of Things (IoT) and Artificial Intelligence (AI) impact supply chain efficiency in Manufacturing Industry. The study also identifies some challenges of digital supply chain (DSC) implementation. Analysis of this study is based on a systematic literature review of 59 studies that were selected using a combination of relevant keywords and specified inclusion and exclusion criteria. The results show that both IoT and AI are the closest technologies related to the autonomy and predictive power of future supply chain expectations. The convergence of the two tech-nologies optimizes all aspects of manufacturing and opens up more possibili-ties for smart factories. This research also explored DSC challenges and problems that take into consideration to expand the approaches to DSC success factors derived from existing literature. Many papers have discussed DSC technology from the perspective of the ap-plication. They demonstrate the positive impact of those digital technologies

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to successfully achieve digital and intelligent supply chains on firm perfor-mance by improving the efficiency of SCM.

Keywords Digital technology · Supply chain efficiency · Manufacturing

1 Introduction

With the continuous expansion and development of the manufacturing industry, an increasing number of enterprises begin to devote themselves to supply chain efficiency [1]. It depends on a smooth network chain structure formed by the upstream and downstream organisations in the process of production and transportation through organizational control of capital flow, information flow and logistics [2]. Specifically, it is aimed at optimizing the process, improving production quality and reducing unnecessary costs to satisfy customs and achieving the maximum economic benefit [1]. Mangan and Lalwani [3] claimed that effective supply chain management in the manufacturing industry is especially important to deliver the right product to consumers at the right time, in the right quantity, in the right quality, and at the right state. However, the rapidly changing market and diverse customer needs have brought unprecedented challenges to manufacturing supply chains, because it relies heavily on timely and accurate data analysis in a complex business environment [4]. Meanwhile, a dynamic and uncertain competitive environment, unpredictable social factors and other random environmental changes aggravate the complexity of supply chain management, leading to high production costs [2]. For example, COVID-19 has seriously affected the manufacturing supply chain on a global scale, such as labour shortage, material shortage, delivery delays and logistics stagnation and so on. The COVID-19 pandemic however has spawned the widespread use of digital technologies to improve the ability of the economy and society to respond to the impact of the pandemic.

Digital supply chain (DSC) is an intelligent, data-driven technology network that is based on massive real-time data processing, excellent collaboration, and communication capabilities to achieve information transparency, advanced planning, demand patterns prediction as well as maximizing the availability of assets [5]. Many studies have acknowledged the positive effects of digital technologies on the efficiency of supply chains. Chase [6] pointed out that DSC has become an inevitable choice for enterprises to improve the ability to anticipate demand and risk through the application of digital technology, which improves not only the market response speed and operational efficiency but also the service level and economic benefits of enterprises. Similarly, Preindl et al. [6] claimed that the DSC enhances the information-sharing capability, which plays a vital role in this cooperation aimed at processing large amounts of information to coordinate related operations to improve efficiency. In addition, Banerjee and Mishra [7] argued that digital technologies improve supply chain collaboration, which requires internal and external coordination and unification amongst suppliers, manufacturers, retailers and customers. However, the practice and application of the digital supply chain are complex and challenging, which requires cross-industry, cross-sector and cross-field cooperation. Although the application of digital technology in the supply chain would effectively improve its flexibility and adaptability theoretically, there are still many obstacles in the practical process. According to the data, 80% of practices related to digital transformation failed [8]. Reyes et al. [9] argued that enterprises should identify whether these technologies could achieve their strategic and operational aims rather than blindly following technology for technology's sake. Tjahjono et al. [10] believed that improvement of organizational ability assures successful applications through efficient configuration and collaboration of technical functions. However, there is little theoretical research in this field. Therefore, it is imperative to explore challenges and the key factors that affect the successful application of digital technologies as well as potential risks to better adapt to enterprises' strategic goals to achieve the desired results after weighing those digital technologies' pros and cons [2].

This study, therefore, discusses and analyses the impact of digital technologies focusing on AI and IoT on the supply chain efficiency in the manufacturing context. AI and IoT are considered to have significant potential amongst the eight most influential digital technologies. IoT currently has a high utilization rate in the manufacturing industry, and its application is becoming mature and has achieved good results in terms of information communication, and AI is the most promising technology based on the Internet of Things. This research will use the systematic literature review (SLR) method to collect existing literature to answer the two research questions. The first one is '*How Do AI and IoT Improve Supply Chain Efficiency?*', aimed at identifying the principles working on SCM performance. The second one is '*What Factors Influence the Successful Implementation of the Digital Supply Chain?*', aimed at exploring the challenges and obstacles of the digital supply chain. The next section briefly introduces the three theoretical bases (IoT, AI and SCM) related to the topic. Section 3 describes the details of the SLR methodology for looking for publications that explicitly study IoT, AI, and the manufacturing supply chain. Section 4 presents the analysis of research results and findings and makes a comprehensive and critical analysis of the two research questions. Finally, Sect. 5 concludes this study by recommending some future research directions.

2 Background

2.1 Internet of Things (IoT)

Ashton [11] came up with the term Internet of Things (IoT) firstly, which refers to identify an object uniquely by connecting physical things through technology and its virtual network [12]. Three elements are required to achieve the function of IoT, and they are data acquisition technology, data transfer technology and data analysis techniques [13]. Thus, different layers of sensors, storage and data transmission with the function of recognition, processing, communication and connection are imperative to achieve connections amongst things [14]. Gnimpieba et al. [15] argued that the connections and communication between physical and virtual 'things' enable transparency and collaboration between them by clear information network. Each sensing device is uniquely addressable by IoT Internet infrastructure, which has dynamic self-configuration capabilities with standard and interoperable communication protocols, standardized communication protocols [16], because each physical and virtual object is given a unique identity, physical attributes and virtual personalities [13]. Similarly, Reaidy et al. [17] argued that IoT is an intelligent internet-based network, which enables devices to collect, process, and transfer data within an interconnected physical global infrastructure. Meanwhile, it could identify, track, and manage products by transmitting real-time information through advanced technologies. Based on collected information by devices, it can not only trace, manage and control the internal and external state of an object but also continuously observe its surroundings [18]. Furthermore, it is expected to anticipate and perceive dynamic changes in the supply chain management to facilitate supply chain management effectiveness and sustainability with its information transparency, tracking and agility [2]. In the same way, this type of control and monitor reduce risks by timely response, control and adaption of the supply chain activities in an uncertain environment [19]. Nevertheless, a large amount of information obtained may hinder supply chain management efficiency due to the amount of useless information [20]. Therefore, information management and effective control are vital for making reasonable predictions for the future and reacting to achieve sustainable development and competitive advantages. Yet, the existing researches are limited and need to be expanded.

2.2 Artificial Intelligence (AI)

Artificial intelligence (Al) can think like humans and mimic human behaviour by simulating human intelligence characteristics in machines such as learning and self-thinking and problem-solving. By absorbing large amounts of unstructured data, such as text, images or video, the ideal characteristic of AI is that it can rationalize and take actions automatically without the help of humans to have the best chance of achieving specific goals. Calatayud [21] pointed out that AI is not a monolithic technology, which depends on the cooperation of various advanced technologies with hardware and software. For example, AI is effectively coupled with the large numbers of data collected by other digital technologies, especially the Internet of Things, to predict the future trends with advanced algorithms and take measures to avoid any deviations from expected performance with minimum error [22]. On the other hand, it focuses on developing computer programs that can learn, understand, reason, plan and act on their own to make decisions automatedly in SCM through the use of simulation models and powerful analytics [23]. Meanwhile, software algorithms automate complex decision-making tasks by analysing real-time data, anticipating and identifying risks as well as automatically taking action to continuously control supply chain performance and prevent risks before they occur. Robots are an excellent product of this combination. For example, in automated warehouses, robots help supply chain material handling automation through planned algorithms to pick, stack and unload after learning. The highly mechanized environment can change the supply chain and create a faster, safer and more efficient logistics supply chain [22]. Meanwhile, they are installed with planning programmes to monitor inventory status and order progress with high accuracy. These robots are safe and agile in predicting the relationship between demand and inventory in the warehouse to achieve higher productivity and lower costs, avoiding the risk of goods disruption with faster service and higher quality [1].

AI is primarily a smarter algorithm that learns more and more by itself through mimicking human thought processes and feelings. Its applications in supply chain management are in transportation, predictive maintenance and demand forecasting facilities autonomous prediction and decision-making of supply chain [24]. AI technology has huge potential in the manufacturing supply chain. Koot et al. [2] argued that AI applications would enable automated production systems and automated logistics systems to change decisions flexibly like the selection of suppliers when they receive real-time information about supply shortages or disruptions. However, there are some sceptical voices about AI like ethical questions. Tazhiyeva [25] claimed that the question of whether intelligent systems such as robots should be given the same rights as humans is controversial. In addition, the extraction of sensitive information may violate privacy security and even break politics [26].

2.3 Supply Chain Management (SCM)

A supply chain is a functional network structure that connects suppliers, manufacturers, distributors and consumers, starting from parts production, making intermediate products and final products, and finally sending the products to users through the sales network [1]. Alternatively, a supply chain is an interface formed between supply chain members through activities so that organizations can meet the internal and external requirements. As for Supply chain management (SCM), it includes a series of activities and processes that plan, control, coordinate and optimizes the whole supply chain system, so that enterprises can integrate and cooperate to address the volatile and complex situation of the external market [10]. SCM is an integrated and coordinated management mode, which requires the members of the supply chain system to cooperate to achieve corporate goals. The practice of SCM was widely used in the manufacturing industry firstly, focusing on logistics management tasks to reduce transportation costs, and over time it extends to all aspects of the supply chain [4]. The data shows that a company spends a lot on its supply chain, accounting for nearly 25% of its operating costs [9]. Thus, effective supply chain management is critical in reducing unnecessary costs to achieve better performance. Many researchers have been working on the efficiency of SCM. Singh et al. [27] agreed that effective supply chain management can help firms to improve their competitive advantages, which promote their performance and lead their competitors. In particular, it can help achieve four goals: shorten cash flow times, reduce the risks faced by organizations, achieve earnings growth and provide predictable revenue [28].

However, it is not easy to achieve efficient supply chain management in the challenging and complex market environment in the era of economic globalization. A large amount of information appears in the market all the time, which provides rich opportunities but also foreshadows risks. For instance, enterprises are unable to timely identify the changes and collect useful information in the supply chain accurately, leading to difficulty in making the right choice and failure of decision-making. Alternatively, in a traditional supply chain is hard to carry out sufficient information sharing to eliminate the communication barriers within the member enterprises. Thus, information development of the supply chain is appearing, which is a grand solution to this problem contribute to the digital supply chain (DSC). Nowicka [29] believes that the digital supply chain can effectively improve information transparency among supply chain members, which greatly promotes information communication efficiency by reducing the time cost, shortening the flow cycle, and reducing unnecessary costs. Effective and accurate communication ensures collaboration and trust among suppliers, manufacturers, and distributors, especially in the application of inventory and logistics, which greatly reduces unnecessary costs, which are not value-added activities [9]. On the other hand, the access of information and the speed of information feedback are also important to the efficiency of SCM due to a large amount of data available in and out of the market [30]. The digital supply chain can improve the traceability, reliability and response speed of the supply chain through real-time monitoring capabilities [31]. At the same time, this ability can predict the risk of the supply chain and make decisions through the high-speed collection, analysis and processing of relevant information organizations and supply chains can realize higher levels of efficiency by responding more quickly to observed internal and external disruptions [19].

3 Methodology

3.1 Systematic Literature Review (SLR)

This study aims to analyse the impact of digital technology on supply chain management efficiency in the manufacturing industry. Practitioners have long been enthusiastic about the impact of digital technology on the efficiency of supply chain management. Thus, a Systematic Literature Review (SLR) is used in this study focusing on the IoT, AI and SCM to show an overview of current related research studies by using search strings, keywords and statistics within the specified database and give an objective assessment by conducting qualitative and quantitative reviews of the existing literature to answer the research questions.

Table 1 The initial number of papers in each elected database

Databases	Entries	Initial number
Springer	44,500	207,800
Wiley	32,600	
Scopus	21,000	
Web of Science	63,700	
ScienceDirect	21,000	
Taylor & Francis	25,000	

This study identified keywords and they are AI, IoT, efficiency, challenge and SCM. According to those keywords in different categories, combining the most common grouping of keywords carefully to identify the search string to screening in a search engine is vital, which ensures proper select coverage. After filtering, four types of search strings are selected and they are "Artificial Intelligence or Internet of Things AND supply chain", "Artificial Intelligence or Internet of Things AND supply chain AND efficiency", "Artificial Intelligence AND Internet of Things AND supply chain AND efficiency", "Artificial Intelligence or Internet of Things AND supply chain AND challenge". For the source selection, this research selected Springer, Wiley, Scopus, Web of Science, ScienceDirect, and Taylor & Francis, which are trustworthy and authoritative. Table 1 displays the initial number of papers in each elected database.

3.2 Selection Criteria

To accurately locate the useful literature in the rough search of the specified databases based on different combinations of search strings, this research needs to further develop selection criteria to refine the "sample poor" by evaluating and discovering the relevance degree and potential contribution of each publication to the research problem. There are three layers of inclusion and exclusion criteria. First, the initial research results should meet the following three inclusion criteria.

(1) The articles should be fully published and written in English.
(2) The articles' subject topics should be consistent with the academic area of study being considered such as Supply Chain Management, Computer Sciences, Decision Sciences, Business Management, Technology Science, and Engineering.
(3) The articles are academic document types such as Doctoral Dissertation, Books (Chapters), Academic Journal/Articles/Papers, Review Articles and so on.

Further selection and screening are carried out for the articles that have met the above three requirements to evaluate the usefulness of the content itself. Articles that do not conform to the following three additional exclusion criteria are screened by title, abstract, keywords, and introduction screening.

(4) Focus on specific actions or applications or challenges of AI or IoT that affect supply chain efficiency. Specifically, remove all improved performance in SCM that is unrelated to the implementation of AI or IoT technology. Two reasons are provided. Firstly, the improvement in supply chain performance reflected in the article may be the result of iterative improvements of the covered technologies themselves. Secondly, the application of digital technologies may not be independent. So, it may be necessary to judge whether the application of these comprehensive technologies is causally related to those two technologies.
(5) The initial data should be processed to show a critical analysis of the impact on the efficiency of SCM.
(6) Besides theoretical support, the factors affecting the implementation of the digital supply chain should provide clear points or specific cases.

The third level is only consistent with exclusion criteria. The following criteria are defined to improve the articles' sample accuracy.

(7) Remove all duplicated articles from different databases and choose the latest version for further reading only.
(8) Remove all case study articles that are not in the manufacturing industry.
(9) The article should be available online (either open access or through a subscription).

3.3 Sample Selection

Following the selection criteria outlined in the previous section, 59 articles were selected from seven databases for the final bibliographic study. They are grouped and classified according to the two research questions posed and divided into two broad areas. The first category is to explore the specific application of the IoT and AI in supply chain management and there are 42 papers. It includes specific implementation cases of IoT and AI in manufacturing supply chains and performance evaluation related to the first research question. The focus of the study is on digital technology with specific enterprise implementation activities and impact on results. The second category is 18 papers (because some articles cover both areas) to identify causes of failure implementation and explore the reasons. This part concentrate on the challenges of implementing digital technology with analyses different angles of causation. This study conducted simple statistics based on the different keywords involved in each article to show the specific research areas and research issues, which provides convenience for the following research.

The scrutiny of the sample illustrates that most of the articles are from engineering and management. IoT is widely used in management accounting for 39% and most of them come from supply chain logistics management A small portion is computer science, focusing on the development and integration of technologies. it shows that most of the current researches on digital technology focus on technology development and innovation rather than application and practice realization. This provides a guide for research to fill in the gaps in the application of digital technology at present.

4 Findings and Discussions

A large number of academic literature has acknowledged that the application of digital technology in SCM has made great breakthroughs in supply chain management efficiency. The network is an imperative element of competition ability and the efficiency of SCM depends on the network connections and coordinated operation, which are based on information sharing and information technology applications between each member [29]. Paul [32] reported that nearly half of surveyed supply chain leaders have significantly accelerated their investments in digital technology to make their businesses more responsive and forward-looking during the pandemic. IoT and AI are the two most promising digital technologies in the manufacturing supply chain of the future [33]. IoT now accounts for 27% and tends to grow to 73% in the next 3 to 5 years. Similarly, AI is promising to increase dramatically from 17 to 62% [34]. Thus, the following sub-sections will focus on IoT and AI's applications using the selected 59 papers in response to the two research questions raised earlier.

4.1 How Do AI and IoT Improve Supply Chain Efficiency

Calatayud et al. [35] argued that the development of AI and IoT has greatly promoted the emergence of industry 4.0 and intelligent factories. Those two technologies complement each other and are closely linked. AI is equivalent to application software, which needs IoT as the foundation. IoT is like hardware that needs AI to drive it [26]. Specifically, the Internet of Things produces a large amount of data collection with perception devices. Subsequently, Artificial Intelligence provides the suitable optimum proposal for the Internet of Things by using data and analysing data with its powerful data analysis capabilities. Tjahjono et al. [10] agreed with the argument and claimed that technologies are closely related, without boundaries or priorities, so it is important to work together to promote supply chain development, especially in supply chain management. Attaran [1] pointed out that the realization of DSC needs to integrate multiple technological advantages to obtain competitive advantages. In addition to improving the efficiency of SCM and reducing organization operating costs, DSC also provides a full-fledged decision foundation for enterprises to formulate the overall industrial development strategy. Similarly, Preindl et al. [6] agreed that the digital supply chain has broken the communication barriers of previous supply chain links, and improved the information transparency and reliability of the supply chain. Furthermore, the application of digital technologies has greatly changed the process of supply chain management, which collects and analyses large amounts of real-time data intelligently and then uses that information to make decisions and implement them [36]. This transformation improves the connectivity and collaboration of all parts of the supply chain members by sharing information more accurately and in real-time, improving the efficiency of supply chain management by making accurate decisions and optimizing operations [37]. At the same time, the prediction of potential risk and simulation of the feasible adoption of risk mitigation measures ensure sustainable and stable performance improvement in an increasingly changeable supply chain management surroundings [21]. This ability to monitor and predict not only improves flexibility and agility on risk management in the supply chain efficiency but also gain sustainable competitive advantages [38].

Nevertheless, Cui et al. [39] pointed out that digital technologies are not the only key elements contributing to the improvement of the efficiency of SCM. Instead, the improvements of collaboration between the supply chain members, the ability to collect and process information and the integration of management information systems are the basic reasons due to the application of those digital technologies. Thus, technology provides only one possible way for improvement. The important thing is how to obtain key capabilities to realise these expected benefits through integrating digital technologies with the realities of enterprises. Similarly, [40] believes that the essence of the Internet of things is to provide information and integrate information.

However, what really improves operational performance is data transmission speed and data transparency level, which promote cooperation between supply chain members and optimize the supply chain information flow, logistics, capital to gain competitive advantages of enterprise's key abilities [41]. The Internet of Things effectively provides a large amount of data, but the transformation of data into information still requires judgment, data processing, and autonomous decision making. Although IoT currently allows decisions to be made by machines without human participation [42], there are still few studies on autonomous supply chain decision-making and smart factories, which combine the Internet of things with autonomous decision-making, are novel and nascent in the field. Meanwhile, [43] argued that an intelligent supply chain needs the combination of different technologies to realize informatization and automation, which is the foundation for achieving a high degree of network-physical interconnectivity. In this case, Artificial intelligence plays a vital role to realize a smart supply chain and push the flexibility and agility of the supply chain to the undiscovered limit [21]. It makes decisions and takes actions to adapt to a rapidly changing environment by analysing information in real-time and monitoring operations on a global scale with predicting the future with a minimum error rate [35]. While artificial intelligence (AI) is on the rise, it also needs to consider how other technologies are coming together in valuable new ways [34].

4.2 IoT Application in SCM and the Impact

IoT technologies are widely used in the manufacturing industry like radio frequency identification, wireless communication technology, laser scanning, etc. Those information and communication technologies (ICTs) could improve supply chain connectivity due to the integration and visibility of information [44]. Supply chain connectivity reflects the impact of digital connections between stakeholders on and off the supply chain, which relies on the extraction of information around all related aspects [35]. Bhaveshkumar and Santosh [45] claimed that IoT achieves collaboration to optimise accuracy, integration and transparency of the information with its four aspects of characteristics and there are extracting data, transferring data, storing data and processing data. Cui et al. [39] identified 16 factors that have impacts on the supply chain and quantified them. Consistent with other researchers, IoT has made outstanding contributions to the supply chain in information processing capacity, information transparency, management system integration, industry standards.

The application in the automotive manufacturing industry provides automobile manufacturers with opportunities to optimize. A large amount of money has been invested in the digitization of various manufacturing processes from design to vehicle production, including design, manufacturing, quality inspection, logistics and inventory management [12]. According to [46], 60% of manufacturers worldwide used data generated by connected devices to analyse processes and make decisions in 2017. General Motors is a good example. In terms of manufacturing, it uses sensor data to determine the humidity of a car's paint environment. The sensor first detects humidity data by sensing the external environment and then transmits the detected data to an algorithmic device that has been set up in advance to determine if it is within the reasonable range. If the system decides the environment is inappropriate, it sends the car to another area in the manufacturing process, thereby minimizing repainting and maximizing plant uptime. This innovation alone saved GM millions of dollars per year [47].

In terms of logistics, [10] pointed out that information transparency and connectivity effectively enable timely and accurate information sharing, which eliminates communication and technical barriers across departments and areas by enhancing the transparency of the operation between suppliers, manufacturers and customers. There are many examples of this in logistics and inventory management. The cost of inventory management accounts for a large proportion of the cost of automobile manufacturers, which directly influences organizations' normal operations [40]. The poor communication among various departments of the enterprise will lead to the waste of resource deployment and other phenomena caused by the lack of real-time coordination and control of resources of all members in the supply chain of the automobile manufacturing enterprise, which will affect the benefits. IoT improves the inventory management level of automobile manufacturing enterprises from two perspectives. Firstly, establishing the inventory circulation network based on the Internet of Things technology facilitates the circulation of idle inventory among enterprises. The other one is to use IoT to monitor the whole process of materials in automobile manufacturing enterprises to improve the inventory management level. For example, providing available real-time data in SC by monitoring the movement of materials, equipment, and products through the supply chain efficiently allocates resources between inventories [15]. In addition, with Enterprise Resource Planning (ERP), Product Lifecycle Management (PLM) and other systems that effectively collect and deliver information to connect factories and suppliers,

All empowered departments in the SC can track inventory, product flow, and product cycles times. That information will help manufacturers reduce inventories and capital requirements by anticipating problems. According to data, smart factory penetration is expected to grow by 35% by 2025 through investments in real-time analytics and dynamic supply chain tracking [10].

On the other hand, IoT is used in the production process to upgrade manufacturing processes through monitoring and tracking. It will not only reduce unnecessary waste, contributing to the sustainable development of the factory but also improve the profit space in the long term. Moreover, information is important to improving supply chain operations [33]. A two-way flow of information not only improves the supply chain collaboration but also achieve the operational excellence of sustainable supply chain management by rapid feedback, interruption reduction, process optimization [39]. For instance, in terms of quality testing and monitoring, the automotive aftermarket has always been a core part of the automotive industry, covering all the services consumers need after buying a car [48]. The physical nature of a vehicle means that it is subject to unpredictable wear and tear and the hardware facilities face functional degradation, inflexibility and other potential problems. By implementing IoT components, vehicle status can be continuously monitored, enabling anticipation of potential damage or failure and then preventive measures. In addition, it can trace back to the production assembly process for optimization through manufacturing data on systems and components [49].

4.3 AI Application in SCM and the Impact

Michel [50] pointed out that with the rise of globalization and the continuous development of science and technology, supply chain management has gradually become a priority for all enterprises. Meanwhile, as sensor costs fall and the Internet of things advances, Al is expected to be one of the most promising technologies in the future of supply chain management due to the increasing access of data throughout the supply chain and improvement in computing technology [51]. A large amount of data is accumulated and deposited in the cloud. Thus, how to make use of big data and give full play to the value of data to predict market demand, assist the decision-making, optimize the operation process, and predict the risk points of each link in SCM are the new challenges. Some pieces of literature have acknowledged the fact that Artificial Intelligence has helped addressed those problems, which results in the in-depth, predictive, and credible understanding of business partners and even competitors in a complex and sprawling supply chain. Moreover, [51] argued that AI facilitates the sustainability of supply chain management in pursuit of improving quality, reducing cost and increasing efficiency. Hassija [26] supported those arguments by quantifying the benefits of AI for organizational in ten aspects of supply chain management.

So far, a lot of AI technology has been applied to supply chain management [52] including Artificial Neural Networks (ANN), Artificial Immune Systems (AIS), Virtual Reality (VR), Genetic Algorithms (GA) and so forth [53]. In supply chain management, these applications are significant for supply chain activities in terms of demand prediction, marketing decision support systems, pricing, product manufacturing and supplier selection. The most common and influential is ANNs, which is a data analysis technique mainly relying on a large amount of experimental data [28]. Li [54] believes that artificial neural networks are becoming more and more important in a changeable competitive environment because they can solve data-intensive problems in the era of big data to discover knowledge, rules or models [55]. Compared with human beings, AI is the computational intelligence related to the input and output streams of processing units, which can effectively solve the problems with complex and difficult algorithms that human beings are incomparable [56].

Amirkolaii et al. [57] claimed that AI effectively helps managers to make predictions and adjust the plan in SCM, which avoids the waste of resources and business risks like the "Bullwhip Effect". Specifically, when the information is transferred from the upstream and downstream of the supply chain without information-sharing in real-time, the information will be gradually distorted and amplified, which results in the increasing fluctuation of demand and supply information and the formation of false bubble space. However, AI can help companies accurately determine supply and demand relationships ahead of time and develop dynamic operational strategies by using historical data analysis, real-time data analysis, prediction model programming and other analysis measures [58]. At the same time, AI makes the optimal distribution of limited resources in the supply chain to achieve the maximum benefit and formulates mitigation strategies for changes [59]. In addition, Smart supply chains harness the power of AI and other emerging technologies to help companies make predictions and risk analyses to maintain business continuity in chaotic and volatile situations. This efficient supply chain control tower system based on artificial intelligence can respond quickly, smooth through or even completely avoid risk with minimal loss or minimize disruption damage when a disaster occurs [60]. Similarly, AI can also be used in daily operations through real-time Omni-directional monitor risks to promote the agility of SCM to respond quickly and mitigate risks by predicting supply chain disruptions risks and recommending solutions. For example, more than 30 counties in Thailand were hit by the worst flooding in 40 years overnight in August 2017. IBM's Singapore factory's supply chain division was immediately clear that the floods would have a huge impact on Thailand's hard drive makers from the purchase orders being executed and pending approval. Based on the potential risks in short supply, the Singapore factory quickly select the Singapore hard disk from the repository suppliers to place orders, lock and prepare goods and coordinate and deploy available transportation ensuring dedicated hard disk supply is in place and the production line is not interrupted [61].

However, correct forecasting is a complex process that depends on many internal and external aspects, such as an accurate database, highly integrated algorithms, market stability and so on [26]. And the wrong prediction will be a significant financial loss to the organization [62]. For example, Nike introduced a demand prediction programme but failed to implement it in 2001, which leads to insufficient inventory in Air Jordans and an excess of less popular types. This failure experience took an unimaginable financial hit to Nike, costing it around $100 million in lost sales [63]. In the process of production and transportation, AI improves the effectiveness and accuracy of logistics decisions by tracking the flow patterns of goods and services, simplifying activities to achieve efficient and transparent partnerships [24]. For example, in terms of inventory siting, planning and cost minimization, and supplier selection issues, Artificial intelligence can eliminate human conditions and personal feelings to build models by analysing historical stock data. The warehouse is the foundation of the development of modern logistics and warehousing location determines the efficiency of logistics. According to simulations and the filter criteria, Artificial intelligence systems forecast future data to select the most appropriate choices and make a decision [64]. In addition, the stand or fall of transport line planning can directly affect the operation of the modern material filling system of the whole with the introduction of AI, which greatly improves the efficiency of delivery batch business and expresses sorting business. There are many application scenarios of AI in the field of logistics, such as packaging material box algorithm recommendation, cargo space planning, vehicle and cargo matching, AGV scheduling, automatic intelligent storage and so on. Klumpp [24] believed that AI and algorithms occupy an increasingly crucial status in logistics. For example, intelligent logistics technology represented by digital and intelligent heavily rely on the core elements of intelligent storage including unmanned distribution, AGV (Automated guided Vehicle) and logistics robots [65].

Furthermore, AI can assist with cruise control, lane-keeping and collision avoidance to achieve high safety of unmanned driving to the destination of goods. It also offers machine learning, sensor fusion, computer vision technology, motion planning and control to autonomously select and improve road safety [47]. On the other hand, AI effectively liberates part of human activity. Specifically, AI can maintain efficient operation for a long time for some simple programmed tasks [28]. For difficult and complex tasks, AI can objectively and intelligently perform fast calculations. Take Audi' parts logistics as an example, which is the key to ensure the efficient production of the whole factory. The Tungsten Network [66] reported that they waste an average of one hundred and twenty-five hours per week on trivial businesses like repeat and simple routines, dealing with supplier inquiries, accounting audits and so on. There are about 6500 h a year wasted on ineffectual work. Thus, some organizations have begun to adopt advanced AI applications like robots to complete repetitive activities automatically. Those AI applications also reinforce each other to optimise the real-time strategies and automatically adjust them according to the surroundings, which enables robots smarter and faster. Audi's intelligent factory is a typical example. The logistics and transportation of parts are all completed by the unmanned driving system. The forklift truck that transfers material also realizes automatic driving, realize true automatic factory [23]. Not only will unmanned vehicles be involved in material transportation, but drones will also play an important role [4]. In Audi's smart factory, miniaturized and lightweight robots replace manual labour to install and fix trivial parts. Flexible assembly cars will replace manual screw tightening. Many mechanical arms are arranged in the assembly trolley. These mechanical arms can be identified and screwed according to the established procedures. The assembly assistance system can inform workers where to assemble and can check the final assembly result. In some wiring harness assembly work also need manual participation. The assembly auxiliary system can prompt workers which positions need a manual assembly, and display whether the final assembly is qualified on the display screen to prevent defective products [67]. The flexible grasping robot invented by Audi Intelligent Factory is different from the current grasping robot. The biggest feature of this robot is the flexible tentacles, which are similar to the tongue of a chameleon and have more flexible grasping parts. In addition to grabbing ordinary parts, the flexible grasping robot can also grab nuts, gaskets and other fine parts.

4.4 Factors Influencing the Successful Implementation of the Digital Supply Chain

A digital supply chain is expected to strengthen competitive advantages through improved product quality, lower operational costs, faster market response and higher collaboration between supply chain members [68]. However, the introduction of digital technologies recently is exposed to various difficulties and obstacles that arise from internal and external factors such as increasing internationalization and interconnection of companies, uncertain demand changes and faster production cycles time [35]. Definitely, digital technologies can greatly improve supply chain management efficiency by avoiding the problems of errors, losses, and costs associated with manual management to achieve better business performance. According to [69], organizations with a digital supply chain and highly digital operations are expected to improve efficiency by 4.1% per year and increase revenue by 2.9% per year. Based on these obvious motivations, manufacturing supply chains are investing more in digital technologies and obtain great results. Around three-quarters of manufacturing, enterprises tend to speed up their digitalization process and will achieve comprehensive and basic digital advances by 2020 around the world [70]. Taking China as a specific example, The Ministry of Industry and Information Technology proposed that digitized manufacturing enterprises above the scale will be popular, and intelligent transformation will be preliminarily realized in key industries by 2025 (more than 2000 smart scenarios for the application of new technologies, more than 1000 smart workshops, and more than 100 benchmark smart factories leading the development of the industry). By 2035, digitisation will be universal in all manufacturing sectors above scale [71]. In terms of performance returns, the results are remarkable. The income of the intelligent manufacturing business gradually increased from 73.467 million yuan in 2017, 147.12 million yuan in 2018, and 264.348 million yuan in 2018 to 413.252 million yuan in 2020. Smart manufacturing in 2020 operating revenue growth of 56% and revenue rose to 29.83% from 24.58% a year earlier [72].

However, in practical application, many enterprises, which spend high cost and are equipped with the most advanced automation technology such as Manufacturing Execution System (MES), Web Mapping Service (WMS), Transport Monitor System (TMS) and other information systems are still not satisfied with the output results in SCM. Furthermore, there are obviously greater difficulties and obstacles to further digitization and intelligent process. Although many enterprises have realized the importance of DSC, only 5% were satisfied with their digital transformation approaches. Thus, it is important to explore how smart supply chains can be successfully applied and what reasons influence their implementation [34]. Ageron et al. [73] believed that technological, organisational and strategic challenges remain to overcome to achieve the success of the DSC implementation. Agrawal et al. [74] identified 12 barriers to the implementation of DSC including the fear of loss of confidential information, lack of budget, lack of digital skills and talents, lack of strategic guidance and so on. From a quantitative perspective, [26] analysed and presented different 13 possible obstacles. The next section explores some of the potential obstacles.

4.4.1 Lack of Budget and Management Support

The lack of sufficient financial support will greatly hinder the digitalization process of DSC such as the improvement of infrastructure, the cultivation of corresponding talents, the integration of introduced digital technologies and so on. According to the data, the information technology (IT) system is critical to DSC, so improving infrastructure is an effective way to promote the digital supply chain. However, since enterprise on large-scale information technology and equipment needs a large number of investments to support, improvement of the infrastructure is a huge barrier to the implementation of the digital supply network [75]. In addition, new digital technologies and resources need to be constantly updated and integrated to drive connectivity of various technologies with appropriate organizational structure [25], which requires financial support setting the threshold for the productization of digital technologies. Those changes also face huge risks such as structure, culture, capabilities, policies and so forth. Specifically, DSC requires organizational structure transformation to provide effective means of communication between organizational members and between the organization and its environment through creating and sharing knowledge. With greater data transparency and synchronization, machines are empowered to make operational decisions to allocate resources for optimal utilization as well as capturing the highest utilization value of investment [76]. Although those activities are designed to improve the efficiency and accuracy of information communication, they may cause disruptions due to the need to redesign the supply chain operation process [1]. In addition, they do not directly present the most direct revenue return, because their return on investment is difficult to calculate [67]. So, they are often underfunded by trade-offs between implementation and running costs and their Return on Investment.

Another important barrier is the lack of relative talents. [73] argued that the talent gap is huge and the scarcity of talent and human consumption may lead to the failure of digital transformation. Large sums of money have been paid to find potential talents since digital transformation requires the training of new talents related to digital technology including data analytics, cloud computing, data security, mobile technology and so forth. Similarly, [74] claimed that new talents such as advanced engineers, data scientists and software programmers in information and communication technology need to be trained in the latest programming languages. At the same time, it is vital to attract experienced software developers, product managers and other technical specialists from Apple, Google, or Facebook to ensure the speed and quality of reform. In addition, behavioural competencies related to personality traits such as business process management, responsibility, social acceptability, innovation, and negotiation are also important, which adapt to the characteristics of the digital supply chain such as agility and flexibility. All of those activities require sustainable purchasing ability and are fundamental to the success of the digital supply chain.

4.4.2 Lack of Guidelines, Strategic Orientation and Knowledge

Although many enterprises are equipped perfect in terms of infrastructure (MES, WMS, TMS, OMS information systems), there are greater difficulties and obstacles to further digitization and intelligent process in DSC due to the lack of industry-specific guidelines, strategic orientation and relevant knowledge. Agrawal et al. [74] pointed out that there's not just one way to digitize a supply chain and companies at different stages have different digital goals. specifically, each enterprise should be based on their specific needs, according to the existing infrastructure and talent reserves, corporate culture and technical requirements for formulation and implementation of the corresponding digital supply network planning [8]. From selected researches, we found that there are many studies on how digital supply chains achieve specific advantages (collaboration, information transparency and so on) from a broad perspective. However, few papers have explicitly focused on the specific activities and implementation steps of the digital supply chain in the industry through case studies [74]. Therefore, the lack of specific route guidance has influenced the successful implementation of DSC. Many organizations recognized the purpose and significance of digital supply chain transformation, but do not have a specific map explaining the approach and sequence in terms of ways of cooperation, internal and external operations and so on. Organizations must thoroughly consider existing procedures and processes to identify areas of improvement to address digital transformation, then define their digital strategy and develop appropriate actions [77]. In this case, the digital strategic plan provides a clear roadmap for DSC adoption and helps managers identify the stages and locations of DSC deployment in the supply chain to avoid inconsistent, fragmented and ineffective activities. organisations could make the cost of input to get the greatest economic benefit [78].

In addition, the lack of professional knowledge and digital vision among leaders and employees about digital means is part of the reason for the slow adoption of the digital supply chain [75]. DSC is a way of managing core operations in the supply chain rather than owning digital products and services. In other words, the decision point that determines the efficiency of SCM is not the application of digital technology, but the matching degree of operation mode and information technology [5]. Several well-known research institutions, such as Accenture, IDC, Deloitte, etc., pointed out that the transformation of business model is the foundation of the success of digital enterprises. A successful digital transformation should leverage emerging technologies to increase stickiness and strengthen connectivity as well as creating an integration platform for digital and non-digital technologies. Therefore, technology is not the end, but the capabilities of real-time visibility, continuous collaboration, organizational flexibility, enhanced responsiveness and prevention. For example, most manufacturing enterprises tend to choose to invest in advanced technology, which is the most popular but may not be the most appropriate choice [79]. When they embrace shiny new technologies such as Robots, machine learning tools, etc., these technologies act as separate parts rather than putting them together to deliver value, which puts companies in an integration dilemma [80]. These technologies become fragmented and fail to build the enterprise into a cohesive platform to obtain the advantages of DSC. Furthermore, a deficient view on the integration of digital technologies may even damage their adaptive strategies [75].

4.4.3 Social Human Rights and Environment

The MIT Sloan Management Review [74] conducted a survey aimed at answering the question of why most companies are failing to reap business benefits from digitization. They found that people play a key role in digital transformation. On the one hand, some business leaders like to be in their comfort zone and resist change, in which case change can be challenging. Hudnurkar [81] claimed that it's hard for people to change because they develop vision and power with familiar things. In fact, 43% of 4500 CIOs in the Harvard Nash/KPMG CIO survey identified resistance to change as the biggest obstacle to a successful digital strategy.

On the other hand, people are unwilling to share information due to safety, security privacy, interests and other restrictions. Digital supply chains rely on information transparency and cross-departmental collaboration. To achieve the smooth operation of the supply chain, a data-sharing system is needed. However, for some sensitive data, such as inventory, life cycle, etc., it damages the privacy of the supply chain and even makes it vulnerable to malicious attacks. Therefore, network security risks become one of the obstacles to the promotion of the digital supply chain [82]. Due to business interests or narrow thinking, departments and companies are not willing to share information, which artificially brings "department wall" and "enterprise gap". For example, to leave room for cost reduction, purchasing fails to share the true cost with finance and sales, sales exaggerate the forecast, and purchasing overstates the demand for suppliers, etc. In this case, when they passing information adding their understanding and selfishness, the information will be distorted and the digital supply chain would be out of shape. All of these have brought obstacles to digitization. Thus, it is imperative to establish a holistic view, more synergy thinking to promote the flow of information.

Munirathinam [83] claims that more than 25% of cyber-attacks come from IoT devices. Although AI has greatly increased the capability of processing data and increased the reliability of decision making, the available way of collecting data can be a security risk. In addition to ensuring the quantity and quality of data, Ethics and a sound sense of responsibility are important for digital development. For example, some applications and devices have been empowered to make decisions automatically through algorithm settings, model parameters, data permissions, etc., which have become "black boxes" [26]. In this case, transparency and accountability are very low. Security loopholes are existing and connections between devices are still immature, which will give many criminals many opportunities to commit crimes. Therefore, there is still a lack of relevant laws and regulations to ensure security issues and increase trust.

In summary, there are three levels of obstacles to the implementation of the digital supply chain. Financial support is the key factor from the first beginning to the whole process, which is the premise and basic guarantee to ensure continuous follow-up. The lack of clear guidance and management knowledge is the root cause why the implementation effect is not achieved in the process of transformation. The lack of acceptance from human beings and the imperfection of legal protection aftermath would hinder the sustainable development of DSC.

5 Conclusions

Many papers have discussed DSC technology from the perspective of the application. They demonstrate the positive impact of those digital technologies to successfully achieve digital and intelligent supply chains on firm performance by improving the efficiency of SCM. However, few studies have explored the causes and mechanisms that promote this effect. This study found that information transparency, accuracy information and decision-making, and collaboration amongst supply chain members directly affect the efficiency of SCM. The realization of these functions depends on the innovative advantages brought by digital technology. The study shows that digital technology is key to the improvement of management efficiency through bringing about the change of supply chain mode, functional advantages, ability improvement and so on. This research selected two key technologies (IoT and AI) to discuss their specific contributions to supply chain management efficiency in the manufacturing industry. The results show that both IoT and AI are the closest technologies related to the autonomy and predictive power of future supply chain expectations. IoT promotes supply chain collaborative management by improving real-time information transparency, information systems integration, and big data processing capabilities. In addition, the ability to track, predict and independent decisions provide suggestions and guidance for enterprises to make decisions. Al accompanied with its analysis, learning capabilities enhance the accuracy of autonomous prediction, classification, decision-making and risk aversion. It enables IoT to generate index values, while IoT will provide AI with an information base and a basis for autonomous decision-making, among other things. The convergence of the two technologies optimizes all aspects of manufacturing and opens up more possibilities for smart factories.

This research also explored DSC challenges and problems that take into consideration to expand the approaches to DSC success factors derived from existing literature. One is the capital barrier, which includes the improvement of infrastructure, the introduction of new technology and the training of talents. These are important foundations of the digital supply chain and require substantial ongoing financial support. The second is the management implementation barriers such as the lack of knowledge of relevant personnel, no clear guidelines, no strategic plan and so on. These are the most common difficulties in the process of digital transition as well as key reasons why companies have invested so much money while it doesn't work. In this case, organizations recognize the necessity of change, but lack specific implementation methods and steps, resulting in the waste of a large number of financial, material and human resources in worthless activities. In addition, they may be eager to achieve financial returns without objectively combining their circumstances and strategic planning. The last one is personal barriers including fear of changing from the comfort zone, inadaptability to changes in working style and reluctance to divulge privacy due to security concerns. Privacy security remains a huge challenge due to technological uncertainty, lack of trust, unwillingness to give up power.

However, our study has certain limitations. In terms of the type of research itself, a systematic literature review is a research method that provides an overview and critical discussion of previous studies and may not cover the details of every research question. Therefore, such analysis from a relatively macro perspective lacks in-depth survey and research. Although it identified the importance of digital technology efforts to improve performance and how they improve supply chain capabilities, there is no specific quantitative analysis to delve into the impact of digital technology on management efficiency into quantitative relationships. All discussions are based on secondary data from cited samples, without collection and analysis of primary data. This study noted the importance of having clear guidelines and roadmaps for the supply chain during the implementation phase. But these need to be developed in the context of a large number of specific enterprises to guide DSC adoption. By understanding the strategic purpose, the different stages and locations of DSC implementation to deploy and develop a clear roadmap. The study also does not examine the status quo of the current supply chain to identify the gaps of practices as well as predicting potential risks.

Based on these research limitations, the following suggestions are proposed for future study. Firstly, design and calibrate specific digital supply chain transformation strategies and routes according to different environments, different industries and different enterprises' specific digital stages; In addition to researching the creation and development of models, frameworks, methods, solutions, etc., attention should also be paid to researching and testing their usability, application or generalization, and possible risks as well as corresponding solutions and optimizations. Secondly, any progress could not be achieved by a single technology, but by their cooperation to improve the level of information system integration. Alternatively, it is the unavailability of a single technology. Thus, a quantitative evaluation framework is needed, which enables us to monitor, control and reflect the performance of digital supply chain implementation in the different applications by combining technologies together in valuable new ways. Thirdly, Strengthen the research on how to solve the supply chain information security. At present, the integration of many technologies has been developed to a certain extent, such as the contribution of blockchain technology to information security compared with AI and IoT [27]. Fourthly, it is necessary to anticipate future developments. For example, the transparency of information between supply chain partners is not only for commercial interests but also provides supervision for the social responsibility of enterprises, which reflects the social responsibility of enterprises. This transparency encourages supply chain partners to develop and share best practices for green operations and logistics. Supply chain partners can demonstrate compliance with industry best standards for worker safety, environmental protection and business ethics [84]. In addition, anticipate potential risks and threats in advance is imperative. Those issues, for example, how to strengthen the improvement of policies and relevant laws in the context of gradually transparent information to prevent criminals from speculating in crimes and how to guarantee people's basic employment, technical authorization and other sensitive issues regarding human rights are expected to be noticed.

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Options, Structure, and Digitalization of Value Chain Management Objects

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Abstract Although the essence and content of chain management concepts by values, demands, and supplies are worked out sufficiently, the problem of their hierarchy and relationships is not solved yet. The article aims to substantiate the options, clarify the structure, and develop the methodology for digitalizing value chain management objects. System analysis, grouping, and classification methods are used as research methods. The article substantiates the value chain management options based on the choice, adaptation, and creation of products and/or services. The management structure of this type is developed, including chain management of formalization, demands, supplies, and consumption. The classification of values is clarified, including the desired value, value prototype, value carrier, and perceived value. The main value types of chain management objects are proposed. The cipher structure of chain management objects is developed, which contains information about the management stage, objects types, stages and options of creating value, forms, and options for solving problems in value chains. The obtained results make it possible to more fully take into account the demands of end consumers; reduce the loss of lost profits when making management decisions; more effectively distribute resources, powers, and responsibilities in chain links.

Keywords Value chain management · Structure · Digitalization

1 Introduction

A well-chosen management concept makes it possible for an enterprise or group of enterprises forming chains to fulfill the demands of the end consumers of products and/or services in the best way, rationally combining and using material and non-material resources, as well as the knowledge and skills of personnel. At the same time, the choice of an effective management concept is rather difficult. On the one

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hand, "the search for a comprehensive definition of 'management' that is not over-generalized still proceeds" [9]. This means that based on several vague definitions of the term "management", management concepts and their options have been created, the copying of which does not guarantee the achievement of the enterprise's goal. On the other hand, even if there is a universal definition of the term "management", the enterprise needs to coordinate the concept content formed on its basis with concepts of suppliers and consumers pursuing different goals in different types of chains, such as supply chains [23], value chains [24], and demand chains [20].

The recognition by the majority of specialists of the effectiveness and prospects of implementing chain management concepts has led to the creation of its three basic concepts, respectively: supply chain management; value chain management; and demand chain management, the definitions of which are also far from perfect. In addition, the turbulence of the world economy [6]; orientation not only to meet the needs of the market but also to create and deliver values to end consumers [19]; need to ensure the sustainability and sustainable development of chains [12]; globalization of their economic activity [27]; development of information technologies and the digital economy [8], etc. influenced the content and development of these concepts largely. Therefore, it is premature to assert the stability of chain management concepts of various types. As a result, the choice of a particular concept involves the study of its content and relationships with other concepts, as well as the hierarchy substantiation of these concepts with their subsequent structuring up to the management concepts of enterprise divisions. The important aspects of solving this problem are:

(a) the orientation of chain management towards the creation of value for the end user of products and/or services;
(b) the study of basic types of value, which include "desired value", "value prototype", "value carrier", and "perceived value", as well as objects of value based on them. So, for example, in order to create the desired value, the researcher needs to give it a tangible form, from a complete misunderstanding of it to an idea, or better yet, a sketch of a future product and/or service, which are the objects of the desired value; and
(c) creation of prerequisites for the development of a clearer structure and algorithms of software and computer support, making it possible to improve the quality of management decisions in the links of circuits of various types. The development of this software is, on the one hand, a consequence of changes in the content and interrelationships of the above concepts of chain management, and, on the other hand, involves the introduction of adequate to these changes machine coding of the actual components of value chain management that ensure the determination of rational combinations of intellectual, organizational, and technical capabilities of chain links, as well as the involvement of necessary material, information, financial, and human resources and effective management by their flows.

The study intends to identify options and phases of the integrated concept of value chain management, requirements, and supplies; to develop a two-level classification of values, including types and objects of value; as well as to offer a methodology for creating ciphers of phases, objects, and components of value chain management for use in software and computer support for managerial activities. As such components, it is proposed to use the stages and options of value creation, forms, and results of solving the problems of chain management.

2 Literature Review

The results of this research are determined by the content of the term "value" largely. It is possible to agree with the opinion that "the value literature emanating from within the marketing discipline consistently refers to value as a complex construct, not well understood" [21]. Nevertheless, in the general case, value is understood to be "the relative worth, utility or importance of something" [7].

Porter defined value as "the amount that buyers are willing to pay for what a firm provides" [24]. This point of view is very popular among specialists, since it is based on the traditional understanding of the profit of the enterprise (in this case, not supplier, but consumer) and measured by monetary equivalent as the main value or goal of this enterprise.

The term "value" has undergone a number of fundamental changes over time. For example, Woodruff argues that the value is a perception that becomes the reference and evaluation in seeing the attributes of products, product performance, and results arising from the use [33]. Considering that "the term 'perception' can be defined as a process of interpreting the environmental factors such as smell, touch, vision, sound within the customer's frame of reference" [29], the value concerns the consumer's sensations, and "value is highly individual to each consumer" [21]. The fact that the value is unique is confirmed by the opinion of Feller et al. that, among other things, "value is an experience and it flows from the customer" [11].

Next, it is necessary to discuss the value determined by sensations, impressions, and experience of end consumers of products and/or services, or about such value types as "functional value" and "hedonic value" [14], as well as "personal value" [11], taking into account the development trends of "experimental marketing" [4]. This understanding of value allowed Potra and Izvercian to offer "a classification of four customer value perspectives" [25], including desired value, creation of value, value appropriation, and perceived value or different value types in the course of their life cycle. Depending on the research task, each of these perspectives or value types can be divided into components, which allows transferring the authority to manage value chains to the lower levels of enterprise management.

Porter defined the value chain as a set of interrelated activities that create value for the consumer [24]. It follows from this definition that the links of the chain are activities, not enterprises. At the same time, the chain of activities is impersonal and mostly unambiguous, and either the consumer him/herself or the set of linearly ordered enterprises, including the possible participation of this consumer, can create the necessary value in a competitive environment. An important aspect of the value chain is that it "describes the full range of activities which are required to bring a product or service from conception, through the different phases of production (involving a combination of physical transformation and the input of various producers services), delivery to final consumers, and final disposal after use" [18]. This point of view is possible to combine with the version of Potra and Izvercian [25], thereby obtaining not only the life cycle of product or service but also the value determined by sensations, impressions, and experience of the end consumer. At the same time, the value of this type can be provided by a separate product and/or service or its set; it can be distributed or unallocated in time once or repeatedly created by both the consumer him/herself and the value chain with the possible participation of this consumer [5]. Based on the terms "value" and "value chain", the authors propose different definitions of the term "value chain management". It is noteworthy that the dictionaries of such well-known organizations as the Council of Supply Chain Management Professionals [10] and the Association for Operations Management [3] ignore this term.

Aimin and Shunxi believe that value chain management is the coordinating management process focused on maximum customer satisfaction based on the coordination of goals of chain links within the business process "consumer relationship management" [1]. Teich uses the term "extended value chain management (EVCM)", which focuses on "the holistic consideration of the value chain" and generating orders "under consideration of previous production steps" [30]. Jörns describes value chain management as "a superset of the management concepts SCM, supplier relationship management, customer relationship management, and enterprise management" [15]. The study of the above and other points of view allowed Kannegiesser to assert that "value chain management is the integration of demand, supply and value decisions from sales to procurement using strategy, planning and operational processes" [17]. Jüttner et al. [16]; Singh and Power [28]; Thublier et al. [31] support this point of view.

To prove this point of view, it is necessary to distinguish between different types of chain management objects. The value chain management concept is focused on the value assessed by the end consumer through sensations and impressions that are transformed into experience. The demand chain management concept operates with information that reflects how future products and/or services will provide the end consumer with the necessary sensations and impressions. The supply chain management concept answers the question of how to create products and/or services ordered by the end consumer and deliver them to the place specified by him/her to get the desired sensations, impressions, and experience. In addition, it is advisable to distinguish between the concepts of value chain management and supply chain management that focused on the same object "the life cycle of products and/or services" currently.

The assumption that the value of the end consumer is determined by his/her sensations, impressions, and experience, which can also be presented in form of a life cycle, allows substantiating the scientific novelty of the results of this research and creating the necessary groundwork for future ideas on the article topic.

3 Material and Methods

The achievement of the research purpose is based on the use of qualitative methods, the basis of which is the classification method. The feature of this method is the identification of actual classification attributes, each of which corresponds to dichotomies [12, etc.]. The joint use of these attributes and dichotomies makes it possible to form and study binary matrices [2, etc.], on the basis of which the logic of this research is built.

The terms "code" and "cipher" are used separately in the research of binary matrices. Codes or symbols "0" and "1" denote dichotomies of the classification attribute. Combinations of codes at the level of one or more classification attributes used both in parallel and sequentially are designated by ciphers and are formed on the basis of several codes (symbols) "0" and "1" depending on the number of attributes of Management object.

Each sector of the created binary matrix is marked with the ciphers "00", "01", "10" and "11", which allows assigning them to one or another control object, as well as their combinations, forming the ciphers of more complex combinations of these objects. As a result, the necessary and sufficient prerequisites for describing specific management situations and adequate solutions to achieve the goals of various types of circuits are created with the help of computers and software. For example, to describe the following situation: the product with the cipher "10" at the workplace with the cipher "00" is rejected (cipher "11") by the feature "surface roughness" (cipher "01"), one should use the machine cipher 10.00.11.01. This cipher is received and processed by the computer, which gives a typical solution: the product with the cipher "10" from the workplace with the cipher "00" should be placed in the container for rejects (cipher "01") and moved by an electric vehicle with the cipher "11" to the warehouse of rejected products (cipher "10"). The machine cipher 10.00.01.11.10 is used for this solution.

4 Background

4.1 Value Chain Management Options

The introduction of the term "value" expands the scope of the term "need", which is traditionally used in the phrase "satisfaction of needs". The hypothesis put forward in this article takes into account the customer's need for not only products and/or services but also values, which allows developing an algorithm of value chain management and substantiating its main options and phases (Fig. 1).

The value in the form of sensations, impressions, and experiences of the end consumer can be obtained by consuming already created products and/or services, or these products and/or services need to be created or mastered. Moreover, in the second case, new products and/or services are either refined based on previously created

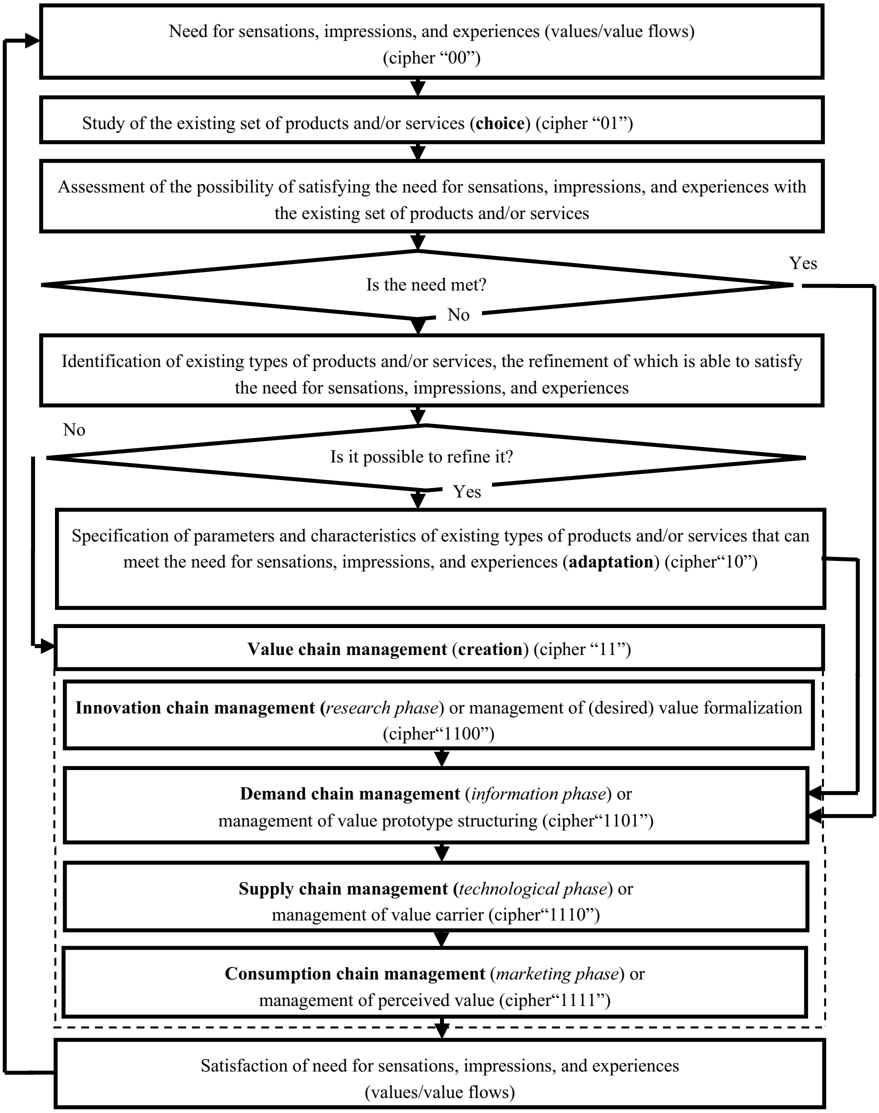

Fig. 1 Value chain management algorithm

prototypes or developed again. Thus, it is possible to distinguish three main value chain management options, based on choice, adaptation, and creation, respectively. If the selected set of products and/or services is not able to create value or satisfy the end consumer's need for sensations, impressions, and experiences, then it is possible to solve this problem with help of their partial refinement (adaptation to demands of this consumer). If the refinement (adaptation) of products and/or services is impossible or impractical, it is necessary to use the value chain management option focused on creation.

As follows from information in Fig. 1, the orientation of chain management to creation includes four main phases, which can be identified based on the synthesis of the above concepts of chain management and "the classification of four customer value perspectives" [25]. It is possible to assume that the value chain management concept operates with the term "desired value", the supply chain management concept is associated with the term "creation of value", the term "value appropriation" partially concerns the demand chain management concept and, finally, "perceived value" and comparing its results with expectations associated with "desired value" is the prerogative of marketing. In order to combine "customer value perspectives" and chain management concepts logically, it is necessary to clarify the relationships between their components as follows:

(1) "Innovation chain management", implemented by the consumer together with the supplier, or "novelty chain management" [30], implemented by the supplier based on the study of consumer values → "desired value" (research phase);
(2) "Demand chain management" → "value prototype" (information phase);
(3) "Supply chain management" → "value carrier" or products and/or services, as well as related resources (technological phase); and
(4) "Consumption chain management" → "perceived value" (marketing phase).

It is easy to notice that the first and fourth phases are interconnected, therefore, the chain management concepts presented in Fig. 1 form the management cycle or the integrated chain management concept focused on choice, adaptation, and creation of value. Although demand and supply chain management concepts are the parts of this concept, they can be used also without focusing on the creation and delivery of values, for example, to meet the needs of customers in products and/or services.

The special feature of Fig. 1, among other things, is the use of ciphers that allow characterizing a particular option of the chain management concept. The cipher is based on the binary codes "0" and "1". For example, the need for sensations, impressions, and experiences (values/value flows) has a two-digit cipher "00".In turn, the ciphers of the "creation" option are more complex. For example, the four-digit cipher "1101" means that the demand chain management concept or the information phase of the chain management concept is implemented in value chains.

4.2 Value Chain Management Structure

The options or phases of the value chain management concept provide for impacts on various value objects, which can be classified using the following qualitative attributes: "priority of the value object" (dichotomies: major and subsidiary); and "function performed by the value object" (dichotomies: creating and attendant of value).The joint use of these attributes and dichotomies makes it possible to distinguish the main, accompanying, auxiliary, and supporting objects in value chains (Fig. 2).

The information in Fig. 2 assumes the management of four basic objects for each value type: desired value, value prototype, value carrier, and perceived value. As a result, it is possible to clarify the structure of the value chain management concept, implemented in its main phases by specifying objects of value types (Table 1).

The information in Table 1 allows making the following conclusions:

(1) the main value types objects, as well as the results of chain management phases, are: images of products and/or services that create prerequisites for determining the method of creating value (sensations, impressions, and experiences); samples of products and/or services that guarantee the possibility of their preparation or development and contribute to the placement of demands for potential suppliers; products and/or services obtained as the result of the

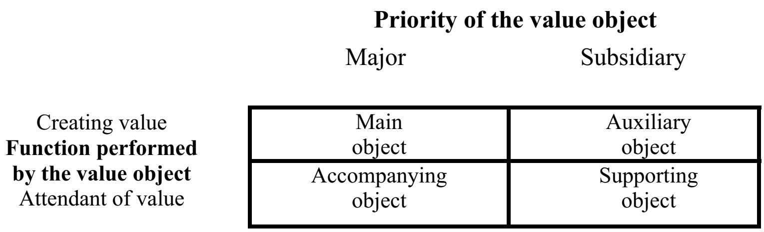

Fig. 2 Classification of objects in the value chain

Table 1 Classification of value types objects

Value object	Value type of end consumer			
	Desired value (00)	Value prototype (01)	Value carrier (10)	Perceived value (11)
Main	Image (0000)	Sample (0100)	Product (1000)	Sensations (1100)
Auxiliary	Idea (0001)	Layout (0101)	Component (1001)	Impressions (1101)
Accompanying	Sketch (0010)	Project (0110)	Energy carrier (1010)	Want (1110)
Supporting	Thought (0011)	Model (0111)	Tare (1011)	Experience (1111)
Result	Method of creating value	Demand for products and/or services	Ordering products and/or services	Satisfaction with the value
Phases of value chain management	Research phase	Information phase	Technological phase	Marketing phase

fulfillment of consumer's order and delivered to a specified place; sensations of the end consumer of products and/or services that contribute to satisfaction of perceived value. When creating value, not only the product itself can be used but also its components, for example, the drill for a puncher or the comb for cutting hair;

(2) according to information in Fig. 1, the technological and marketing phases of value chain management are aimed at the consumer's choice of products and/or services from their existing assortment. The information, technological, and marketing phases of management are implemented within the adaption of existing products and/or services to the value of this consumer. Creation, as an option of the chain management concept, provides for the passage of not only the phases listed above but also the innovative phase additionally;

(3) each type and object of value presented in Table 1 has the corresponding cipher (two-digit for a type and four-digit for a value object), which allows them to be recognized using software in the chain management process; and

(4) value objects presented in Table 1 form the typical sequence of their transformation or life cycle (Fig. 3).

The analysis of information in Fig. 3 allows making the following conclusions:

(1) if there is the need for sensations, impressions, and experiences (values/value flows) (Fig. 1), the flow of thoughts is formed at the innovation phase, both of consumer and of suppliers specializing in the development of new types of products and/or services. This flow leads to the appearance of ideas that are formed as images and fixed in form of sketches. The sketches are discussed

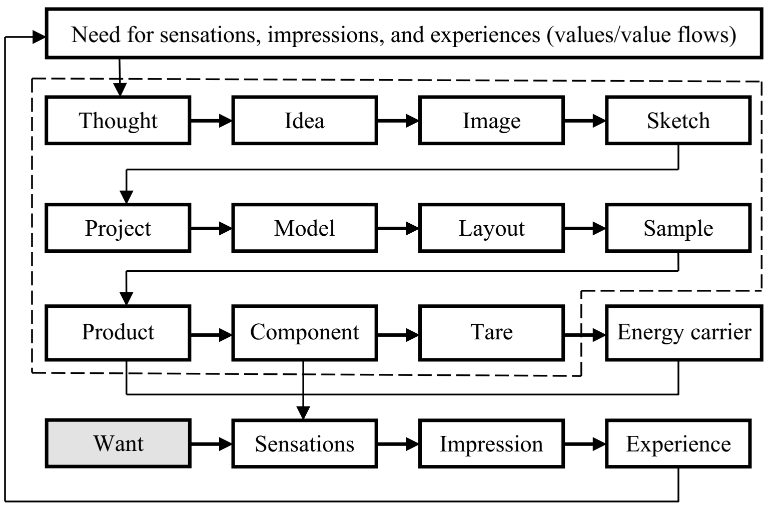

Fig. 3 Typical sequence of transformation of objects in chain management

by participants in the innovation phase, and if approved, the final sketch is transferred to the next phase of chain management;

(2) on the basis of the approved sketch, the project of products and/or services is developed, which is the basis for their modeling. The most successful model allows creating a layout that is tested in real conditions of consumption or operation. Successful tests of layout contribute to the manufacturing of a prototype product or installation batch for their subsequent testing and certification;
(3) during the technological phase, the necessary products and their components are manufactured, related resources are prepared, their packaging, packaging, and delivery to the place specified by end consumer are carried out;
(4) the product, components, and energy carrier (autonomous or non-autonomous), if desired, must provide the end consumer with the necessary sensations and impressions, as well as form the experiences that later influence his/her new values; and
(5) the sequence shown in Fig. 3 may have different options due to the particular chain management concept, the need to correct mistakes made and sometimes unavoidable, the existence of alternatives when making managerial decisions, the experience of those making these decisions, etc.

4.3 Digitalization of Value Chain Management Objects

Earlier, in Fig. 1 and in Table 1, management objects were represented, indicated by binary codes and ciphers. In order to use software for making appropriate management decisions in value chains, it is advisable to develop a complex machine cipher that includes simpler ciphers:

(1) stages of value chain management;
(2) the type of object of value;
(3) the stage of creating an object of value;
(4) options for its creation;
(5) forms of solving the problem of value chain management; and
(6) variants of the result of solving this problem.

The stages of creating value objects reflect the sequences of formation of "inputs" (some value objects) into "outputs" (other value objects), for example, thoughts into the sketches or ideas into the products and its components (Table 1). These stages should be unified, i.e. their application involves taking into account the generalized characteristics of specific value objects and using it at any stage of managing the chains of its creation.

To solve this problem, it is necessary to identify the preceding "k" and the subsequent "k + 1" value objects (Fig. 4); determine their actual classification attributes and dichotomies; identify the desired stages of creating these objects, as well as form the sequence of performing the selected stages.

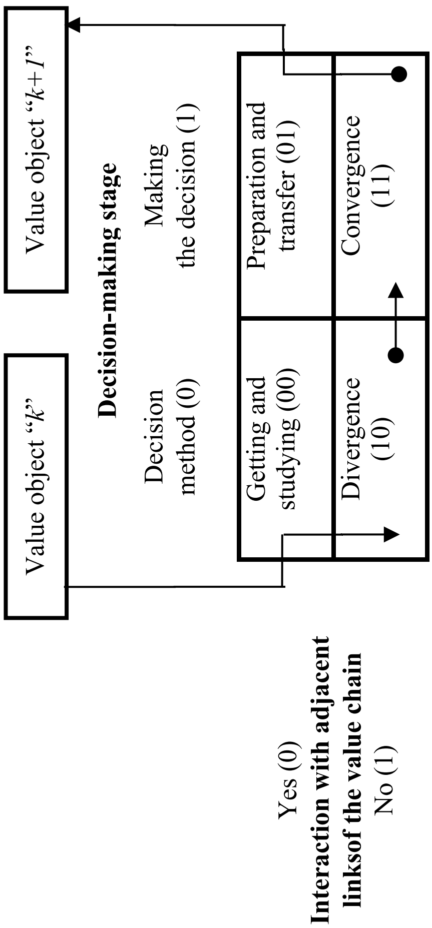

Fig. 4 Classification of stages of object creation

If to use such classification attributes as "decision-making stage" (dichotomies: method, code "0", and making, code "1", decision) and "interaction with adjacent links of the value chain" (dichotomies: yes, code "0", and no, code "1"), then the following stages of value creation can be substantiated: obtaining information about the created object from the previous link and studying it, cipher "00"; divergence, cipher "10"; convergence, cipher "11"; as well as processing information about the created object and its transfer to next link of the chain, cipher "01".

As it was shown earlier, either the consumer, or the supplier, or together the consumer and the supplier can create value. The value creation option can be substantiated using the following classification attributes and dichotomies: "consumer participation in value creation" (dichotomies: does not participate, code "0" and participates, code "1") and "supplier participation in value creation" (dichotomies: does not participate, code "0" and participates, code "1") (Fig. 5).

The joint use of these attributes and dichotomies makes it possible to identify the following options of creating values: waiting, cipher "00", self-service, cipher "10", service, cipher "01", and joint service, cipher "11".

Using the information in Fig. 5, it is possible to track options for managing the flows of consistently created values, taking into account their main types (Table 2).

For example, the creation of the desired value "2" is carried out by the consumer and supplier together, the prototype of this value by the consumer, value carrier by the supplier, and the perceived value by the consumer and supplier (in this case, the supplier creates necessary conditions for the consumer to receive desired sensations, impressions, and experiences). The need for value "3" has not yet arisen, which corresponds to the waiting stage.

The consumer plays a key role in creating value. If he/she attracts suppliers to cooperate, then the relationship between consumers and suppliers is formed to solve

Supplier participation in value creation	**Consumer participation in value creation** Does not participate (0)	 Participates (1)
Does not participate(0)	Waiting(Wt) (00)	Self-service (Ss) (10)
Participates(1)	Service (Sr) (01)	Joint service (Js) (11)

Fig. 5 Options of creating values for the end consumer of products and/or services

Table 2 Options for creating types of values

Options of creating values	Values types			
	desired	prototype	carrier	perceived
Value 1	Ss	Js	Js	Ss
Value 2	Js	Ss	Sr	Js
Value 3	Wt	…	…	…

	Number of problems facing the consumer: One (0)	Number of problems facing the consumer: Several(1)
Number of suppliers involved in solving problems: One (0)	Task (00)	Long-term relationships(10)
Number of suppliers involved in solving problems: Several(1)	Competition or cooperation(01)	Economically feasible relationships(11)

Fig. 6 Variants of forms of solving value chain management problems

certain problems. The main forms of solving these problems can be established using such classification attributes as "number of problems facing the consumer" (dichotomies: one, code "0", and several, code "1") and "number of suppliers involved in solving problems" (dichotomies: one, code "0", and several, code "1") (Fig. 6).

The joint use of these attributes and dichotomies makes it possible to identify the following options for solving value chain management problems: task, cipher "00", competition or cooperation, cipher "01", long-term relationships, cipher "10", and economically feasible relationships, cipher "11".

The results of solving the problem by the consumer or suppliers may be different. It is possible to establish options for solving a specific problem in value chains on the basis of such classification attributes as "effectiveness of solving the problem" (dichotomies: not effective, code "0", and effective, code "1") and "planned deadline for implementing the result of solving the problem" (dichotomies: came, code "0", and did not come, code "1") (Fig. 7).

The joint use of these attributes and dichotomies leads to the following types of results of solving problems in value chains: operational optimization, cipher "00", analysis of reasons for the inefficiency of solving the problem, cipher "01", implementation of the result of solving the problem, cipher "10", and waiting for the implementation of the result of solving the problem, cipher "11".

The information presented in Figs. 1, 4, 5, 6 and 7 and in Table 1 allows proposing the approach to the digitalization of value chain management objects. The logic and example of the formation of these object ciphers that ensure the use of software for making appropriate management decisions are presented in Table 3.

	Effectiveness of solving the problem: Not effective (0)	Effectiveness of solving the problem: Effective(1)
Planned deadline for implementing the result of solving the problem: Came (0)	Operational optimization (00)	Implementing the result (10)
Planned deadline for implementing the result of solving the problem: Did not come(1)	Analysis of reasons for the inefficiency of the solution (01)	Waiting for implementation (11)

Fig. 7 Variants of the results of solving the problem in value chains

Table 3 Logic and example of the formation of ciphers of value chain management objects

Classification attribute	Source	Ciphers
Value chain management option	Fig. 1	10
Types of value objects	Table 1	0101
Stages of value creation	Fig. 4	11
Options for creating values	Fig. 5	11
Form of solving problems of value chain management	Fig. 6	01
Variants of results of solving the problem in value chains	Fig. 7	01
The cipher of the result of value chain management		10.0101.11.11.01.01

Table 3 shows the example describing a specific situation in value chain management. The concept in the form of adaptation (Fig. 1) is characterized by the fact that at a given time, the analysis of causes of inefficiency (Fig. 7) of value layout (Table 1) created as the result of convergence (Fig. 4) is carried out jointly with the supplier (Fig. 5) selected on the basis of competition (Fig. 6), while the management situation has the cipher "10.0101.11.11.01.01". This cipher can be entered into the computer, after which it can propose the following management decision: return to the stage of divergence (cipher "10") value model (cipher "0111"), abandoning the services of the supplier (cipher "10"), issuing a task (cipher "00") to the consumer enterprise division in the conditions of operational optimization (cipher "00"). The cipher of this management decision: 10.0111.10.10.00.00.

Thus, digitalization makes it possible to characterize any options and situations of value chain management, which allows chain links to receive up-to-date information about its effectiveness. Based on the received information, management objects can make and implement management decisions in conditions of competition in a timely manner aimed at obtaining desired sensations, impressions, and experiences by the end consumer of products and/or services with the maximum degree of reliability and quality.

5 Discussion

The results presented in this article are initially debatable. In order to reach mutual understanding on theoretical and methodological aspects of research, it is necessary to consider the end consumer of products and/or services as an organism that depends on vital resources for it, and as a person who has the right to choose a particular resource in one or another of its execution and combinations with other resources. Therefore, in some cases, the value should be perceived as an opportunity to eliminate the lack of something: products and/or services or monetary resources to obtain them. In other cases, the value comes in the form of feelings, impressions, and experiences of the end user of these products and/or services. This aspect of the study involves the use of a set of "value" terms, ordered, for example, according to Maslow's hierarchy of needs

[22], beginning with the term "value", meaning human survival in the environment, and ending with the term "value" reflecting the degree of pleasure or enjoyment from its objects and processes.

According to the authors of the article, the discussion on the problem of value chain management can be productive in developing a classification of the lack of something felt by the end consumer and how suppliers can eliminate it, depending on the state of the environment.

6 Conclusion

The following results with signs of scientific novelty were obtained in the research: an algorithm for value chain management containing the main options and phases of management (Fig. 1); classification of management objects by types of values of the end consumer of products and/or services (Table 1); methodology for forming ciphers of value chain management objects (Table 3) for the purpose of their use in software support of management activities. The important result of the research is the creation of an integrated chain management concept based on the concepts of value (or novelty) chain management, demand chain management, and supply chain management.

Taking into account different objects of chain management (values, demands, resources), in the course of further research, it is planned to clarify the content of the integrated value chain management system by such components as goals, tasks, principles, functions, methods, and approaches and to establish the structure of this system depending on trends of the external environment. Based on the obtained results, it is advisable to work out theoretical and methodological aspects of sustainability and sustainable development of various chains, while maintaining the orientation of their development to create the sensations, impressions, and experiences necessary for end consumers. In addition, the process of transformation of value chains into networks is of considerable interest [26], which requires more complex software support for research and management activities, discussed in this article.

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Artificial Intelligence Disclosures in Sustainability Reports: Towards an Artificial Intelligence Reporting Framework

Enrique Bonsón and Michaela Bednárová

Abstract With the rapid proliferation of the use of artificial intelligence (AI) in organizations over the last decade, certain concerns arise regarding human rights, data security, privacy or other ethical issues that could be at stake due to the uncontrolled use of AI. However, concerns regarding transparency in the use of AI are not yet reflected in any standards for the disclosure of non-financial information, nor in current regulations. Voluntary disclosure of AI, being a novelty, is scarce, implies a lack of standardization and is limited above all to the financial, technology and telecommunications sectors. Therefore, the main objective of this paper is to seek consensus and to propose a set of relevant elements to structure the information on the use of AI by companies, to improve transparency, mitigate risks and demonstrate a real responsibility in its use. For the purposes of this study, a set of disclosure elements had been proposed based on multi stakeholder approach with the collaboration between the New Technologies Commission of AECA and the BIDA Observatory. The final proposal has been validated by online questionnaires and includes a guide to the general information elements (AI governance model; Ethics and responsibility; Strategy) as well as more specific disclosure requirements for each medium–high risk automated decision making (ADM) systems. Thus, this research attempts to contextualize the development of artificial intelligence reporting standards.

Keywords Artificial intelligence · Disclosure · Standardization

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1 Introduction

The rapid evolution of the new technologies over the last decade has brought significant benefits to companies in terms of higher efficiency, cost savings, revenue generation, higher quality work, or increase employee satisfaction. Rapid technology adoption will only continue to accelerate as its increased efficiency becomes more evident. Indeed, intelligent automation is recently a key investment for businesses all around the globe. The major investments flow to business process management software, machine learning, deep learning, and robotic process automation [7].

Nevertheless, at the same time certain concerns are being raised regarding the human rights, data security, privacy or other ethical issues, which might be at stake when the AI is incorporated into decision making processes. In particular, disruptive artificial intelligence tools with a high level of automation, massive data collection and manipulation, and possible inherit biases are reasons for a wider society to worry. Thus, proliferation of these new applications increases both stakeholders' scrutiny and regulatory interest. Yet, despite its significant potential risks, recently there is no legislation put in place to mitigate the risks of AI usage by requiring companies to be fully transparent about it. Nevertheless, some companies have already started to respond to this request by voluntarily disclosing such information in their non-financial report. Inspired, in part, by European Commission initiatives such as the Ethical Guidelines for Trusted AI, published in 2019 [23], or the White Paper on AI: A European Approach to Excellence and Trust [24] that have laid the foundations for the European regulation of AI, Artificial Intelligence Act, published in April 2021 [25].

Over the last two decades we could have witnessed how organisations all around the world initiated and evolved the non-financial disclosure to complete their financial statements [8]. Initially, there was the same stakeholder pressure, which required companies to be transparent about their environmental, social and governance performance due to possible negative impacts on the environment and society as a whole. This further led to the development of generally accepted reporting standards such as Global Reporting Initiative (GRI), EMAS, ISO 26000, SA 80,000, etc., which developed guidelines and key performance indicators (KPIs) of the non-financial disclosure. Soon after, in some countries, the legislation was put in place and non-financial disclosure became obligatory, in particular, for large companies. The European Council, as one of the earliest promotors of non-financial reporting, on October 22, 2014, adopted a new Directive 2014/95/EU on the disclosure of Corporate Social Responsibility (CSR) by large companies and groups, which modifies the previously adopted Directive 2013/34/EU on annual financial statements, consolidated financial statements and related reports of certain types of companies [26]. This was followed by the publication of Commission Communication 2017/C 215/01 (Guidelines for the presentation of non-financial reports) [22].

In June 2020, the European Financial Reporting Advisory Group (EFRAG) have initiated work for the elaboration of possible EU non-financial reporting standards [27]. In line with the European Commission mandate, the project Task Force on preparatory work for the elaboration of non-financial reporting standards has been carried out based on the multistakeholder approach within the European Corporate Reporting Lab. The main aim was to propose a roadmap for the development of a comprehensive set of EU sustainability reporting standards. The final report was published in February 2021 and provides 54 proposals for the elaboration of EU non-financial reporting standards. Their objective was mainly to describe the scope and structure of possible future sustainability reporting standards, not to set- out specific disclosure requirements, indicators or metrics. Built upon the proposed target standards architecture which would cover three layers of reporting (sector-agnostic, sector-specific and entity-specific), the ESG classification (the Planet, the People, and the Business) was recommended.

Regarding the social sub-topics, in the proposal #37, they point out that those might range from the Human Resources management perspective, to the broader Human Rights perspective. Thus, this disclosure should be aligned with international and EU reference frameworks and standards, including the UNGP on Business and Human Rights, the OECD Guidelines—and the other international declarations and principles—as well as with the Charter of Fundamental Rights of the EU. Nevertheless, a clear articulation of what should be reported in this category remains to be further explored and challenged. Similarly, despite that there are no specific instructions on how to report on data privacy, this issue has been raised within the proposal #38, related to Governance sub-topics, in particular, related to business ethics. Although there is no specific mention regarding the AI disclosure, due to its strong relation with the human rights and possible infringements of them, this area is worth exploring as a possible future component of the sustainability disclosure.

On 21st of April 2021, the European Commission proposed a legal framework, which serves as a proposal for a regulation on a European approach for AI, together with a coordinated plan with Member States on AI [25]. The main aim is to define rules and actions for excellence and trust in AI within the scope of a Europe fit for the Digital Age and to guarantee the safety and fundamental rights of people and businesses. The framework follows a risk-based approach and distinguishes four categories of AI systems: (1) unacceptable risk; (2) high-risk; (3) limited risk; and (4) minimal risk. Depending on the level of risk, the company would be obliged (or not) to a certain level of disclosure. E.g., the AI systems classified in a category of unacceptable-risk (applications and AI systems that could cause physical/psychological harm, manipulate human behaviour or exploit human vulnerabilities, or any application that would allow social scoring or real time remote biometric identification in public places) will automatically be banned. High-risk AI systems would require a comprehensive risk management and to guarantee quality of data, accuracy, robustness, traceability of results and cybersecurity. Limited-risk AI systems will be subject to lower transparency requirements (e.g., users should be at least aware that they are interacting with an algorithm). On the other hand, for minimal-risk AI systems no disclosure will be required (e.g., video games or spam filters).

Reporting on AI, being quite a novelty, implies a lack of standardisation in such a disclosure. To standardise it, first, a consensus has to be reached on what and how to report; what would be the key elements and what information should be disclosed to satisfy the information needs of different stakeholders. Therefore, the main objective of this paper is to propose and validate a set of general elements that should be disclosed to structure the information about AI (an important part of corporate digital responsibility—CDR); improve the transparency; mitigate the risks and prove a real responsibility in the usage of AI.

The paper can be considered one of the first attempts to structure and standardize the information related to AI in the non-financial disclosure context. Thus, a proposal and an external validation of the AI reporting framework can contribute to both literature and practice. Practical implications of this paper lays in helping companies to organize the information related to AI in a structured way focusing on relevancy. This research can be used as a springboard for further discussion, analysis and standardization.

2 Background

2.1 AI Disclosure Practices in European Companies

Nowadays, only few companies report on AI in their sustainability or annual reports. The early adopters of this new form of non-financial disclosure are mostly companies operating in financial, technological and telecommunication sector.

Recent study on AI ethical disclosures in corporate reports from 2018 and 2019 analysing IBEX 35 and DAX 30 companies shows that this type of disclosure is in its early stage and the companies providing such a disclosure are mostly from technological and telecommunication sector [9]. Similarly, a study regarding the AI disclosure in the annual reports of IBEX-35 companies show that this kind of disclosure is in a very early stage [10]. Nevertheless, the recent initiatives such as Ethics Guidelines for Trustworthy AI issued by the European Comission (2019) as well as the White paper on AI [24] are expected to increase the interest in AI transparency in the upcoming years.

Another recent study on ADM disclosure on the sample consisted of 962 annual/sustainability reports of the listed companies on the Western Europe countries (13 countries) stock markets published in 2018 and 2019 shows that ADM disclosure has still a long way to go and the first adopters are mostly companies operating in financial sector. Only 20 Western Europe companies disclosed the information related to ADMs in their annual/sustainability reports. Main categories of ADM disclosure that were identified in our study were: ADM for credit risk assessment (CRA); ADM responsibility; medical algorithms and diagnostic; and other. The latter being related to electronic sector disclosing the AI technology used in devices such as smartphones, smartwatches or home robots. The most frequent disclosure was related to CRA by companies operating in banking and financial services and ADM responsibility.

Nevertheless, despite the fact that the ADM for CRA was the most frequent reporting category, disclosure itself was rather general and there was a lack of details on which processes are fully automated and which are just assisted by the AI.

The second most frequently reported category was ADM responsibility. However, the way how this category was reported on shows weaknesses as well. We might have observed different approaches in this type of disclosure. Some companies were simply expressing general concerns regarding unacceptable effects of the decisions made by AI or regarding future scenario when the decisions will be taken only on the basis of some algorithm. Other companies were more specific regarding the ADM responsibility toward the issues such as avoidance of bias and discrimination; digital rights; or transparency that ADM is being used for personal data processing and clients' profiling.

However, extensive research is needed to properly explore what are the current practices in AI reporting of large European companies, and what are the determinant factors and incentives for such a disclosure.

2.2 Previous Studies

The studies of Mason [44] and Moor [45] were one of the first studies dealing with the information technologies' responsibility followed by studies focusing on ethics in emerging IT [13, 14, 17, 29, 51].

When the AI has become an integral part of business processes, concerns related to AI ethics started to be a topic for investigation [4, 9, 16, 28, 29, 33, 34, 36, 37, 50, 58] as well as data protection and privacy [3, 5, 12, 19, 41].

The term corporate digital responsibility is relatively new but there already are some studies focusing on this topic [39, 42, 43]. Nevertheless, the scope of those studies is rather narrow and there is a lack of conceptualization. On the other hand, there is an increased attention paid to this area by professionals.

2.3 Corporate Digital Responsibility

The Institute of Consumer Policy provides the following definition of CDR: "*companies' responsibility for the consequences of their business processes, products and services for employees, suppliers, customers, society as a whole and the environment encompassing: (1) data and algorithmic decision making, (2) participation and reduction of inequality, (3) digital education, (4) future of work, and (5) digitalization in service of an ecologic transformation*" [18].

According to Lobschat et al. [43] who developed a framework of CDR culture, organizations should be transparent about their responsibility in the digital age. Thus, CDR should focus on the ethical aspects that are inherent to the digital context.

2.4 Corporate Digital Responsibility as a New Layer of Corporate Social Responsibility

Although CDR has its own particularities due to the digital context [43, 54], some authors see a clear connection between the CDR and CSR as they share the same basic principles related to environmental and social concerns [55]. Early adopters organizations consider CDR a complementary aspect of CSR [21, 31, 48]. Indeed, professionals [21, 48] point out the importance of CDR to increase stakeholders' trust in the digital world and call for extending the scope of CSR by CDR arguing that companies have embraced the environmental and social responsibility idea but the digital revolution has brought new responsibilities. Gärtner et al. [31] point out the importance to adjust the way in which companies approach their responsibility as the digitalization affects almost all aspects of our lives.

2.5 Theoretical Background (Legitimacy Theory)

As CDR can be considered a new layer of CSR [21, 31, 48], the question arises, how the motivation of organizations to voluntarily disclose information about AI systems could be explained.

CDR approach can increase stakeholders' trust in digitalization [48]. As several studies suggest that legitimacy theory may provide a satisfactory explanation of voluntary non-financial reporting in general [6, 15, 20, 32, 35, 46, 53]; considering the parallel between the two, legitimacy theory seems to offer a reasonable explanation for voluntary AI or ADM disclosure [10].

Corporate legitimacy is a general assumption that the actions of a company meet the norms, values and expectations of a society [56]. Companies need to legitimate their practices and gain the acceptance from stakeholders in order to conduct their business successfully [20]. Higher transparency helps to increase the trust to the company and therefore improves its legitimacy. To gain the legitimacy, companies should continuously adjust their disclosure practices by focusing on the most relevant issues. By other words, they should focus on topics that raise certain concerns of a wider society in a particular moment of time. Nowadays, such concerns are related to the increased use of disruptive AI systems, in particular those that represents high risks and might raise some ethical issues such as facial recognition or black box ADMs [47, 57].

2.6 Technology Overview

Before opening a discussion about which information elements should be included into AI reporting framework, a brief technology overview is provided.

Intelligent automation refers to the use of technology to conduct work task, those are i.e.: Robotic desktop automation (RDA); Robotic process automation (RPA); Visual recognition technology; Artificial Intelligence (AI). AI helps automation evolve by combining Machine Learning (ML), predictive and adaptive models, natural language processing (NLP) and Deep Learning (DL) as a subset of ML.

2.6.1 AI Versus Automation

While automation focuses on streaming repetitive tasks, saves time and cost on monotonous and voluminous tasks, AI mimics human intelligence decisions and actions. Therefore, AI technologies and processes mimic how human beings react, speak, hear (even understand), and make decision. Machine Learning (ML) as a subset of AI, learns from data, identifies patterns and recommend decisions without human involvement. Deep Learning (DL) as a subset of ML, is based on artificial neural networks which continuously learns and even adjusts itself automatically to improve accuracy.

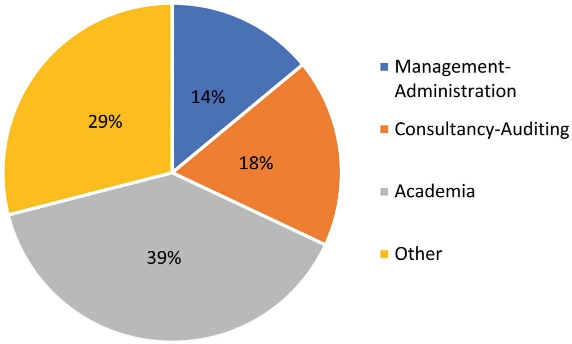
There is an immense variety of AI tools. Therefore, it is important to distinguish AI that is autonomous in making decisions and learns from data on its own, but the purpose and scope of its usage does not imply any harm or ethical issues and those, which are highly autonomous, learn and train themselves and might imply more harm to individuals by area where they are applied.

The first group would be AI applications such as textio, AI tool using predictive technology to write job listings to make them sound lucrative to potential candidates. Companies such as Twitter, Microsoft, Starbucks are using it. Another example of so called "low risk" AI app would be conversica, which is used to manage gross sales needs. It is an AI app that connects with the leads through automated two-way email conversation. X.ai is a smart assistant for handling meetings; Digital Genius is based on NLP and is able to maintain human like conversations with customers. Intraspexion is an AI tool to prevent and warn companies against litigation risks by regularly scanning company's internal emails and flagging potential litigation risks for future review. Similarly, a facial recognition app which is used for tagging photos on the social network such as FB, does not imply any harm.

3 Material and Methods

A set of indicators was proposed based on the European Commission's White Paper on AI—A European approach to excellence and trust (2020), Artificial Intelligence Act (2021) and Digital Rights Charter—XXIII Digital rights related to AI [52], and discussions with the BIDA Observatory and the New Technologies and Accounting Commission of AECA. The collaboration between BIDA Observatory and New Technologies and Accounting Commission of AECA represents a combination of business world, public organizations, regulatory bodies and academics.

Fig. 1 Respondents based on professional profile



Hence, following a multistakeholder approach. Such a proposal was later validated by international respondents through online questionnaire.

The objective of the questionnaire (Appendix 1) was to know the opinion about the relevance of each of the elements proposed as a guide to disclosure of information related to the use of AI in the non-financial information statement. The respondents were asked to rate each item on the scale 1 (least relevant) to 5 (most relevant) based on how important they think the information might be in the non-financial reporting context. They were also asked to add any other item they would consider relevant.

The final proposal of the elements was approved by the members of the New Technologies and Accounting Commission of AECA and the BIDA Observatory through followed-up discussions. The questionnaires were sent in the period of January-March 2021. In total, 44 questionnaires were responded (response rate 58.6%). Professional profile of the respondents is depicted in Fig. 1.

4 Results

Based on the scale 1 (least relevant) to 5 (most relevant), the average evaluation of proposed reporting items is depicted in the Table 1. As can be seen, every item received at least 4 points on average, which implies a high relevance of a proposed particular item in the context of non-financial reporting.

After the validation of the proposed reporting elements (all of the items are considered validated as they had obtained equal or more than 4 points on the scale 1–5) a framework which consists of two main parts: general elements and specific ADM disclosure was developed.

Table 1 Average evaluation of proposed reporting item

Category	Reported item	Evaluation
AI governance model	GM1	4.3
	GM2	4.4
	GM3	4.2
Ethics and responsibility	ER1	4.4
	ER2	4.3
	ER3	4.0
Strategy	S1	4.4
	S2	4.1
	S3	4.1
	S4	4.1
ADM disclosure	ADM1	4.4
	ADM2	4.2
	ADM3	4.3

4.1 General Elements Disclosure

When disclosing the information about AI, it is important that each organisation first describes the context in which the AI technology is used, why and how. As AI disclosure is rather a new trend, there is a lack of guidelines on what and how to report. Therefore, below we provide a brief guidance on narratives related to general elements, which we consider relevant to be reported on.

Nevertheless, there is an urgent need for internationally recognized and generally accepted AI reporting Standards, which would represent global consensus and best practice for reporting publicly the impacts of organisation's AI usage. AI reporting based on the Standards would also aim to guarantee an organization's commitment to fundamental rights such as freedoms, privacy, data protection and non-discrimination while incorporating AI technology, by other words it would demonstrate its corporate digital responsibility (Table 2).

I. *Governance Model and System Control*

Organisations should be transparent about how the AI is governed within the organisation. Hence, the following information should be provided: what is the governance structure; who is being held for responsible; existence of departments or committees such as data protection officer or monitoring committee; information about continuous monitoring as well as external verification systems and processes.

II. *Ethics and Integrity*

Some companies might rely on international principles regarding the ethical use of AI such as IEEE, EU, OECD, etc., while others might design their own principles or code of ethics related to the AI usage. In this point, the organisation should provide some information about the main ethical issues as well as mechanism for advice and

Table 2 Information about AI in the non-financial report

General elements	
I. AI governance model	(GM1) Governance structure, roles, responsibilities, departments and committees
	(GM2) Continuous monitoring, control and internal verification
	(GM3) External verification systems or processes (of black box ADM and high sensitive applications)
II. Ethics and responsibility	(ER1) AI principles followed by the company (own, EU, IEEE, OECD, etc.)
	(ER2) Relevant ethical issues, especially in relation to sensitive applications such as facial recognition, black box ADMs and recommendation systems
	(ER3) Mechanisms for users to receive meaningful explanations
III. Strategy	(S1) AI risk and impact analysis
	(S2) Relations with stakeholders, participation in organizations and forums related to the responsible development of AI
	(S3) Training activities (internal and external) on responsible use of AI
	(S4) Projects focused on meeting the Sustainable Development Goals (SDG)

concerns about ethics regarding the responsible use of AI. Thus, the scope of AI disclosure should be outlined starting with the list of material topics such as privacy matters; the usage of highly sensitive apps such as facial recognition; and ADM.

In addition, there should be a contact point where individuals can direct their queries regarding AI report as well as information about the fundamental rights of individuals who were treated by the AI of the company.

III. *Strategy*

Perhaps the most relevant part in this section would be how the AI related risks are identified and managed. Company can also report on ongoing training activities related to responsible usage of AI and any projects focused on SDG, where the AI plays a crucial role. Relations with stakeholders, participation in organizations and forums related to the responsible development of AI can also be disclosed here.

Nevertheless, the most attention should be paid to the risk assessment. Some applications such as the facial recognition might be more sensitive for a societal approval due to various practical or ethical implications. To identify which applications implies higher risks than other, a proper risk assessment has to be conducted and described.

Company should be transparent about in which areas of the company the AI is being involved. Some applications might involve more ethical issues due to the purpose they are used for, e.g., AI used in the HR, which involves decision about humans in comparison to AI in the manufacturing. Other applications become riskier when they are left autonomous with low or no human supervision. Thus, the purpose of AI usage and the level of automation and independence should be considered as relevant factors in the risk assessment.

4.2 ADM Transparency

4.2.1 Risk Assessment Following the EC Approach

After performing the risk assessment, AI applications should be categorized based on their risk level. This way, applications with higher risk level would require more detailed disclosure on how the data are collected, stored, and managed; how the algorithm works; potential risks, biases and mitigation plans; strategy to ensure transparency, auditability, explicability, accessibility, usability, trust; and verification internal/external.

More transparency, for example, would be required for black box ADM in the critical areas as they imply the highest potential risk.

The aim of distinguishing 4 level AI risk categories, such as the approach of EC, is twofold, to protect individuals against negative impacts of highly sensitive AI applications, and not cause unnecessary burden for companies which are not using invasive AI technology.

4.2.2 ADM Disclosure

As described above, a special attention should be paid to highly autonomous AI tools—algorithmic decision systems (ADS) also known as Algorithmic decision making (ADM) which are based on the analysis of large amount of data to infer correlations or to derive information to make decision. Such applications imply, per se, potential practical and ethical concerns as the decision making is left on the machines. Humans are error-prone and biased, but systems can be biased too. That is why, it is important to know who built them, how they are developed and how they are ultimately used. To avoid bias in the algorithm, it should be fed with a representative dataset, the right model should be chosen, and the algorithm should be continuously reviewed and monitored. Therefore, the transparency on these aspects might not only increase the trust to the ADM but also serve as a proof of a company's commitment to corporate digital responsibility (CDR).

Regarding the ADM, we should distinguish between those which are rather predictable, so with certain input we obtain an expected and repetitive output (such as ADM in automating quality control) and those which are based on Machine Learning (so the decision is made within a "black box"), in particular, when they might have an impact on individual's life. ADM processes are fed with data, which might be biased. If there is a bias in the data the ADM is trained with, this bias would be reinforced and amplified which ultimately leads to unfair or discriminatory decision.

Table 3 ADM disclosure framework

ADM disclosure	
Automatic decision-making system (ADM) transparency (of systems that may imply a potential risk for the subject on whom it is decided)	(ADM1) System description: type, input data, algorithm design, human supervision, etc
	(ADM2) Statement that the system complies with the digital rights regulation related to AI or, if applicable, that algorithmic non-discrimination, transparency, auditability and explicability of the algorithm are ensured, as well as its accessibility, usability and reliability
	(ADM3) Verification of compliance by independent agents

Thus, the results yield by the ADM can be discriminatory without decision-makers to be motivated to discriminate. E.g., there might be some variables, such as gender or race, which normally can not be taken for consideration while making a decision but are often statistically associated with seemingly inoffensive characteristics, such as height or postal code. As ADM works with huge datasets of correlated data, it can lead to indirect discrimination. Therefore, individuals should have two basic rights when the decision has been made based on the "black box" ADM, (1) right to a meaningful explanation and (2) right to contest. Hence, companies should ensure individual awareness of the processes where "black box" ADM has taken place, as well as of their associated rights.

Thus, the disclosure in this section should cover basic system descriptions such as: type of algorithm, input data, algorithm design, information if there is human supervision or not, etc. Together with the statement that the system complies with the digital rights regulation related to AI or, if applicable, that algorithmic non-discrimination, transparency, auditability and explicability of the algorithm are ensured, as well as its accessibility, usability and reliability. The company can increase the credibility of such a disclosure by having it verified by independent agents (Table 3).

5 Discussion

As CDR seems to be a new layer of CSR, we might expect certain changes in corporate disclosure in the upcoming years [31]. Following the pattern of CSR disclosure evolution, first we might expect early adopters, normally large corporations, which will voluntarily disclose CDR aspects in order to legitimate their digital practices. This will likely continue with seeking a global consensus on what and how to disclose which would be later followed by legislation [7]. Nevertheless, while CSR disclosure took more than two decades until the legislation was put in place, with CDR we face higher urgency to address the risks associated due to the exponential advancements of technology where the damage might take decades to repair, in particular, when we are talking about the ADM.

The aim of this paper is to draw attention to an emerging trend, AI usage and reporting, discuss the need of a global Standard for such a disclosure and contribute to its creation by proposing the draft of general elements, which should be reported on.

The main aim of the new Standards for AI disclosure should not be to cause more burden on the companies to prepare their non-financial reports or to demonize the usage of AI which can be indeed highly beneficial, but there are certain fundamental rights of individuals that should be guaranteed. Hence, it is important to act quickly as the negative impacts of irresponsible AI usage might take decades to correct.

The main concerns are human rights, data security, privacy or other ethical issues that could be at stake due to the uncontrolled use of AI. Therefore, on one hand to require from companies to be more transparent about the use of AI and on the other hand, to provide them with a clear guidance on what and how to report might help society as a whole to prevent undesirable events to happen. For better illustration, we can focus on e.g., privacy, a fundamental human right, some AI are based on personal information which has consequences for their privacy. Initiatives such as Personal Information Protection and Electronic Documents Act (PIPEDA) in Canada but also institutions such as EU point out the importance of privacy as a fundamental human right, therefore, when organizations want to feed their AI tools with personal data, they should complete so called privacy impact assessment (required in Canada) form and perform balancing test in which they compare the necessity and proportionality of the measure with interests, fundamental rights and freedoms of individuals. Such transparency and accountability should help to avoid collecting data for data sake (or even doing business with data) and to use disproportional measures (e.g. the usage of facial recognition if other less invasive method could be applied based on less sensitive data). Hence, the main aim of this paper is to contribute to a creation of such an accountability tool, which would deal with this and other ethical issues that might arise.

6 Conclusions

Given that the AI technology in a modern and interconnected world is a global problem, global consensus based on multistakeholder approach should be pursuit. Only this way, we as a society can guarantee the respect of fundamental rights such as freedoms, privacy, data protection and non-discrimination while using AI technology and benefiting from it.

This study is one of the first attempts to standardize AI disclosure by proposing and validating the most relevant elements of AI reporting and developing an initial AI reporting framework. Nevertheless, before closing, limitations of the study should be acknowledged and future research outlined. Still, extensive research is needed to properly explore what are the current practices in AI reporting of companies, and what are the determinant factors and incentives for such a disclosure.

The proposal of the elements was validated through multistakeholder approach by the members of the New Technologies and Accounting Commission of AECA and the BIDA Observatory and may represent a first attempt toward the AI disclosure standardization. Nevertheless, due to a fast evolution of AI technology, a continuous assessment of disclosure elements should be performed.

Appendix 1

QUESTIONNAIRE: Information About AI in the Non-financial Report

The objective of this questionnaire is to know your opinion about the relevance of each of the elements that are proposed as a guide to disclosure of information related to the use of Artificial Intelligence (AI) in the non-financial information statement.

Please rate each item based on how important you think it might be in the non-financial reporting context. Use the scale 1 (least relevant) to 5 (most relevant).

Your professional profile*

- Consultancy-Auditing
- Management-Administration
- Academia
- Other:

Company or institution*

Your answer

AI governance model

Governance structure, roles, responsibilities, departments and committees.

Continuous monitoring, control and internal verification systems.

External verification systems or processes.

Ethics and responsibility

AI principles followed by the company (Own, EU, IEEE, OECD, etc.).

Relevant ethical issues, especially in relation to sensitive applications such as facial recognition, black box ADMs and recommendation systems.

Mechanisms for users to receive meaningful explanations.

Strategy

AI risk and impact analysis.

Relations with stakeholders, participation in organizations and forums related to the responsible development of AI.

Training activities (internal and external) on responsible use of AI.

Projects focused on meeting the sustainable development goals.

For each automatic decision-making system (ADM) that may imply a potential risk for the subject on whom it is decided:

System description: type, input data, algorithm design, human supervision, etc.

Statement that the system complies with the digital rights regulation related to AI or, if applicable, that algorithmic non-discrimination, transparency, auditability and explicability of the algorithm are ensured, as well as its accessibility, usability and reliability.

Verification of compliance by independent agents.

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Economic Indicators of the Algorithm for Introducing Artificial Intelligence into the Automated Process Control System

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Abstract The relevance of the paper is due to the digitalization of the economy and the introduction of artificial intelligence in production processes. This paper attempts to assess the effectiveness of artificial intelligence for the automation of production. Thus, the purpose of the work is to evaluate the effect of the introduction of artificial intelligence into automated process control systems. For this, an algorithm for implementing artificial intelligence was developed, i.e., procedures and their sequence were identified when implementing artificial intelligence in automated process control systems. The following procedures were considered: selection of implemented artificial intelligence functions, selection of an artificial intelligence system, selection of hardware implementation and acquisition of artificial intelligence, formation of tests for artificial intelligence training, implementation of artificial intelligence, and evaluation of results of implementing artificial intelligence. When implementing artificial intelligence, one should choose artificial intelligence based on neural networks with deep learning. The ambiguity of the cost estimate existed when selecting hardware due to the lack of data from developed artificial intelligence versions. This complicates the definition of capital expenditures. A formula for calculating costs of implementing artificial intelligence costs in automated process control systems is proposed. The introduction of artificial intelligence into an automated process control system will not provide significant savings. Such conclusions are drawn on the basis of the calculation method.

Keywords Artificial intelligence · Automated process control system · Economic efficiency

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1 Introduction

The fourth industrial revolution (Industry 4.0) is characterized by "the transition to fully automated digital production, controlled by intelligent systems in real time in constant interaction with the external environment, going beyond the boundaries of one enterprise, with the prospect of combining things and services into a global industrial network. Broadly speaking, Industry 4.0 characterizes the current trend in automation and data sharing, which includes cyberphysics, the Internet of Things, and cloud computing. It represents a new level of manufacturing and value chain management throughout the product lifecycle" [1].

The development of technological processes at this stage is unthinkable without the use of artificial intelligence (AI) [2]. In his study, Viskhan [3] noted the importance of AI in building a business model. Human intelligence is a property of the psyche, which consists of the ability to understand the new environment situation, learn and memorize based on experience, understand and apply abstract concepts, use knowledge to manage the human environment. AI has more modest capabilities. There are different points of view on AI. Non-experts believe that AI has human intelligence, self-consciousness and can work independently. However, in practice, the abilities of AI are due to predetermined rules and norms, i.e. AI is not an autonomous technology that can think independently, and does not have imagination and creative abilities. There are also many other definitions of AI. AI is a property of intelligent systems to perform creative functions, which are traditionally considered human prerogative. AI is the science and technology of creating intelligent machines, especially intelligent computer programs [4, 5]. Table 1 shows the general (conceptual) definitions of AI.

The definitions given are essentially identical but differ in the terms used. Line 2 of the table deals with software and hardware, and line 4 with hardware and software. The difference between these points of view is insignificant. Row 3 of the table uses the concept of intelligent agents, which implies a combination of AI and its connections with the external environment. The external environment does not affect AI functions. The principles of its development, training, and implementation do not depend on the external environment. For this reason, the AI definition in line 3 appears redundant.

As a result of the analysis, the authors proposed a definition from a practical point of view. AI is hardware and software that partially models elements or functions of the human psyche such as: perception; memory; understanding of the subject area; attention.

Table 1 Comparison of views of various authors on artificial intelligence (AI)

Author	Concept	Advantages of the definition	Disadvantages of the definition
Raikov [6]	AI is computer philosophy, computer psychology, and advanced computer science	Conceptual definition	It is not clear from this definition how to implement AI
Voronovich et al. [6]	AI is the concept of creating software and hardware that can carry out intellectual activities comparable to the intellectual functioning of a person	Main AI capability specified	It is not clear how this ability can be realized
Russell and Norvig [6]	AI is the design and construction of intelligent agents that perceive environmental objects and take actions that affect the environment	Introduced the concept of intelligent agents—AI with links to the environment	It is not clear how to implement agents
Batyrkanov and Saitov [6]	AI is the field of informatics, the purpose of which is to develop hardware and software tools that allow a non-professional person to set and solve intellectual problems	More specific definition	Turning to computer science complicates the definition

2 Background

Today's intelligent systems have very narrow applications. For example, programs that can beat a person in chess cannot answer questions, etc. AI is defined as a set of technologies for implementing cognitive tasks carried out by a person using information processing means. These include technologies such as: computer vision; natural language; virtual assistants; software robots, robotic process automation; neural networks; machine learning; deep learning, and a number of other technologies.

The introduction of AI in a number of areas of human activity will allow achieving a significant increase in GDP. The article "How artificial intelligence is used in business: overview and cases" [7] states that the introduction of AI by 2030 will increase global GDP by 14%, that is, approximately $15.7 trillion. According to PricewaterhouseCoopers (PwC), an international network of companies offering consulting and auditing services, this is more than the current total industrial production of China and India. According to the Terata research, the vast majority of large companies

(80%) invest in AI technologies, and according to Gartner forecasts, by 2020 they will be present in almost all new software products and services.

The sources have a lot of data on the use of AI in the financial sector and business. The use of AI in business and in banks gives a great effect.

The main properties of AI (machine translation, speech recognition, text processing in natural languages, computer vision, automatization of driving cars, and much more) are due to deep learning. This is a subset of machine learning, characterized by the use of models of neural networks, which can be said to mimic the work of the brain. Any neural network model is trained on large data sets, thus it gains some "skills".

AI technologies are in demand in the digital economy. It is known that AI is used in banks, for example, in Sberbank of Russia. AI can perform the following functions [8]:

- issue all loans at Sberbank by the end of 2020; for this, AI will compare the client's biometric data, credit history, income, costs, and will independently make a decision (savings on the operator's salary and reliable loan repayment);
- Sberbank's Online Preferences application will analyze 50 million users according to 1000 parameters and form a package of services and information individually for each user—frequent transfers and payments, spending statistics, etc.;
- preliminary interviews with candidates for mass vacancies are already conducted by a robot, which asks questions depending on the situation and, if the candidate meets the requirements, switches the conversation to a person—an HR service employee (savings on the operator's salary and high-quality personnel selection).

AI can also be successfully used in the fight against fraud, as chatbots and voice assistants, in biometrics, when assessing credit ratings, for risk management. AI is widely used in trade [9].

AI strategies should be used in business to completely transform it, and not only in pilot projects. The use of AI for sales growth is more profitable than for reducing costs, and the development of AI brings more benefits than the use of other people's technologies. It is profitable to use AI to recognize customers and transfer specialized offers to them. For example, engineers of the Facebook laboratory for the study of AI presented in June 2017 the results of work on a bot that can lie and bargain with people. According to Quartz, during the training, the system used more than 5.8 thousand real human dialogues during negotiations collected using the Amazon Mechanical Turk crowdsourcing online platform.

The introduction of AI affects the physical, socio-emotional, and intellectual aspects of human activity, the retraining of personnel [10–12]. From these positions, it is relevant to introduce AI into production, for example, in automated process control systems (APCSs). AI will improve the accuracy of the processed information and improve interaction with operational personnel. AI is used for the following purposes: analysis of programs [13], monitoring of tool condition [14], results of operation [15], simulation of robot systems [16], metering of devices [17].

3 Results

3.1 Purpose of the Work

The problem was identified—insufficient research in the field of assessing economic indicators when introducing AI into technological and production processes, insufficient elaboration of the methodological apparatus for supporting each stage of the introduction of AI into APCSs.

The purpose of the work is to identify the components of economic indicators when introducing AI into production—into an APCS. The relevance is due to the significant spread and gradual introduction of AI into enterprises' production processes. In addition, the growth of digitalization, in turn, determines the relevance of the introduction of AI as a tool that increases productivity and product quality.

3.2 Implementation Object—APCS

The study hypothesis—the introduction of AI leads to an increase in industrial productivity.

APCSs have a hierarchical computer system. At the upper level of an APCS, there are powerful servers that contain a mathematical model of the technological process and all the necessary knowledge bases and databases for the operation of expert systems. When implementing AI, these servers cannot be used. So powerful AI-based PCs will have to be purchased separately.

At the other level, there are automated workplaces (AWSs). Using AWSs, process operators monitor the state of the process and, if necessary, issue control commands. Thus, a 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, a correct decision to correct the process. Such problems can lead to disruption of the optimal process flow until the process stops in emergency situations.

Microcontrollers and programmable logic controllers (PLCs) interact directly with process objects. Programs in the PLC are performed 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 are used, operating according to a special algorithm.

At the lower level, there are actuators.

All layers are connected by different types of computing networks.

The implementation of APCSs allows increasing the productivity of technological processes due to improving the quality of their management under the following conditions: increasing production; increasing the unit capacity of equipment; use of forced critical modes of equipment operation; complication of production processes; increasing requirements for the quantity and quality of products produced; lack of manpower. Implementation of process control automation has the following functions: automating the receipt, collection, processing, and presentation of information; remote control of the object; introduction of automatic regulators; coordinated control of regulators; higher reliability of automatics operation; automating decision-making. The listed functions in the current APCS are performed by the existing computing means in it. These functions can be performed with high efficiency by AI. In automation systems, the process operator has other functions: control of automatics operation; monitoring of the operation of non-automated equipment and technological processes; assessment of equipment operability and quality of technological process within the limits of regulations; process control in emergency situations, including failures of individual automation systems. Each operator analyzes a specific set of information for making decisions within the framework of one's functionality. However, in any case, all these decisions are a priori influenced by the "human factor", which means that they may be erroneous. The price of such mistakes can have huge economic, environmental, and social consequences. To eliminate these errors, it is advisable to use AI in APCSs in order to reduce the influence of the "human factor".

3.3 Algorithm of AI Implementation in APCSs

Stages of AI implementation in APCSs are presented in the form of an algorithm diagram in Fig. 1. Most blocks of the algorithm are identical to the stages of development and implementation of automation systems. The difference is the need to form tests and teach AI.

3.4 Evaluation of AI Implementation Stages

This choice is made at the design stage of the AI-based modernization of APCSs. It is not advisable to assign all functions to AI in the current APCS, since many functions in such systems are already performed by conventional computing tools. The following statement is based on the assumption that AI implements part of the APCS functions.

In the known APCSs, the traditional approach to modeling was implemented, assuming the completeness and accuracy of knowledge about the process. This approach is practically not applicable in the consideration of complex multifactorial processes, which in general are difficult to formalize. The complexity of real processes leads to the search for unconventional methods for building their mathematical models and optimizing their management. At the same time, not only the aspect of optimal control is very important but also the aspect of analyzing the current state of the process, since it is the conclusion about the current state of the process that allows choosing the optimal control in a given situation. Such analysis can be

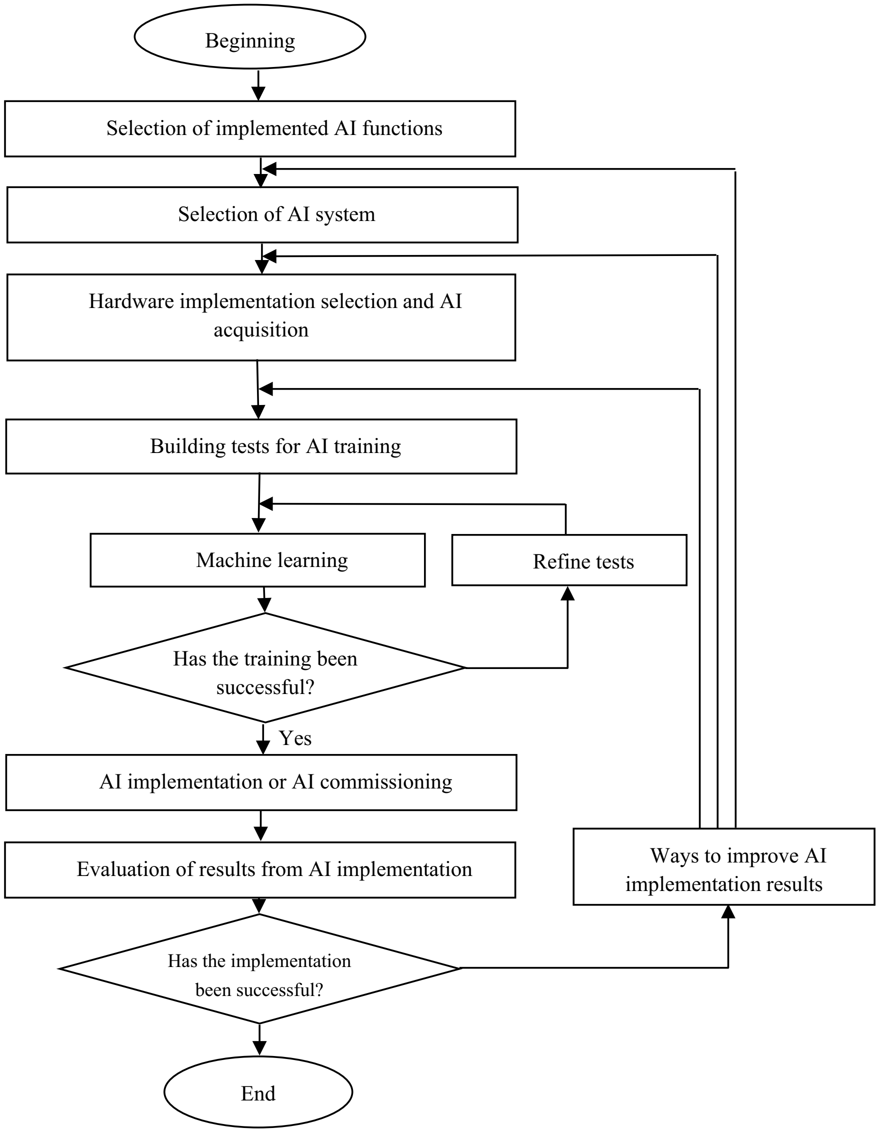

Fig. 1 Diagram of the algorithm for introducing artificial intelligence in an APCS

performed by AI on the basis of a system of structure-flow-multilevel recognition of the technical state of the process in real time [18].

For the initial processing of incoming information, it makes no sense to use AI, since the known processing algorithms cope with this task. Verification of data may involve more complex analysis. APCSs use very simple algorithms such as permissible range control. However, the operator includes multifactor solutions for data verification. In this case, the operator takes into account not only the values but also the dynamics of the indicators. In such situations, a person relies on a complex model, including knowledge not only about the measurement process but also about the object and its model, and if the task is to replace a person with AI, it is necessary to teach it that way.

The next function is signaling, that is, estimating the deviation of the parameter from the set range, both by values and by their rate of change. To replace a person here, AI must take into account the causal communications in the process and operation of the equipment and, on their basis, conclude the root cause of the alarm, and then make an appropriate decision.

The next function is emergency protection. In an APCS, it is performed automatically without human participation, using rigid algorithms that fully reflect technological regulations and regulatory document installations. Here, possible uncertainty through the use of AI is an unacceptable risk. However, if one teaches AI to verify the data and replace it with reliable ones, then at this stage there will be a significant reduction in the number of false shutdowns, and, therefore, losses from downtime and restart. The use of even the simplest AI algorithms for data verification demonstrates the effect of reducing the number of false stops by 5–10 times.

The function of automatic regulation is the most difficult for AI, because, despite repeated attempts to use smart algorithms, including neuroregulators, regulators with fuzzy logic, etc., so far "smart" algorithms have not found wide application. At the same time, the request for the implementation of this function is increasing, since there is a shortage of highly qualified regulators in the market.

A classic PID controller is good when regulating stationary objects, however, if the properties of the object change, the problem arises of calculating new optimal values of adjustment coefficients. Here, a specialist in the maintenance of automatic control systems is required. This competence requires a lot of practical experience and an accumulated knowledge base, as well as time. It is known that there are a number of attempts by both foreign and Russian companies to create software for automatic adjustment of regulators, where coefficients are read by classical mathematical methods. After implementation, such regulators are turned off due to a lack of qualified specialists with knowledge of the theory of automatic regulation. Such professionals are in manufacturing companies, but customers do not have them.

Thus, there is a problem that AI completely replaces a person—a specialist in setting up automatic control systems. To do this, one may need to adequately model the behavior of a very experienced regulator tuner. However, the emergence of systems of "smart" adjustment of regulators based on other logic is likely.

The next function is remote control. In today's reality, it is carried out in some cases by a person who independently makes appropriate decisions to turn on or off the equipment, to change the position of the actuators, and so on. There is a huge influence of the so-called "human factor", which leads to tens and hundreds of thousands of erroneous decisions, the result of which is damage, in some cases catastrophic. Such situations are eliminated by the use of a digital advisor or digital assistant. Its functions are: intelligent monitoring and analysis of process and equipment flow;

creation of appropriate messages for users (in natural language); monitoring and analysis of personnel actions; warning about possible adverse situations caused by failed operator decisions; development of tips on correct sequential operations, including with non-automated equipment and in emergency situations (for example, in case of emergency situation elimination); recognition of the operator's speech and execution of his/her commands.

The digital advisor should be self-taught and constantly develop its skills in control and interaction with the operator, which can implement AI. In the case of fast-flowing technological processes, automation of decision-making is necessary, since the operator will not be able to provide control of such processes.

The cost of this phase corresponds to the cost of the project work. The duration of the stage is several months.

It is advisable to choose an AI system in the form of a neural network. Algorithms of neural networks operation are formed during training [19, 20]. Neural networks are used to solve complex problems, for example, recognition of geometric shapes or clustering of objects. The genetic approach is based on the idea that a certain algorithm can become more effective if it borrows better characteristics from other algorithms ("parents"). A relatively new approach, where the task is to create an autonomous program—an agent that interacts with the external environment, is called an agent approach. There are several main, basic directions in the development of AI, but at the moment, the most effective algorithms are based on CNNs (convolutional neural networks) and RNNs (recurved neural networks). A CNN is a unidirectional (non-backward) multi-layer network that is excellent for working with data such as images and videos, where the data is placed in the form of a grid of pixels. In turn, an RNN handles sequential data such as text and audio well. A CNN is called a "forward network", and an RNN is called a "feedback network".

AI properties: hearing, speaking ability, vision, and predictive intuition are based on the use of both networks (CNN and RNN), as well as natural language processing technologies that complement each other. For example, Intel processors implement computer vision [21–24]. Intel technology allows creating solutions based on computer vision. The Intel vPro® platform provides performance, built-in security, and remote management capabilities to keep major computing devices running smoothly. Scalable Intel® and Xeon® processors deliver high-performance machine learning and deep learning in the cloud and have built-in features to accelerate AI.

Similar technologies are used in Alexa, Siri, Google Now, Cortana, and other intelligent voice assistants.

The cost of this phase is included in the cost of the project work.

The main component of AI is a powerful personal computer (PC)—a workstation—with means of connecting to computer networks. However, the computing equipment existing in the APCS is loaded with the solution of its problems and is not suitable for the implementation of AI on it.

The difference between neural networks of three or more levels is not known, which excludes conscious choice. In APCSs, the number of information sources is thousands. These sources are divided into clusters.

The hardware implementation should be chosen by the number of output neurons, assuming that ten outputs form the address of the device and ten outputs form the command. The exit price is determined by

$$P_e = C_{hi}/N_{out}, \tag{1}$$

where P_e is the exit price; C_{hi} is the hardware implementation cost; N_{out} is the number of output neurons in this hardware implementation.

Input neurons receive signals from sensors.

The cost of this stage is determined by the price of the workstation and special programs. The duration of the stage is insignificant.

It is a sufficiently voluminous and expensive procedure. It is used to train neural networks. It is necessary to draw up tests with AI reactions based on the results of the analysis of possible situations.

The cost of this phase corresponds to the cost of the project work. The duration of the stage is significant.

Machine learning according to the generated tests by the method of reverse error propagation occurs according to the following algorithm: after processing the data, the network compares its result with the desired one and transmits information about the deviation from it back to all layers of neurons. Now it is used in many types of neural networks, and it was practically not recognized before Hinton. Given the speed of computing, this procedure does not take much time.

The cost of this stage and the duration of the stage are insignificant. The check is performed on tasks other than test ones. If more than 95% of the tasks are solved correctly, then the training was successful. Otherwise, one should refine the tests and repeat the machine learning process.

To implement AI, it is necessary to carry out installation work by connecting the output ports of AI to the necessary devices. This work is long enough and painstaking. After such works, it is necessary to check the operation of AI. The cost of this step is significant. The duration of the stage is several months.

It is impossible to assess the effectiveness of AI implementation in intelligent APCSs in a general form. Let us try a pretentious assessment. Suppose that the introduction of intelligent regulators increases control accuracy by 3% in all circuits. This leads to a decrease in resource costs in the *i* loop Resi. Assume that the APCS has N control loops. Resource savings will be

$$\Delta Pec = \sum_{i=1}^{N} 0.03 \cdot Pec_i = 0.03 \cdot \sum_{i=1}^{N} Pec_i = 0.03 \cdot Pec_{\Sigma}, \tag{2}$$

where is Pec_{Σ} total resource consumption. In practice, all N regulators will have different values for improving control accuracy. As a result, the savings will not look so impressive.

Table 2 Costs of implementation of an intelligent APCS

Item of expenditure	Designation
Design works of the system	*Dw*
Purchase of equipment	*Pe*
Purchase of the software product	*Ps*
Installation works	*Iw*
Adjustment	*A*
Machine learning	*Ml*

Consider another aspect of implementing intelligent APCSs. More accurate maintenance of the technological process management mode leads to an increase in the quality of the product and a decrease in its cost. It is impossible to predict how an increase in its quality will affect the price of products. This is determined by the market. Reducing costs will increase the income of the enterprise until the rest of the enterprises reduce their costs.

The digital advisor will be able to ensure that the process is conducted in an optimal manner. This will lead to saving resources, improving the quality of the product, reducing its cost. However, assessing these effects is difficult.

Implementation of intelligent APCSs is associated with high financial costs, which are listed in Table 2. These costs are compensated for the payback period during the operation of the system by raising the price of the output product.

The introduction of an intelligent APCS allows reducing the staff of process operators but will require the recruitment of specialists in AI operation. The introduction of an intelligent APCS, at the same time, leads to a reduction of emergency outages. Improving the quality of products leads to an increase in the price of products. Optimization of technological progress allows producing products with less energy and resources.

As a result, the introduction of AI in APCSs will lead to the following savings per year:

$$S = Ro \cdot Spo + Ed \cdot Cd + Sr \cdot Cs + Api \cdot -Ns \cdot Sas - (DW + Ps + Iw + a + Pe)/Pp. \quad (3)$$

where *Ro* is the number of reduced process operators; *Spo* is the annual salary of reduced process operators; *Ed* is emergency downtime per year; *Cd* is the cost per unit downtime; *Sr* is savings on material and energy resources; *Cs* is the cost of saved resources per year; *Ns* is the number of AI specialists accepted; *Sas* is the annual salary of accepted AI specialists; *Api* is the added price from product quality improvement; *Pp* is the payback period.

The component calculated by the formula:

$$Ro \cdot Spo - Ns \cdot Sas, \quad (4)$$

at a certain ratio of its members is zero. The main economic effect of AI implementation is mainly determined by the member Ed·Cd. However, the use of modern SCADA systems reduces operators' input of unacceptable data and commands, which reduces the time of emergency downtime. Thus, it follows from Formula (3) that the introduction of AI in APCSs will not provide significant savings.

The effect of improving the quality of products is not included here, since the degree of increase in the price of such high-quality products is not known and how much such a product will be in demand by consumers. Also, the following factors are not taken into account:

- losses due to the presence of uncompensated harm from aggressive man-made formations and a decrease in the benefit of benign man-made objects caused by the imperfection of the management system;
- losses related to possible loss of an APCS as a result of aggressive action of the external environment of man-made formations;
- losses related to possible loss of an APCS as a result of the aggressive influence of the external environment of man-made formations;
- losses due to increased fuel or electricity consumption due to a suboptimally selected control strategy.

Resource savings affect the indicator of cost-effectiveness of investment implementation, since, in addition to positive changes in the activity of the facility, the costs of creating APCSs are reduced.

By the APCS cost-effectiveness R is meant the ratio of the financial assessment P of the expected changes in the activity of the facility to the assessment of the expected costs C for the creation of an APCS:

$$R = P/C. \tag{5}$$

4 Conclusion

A practical definition of AI has been proposed. The main emphasis in this definition is on functions implemented by AI.

An algorithm for introducing AI into APCSs has been developed. Such a scheme is applicable when introducing AI in various industries. Stages of its implementation have been identified, making it possible to evaluate the implementation in terms of financial (it is possible to calculate the work of each stage) and time costs.

It is difficult to assess the effect of improving product quality and reducing losses from downtime and accidents when implementing AI without specific data on the cost of equipment, software product, test development work, AI training, installation, and adjustment of the system. The introduction of AI in the current APCSs will not provide significant savings in the short term. In the long term, the economic effect can be expected from improving product quality and reducing downtime in case of accidents due to the exclusion of the human factor from the control loop.

Identification of the sequence of procedures in the algorithm of AI implementation into the current APCSs made it possible to carry out an estimated calculation of the cost and efficiency of such an implementation process. Unfortunately, known AI publications indicate numbers about the effectiveness of implementing AI without deciphering how to achieve such values.

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Integrating a Project Risk Model into a BI Architecture

Marco Nunes, António Abreu, Jelena Bagnjuk, Célia Saraiva, and Helena Viana

Abstract In today's unpredictable and disruptive business landscape organizations face challenges that severely threatens their existence. To efficiently respond such challenges organizations must craft strategies to become more data-informed, agile, adaptative, and flexible. Integrating dynamic data analytical models in organizational structures to collect, analyze and interpret business data, is critical to organizations because it enables them to make more data-informed decisions and reduce bias in decision-making. In this work is illustrated the integration of a heuristic project risk-model used to identify project critical success factors into a typical organizational business intelligence architecture. The proposed integration enables organizations to efficiently and in a timely manner identify project collaborative risks by addressing people, environment, and tools, and generate actionable project-related knowledge that helps organizations to efficiently respond business challenges and achieve sustainable competitive advantages.

Keywords Industry 4.0 · BI architecture · Digital transformation · Project risk management · Artificial intelligence · Machine learning

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1 Introduction

To efficiently respond today's challenges organizations should become more data-informed, adaptative, and flexible. To do this, organizations can act in three different interrelated dimensions—(1) people, (2) environment, and (3) tools. In the people dimension organizations should implement effective working cultures that increase productivity and reduce costs, by addressing behavior and leadership [1, 2]. Effective leadership develops empowerment and commitment leading to a more customer centric and a better customer experience across an organization's mission, vision, and values [1, 2]. In the tools dimension organizations should develop and implement processes, frameworks, and procedures to increase productivity, quality, safety, and customer satisfaction while keeping a sustainable way of working [1, 2]. Tools such Agile methodologies, Six Sigma, Lean Management, Design thinking, Brainstorming, WCM (world class manufacturing), Total Quality Management, Balanced Score Card, Flow Tree Diagrams, Cost Benefit Analysis—just to name a few—, have been helping organizations to become more efficient and sustainable.

Today, computers, internet of things, artificial intelligent, machine leaning (industry 4.0) are redefining human experience at an incredible pace, providing new solutions and unlocking secrets of the universe [3–5]. From self-driving cars to diagnosing diseases, from sorting photographs to flying planes, from optimizing crop yields to predicting climate patterns, today's computing platforms are advancing the human experience in a positive and unpredictable way [3–5].

The advances in the data science field provides organizations analytical tools to run their business more efficiently [3, 4]. Analysing data such as Big Data (which defined as a huge amount of diverse data being generated at a high speed [3]) with artificial intelligence (AI) and machine learning (ML) tools and techniques such as data reduction, clustering, classification, association, regression, and mining [5], is becoming more critical in the decision-making processes [3]. By analysing data using methodologies such as CRISP-DM or SEMMA frameworks [4, 5], organizations can identify hidden patterns, trends and relationships that reveal unique knowledge regarding business in several dimensions [3–5].

Nevertheless, if not properly managed, analysing data can be challenging and ultimately lead to misleading decisions [3–5]. To efficiency collect and analyze business data, organizations need a networked structure that interconnects the different organizational departments. This can be achieved through the implementation of a Business Intelligence architecture (BI) [3, 4]. For example, research shows that BI architectures are responsible for predicting over 70% accuracy in online marketing campaigns [6]. In the environment dimension—which it refers not only to the nature of mother earth but also where organizations exist and operate -, are of critical importance to organizations [7, 8]. These include how organizations position themselves in the market, analyze and understand the different customer's needs, develop local and global strategic business plans, integrate different working cultures, predict how disruptive changes may affect well-established business models, organizational structures, sustainability, circular economy, just to name a few.

Focusing on the tools dimension, is proposed in this work the integration of a heuristic project risk-model used to identify project critical success factors (the POL model [9]) developed based on three key pillars ((1) project management, (2) risk management, and (3) social network analyses) into an organizational BI architecture. The proposed integration creates a dynamic learning system that generates actionable knowledge to improve decision-making processes and helps organizations to successful drive their digitalization process as suggested by several research [3, 4, 7].

2 Literature Review

2.1 Project Risk Management in Organizations

Project risk management can be defined as the application of knowledge, skills, tools, and techniques to project activities, to meet project requirements across project lifecycle [9]. Some authors define project management as risk management in projects [8, 10]. However, regardless of how well an organization is equipped with tools and techniques, delivering projects always comprise risks (threats and opportunities). In projects, risk is an uncertain event that, should occur, will have an effect (positive or negative) on the achievement of one or more project objectives impacting scope, quality, schedule, costs, and resources [30]. Project risks may include event risks (an event that has not yet happened, but if it does it will impact on project objectives), variability risks (number of known possible outcomes but one knows exactly which occur), ambiguity risks (uncertainties that emerge from a lack of knowledge or understanding which may include new technology, market conditions, competitor capability or intentions, etc.), emergent risks (known as "Black Swans" cannot be seen or predicted because they are outside a person's mindset which usually arise from disruptive inventions or products), collaborative risks (arise from the different behavioral patterns of project stakeholders across a project lifecycle) [8, 10].

Project management is important because it helps to see project risks as potential critical success factors [8–10]. A popular standard that helps to manage risk in organizations and interprets risk as critical success factors is the ISO 31000:2018 [11]. This standard comprises a set of eight well-defined steps ((1) establishing scope, context, and criteria, (2) risk identification, (3) risk analysis, (4) risk evaluation, (5) risk treatment, (6) record and reporting, (7) communication and consultation and finally (8) monitoring and review) that aim the creation of value by effectively identifying and managing project risks.

2.2 Social Network Analysis in Organizations

Social network analysis (SNA) can be defined as the application of graph theory to study entities dynamic interactions within a network [8, 10]. The application of SNA is critical to identify hidden problem-solving, advice, and trust networks—just to name a few—, which are responsible for how the work gets done in organizations [8, 10]. In Fig. 1 are illustrated the eight key steps ((1) identify an important group, (2) assess actionable relationships, (3) map relationships, (4) visually analyses results, (5) quantitatively analyze results, (6) follow up, (7) implement actions, and (8) assess progress and effectiveness [8]).

In step 3 is illustrated a typical organizational network where entities are represented by colored dots representing different departments and the respective links between them that represent choices or preferences with different intensities (levels *L*). By mapping such interactions that may arise from the assessment of SNA strategic surveys it can be identified critical actors as for example E8 in Fig. 1, where it has a very central role within the organizational social network. The key location of E8 can be either visually identified or by the application of SNA centrality metrics based in graph theory.

Graph theory is a mathematical structure that is used to model pairwise relationships between entities such as persons, organizations, departments and so on, that contribute to quantitatively explain how social structures evolve across time, and how they impact the environment where they do exist [12]. Centrality quantitatively describes how centralized or de-centralized a network structure is regarding the structural location of the several entities that exist within the network [36]. Centrality metrics include in-, out-, and total-degree, betweenness, closeness, density, just to name a few [10], and are a measure of importance, influence, prestige, control, and

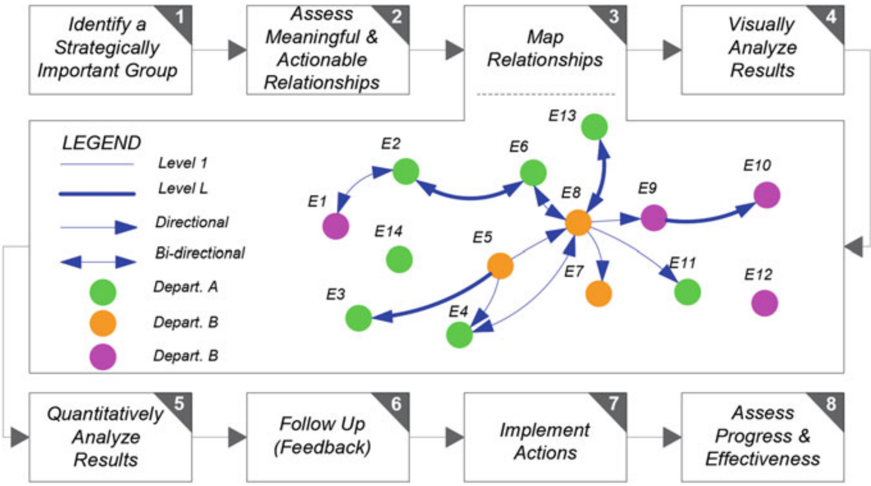

Fig. 1 Typical SNA assessment

prominence that will influence coordination and decision-making in an organization [8, 10, 12]. Business intelligence (BI) can be defined as a set of strategies and technologies used by organizations to analyze business data [13].

2.3 Business Intelligence in Organizations

A BI architecture comprises systematic processes and technologies, that acquire, transform, and analyze business data from both internal and external environments, into valuable, actionable, and meaningful business insights that organizations can use to understand past, actual, and future business trends such as consumer behavior, collaborative initiatives outcomes—just to name a few—, and improve decision-making processes [13]. BI comprises many interrelated dynamic components such as data science, data mining, machine learning, big data, data analytics, business analysis, systems engineers, risk management, programming, just to name a few [10, 13]. Although several literatures show the countless benefits of a BI architecture, research argues that such benefits are not always clear, essentially due to the application of non-efficient metrics [13].

A typical organizational BI architecture as has four major stages and requires an organizational interconnected network of communication where data from diverse organizational areas is easily accessed [10]. In stage 1 data from diverse organizational areas such as sales, finance, HR, engineering, marketing, and so on, is collected and stored into dedicated data bases. In stage 2 collected data undergoes a ETL process which consists in extracting, transforming, and loading data into a major data warehouse. In this process data is cleaned and prepared to be analyzed. In stage 3 data loaded in the warehouse will be analyzed by the application of business analytics tools and techniques based on statistics and mathematics. Finally in stage four, results will be analyzed and correlated with business outcomes too help in organizational decision-making processes.

One of the most important components of a BI system is the business analytics (BA). BA can be defined as a continuous and iterative exploration of past business performance [11]. BA is the component of BI that analyses collected data in the search for patterns and unique insights. One popular technique used in BA is the data mining, which is a circular process that continues to improve data analysis across time, finding problems and testing solutions [10, 11]. Data mining techniques include CRISP-DM or SEMMA [4]. Data mining can have six different analysis types where three are related with the analysis of the past and three related with the analysis of the future. They are: (1) descriptive (explains what happened), (2) exploratory (explains what is going on), (3) explanatory (explains why it happened), (4) predictive (predicts what will happen), (5) perspective (explains what to do) and (6) experimental (explains how well it will work) [10, 11].

3 Integration Process of a Process of a Project Risk-Model into a BI Architecture

The heuristic project risk-model to be integrated into a BI architecture is named as POL model and is divided in two parts as illustrated in Fig. 2 [9].

In part 1 the model will analyze delivered successful and unsuccessful projects searching for repeatable dynamic behaviors that are associated with success and failure outcomes. The model quantitatively measures dynamic behaviors comprised in five relational data dimensions ((1) communication and insight, (2) internal and cross collaboration, (3) know-how and power sharing, (4) clustering, and (5) teamwork efficiency) by applying SNA centrality metrics developed based on graph theory [9]. In part two the model uses identified repeatable behavioral patterns to guide ongoing/upcoming projects and estimates an ongoing project outcome likelihood by calculating the deviation between an ongoing status and a desired status. In Fig. 3 are illustrated in grey color the typical components of a BI architecture (data sources, master data management, data warehouse, analytics, and reporting) and in blue color the integration process of the heuristic risk-model—the POL model into the typical organizational BI architecture.

The BI architecture illustrated in Fig. 3 provides the heuristic risk-model the structure for the flow of project related information across the different stages of the analysis for both, part 1 and part 2 of the model. In part 1 of the model the objective is to identify project critical success factors. For this it is necessary to either have

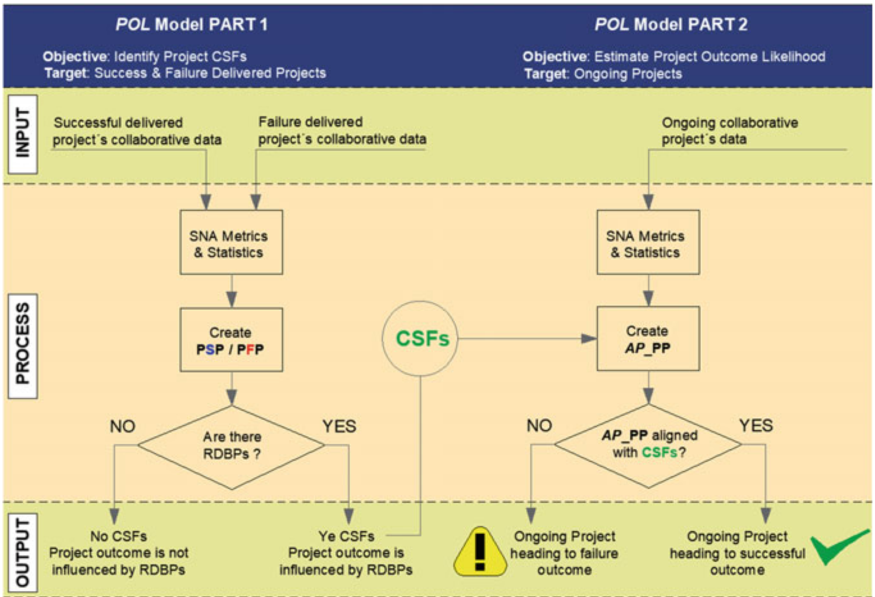

Fig. 2 The POL model functioning principle, adapted from [9]

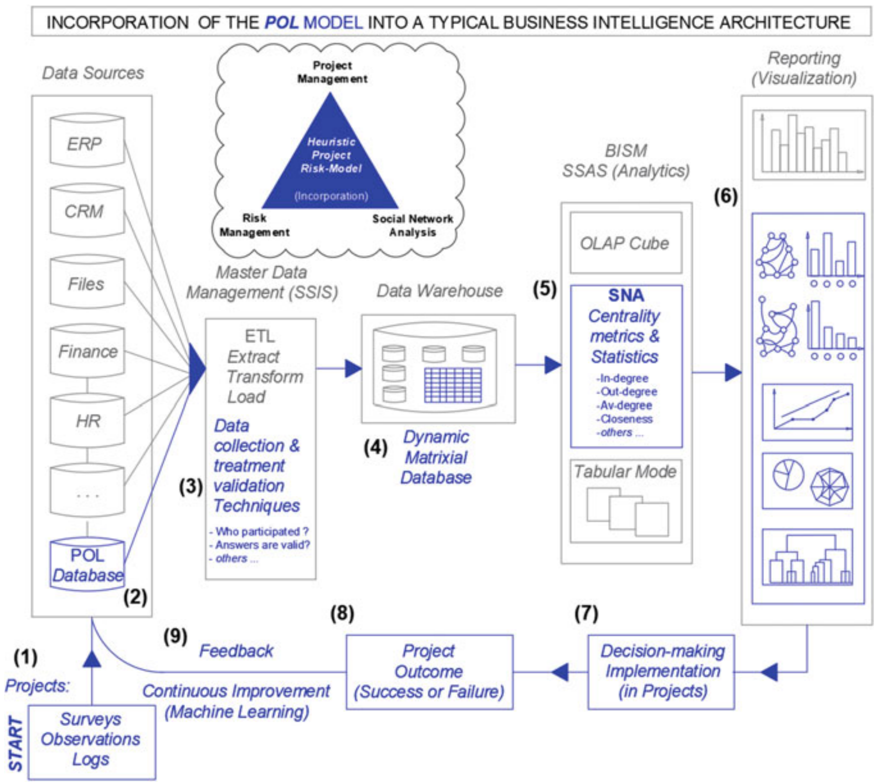

Fig. 3 Integration of the heuristic project risk-model into a typical BI architecture

delivered project data from successful and unsuccessful delivered projects available or initiate the collection process as projects are being delivered.

The process goes as follows.

First (1), relational data from a substantial number of delivered projects is collected through surveys, observational, or logs (emails, chats, and others).

Second (2), collected data is loaded in a dedicated database for the POL model.

Third (3), loaded data undergoes a ETL (extract load and transform) process which consists in cleaning and treating relational data. Here a first validation is done regarding the suitability of the data go to the next stage.

Fourth (4), treated relational data will allocated in a matrixial form and loaded into a data-warehouse where it will be the source for the next stage.

Fifth (5), data in the warehouse will be analyzed through the application of BA tools and techniques. In this step, several SNA centrality metrics such as degree, in-degree, out-degree, betweenness, closeness, among others, are applied to the relational data to quantitatively measure the dynamic interactions of project people across the different phases of a project lifecycle captured in project meetings, mails, and surveys.

Sixth (6), once the calculations have been executed, the results may be displayed in bar, circular, spider or other chart types, and in network diagrams (graphs). Results illustrated in charts are quantitatively characterize the structure of the different project social networks. The results illustrated in a network form (graphs), show the mapping of organizational relationships that are the mirror of the mix of formal and informal dynamic relationships between project stakeholders across the different phases of a project lifecycle. Both, charts, and networked results, are vital to the next step where decisions are to be taken. This concluded part 1 of the POL model. In part 2 of the POL model, once project critical success factors have been identified, these will be used to guide ongoing/upcoming projects.

Here (7), it starts the decision-making process. Function of the results obtained in the ongoing projects managers take decisions to align ongoing dynamic behavioral patterns with the critical success factors, if needed.

Eighth (8), once decisions have been agreed it is vital to implement them in the most efficient way possible. In this step, it will be measured and monitored to which direction a project (ongoing project) is heading to (success or failure).

Ninth (9), once ongoing projects are delivered all the produced project relational data will be collected and associated to the respective project outcome—successful or unsuccessful. This data then goes to the POL database (2) as new input data which will refine the whole process comprised by parts 1 and 2 of the model.

4 Conclusions, Implications and Further Developments

The proposed integration in this work illustrates how organizations can efficiently automatize their processes connecting different departmental areas in the search for critical success factors. This in turn enables organizations to save time, resources and increase accuracy as they apply the heuristic risk-model [9].

4.1 Academic Implications of the Integration

The proposed integration contributes to the development of the three pillars that support the POL model. In the project risk management dimension, the proposed integration enables to gain unique insight into the project dynamic relationships across the different phases of a project lifecycle regarding common projects risks as proposed by [14, 15]. The application of SNA centrality metrics in an automated way in the BA stage, contributes to a more efficient development of existing and new social networks analysis centrality metrics as a critical tool in the identification of project critical success factors.

4.2 Managerial Implications of the Integration

In a managerial perspective the proposed integration helps organizations to have and efficient 360° view across the interconnection of the different organizational areas [15–17]. It enables to identify and refine in an automated way project critical success factor across the different phases of a project lifecycle. Consequently, organizations can make more, better, and timely decisions more supported on data while relying less in best guesses and gut feelings and eliminating or minimizing bias. This in turn improves performance which contributes the achievement of sustainable competitive advantages and is fully aligned with the industry 4.0 environment concepts.

The integration of the model into a BI architecture provides organizations an efficient tool to develop their digitalization process. It provides organizations a set of competitive advantages that can be translated by the optimal management of organizational resources, becoming thus more resource-management sustainable and promoting alignment with the 17 UN Global Goals and the three major components of sustainability—people, planet, and profit [18]. This fact provides organizations and their customers a higher sense of awareness regarding a sustainability mind-set, which is translated into a more profit for organizations which according to research can increase revenue up to 20% [17, 19]. Furthermore, the proposed integration in this work in the long-term functions as a supervised machine learning model in the identification of project critical success factors.

As for future works it is suggested that more research on the collecting data methods that minimize bias to capture information that flows in other communication channels such as phone calls or corridor meetings.

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Impact of Digital Transformation on Labor Productivity Growth in the Manufacturing Industry in Russia

Olga Romanova and Alena Ponomareva

Abstract Modern information and communication technologies are the essential factors in the transformation of the industrial sector of the Russian economy. The purpose of the article is to assess the impact of digital change on labor productivity in the industrial regions of Russia. We hypothesize that in the new reality the digital transformation of industry is becoming an independent factor in labor productivity growth. Scientific works of Russian and foreign researchers in the field of the digital economy, the efficiency of industrial production, factors in labor productivity growth constitute the methodological basis of the study. The authors use the methods of structural-logical and statistical analysis, as well as linear regression modelling. The information base included data from industrial and regional statistics, indicators of government programs and sectoral strategies. The paper reviews modern research in labor productivity and total factor productivity and determines the differentiation of regions and federal districts of Russia in terms of labor productivity. Furthermore, the authors clarify the set of indicators characterizing the total factor productivity, analyze indicators of industrial regions' digital development and digital expansion. Finally, the study establishes a statistically significant relationship between the most critical hands of industry digitalization in the regions and the level of labor productivity. The study shows that the high rates of digital transformation of industry in modern conditions can solve such fundamental problems as increasing labor productivity and improving the population's well-being.

Keywords Digital transformation · Labor productivity · Industrial regions

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1 Introduction

The modern world is distinguished by a variety of new technological, institutional, socio-economic trends. A common feature of the technologies underlying them is digitalization of all processes. Fundamental changes occurring due to the introduction of digital technologies determine the “digital transformation” of the industry, that is, qualitative changes on this basis of business processes, ways of carrying out economic activities, established formats of interaction between participants in value chains. During their implementation, such modifications allow obtaining a variety of socio-economic effects.

In current conditions, the impact of the economy and industry’s digitalization on the efficiency of socio-economic and production systems’ functioning is increasing. In our opinion, digital transformation is, on the one hand, a necessary prerequisite, and on the other, a driver for improving production efficiency due to an increase in labor productivity. Our research hypothesis is that the digital transformation of industry in a new reality is becoming an independent factor in labor productivity growth. Today, however, the capital-labor ratio, human capital, and total factor productivity are considered the key factors influencing labor productivity growth. The last factor is identified by different authors not only as total factor productivity (TFP) [6, 16, 22] but also as total productivity of factors (TPF) [8], multifactor productivity (MFP) [26]. Oftentimes, these indicators are viewed as synonyms and interpreted simply as the “technology level”. In addition, TFP can be defined as an indicator reflecting the overall efficiency of production factors or, in Acemoglu’s interpretation, the relative technological level of a country’s development [3].

Although TFP is interpreted as a technological level, in reality, this indicator includes, in addition to technology, a large number of different factors. Among them are the quality of the capital used, management quality, employment organization, and all types of infrastructure. Of particular importance is the institutional environment that determines the quality of economic life regulation, the system of legislation, etc. Frequently, TFPs consider factors such as export activity, market share and access to new markets, R&D expenditures, innovations, primarily technological innovations, as drivers of labor productivity growth. The set of these factors is determined by the purpose of the research and the availability of reliable information. In addition, it is essential to take into account that TFP is a very volatile and dynamic parameter. Therefore, the significance of the indicators that form it and the set of these indicators itself is far from being constant.

Therefore, it seems appropriate to consider the digital transformation of industry not as one of the factors in the TFP but as an independent, key factor that determines the growth of labor productivity, which is the purpose of this article. The article sets the following objectives: to review research in this area; analyze labor productivity in the industrial regions under study; and identify the impact of industrial digitalization in these regions on labor productivity growth.

2 Literature Review

Labor productivity, as well as total factor productivity, is the subject of numerous studies. It is important to note that the Russian economy's productivity problem is analyzed both at the level of individual companies [7, 8, 14, 18, 22, 24] and regions [8, 20, 22]. It is essential to analyze productivity by considering the characteristics of resource or non-resource regions [12, 13, 17, 20].

At the international level, there is also the practice of analyzing the total factor productivity for the resource and non-resource parts of the economy [26]. Thus, more than a threefold excess of labor productivity in the non-resource part of the German economy compared to Russia is explained by 38% of its higher capital-labor ratio and by 58%—by the level of technology, that is, TFP. The higher level of human capital in Germany accounts for only about 4% of labor productivity. Similar data characterize the lag of Russia in terms of labor productivity from the United States. It is 34% due to an excess of the capital-labor ratio of the American economy by 3.2 times in comparison with the Russian one and by 65%—by a higher level of technology, that is, TFP, which exceeds the domestic indicator by 2.3 times [26]. Thus, in terms of the influence of human capital on labor productivity, Russia is actually on an equal footing with both Germany and the United States.

Almost threefold lag of Russia in labor productivity in the non-resource part of the economy is also noted compared to such countries as Canada, Norway and other developed countries of the world. Such a lag is explained by a 35% lower level of capital equipment and a 65% lag in the SPF [25]. Similar conclusions can be drawn from cross-country comparisons of productivity levels per hour worked. Currently, there is an almost threefold lag of Russia from the developed countries in this indicator. Moreover, it has persisted over the past 30 years. For example, in 1992, labor productivity per hour worked in the domestic economy was 34% of the corresponding hand of the United States. By the end of the second decade of the twenty-first century, it reached 36.5% (increased over this period by only two percentage points) [18].

Some works investigate the dependence of GDP per capita on labor productivity. For example, for high-income countries the World Bank has set the threshold value of GDP per capita at 12,535 dollars. The corresponding indicator in Russia is about 80% of this value. But if back in 2010 Russia outstripped, for example, the PRC in this indicator by 2.5 times, then, according to the IMF (in current prices), in 2020 in China, the GDP per capita indicator turned out to be higher than in Russia ($10,582 and $9972, respectively) [1, 13, 25]. Comparison of these indicators in the Russian and foreign economies, identification of differences in the levels of well-being between countries allowed us to conclude that the lower labor productivity in Russia determines its lagging behind developed countries in terms of the population's standard of living and economic development [5, 23, 27].

A particular aspect in the study of productivity is associated with the possibilities of lending to industrial companies in crisis conditions, particularly during a pandemic. One of the numerous structural problems of the Russian economy is the problem of a high proportion of low-productivity firms that are unable to catch up with leading firms in productivity [7]. Firms' productivity is not only a significant factor in terms of GDP growth, but, as the situation during the pandemic has shown, it is also a decisive factor in the availability of credit. The studies presented in [9, p. 133] confirm that banks in a crisis prefer to issue loans to more productive companies. The authors obtained this conclusion based on an analysis of labor productivity calculated as the ratio of proceeds to employees for more than 352 thousand enterprises. A positive correlation between the level of productivity and the size of an enterprise was confirmed. It was shown that more productive and large enterprises more often use credit resources in their activities [26]. The government maintains a lending structure aimed at supporting companies with high productivity potential. It is these companies that are capable of acting as drivers of recovery growth. Modern research confirms this conclusion [11]. At the same time, although there are numerous studies into identifying and solving problems of increasing labor productivity, there are very few works considering digital transformation as a critical factor in increasing labor productivity.

3 Regional Labor Productivity

The above differences in labor productivity between countries were revealed when comparing data at the aggregate level. But the average values are influenced by the economic structure and the prevalence of a particular industry within each country. So, Russia is characterized by the highest labor productivity in the extractive sector, which is due to a long period of favorable conditions for its products and high natural rent in profit. A significant differentiation of labor productivity is observed in Russia, both between individual sectors of the economy and subjects. The main factor of such differentiation is the differences in the regional economy structure, determined, first, by the ratio of the extractive and processing industries [10, 15]. The country's manufacturing industry in the passport of the National project "Labor Productivity" is classified as a primary non-raw material sector of the economy. The analysis of labor productivity in this industry is of significant interest, confirmed by the literature review above. The magnitude of this indicator, defined as the ratio of revenue to the number of employees, is equal to 4.76 million rubles on average in Russia per person. But labor productivity in manufacturing industries of the constituent entities of the Russian Federation differs significantly. It ranges from less than 0.1 million rubles in the Republic of Ingushetia up to 134.69 million rubles in the Chukotka Autonomous Okrug.

Following the current level of labor productivity [19], we have divided all subjects of Russia into four groups (Table 1), in each of which the top 5 regions are marked.

As seen from Table 1, 55 constituent entities of Russia, or 65.4% of their total number, have a labor productivity of less than 4 million rubles per person, which is lower than the national average. A significantly smaller difference in the level of average labor productivity in the manufacturing industry compared to the constituent

Table 1 Distribution of Russian regions by labor productivity in manufacturing, 2019

Annual labor productivity, mln rubles/person	Russian regions		
	Quantity	%	Top-5 regions in the group
Over 10	4	4.8	Chukotka Autonomous Okrug, Magadan Oblast, Yamalo-Nenets Autonomous Okrug, Khanty-Mansi Autonomous Okrug-Yugra
From 4 to 10	25	29.8	Kamchatka Krai, Moscow City, Kaliningrad Oblast, Leningrad Oblast, Krasnoyarsk Krai
From 3 to 4	18	21.4	Irkutsk Oblast, Sakhalin Oblast, Republic of Khakassia, Chelyabinsk Oblast, Samara Oblast
Less than 3	37	44.0	Saratov Oblast, Udmurt Republic, Smolensk Oblast, Kursk Oblast, Primorsky Krai

entities of the Russian Federation is observed when comparing this indicator across federal districts (Fig. 1). Here, the maximum labor productivity in the Northwestern Federal District is 5.91 million rubles per one employed with the minimum level of this indicator in the North Caucasian Federal District—1.18 million rubles. That is, labor productivity in the federal districts, in contrast to the constituent entities of the Russian Federation, differs by only five times.

The sample of objects for further research is limited to 18 regions in the GRP structure of which the share of manufacturing industries exceeds 28%. These are the so-called industrial regions. As noted above, the critical factors in labor productivity growth are the capital-labor ratio, human capital, and TFP. In a very rough approximation, the quality of human capital can be assessed under the share of the employed in the constituent entities of the Russian Federation with higher education.

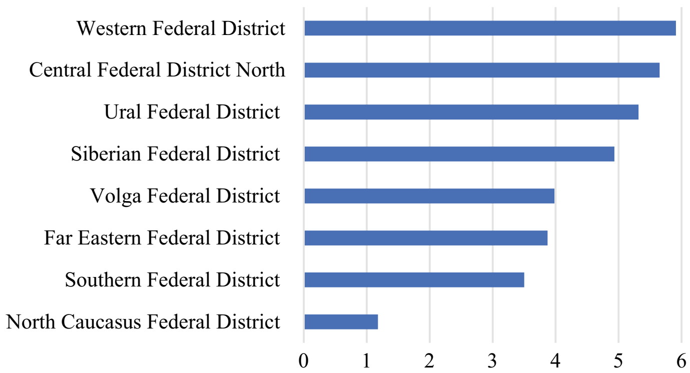

Fig. 1 Average labor productivity in the manufacturing industry by federal districts, million rubles [19]

A preliminary qualitative analysis of these data shows that labor productivity in 9 industrial regions, which make up half of the total number of the territories analyzed, exceeds the same indicator for Russia as a whole from 1.1 to 1.7 times. However, the situation is different in the regions under study with the ratio of labor productivity indicators and the share of the employed with higher education. The percentage of specialists with higher education in none of the regions exceeds the average Russian value of this indicator, lagging behind it in the range between 0.6 and 9.6 total percentage points. Using the method of paired regression modelling makes it possible to more clearly establish the influence of capital-labor ratio and the share of the employed with higher education. That is, in our case, as an indicator characterizing the quality of human capital on labor productivity in the regions under study.

18 regions of Russia with a predominance of the manufacturing industry in the economy are the subject of research. The choice is related to the purpose of the study, i.e., to assess the impact of the digital transformation of industry on labor productivity growth in this industry sector. The method of regression analysis is widely used to study various aspects of the socio-economic state of regions, as well as to identify the reasons for lagging behind or advancing in development in certain areas. In particular, the method of constructing paired linear and nonlinear equations is applied in the regional economy to determine stable patterns of change in the socio-economic indicators of regions and the degree of their mutual influence.

The regression analysis results (Fig. 2) indicate that the influence of the quality of human capital on regional labor productivity is statistically insignificant. This outcome can be explained, first of all, by the incomplete consideration of the components of human potential that affect labor productivity in industrial regions. This conclusion actualizes the need for a deeper review of the role of TFP in ensuring

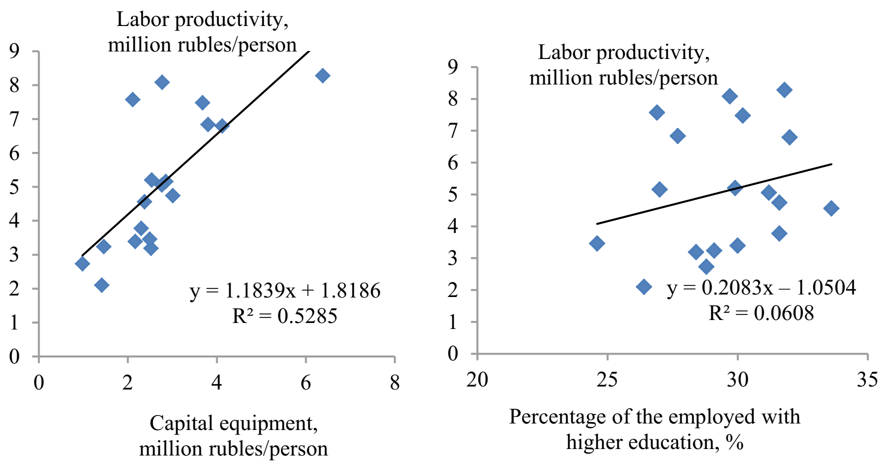

Fig. 2 Influence of capital-to-labor ratio and the share of employees with higher education on labor productivity in the manufacturing industry of industrial regions

the growth of labor productivity in the regions under review. For this purpose, we analyzed some of the available components of the total factor productivity:

- Total costs of innovation;
- Investments in fixed assets of manufacturing industries;
- Used advanced production technologies;
- Issued patents for inventions and utility models.

Data on these factors are given in the statistical book [2, 19]. The construction of paired linear regressions made it possible to assess the influence of the listed factors on labor productivity growth. Significant positive correlations are observed when analyzing the following dependencies: labor productivity and investment in fixed assets (0.77), labor productivity and advanced production technologies (0.63). Thus, the statistical insignificance of the influence of innovations costs on labor productivity growth has been established. This can be explained from the state's position of the Russian economy, far from the technological frontier. The latter is understood as the maximum achievable volume of output at certain costs of production factors. Obviously, in the Russian economy, which is characterized as far from the technological frontier, there is no direct relationship between innovation and labor productivity [21]. This situation is typical for not only Russia but many countries, determined by the level of technological development and the structure of the national economy [4].

4 Digitalization of Industry in Industrial Regions

The performed literature review made it possible to establish the special significance of the digital transformation of industry in the context of the new reality. But, as noted, there is very little research in identifying the impact of digitalization on labor productivity. Therefore, confirming the above hypothesis, indicators of digital development of industrial regions were formed, and their effects on labor productivity were determined (Table 2).

To assess the influence of the factors listed in Table 2, we used the method of paired linear regression (the dependent variable is labor productivity). A statistically significant relationship between the digitalization index and labor productivity has not been established, which was the basis for constructing paired regressions for individual indicators of the digital development of industrial regions.

Sufficiently significant positive correlations were obtained when analyzing the following dependencies: labor productivity and special software for managing automated production (0.60), labor productivity and used CRM, ERP, SCM-systems (0.56), labor productivity and broadband access to the Internet (0.51), labor productivity and costs of introducing and using digital technologies (0.59). Some results of the regression analysis are shown as an example in Fig. 3. The performed calculations confirm the relevance of digitalization of manufacturing industries from the standpoint of the influence of this process on the growth of labor productivity. However, it should be borne in mind that there is a significant digital gap between the studied

Table 2 Indicators of digital development of industrial regions, 2019 [2, 19]

Regions	Business digitalization index	Labor productivity, million rubles per person	Capital equipment, million rubles per person	Organizations and enterprises using in work (%)			Costs for the implementation and use of digital technologies, million rubles
				Automated production management	CRM, ERP, SCM	Broadband internet	
Russia	31	4.76	2.29	16.5	20.5	86.6	2,316,831.4
Vladimir Oblast	24	3.24	1.46	14.5	19.1	91.6	4726.3
Kaluga Oblast	26	7.48	3.68	19.4	23.7	87.7	4818.2
Lipetsk Oblast	25	6.79	4.12	15.4	18.9	91.0	5716.9
Ryazan Oblast	25	3.39	2.16	15.6	20.6	85.6	3366.2
Tula Oblast	24	4.74	3.01	18.5	23.0	85.3	6427.9
Yaroslavl Oblast	26	3.19	2.52	18.6	25.1	90.7	4390.3
Vologda Oblast	25	6.83	3.80	16.5	18.2	93.7	8674.6
Leningrad Oblast	26	8.28	6.38	18.5	23.2	89.6	6748.1
Novgorod Oblast	25	3.46	2.49	22.5	25.6	86.6	1957.6
Republic of Bashkortostan	27	5.20	2.54	19.1	21.2	87	20,802.7
Mari El Republic	28	2.73	0.98	15.2	16.5	86.9	3197.3
Perm Krai	26	5.15	2.85	26.2	28.3	89.7	19,087.0
Kirov Oblast	29	2.10	1.42	15.7	16.3	91.3	4823.0

(continued)

Table 2 (continued)

Regions	Business digitalization index	Labor productivity, million rubles per person	Capital equipment, million rubles per person	Organizations and enterprises using in work (%)			Costs for the implementation and use of digital technologies, million rubles
				Automated production management	CRM, ERP, SCM	Broadband internet	
Nizhny Novgorod Oblast	24	4.56	2.37	17.7	23.6	92.3	24,009.3
Sverdlovsk Oblast	22	5.05	2.76	18.0	22.7	89.6	33,326.7
Chelyabinsk Oblast	28	3.77	2.30	18.8	23.5	86.8	16,536.7
Krasnoyarsk Krai	25	8.08	2.77	15.2	17.9	86.1	16,890.4
Omsk Oblast	25	7.57	2.11	13.4	17.3	88.6	5291.9

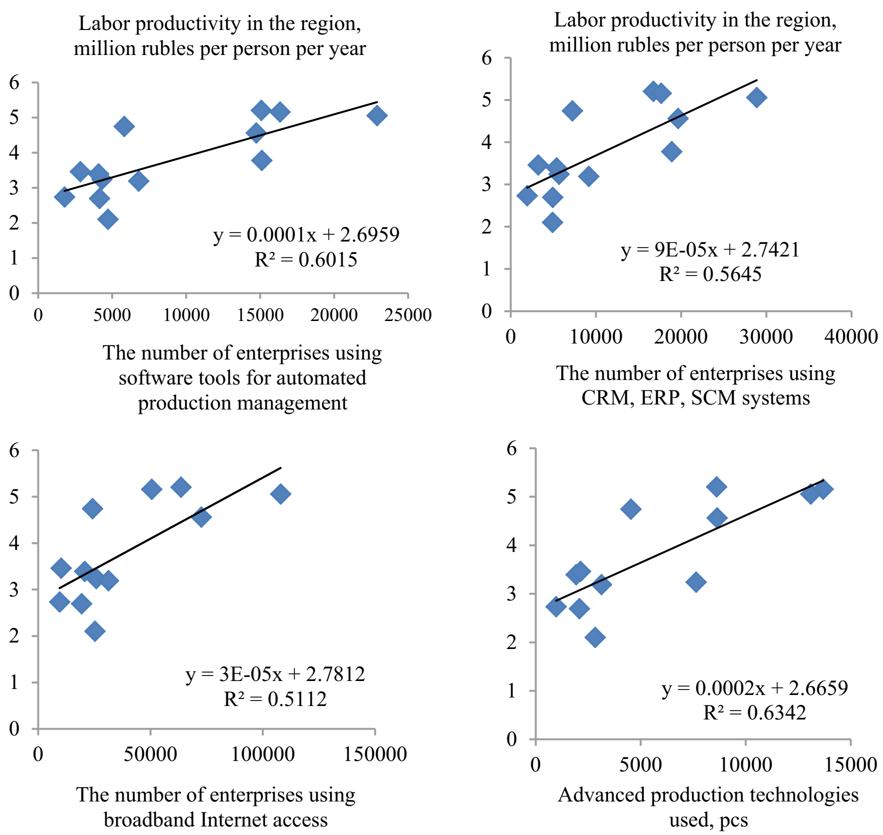

Fig. 3 Influence of digital development factors on labor productivity in the manufacturing industry of the regions

industrial subjects of the Russian Federation and between them and other regions that form the manufacturing industry as a whole. In addition, the existing lag of Russia in the development of digital technologies, which, according to various experts, is about 5–10 years, significantly reduces the role of digitalization as a critical factor in increasing labor productivity.

5 Conclusion

The manufacturing industry plays a unique role in the Russian economy. It has been established that the new digital solutions used here for managing production systems allow solving a wide variety of tasks, the most important of which is the growth of labor productivity.

The review of studies in the field of labor productivity at the level of individual industrial companies and regions of Russia made it possible to systematize the existing practice of analyzing the total factor productivity, including the resource and non-resource part of the economy.

A cross-country comparison of labor productivity indicators revealed a significant lag of Russia, which determined its lag in terms of GDP per capita. An essential differentiation of the level of labor productivity across the regions of Russia has been established. The indicators of labor productivity and its determining factors in the industrial regions of Russia were analyzed.

The study made it possible to establish a positive correlation in analyzing the dependence of labor productivity in industrial regions on the capital-labor ratio; investments in fixed assets used advanced production technologies. The influence of innovations costs and the share of the employed with higher education in industrial regions turned out to be statistically insignificant. The article highlights the indicators of digital development of industrial regions to determine their impact on labor productivity. Significant positive correlations were obtained when analyzing the effect on labor productivity of the number of enterprises in industrial regions using special software for managing automated production, CRM, ERP, SCM-systems, and broadband Internet access. According to the estimates of the Higher School of Economics, it is digital transformation, consistent with our estimates and the stated hypothesis of the study, that will increase labor productivity in the manufacturing industry by 20.2% (cumulative) until 2030 [1].

The relevance of the digital transformation of industry is determined not only by the fact that it is a driver of growth in labor productivity. Digital transformation is of particular importance for raising the status of the industrial regions under consideration because the quality of the digital environment in modern conditions is becoming one of the critical factors of living comfort in a particular region. Here, the most dynamic, innovative-thinking, highly professionally motivated part of the population flocks, capable of effectively developing the digital environment in the region. Only high rates of digital transformation in modern conditions can solve such fundamental problems as boosting labor productivity growth, improving the well-being of the population, implementing decarbonization of the economy, and increasing the country's competitiveness in the world market.

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Trends, Factors and Guidelines for the Development of Human Resources for Industry 4.0

Daria Mikhalkina and Anastasia Nikitaeva

Abstract Human resources have proven to be a determining factor in the implementation of Industry 4.0. This is because the digital transformation of society critically depends on mental attitudes, behavioral patterns, motivational attitudes, the specifics of different generations, and the qualification and competence of people. In light of this, research shows the mutual influence of Industry 4.0 and human resource development. It has been proven that demographic trends, as well as technological trends in conjunction with trends in the transformation of the labor market under the influence of digitalization, have a significant impact on the search for approaches and methods of human resource development adequate for new conditions. This paper substantiates the importance of taking into account the differentiation of generations to create a new digital reality and adapt to it. Based on the identification of key factors of human resource development, the study identifies methods and development techniques of human resources in the context of Industry 4.0 at the organizational level.

Keywords Human resources · Industry 4.0 · Digital transformation · Differentiation of generations · Employee competencies

1 Introduction

Currently, the success of the Fourth Industrial Revolution and the associated achievement of the digital transformation of society depend on the connection between a new reality and a new mentality. Industry 4.0 (as a core strategic representation of the Fourth Industrial Revolution) is associated with technological breakthroughs, integration of the physical and digital world, and cutting-edge technologies in the digital economy. Despite this fact, its actual implementation depends on people and not technology. Finding appropriate human resources for Industry 4.0 is not an applied

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but a fundamental research issue that determines the strategy and tactics of digital transformation. It is the transformation of public consciousness that is the engine of the new industrial revolution.

The transformation of public consciousness is connected to the search for answers to numerous questions: is stability more important than change; are modern technologies hostile or an inevitable simplification of everyday life; what is the social norm; what is acceptable and what is not; what are the ethical boundaries of artificial intelligence, etc. The answers to these questions directly affect the scale and success of digital transformation and the transition to new industrial development. Evidently, the exploration of trends, factors, and guidelines for the development of human resources under the conditions of Industry 4.0 is becoming more relevant to research.

Human resources are not a monolithic mass. Each generation has a specific attitude towards the future, political regimes, the conjuncture of the economy, the hierarchy of public life, etc. Based on this thesis, it is becoming more important to discuss the global changes related to digitalization and look for solutions to the problems of creating modern technologies and adapting to them through specific strategies and mechanisms to the development of human resources, taking into account generational differentiation. Jorge Luis Borges wrote: "Yesterday's man is no longer the same as today" [4]. This quote not only describes the problem of a person's inner perception of him/herself but also generally touches on the issue of generations.

It is also necessary to take into account the trends of socio-economic and technological development, which helps to further determine the opportunities for the improvement of human resources development in Industry 4.0. Therefore, modern research also considers demographic, technological, digitalization trends, and transformation of the labor market. It is advisable to benchmark from developed countries as a model example in this case. Developed countries can be considered as a reference point and an example of the development patterns that other countries are likely to adopt in the future. This is also true for revolutionary technological changes. In a particular time frame, everyone lives in the same year and in the same historical stage. The concept of "lag" in progressive development is no longer connected with the "isolation" concept, since digital technologies take individuals out of the system of hierarchies and into horizontal networks of interaction. This interaction is typical for digital generations. However, there is a question about the readiness for new forms of social communication and interaction with people and technologies for older generations. A related research question is—what actions should be taken to develop human resources in Industry 4.0, taking into account the above factors.

Thus, on the one hand, the success of Industry 4.0 depends on the development of human resources. On the other hand, Industry 4.0 itself leads to changes in human resources, approaches, and ways of their development. With this in mind, this paper aims to study the factors, trends, and guidelines for the development of human resources in the conditions of Industry 4.0.

2 Literature Review

The concept of Industry 4.0 has appeared relatively recently—there is only a decade of research concerning the relevant issues [8]. Economics, along with other fields of knowledge, has shifted the focus of studies towards the end-to-end digitalization of the economy and a new technological revolution [26]. This scientific work is based on studies devoted to economic digitalization research and Industry 4.0, reflecting on the transition from digitalization to digital transformation, changing societies and the structure of relations in society [3]. Research on changes in the labor market, trends, and digitalization links with different generations are also considered [14].

An analysis of various scientific sources made it possible to draw several conclusions. The development of human resources in the professional plane is directly related to the issues of the formation of qualified workforce. In modern realities, the need for employees who can create and apply high-tech technologies in their work or learn this quickly is an organizational function. Accordingly, organizations face several skill alignment problems. They need to change the trajectory of employee training and retraining, design new workspaces, organize the high-quality implementation of work associated with employee interaction with computer technology. The availability of the relevant human resources competence profiles is a trigger for a company's development, stimulating the active introduction of Industry 4.0 technologies, including industry-specific ones, robots, Big Data, the Internet of Things—everything that modifies, transforms, and accelerates production processes [7]. The introduction and scaling of modern technologies require adaptation for employees [20].

Modern technologies are not only appropriate to use to improve the efficiency and productivity of labor. They also allow the creation of new formats of human interaction with machines. This helps to improve the adaptation to digital technologies by the older generation. It can also be achieved, for example, by the organization of a pleasant workplace, a working atmosphere, an emphasis on self-development, and employee autonomy [12].

Thus, human resource development should be expanded to the formation of strategies and methods for creating comfortable working conditions in the organization, especially in the digital aspect [25]. This includes professional development, hiring, training, and retention mechanisms. The practice of human resource management is redirected to maintaining an environment of high qualifications and a high level of knowledge [11]. Despite a large number of publications in the designated subject matter, the research of these issues remains insufficient and requires further study. To a large extent, this is due to the novelty of the trends and conditions accompanying Industry 4.0 and the importance of finding ways to develop human resources that are adequate to these trends and conditions. Existing scientific papers usually consider either the issue of human resource development in Industry 4.0 in the context of generations or age groups, or in the context of changes in the labor market under the influence of digitalization, or in terms of organizations' reactions to the changes taking place. This paper aims to study the relationship of trends, factors, and guidelines for the development of human resources for Industry 4.0. The study covers external and internal factors of human resource development in a new organizational context, which is also its significant distinguishing characteristic.

3 Methods

In order to uncover the problem of human resource development in the context of digital transformation in the economy, a literature review was conducted using databases such as Web of Science (WoS), Elton B. Stephens Company (EBSCO), Scopus, and Google Scholar.

The research selection process is shown in Fig. 1.

The systematic analysis consisted of reviewing publications mainly no older than 2018 (earlier sources were considered in terms of studying the impact of digitalization on different generations and age groups).

Articles in English and German were analyzed as the term Industry 4.0 originated in Germany where strategies of the new industrialization are being successfully implemented [13].

Initially, research was conducted for combinations of keywords from selected subject areas. When formulating keywords for the search, the issues of human resource development in Industry 4.0 in the context of generations, demographic and technological trends in their connection with the transformation of the labor market, digitalization of labor in organizations were taken into account.

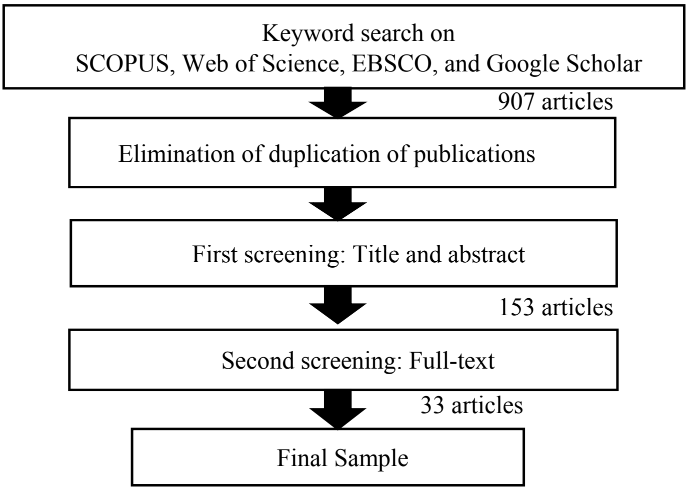

Fig. 1 Research selection process

Based on this logic, content analysis, categorical analysis, comparative, and evolutionary analysis were further carried out, making it possible to identify particular trends, factors, and guidelines for the development of human resources in the context of Industry 4.0.

4 Results

Digitalization is associated with the transformation of society and directly related to the transition from the "Old" world to the "New" one. That is, from a hierarchical system (SPOD—Steady, Predictable, Ordinary, Definite) to a decentralized (network, chaos) system VUCA (Volatility, Uncertainty, Complexity, Ambiguity) [28].

Technological trends in the context of digitalization are [28]:

- digitalization of all life spheres,
- Internet of Things and Internet of everything,
- Big data, machine learning and artificial intelligence,
- transition to the digitalization of personal space,
- development of bio- and neurointerfaces,
- automation and robotization.

The aforementioned trends lead to the automation of cognitive work, changes in the structure of professions, quantitative and qualitative characteristics of human resources.

Digital reality gives birth to "a new person". This new kind of person is faced with complex and dynamic changes in their surrounding world. It is much more difficult for them to make decisions. This is made lucid by the example that earlier, the most important decision for a person was the choice of a profession. This decision was made once and forever. In the realities of the modern information society, it is necessary to constantly study, develop one's skills and competencies, retrain, that is, to deal with the problem of choice again and again [6]. Now a person is constantly in the flow and must be able to navigate permanently changing situations. Digital consciousness destroys the usual, traditional guidelines and values, but at the same time, no obvious new ones have been formed. The problem of digitalization is the development of personnel, human capital, what to teach, and how to teach. In modern realities, where everything changes so quickly, it is hard to achieve an understandable goal, and the team, human resources are the most relevant tools for achieving long-term goals.

At the same time, the formation and development of human resources are influenced by more general demographic trends [19]. These include [32]:

- population decline—especially in Russia, according to experts, it will continue until 2024–2025. To the greatest extent, this is felt in the field of recruiting, since the number of applicants is not excessive;

- aging of the population—the median age is 45 years, and 69% of the population have secondary special and higher education;
- an increase in life expectancy from 65 years in 2000 to 73 in 2019. This leads to an increase in the age at the workplace;
- by 2025, generation Z (born in 1997 and younger) will make up about 25% of the total workforce;
- reducing the importance and relevance of the experience of older generations.

These trends lead to the fact that in addition to the aging of the population, the number of young, digital people in the workplace is also increasing, and the mechanism for managing this category of human resource is still questionable. In this regard, a difficult management situation occurs, as it is impossible to find a unified model of human resource development. It is necessary to link the trends of digitalization and their impact on human resources with the general concept of the transformation of society. Society is inexorably changing, and this does not only refer to constant progress, but each stage of change is associated with a transition factor closely related to and implemented by a specific generation.

The theory of generations was developed by Strauss and Howe in 1991 and was first mentioned in their joint publication "Generations: The History of America's Future, 1584–2069" [10]. It describes generational cycles by the example of the United States of America and is also actively interpreted for various countries and social groups. By itself, this theory is ambiguous. Critics, for example, David Brooks [5], Diana Gomez [9], and Jonathan Alter [2], mostly note that this is not a scientific justification of the patterns of changes in society, but rather a generalized horoscope prediction filled with stereotypes. Nevertheless, the concept of allocating generations to analyze the effects of digitalization on human resources is relevant and acceptable.

The concept of "a generation" implies a group of people born in a certain period and possessing a specific, similar set of values that have developed during the process of socialization, so the conditions, external externalities are the same [10]. The term "generation echo" is also defined. It is the group of the population formed at the junction of the transition from one generation to another. The conflict between generations is not only related to age characteristics but is based on differences in values. There are a lot of interpretations of the names of generations, as well as time intervals to which certain generations belong.

It is already becoming clear that if strategies for adapting to the digital environment of older generations are not developed, this will lead to an increase in digital inequality and several negative effects. Moreover, research shows that there is a digital divide not only between generations but also between different socio-economic groups of older adults [22]. Furthermore, the digital generation perceives the new reality in a completely different way, constructing it rather than adapting to it. At the same time, even children who are prone to interact with smart devices may not trust the information they receive [31].

In addition to demographic trends, it is important to note new trends in the labor market caused by Industry 4.0 [32]:

- the norm of life has become remote employment of the population and freelancing; many IT companies prefer to transfer employees to remote employment, which allows companies to reduce costs, and employees receive additional preferences in the form of convenience. However, there are also limitations: without the skills of self-organization and time management for employees, this mechanism will be a failure. Freelancing as a form of employment is also growing;
- due to the increase in information and its accessibility, education is being transformed, this is due to the technologies of remote interaction. This changes self-education, technologies, approaches, and focuses in education;
- platform solutions (Uber, YouDo, etc.) connecting service providers and consumers without intermediaries. This allows people to switch to self-employed mode;
- the disappearance of traditional professions, and the formation of new ones under the category of "Knowledge", that is, those professions that are not supported by algorithms, but are based on skills;
- globalization of demand for a number of the most popular professions (basically it concerns the IT sphere);
- polarization of qualifications—demand for human resources categories of "Knowledge", decrease in demand for the category of "Skills";
- high rate of productivity changes, their complexity, and novelty;
- general complication of all professions and branches of knowledge.

Thus, it is important to note changes in competencies, but also the complexity of the profession as a whole. For example, just 10 years ago, such a profession as a Web designer was a single one in this segment, and by 2021 it had transformed into about 20 new professions (Fig. 2).

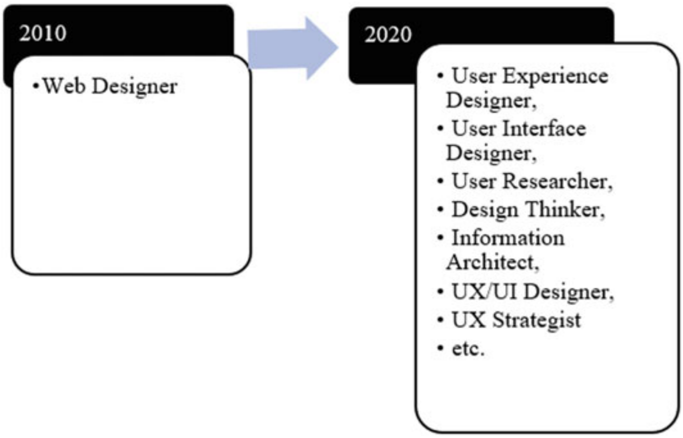

Fig. 2 The tendency to complicate professions by the example of the profession of a Web designer [32]

This indicates that the labor market is shifting, and the problem of human resource development is expanding.

Based on the trends described above, the definition of the problems of Industry 4.0, and the connection of the theory of generations with the transformation of society, it is advisable to note that the complexity of political, social, and business structures in modern realities tends to reach the limit, the point of bifurcation.

The system is in a near-critical state, and at any moment, the "phase transition" can occur—an irreversible change. Nassim Nicholas Taleb, who analyzes the impact of random events on the global economy, in his book *Skin in the Game: The Hidden Asymmetries in Daily Life* [27] notes that in the digital world, it is possible for a person to adequately assess the situation and perceive the growing difficulties only by risking everything and "putting his skin on the line". All the risk and responsibility must be assumed, not to be afraid to act. The transformation of a human resource is a risk and efficiency; they are inextricably linked, since only by venturing to master new technology, change a profession, one can talk about a human resource transformation, of its consciousness and view of the digital world.

Therefore, to form new strategies for the development of human resources, it is important to assess the factors of effectiveness. These include the influence of expertise and the influence of personality.

The first aspect includes knowledge in a specific professional field, the ability to apply it to solve professional problems, i.e., hard skills. The second aspect is the influence of personality—ways of actions, behaviors that ensure effectiveness outside the professional context—soft skills. The modification of the competence of human resources is primary since knowledge and information that was relevant 5 years ago may be considered outdated today. The general knowledge system has remained relevant, but the specifics of implementation have changed—long-term goals are not set, effectiveness is needed for a particular task only at present. Narrowly focused specializations are emerging and manual labor is transformed into automated labor. It follows from this that basic competence is the willingness to learn, master new knowledge, digital skills are key competencies, and specialization has been transformed into a narrower one that requires in-depth expertise. It is also important to "raise" ready-made experts, but it is much easier to do this than to retrain. In turn, to form an effective human resource management mechanism, it is necessary to focus on "new" expertise, which will include such new management principles as: trust, engagement, teamwork, culture of space for experiments and mistakes.

At the same time, different strategies and tools are required for the formation of digital competencies [15].

This analysis shows that professional competencies are becoming less important. The focus shifts to the modification of people, a systematic understanding of the professional field on the part of the employee—the basic laws, relationships, and solutions. It is all connected exclusively with people and working with them without formal guidance.

The following basic competencies of the digital economy were formulated in the SHL 2019 research [24, 28]:

- Continuous learning and innovation—the ability to adapt, learn quickly and innovate.
- Insights—when creating ideas, analytical and logical skills, critical thinking are required.
- Networking is the ability to build productive relationships, collaborate, and influence others.
- Perfection of execution—determination and consistency of actions when working on a task.

Within the framework of the World Economic Forum, the following Industry 4.0 skills were highlighted: complex problem solving, critical thinking, creativity, people management, coordination with others, emotional intelligence, judgment and decision making, service orientation, negotiation, cognitive flexibility [32].

It is necessary to create a culture of innovation that will involve all categories of generations in the process of digitalization of human resources. Two problems need to be solved: how to overcome the reluctance to develop; how to form a willingness to put into practice all that one has learned.

It is important to understand that people do not want to change. The transformation of competencies is possible only through the process of self-awareness on the spot. Attitudes hinder transformation and adaptation to new realities, especially for older generations of the population. Figure 3 shows a schematic structure of stereotypical human behavior in this sense.

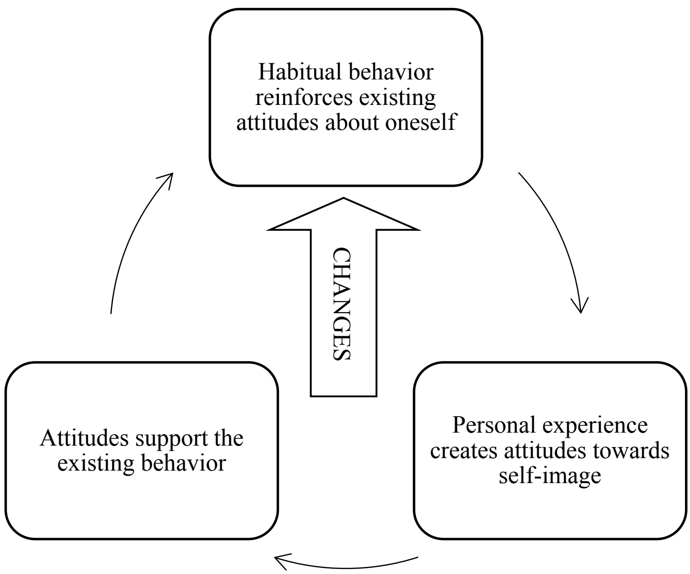

Fig. 3 The structure of stereotypical behavior

The implementation methods of this manipulation include the evaluation of human resource activities, receiving critical feedback, introspection on the part of the individual of his/her weaknesses and strengths, areas for development. As a solution at the organizational level, a number of measures can be taken and such tools can be used [30]:

- Conducting introductory courses, lectures for employees—determining the problematization of what one has to work with during the management process of multi-generational human resources.
- Evaluation of participants in the process of digitalization and modernization of the organization and workflow. This includes dynamic aptitude tests, professional and personal questionnaires, and motivational questionnaires.
- Analysis of the results of this assessment, the formation of quantitative and qualitative reports. These are reports such as “aptitude test profile”, “potential assessment report”, “recommendations on development tactics”.

These solutions can be used both for the main human resources and for reserves.

This is due to the fact that it is necessary to raise and develop personnel independently, and by forming a reserve base, one can be confident in the long-term effectiveness of the organization. So, the use of such tools will allow one to identify and assess:

- the level of “striving to achieve goals”—an assessment of the desire for professional development, career growth, achievement of ambitious goals;
- competencies—assessment of readiness to effectively solve work tasks in conditions of great responsibility, complexity, and uncertainty;
- potential level: moderate level of potential—formation of a development recommendation for the current position; high level—development both in the current role and in the future; very high level—complex developmental tasks are needed.

The determination of the level of one’s potential consists of an assessment of the indicators of “striving for achievements” and “average level of abilities”. Based on the evaluation results obtained, it is more possible to conduct group feedback with a team, plan for an individual course of human resource development, form a group training track for participants with high and very high potential (the result at the moment). This includes project activities and forming a personnel development system (the result is aimed at the future).

5 Discussion

The study showed several results. It is necessary to pay attention to new needs in professions, competencies, and the working environment to determine priorities for the human resources development for Industry 4.0. With this in mind, the paper suggests recommendations for human resources development at the organizational level. At the same time, there are also restrictions on using the proposed guidelines.

The situation is different, for example, for large industrial, medium-sized and small enterprises. Small businesses have a gap in the development of employees' soft skills and hard skills for Industry 4.0 [16]. In addition, it is necessary to consider the shift in the allocation of human resources between different sectors of the economy in various countries [33]. This will allow establishing strategies for personnel development in specific conditions.

The processes of digital transformation are implemented unevenly and with specifics in different regions of the world (including developed and developing economies). The balance of priorities in the development of human resources can change in numerous economic conditions. For instance, it is necessary to provide job security and continuous training opportunities for employees in developing economies such as India under Industry 4.0 disruptions [1]. In turn, for companies in Brazil, the development of methods for evaluating employees in the context of Industry 4.0 and evaluating resources for the transformation of organizations is of particular relevance [21]. For European countries, it is reasonable to involve employees during the implementation of Industry 4.0 [29].

Also, the novelty of the issue of human resource development in the context of Industry 4.0 requires further research. The authors will focus future efforts on studying the differentiation of the directions of human resource development strategies in different conditions of implementing Industry 4.0.

6 Conclusion

Therefore, in the context of Industry 4.0, the development of human resources needs to be considered from several positions.

First, it is necessary to consider human resources development in correspondence with the impact of new trends in digitalization and technologization on the labor market. Transformation on both the demand side and the supply side of the labor market needs to be considered. In this sense, Industry 4.0 sets the conditions for the development of human resources and is at the same time dependent on such development. It covers changes in professions, competencies, working environment, governance approaches, and other issues.

Second, the choice of guidelines and methods for the development of human resources requires taking into account demographic trends and the differentiation of generations. It is necessary to take into account that, first, the general demographic situation is changing, which affects the development opportunities of human resources with different characteristics. Second, different generations demonstrate different mental attitudes and behavioral patterns in the context of Industry 4.0.

Third, the development of human resources receives a concrete embodiment in the plane of the labor market at the level of specific organizations. This determines the importance of developing holistic strategies for personnel development, including the creation of a new digital environment and culture, as well as the adaptation of management models to new demands using specialized methods and tools.

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Digital Transformation and Its Staffing in the Russian Economy

Michael Djanelidze and Nataliia Shestakova

Abstract The purpose of the article is to study the transformation of the personnel system in the context of Industry 4.0. The economic and social consequences of Industry 4.0 determined the research methods—historical, critical and comparative analysis. The authors concluded that there is a discrepancy between the training system of IT personnel and the requirements of "digital" workplaces. The study revealed that during the transition to Industry 4.0, the requirements for employee competencies are changing revolutionarily, as well as new forms of connections between demand from new industries and supply from educational and personnel institutions are emerging. The authors proposed a classification of these forms of connections.

Keywords Industry 4.0 · Staffing of digital economy · Additional vocational education · Digital skills

1 Introduction

We live in the era of the fourth industrial revolution, described by the concept of Industry 4.0. The term "Industry 4.0" was coined in 2011, when an initiative group of German politicians, industrialists and scientists began to develop new approaches to improving the competitiveness of the German manufacturing industry. In the same year, the Industry 4.0 concept was announced by the President of the World Economic Forum in Davos Klaus Schwab. The essence of "Industry 4.0" is the accelerated integration of cyber-physical systems into factory processes, as a result of which a significant part of production takes place without human participation.

The implementation of the Industry 4.0 program was preceded by three major industrial revolutions earlier:

The First Industrial Revolution—Industry 1.0 (the end of the eighteenth century—the introduction of machine production on a steam engine);

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The Second Industrial Revolution—Industry 2.0 (the beginning of the twentieth century—the introduction of mass production, the use of an electric motor and an internal combustion engine);
The Third Industrial Revolution—Industry 3.0 (the early 70 s of the twentieth century—the introduction of electronics and information technology achievements, further automation of production).

Originally, Germany initiated the development of the Industry 4.0 program. Subsequently, similar programs were launched in the Netherlands, France, Great Britain, Italy, Belgium and other countries. In the USA, since 2012, there has been a non-profit "Coalition of Smart Manufacturing Leaders" that unites businesses, universities and government agencies in the development of Industry 4.0.

2 Background

The development of the Internet, information technologies (IT), stable communication channels, cloud technologies and digital platforms, as well as the significantly increased volume of information generated from various sources, ensured the emergence of open information systems and global industrial networks. This, in turn, had a transformative impact on all sectors of the modern economy and business outside of the IT sector itself, leading to the Fourth Industrial Revolution. The concept and program of Industry 4.0 became a reflection of such developments.

McKinsey experts define Industry 4.0 as the digitalization of the manufacturing sector, combined with sensors that will be embedded in almost all components and equipment, the widespread introduction of cyber-physical systems and analysis of all available data. McKinsey experts divided all technologies driving the new revolution into four clusters: (1) related to data, computing power and information transfer (big data, Internet of Things and machine-2-machine technologies, cloud technologies); (2) related to analytics (digitalization and automation of scientific work, advanced analytics); (3) related to the interaction of man and machine (new interfaces, virtual, augmented and mixed reality technologies); (4) related to the transition from the digital world to the physical (additive manufacturing technologies, for example, industrial 3D printing, robotics, new ways of generating and storing energy). All these technologies are now experiencing a tipping point: manufacturing companies must decide how to respond to them [3].

Despite the society's controversial opinions on Industry 4.0, the world economy is on the verge of the Fourth Industrial Revolution, which will lead to the complete automation of most production processes, and, as a result, an increase in labor productivity which will ensure economic growth and competitiveness of leading countries. Industry 4.0. is characterized by unprecedented speed and volume of receiving, collecting, aggregating, processing and transmitting data, which makes it possible to move to a fundamentally higher level of production process management.

An important point for Russia is that the development of Industry 4.0 provides a chance for a radical increase in the competitiveness of the country's industry. In the Russian Federation, the analogue of the German program "Industry 4.0" is the National Technology Initiative (NTI), which was designed to ensure the expected industrial revolution in 2025–2035.

At the beginning of 2017, the industrial digitalization program in Russia was launched and the first roadmap of the National Technological Initiative (NTI), Technet, was approved [7]. According to it, the most promising areas for development should be digital design and modeling, new materials, additive technologies, industrial Internet and robotics.

The implementation of the concept and principles of Industry 4.0 in a separate company implies digitalization (automation) and integration of technological, production and business processes vertically and horizontally throughout the enterprise, from product development and procurement to production, logistics and maintenance during operation. Simultaneously, the horizontal integration of a digital enterprise goes beyond internal operations and covers suppliers, consumers and all key partners in the value chain. All this taken together must be supported by an appropriate integrated digital platform (which means an automated information system that uses all the necessary set of data, models, algorithms, methods and tools), which, combined with the entire chain, makes up the ecosystem of a digital enterprise.

3 Materials and Methods

The relevance of the research topic is due to two circumstances. Firstly, an analysis of literary sources and scientific studies on the disparity between changes in the requirements for workers during the formation of Industry 4.0 (as a consequence of the digitalization of production and workplaces) and the transformation of the staff system showed the inconsistency and insufficient knowledge of the interrelationship of these areas from the perspective of economic theory. The present research is aimed at filling these gaps. The results obtained in the course of the study outline the promising directions for solving practical problems of forming the mechanisms of interaction between the production spheres and staffing during the transition to Industry 4.0.

The research purpose is to study the problems of transformation of the staff system associated with the formation of Industry 4.0 and propose relevant solutions.

The methods were chosen in accordance with the examined subject, namely, the economic and social conditions and consequences of the formation of Industry 4.0 and their impact on the education system. Therefore, the methodological basis of the study is the scientific approaches of institutional and evolutionary economics, comparative and sociological analysis, historical and systemic approaches. The theoretical and practice-oriented aspects of the stated problem were investigated using general scientific analytical and synthetic methods, the study of domestic and foreign scientific publications, as well as the analysis of statistical and Internet sources. Scientific, regulatory, documentary and statistical materials were examined to ensure the reliability of the research results.

4 Results

Industry 4.0 is based on the industrial Internet of Things (IoT) and cyber-physical systems (CPS). Modern manufacturing heavily relies on the Internet of Things. It is a network in which most of the production equipment is supplied with sensors and controllers connected to the Internet. IoT allows combining mechanisms, sensors and computers in a single production process with a new level of production support and quality assurance.

If IoT is used for monitoring and controlling the equipment on the network, then CPS is a way of automating production processes that combines human labor and machines connected to the Internet into a single digital enterprise system.

The principles of Industry 4.0 permeate all production processes, including design, creation of a sample and prototype, technological preparation of production, adjustment and maintenance of production processes, production control, and collection of information from consumers. Industry 4.0 is a radical systemic innovation that transforms the processes of production, improvement, distribution and sale of products. Its tools enable the integration of advanced manufacturing technologies, including the Internet of Things, cloud computing and analytics, AI and machine learning into a single production process on a new basis.

The main approaches of Industry 4.0 are based on: Big Data (big data machine processing); Smart Factory or "smart production"; Product Lifecycle Management (PLM) (management and electronic control of the entire product lifecycle); Interoperability of equipment, systems and communications of the enterprise.

The most important technologies of Industry 4.0 include: Internet of things; Additive manufacturing; Artificial intelligence, machine learning and robotics; Big data, blockchain and cloud computing; Virtual and augmented reality.

In general, Industry 4.0 is a digital strategy for the development of high-tech industry. Enterprises that have moved to Industry 4.0 use "smart" sensors, embedded software and robotic systems that provide real-time data collection and analysis. The analysis of large volumes of data collected from sensors at the production facility ensures transparency of production processes and a new level of their control. The use of IoT devices in enterprises contributes to an increased productivity and quality. At the same time, Industry 4.0 technologies can be applied in industrial companies of any sectors, including discrete and continuous production, as well as companies in the oil and gas and mining industries, etc.

The predicted consequences of the development of Industry 4.0 will be following: Industry 4.0 is expected to become a driver of the global economy. Thus, it is predicted that artificial intelligence technologies will provide about 14% of global GDP growth in the amount of about $15.7 trillion; Transformation of the sectoral structure of the economy; Reduction of the share of physical labor due to mechanization and robotization; Automation of routine intellectual operations through the use of artificial intelligence; Increase in the share of intellectual and creative work, a decrease in the role of routine work, the loss of the importance of some working specialties.

The development of Industry 4.0 revealed that the expansion of the post-industrial service sector did not lead to a reduction in industrial sectors. The introduction of digital technologies into production processes, economic relations and everyday life transformed the relationships between companies (and, equally importantly, their relationships with consumers), and increased labor productivity and modernization of social practices.

The digitalization of industry has its advantages and disadvantages. The advantages include the following: labor productivity growth; effective promotion of goods and services; transparency of production and financial transactions; monitoring and controlling of the production process; acceleration of production processes; speed of adaptation to market changes; cost reduction; exclusion of intermediaries.

As for the disadvantages, they are related to two aspects. The first is an increase in the information vulnerability of production know-how and personal data of employees. The second is the changes in the labor market associated with the replacement of human labor with machine labor and the disappearance of a number of professions.

According to the results of the 2020 study [11] conducted by Deloitte CIS and SAP ("From strategy to implementation—how to increase the value of digital transformation"), digitalization leaders in Russia are banks, retail and telecommunications companies. Among the laggards are the branches of mechanical engineering and pharmaceuticals.

The banking sector is more digitalized than other industries due to the high proportion of online services. The Covid-19 pandemic also pushed companies from the trade sector to move online. According to Deloitte researchers, the fuel and energy sector, metallurgy, healthcare and mechanical engineering industries face the problems of digitalization to a greater extent.

At the same time, the results of an expert survey conducted by the Higher School of Economics (HSE, Moscow) in 2020 show the uneven demand for advanced digital technologies across the sectors of the Russian economy and social sphere [15, 27]. According to Russian experts, today the industries with the greatest need for digital solutions are housing and communal services, energy, culture, tourism, state and municipal services, sports, education, ecology. Simultaneously, there are industries with the greatest number of barriers hindering the introduction of digital technologies, including construction, agriculture, transport and logistics, new generation networks. According to the results of this study, they are most in demand in the fuel and energy sector, healthcare and the financial sector. The high demand in healthcare is largely due to the need to solve the urgent tasks of combating the pandemic. The rapid growth of digital maturity of financial sector companies is facilitated by the active introduction of digital technologies by large Russian banks.

The task of providing personnel for the digital economy is set and disclosed in the federal project of the same name "Personnel for the Digital Economy" (2018–2021)

[16] of the national program “Digital Economy of the Russian Federation” [19]. The main goal of the project is stated to be “ensuring the training of highly qualified personnel for the digital economy”.

The achievement of this goal is assumed by solving the following tasks (an abbreviated version is presented on the official website of the Ministry of Digital Development) [16]:

- Ensuring accessibility of additional education programs for the population to obtain new digital competencies in demand on the labor market.
- Ensuring the needs of the labor market for specialists in the field of IT and information security, as well as for specialists with digital competencies who have been trained in the relevant programs of higher and secondary vocational education.
- Providing online services to educational organizations implementing programs of primary, basic general, secondary general and vocational education.

The project includes three components: (1) The Digital Professions project, which offers Russians to get additional IT education in 24 areas of educational programs from popular IT organizations and educational institutions for half the cost4 (2) The project “Ready for Digital”, which is an aggregator of services for testing the level of digital literacy, allows visitors to the corresponding site to assess their level of digital literacy, learn about the possibilities of online environment and form the necessary IT skills to teach safe and effective work with digital technologies.; (3) The CLICK project, which is an educational program that allows representatives of federal and regional authorities responsible for the implementation of the national Digital Economy program, managers of Russian companies, representatives of higher educational institutions, industry and scientific organizations interested in digital development to gain new digital competencies.

“Today, the state is making a serious bet on digital personnel, and programmers are highly sought-after specialists. Therefore, the Russian government is implementing a number of major educational projects that affect students, schoolchildren and professionals from other fields who are ready to retrain to work in the IT sphere,”—said Deputy Prime Minister Dmitry Chernyshenko in this regard [28].

Thus, the federal project is fundamentally focused on training personnel not for the digital economy as a national economic complex, but for the IT sphere: personnel with digital competencies and/or supporting them, as well as providing online services to educational organizations of various levels.

However, in our opinion, these positions do not exhaust the full breadth of the problem. In addition to those stated in the profile federal program, the problem of staffing the so-called Industry 4.0 or the digital economy opens up a number of directions for theoretical research and practical implementation, including: providing the digital economy with personnel in terms of their sufficient quantity, quality and structure; developing employee competencies for those involved in the digital economy; maintaining and/or updating the initially received education.

Note that the above list is not exhaustive: other research vectors are also possible.

4.1 Providing the Digital Economy with Human Resources

Only quantitative guidelines of preparation can be found in the profile materials, and only in the most general terms and fragments. Thus, according to the results of a joint study of Information and Computer Technologies Industry Association (APKIT) and ANO "Digital Economy" [27], the total need for highly qualified ICT personnel is estimated at 220 thousand people, and 80 thousand people per year for medium-qualified personnel. By 2024, the need for highly qualified personnel will increase to 300 thousand per year. At the same time, the national system of higher education does not have sufficient material and human resources to train specialists in the digital economy in the required volumes. Moreover, we are not talking about engineers, doctors or teachers, but about the training of IT specialists. As for training in other areas, the number of graduates of the vocational education system with key competencies of the digital economy is expected to increase to 800 thousand people by 2024. In addition, the number of people accepted for higher education programs in the field of IT should increase up to 120 thousand people a year. This will allow getting closer to the necessary level of personnel reproduction for the outstripping growth of the IT industry.

However, the problem of providing the digital economy with human resources is not limited only to quantitative parameters, as the high quality of training of specialists in the field of IT should also be noted. Thus, the head of the working group on the direction "Personnel for the digital economy" at the ANO "Digital Economy" and the head of the APKIT Committee on Education B. G. Nuraliev states: "Russian education in the field of IT has a high level of development: our specialists are in demand all over the world, and Russian companies mainly cope at the expense of personnel trained in Russia" [27].

The issue of personnel training for the digital economy is not limited to quantitative and qualitative parameters. It is much broader and is associated with a number of aspects.

First, it is necessary to talk about drawing up the promising professional and qualification structure of labor resources in the sectoral (or by type of economic activity) context.

Secondly, it is necessary to take into account the pace of bringing the national system of personnel training into compliance with the requirements of the digital economy: the list of professions taught in higher and secondary (which currently includes primary) vocational schools, educational documentation (including Federal State Educational Standards, curricula and programs, etc.). According to the Ministry of Digital Development, Communications and Mass Media of the Russian Federation, as of September 2021, 340 Russian universities and institutions of secondary vocational education have adapted educational programs to the requirements of the digital economy. This corresponds to the share of 8.5% of their total number (For reference: a total of 3983 educational organizations carry out educational activities in the Russian Federation at the beginning of the 2020/2021 academic year, including 3273 educational programs of secondary vocational education, and 710 programs of undergraduate, specialty, master's degrees [13, 13, 13]. In addition, another 25 universities in the framework of the pilot project began testing 30 educational programs that were developed at the request of commercial companies representing 11 priority sectors of the economy. At the moment, the approval of the working programs of the disciplines is being completed [2].

Thirdly, it is necessary to consider such a parameter as bringing the national system of additional education into compliance with the requirements of the digital economy. It is important to ensure the up–to–date maintenance of previously acquired/primary knowledge, skills and competencies from the point of view of their compliance not only with the current, but also with the promising requirements of the digital economy.

4.2 Development of Employee Competencies Involved in the Digital Economy

Both individual researchers and research teams are engaged in the development of employee competencies as part of the study of human capital. Here are examples from foreign and national practice.

The first example. According to opinion of McKinsey analysts, in the context of the growing digital transformation of the economy, "all employees must adapt … to activities that require social and emotional skills, creativity, high-level cognitive abilities and other skills that are relatively difficult to automate" [17]. Accordingly, employees should have the following set of qualities: social and emotional skills; creativity; high-level cognitive abilities.

Similar development results were obtained by Deloitte researchers: they came to the conclusion that when a person's labor is "divided" with a machine, the employee will have these actual human properties and qualities that cannot be replaced by a machine [10]. These included: empathy; ability to communicate; ability to convince; skill/proficiency in personal service; ability to solve problems and make strategic decisions.

As a result, Deloitte analysts recommend: to invest in critical human skills for the future of the workforce, such as "problem solving, creativity, project management, listening, making moral and ethical decisions—all these are, in fact, human skills that every organization needs—both now and in the future. When planning for the future of the workforce, consider these long-term human skills needs". This was the second example.

The third example. The most complete version of the set of competencies that will be in demand (listed in descending order of importance) was proposed by the analysts of the World Economic Forum [1] with reference to [12]: complex problem solving; critical thinking (one of the key competencies in the forecasts for 10–15 years.)—the skill to select, analyze and comprehend information due to the huge volume of data and its accessibility; creativity—the ability to overcome stereotypes and make non-standard decisions in various situations; people management—the skill for working with people in a complex environment (a symbiosis of human and artificial intelligence) (according to the authors' curve, either the cheapest employees (whose labor is cheaper than robots) or highly professional ones will be in demand); coordination and interaction skills (coordination with others)—the ability to communicate, work in a team and perform various roles in it; emotional intelligence—the ability to react sensitively to the emotions, feelings, intentions and state of another person, as well as the ability to manage them [32]; judgment and decision-making—the speed and quality of decision-making; customer orientation (service orientation, service orientation)—the competence closely related to the development of emotional intelligence; ability to negotiate (negotiations);cognitive flexibility—the ability to switch from one thought to another, as well as to think about several things at the same time. Possession of it contributes to the realization of the properties of creativity and the ability to solve complex problems.

Today, in 2021, we can already appreciate the high degree of foresight of WEF experts.

The fourth example. At the national level, the matrix of the target competence model (2025) was compiled by Sberbank specialists (Table 1). It includes three blocks of competencies: cognitive, socio-behavioral and digital skills. Let's pay attention to the substitution of the concepts of "competence" in the process of their disclosure for "skills".

The fifth example. The website of the Ministry of Digital Development, Communications and Mass Media of the Russian Federation offers a "list of rigid, flexible and special digital competencies". Here is an appropriate excerpt [18].

"The implementation of breakthrough technological projects in the digital economy creates a demand for specialists who possess the complex of rigid, flexible and special digital competencies, including: deep understanding of their field, as well as knowledge and experience in related fields ("T-shaped specialist"); understanding the opportunities and risks associated with the use of new technologies; knowledge of project management methods; "digital dexterity"; knowledge of big data tools and visualization tools; understanding the basics of cybersecurity; database skills; systems thinking; emotional intelligence; teamwork; ability of continuous learning; ability to solve turnkey tasks; adaptability and work in conditions of uncertainty.

At the same time, no official documents are presented on the site. However, the following thesis is given: "Big data analytics becomes the key competence determining the competitive advantages of companies of the future."

The sixth example. The official website of the Competence Center, created on the basis of the NTI 2035 University [14], also provides a list of officially approved key competencies required in the conditions of global digitalization of public and business processes specific to human activity in the context of widespread and use of digital technologies and related products and services. These are the competencies of digital literacy in everyday and professional contexts, as well as the professional competencies of the digital economy; the key competencies of the digital economy can be

Table 1 Target model of competencies 2025 [8]

Cognitive skills			Socio-behavioral skills		
Self-development	Organization	Management skills	Communication	Interpersonal skills	Cross-cultural interaction
• Self-awareness	• Organization of their activities	• Prioritization	• Presentation	• Teamwork	• Awareness
• Learnability	• Resource Management	• Task Setting	• Written	• Ethics	• Social responsibility
• Perception of criticism and feedback		• Formation of teams	• Negotiation	• Empathy	• Cross-functional and cross-disciplinary interaction
• Curiosity		• Development of others	• Openness	• Customer orientation	• Foreign languages and cultures
		• Motivating others		• Stress management	
		• Delegation		• Adequate perception of criticism	
Achieving results	Solving non-standard tasks	Adaptability	Digital skills		
			Creation of systems		Information management
• Responsibility, risk-taking	• Creativity, including the ability to see opportunities	• Work in conditions of uncertainty	• Programming		• Data processing and analysis
• Perseverance in achieving goals	• Critical thinking		• Application development		
• Initiative			• Design of production systems		

distinguished separately. While it is stated that the list is not final, five main competencies are identified [9]: communication and cooperation in the digital environment; self-development in conditions of uncertainty; creative thinking; information and data management; critical thinking in the digital environment.

5 Discussion

Comparison of the above models reveals a difference in approaches: if in foreign versions of digital competencies are not distinguished separately (they are implied to be present "by default"), then in Russian models, digital competencies are not only spelled out in the separate block, but also divided into two groups (as in the example with Sberbank) or are strangely disclosed (for example, the item "digital dexterity" as presented on the website of the Ministry of Digital Development).

The activity of "promoted" digital competencies continues in Russia to this day. As it was shown above, the federal project "Personnel for the Digital Economy" is largely focused on the formation of such competencies. An echo of this approach was the proposal to classify IT professions as those that "in the list of general professional competencies include the ability to develop algorithms and programs suitable for practical application" [27].

In this regard, it is interesting to cite some of the results of the first of the three parts of the Global Skills Report, prepared by the Coursera educational platform [22]. The data obtained were classified in the fields of business, technology and data analytics (Table 2). The cross-cutting index of countries has been compiled for each sphere, and the overall rating was calculated on the basis of these indices.

Russia ranks ninth in the overall world ranking, and eighth in the European ranking.

The other side of the coin is a set of the least developed digital competencies by Russians. According to a study by the Russian Public Opinion Research Center (VCIOM) and Social Business Group LLC (SBG) [31], it includes: software installation and configuration, photo and image editing, presentation preparation, video editing on the phone or computer.

Meanwhile, an objectively universal, standard or basic model of the competencies of employees involved in the digital economy has not yet been presented. Such a model is declared as developed, but the actual model could not be found.

Table 2 Top 3 competencies that interest students from Russia [22]

Business	Technology	Data analytics
Operational strategy	Theoretical foundations of Computer Engineering	Python programming
Microsoft excel	Programming in C	Statistical theory of learning
Project management	Programming principles	Probability and statistics

At the same time, one of the profile publications presents an up-to-date private model of the competencies of the digital transformation team in the public administration system. Structurally, it consists of four interconnected blocks [23]:

- competencies, understood as the minimum necessary level of knowledge and skills of using information and communication technologies (ICT) in everyday and professional activities;
- personal competencies (soft skills) in the field of digital development: a group of competencies reflecting individual personality traits that allow people to successfully participate in the implementation of digital transformation strategies and digital development projects (the block includes the following positions: focus on results; client-centricity; communication; emotional intelligence; creativity; criticality);
- professional competencies (hard skills) in the field of digital development: a group of competencies related to the functional use of methods and tools for managing processes, projects, products of digital transformation and the regular solution of complex professional tasks in the digital environment (the block includes the following positions: Digital development management; Development of organizational culture; Management tools; Data management and use; Application of digital technologies; Development of IT infrastructure);
- digital culture, understood as a system of values, attitudes, norms and rules of behavior that is accepted, supported and broadcast by the digital transformation team.

There may be several comments on the above model, as well as other national models. Firstly, the presented model is largely based on the experience shown above in the development of a set of competencies of the World Bank. Secondly, national models and/or lists of digital competencies contained in various more or less official sources differ significantly among themselves. Thirdly, the last of the above models (the team of authors of the RANEPA) is the most complete: it seems that, with some adjustment, it can be extended to other areas of activity.

In this context, one of the Deloitte reports [30] showed the emergence—along with standard types of work (Standard jobs), based on the use of the given and narrow set of skills to perform repeatable work tasks and standard processes—of new types of work (the most in demand and providing the highest wage growth rates): "hybrid works" (hybrid jobs), which require the combination of technical skills, including technological, data analysis and interpretation skills, with "soft" skills in terms of communication, service and the ability to work in the team (cooperation); "super types of work" (super jobs), which combine, on the one hand, the types and responsibilities of several traditional types of work, and, on the other hand, the use of IT technologies to increase and expand the volume of work performed, accordingly implying the complex set of subject, technical and human skills.

Super jobs require the breadth of technical and soft skills, as they combine parts of various traditional types of work into integrated activities and work in conditions of human interaction with smart machines, data and algorithms in order to significantly increase productivity and labor efficiency.

Regarding the formation of promising skills of employees in the context of the digital transformation of the economy, Global Technology Leadership Study states that in the next three years, analytics and cognitive functions will have the second most important impact on organizations. AI is projected to add $13 billion over the next decade into the world economy. 60% of the more than 1300 IT directors and senior technology leaders surveyed by Deloitte said that their organization uses AI to provide assistance, not to replace employees. In addition, the majority of respondents believe that the number of jobs in companies will either remain at the same level or increase because of the use of artificial intelligence [29].

5.1 The Issues of Maintaining and/or Updating the Initially Received Education

It is obvious that a direct consequence of the dynamic renewal of digital technologies is the accelerated obsolescence of the knowledge and skills of workers.

10 years ago, the Russian researcher A. L. Safonov pointed out that, for example, "in metallurgy, knowledge becomes obsolete every 3.9 years; in mechanical engineering—5.2 years; in the chemical industry—4.8 years; in advertising—5 years; in business—2 years, etc. The half-life of knowledge in the most knowledge-intensive industries is less than 2.5 years. And for a graduate of the XXI century, the obsolescence of knowledge occurs in 2–3 years" [24].

Thus, the question arises about the need to maintain and/or update the knowledge originally acquired by an employee. This fully corresponds to the concept of long-life education and occurs through participation in additional education.

The continuous progress of digital technologies means that today software engineers must update their skills every 12–18 months according to Deloitte experts. Specialists in the field of marketing, sales, production, law, accounting and finance work in similar conditions [10].

Updating of knowledge and skills can occur through advanced training or professional retraining.

In foreign countries, intra-company professional development is recognized as a promising form of additional education. This, in particular, is indicated in the reports of Deloitte 2014, 2015, 2016, 2017 [5, 6, 10, 25].

The topic of staff training as a way of forming promising skills in demand is disclosed in detail in the Deloitte 2017 report [10]. In particular, the training function is considered by corporate units responsible for training and staff development as a strategically important business area focusing on innovation and leadership development, promoting lifelong learning in order to prolong careers, as well as uniting multifunctional teams for integration and collaboration.

The introduction of new employee training systems is currently the fastest growing segment in the expenditure of human resources services. In this regard, heads of company departments responsible for the personnel training in the new conditions should, on the one hand, create the learning environment that prepares the ground for increasing the mobility of employees, and, on the other hand, develop interdisciplinary skills.

In Russian practice, the Institute of Additional Education (Additional Vocational Education, AVE) is responsible for the organization and implementation of the idea of continuing education.

In Russia, some categories of workers (based on the need to update knowledge) are objectively recognized as requiring mandatory regular professional development. These are such specialists as: medical professionals; public procurement officials; officers of the Investigative Committee and the police; prosecutors; notaries; auditors; specialists whose work affects the safety of capital construction facilities; employees of organizations for the extraction (processing) of coal (oil shale), managing mining and blasting operations; heads of private security organizations, etc.

Many large companies, in particular, Sberbank, Rosatom, Russian Railways, Gazprom and other holding structures have followed the path of organizing their own corporate universities and training centers in Russia. According to the researchers of the Analytical Department of Scientific and Technological Development of Skoltech, "In the structure of the offer, the main trend is an increase of more than two times in the number of specialized AVE organizations (including corporate universities) with the drop in the share of universities in the total number of organizations providing AVE services. Corporate universities are both partners and competitors for universities" [26]. According to financial indicators, companies occupy leading positions in the market of AVE (Table 3).

According to RBC rating [20], companies spend from 0.11 to 3% of the payroll on corporate training. Table 4 shows an estimate of the expenses of the largest companies in Russia for staff training.

Thus, the total investment in personnel training and development of the 23 companies listed in the table in 2018 amounted to 29.6 billion rubles [26], which, according to Skoltech experts, was equal to 80% of the total expenses of Russian companies for personnel training. The largest investors in additional education are Gazprom, Sberbank, Russian Railways, Rosneft and Rosatom. With the exception of Rosneft, all of these companies have corporate universities.

Table 3 Assessment of the volume of the AVE market in 2018 [26]

	Market volume	
	Billion rubles	%
Total	82.0	100.0
Including		
Companies	37.0	45.2
State	33.0	40.2
Population	12.0	14.6

Table 4 Assessment of personnel training costs of the largest companies in Russia and the availability of corporate universities, 2018 [26]

Company	Assessment of training costs, billion rubles	Availability of a corporate university
Gazprom	5.8[a]	Yes
LUKOIL	0.8	No (internal system)[b]
Rosneft	2.5	No (internal system)
Sberbank of Russia	4.6	Yes
Russian Railways	3.4	Yes
Rostec	1.6	Yes
Surgutneftegaz	0.7	No (internal system)
X5 Retail Group	0.2	No (internal system and external contractors)
VTB	1.1	No
Magnet	0.7	No
Rosatom	2.3	Yes
Russian networks	1.3	No
Inter RAO	0.4	No
Transneft	1.1	No
Tatneft	0.3	Yes (division of the main legal entity)
NOVATEK	0.1	No
Evraz	0.6	No (internal system)
Sistema Public Joint Stock Financial Corporation	0.4	No
En +	0.5	Yes
NLMK	0.3	Yes
Norilsk Nickel	1.0	Yes
Megapolis Group of Companies	0.0	No
Rusal	0.1	Yes
TOTAL	29.6	

[a]Gazprom Neft (the subsidiary of Gazprom) spent 1.1 billion rubles on employee training in 2018
[b]Internal corporate training/knowledge management system is a systematic implementation of staff training either in the form of special formalized programs or on the basis of portal technologies, without allocating these programs and corporate portals to the structure of a corporate university

The undoubted advantages of corporate universities, including in the aspect of digitalization of the economy, are [26]:

- implementation of programs for the development of competencies in the field of digitalization (among the largest companies, this area of AVE is being developed, in particular, by Lukoil, Rosseti, Rosatom);

- adaptation of infrastructure to support the implementation of corporate changes, including those related to digitalization;
- building a full cycle of competence management at the enterprise at the level of the corporate university;
- real interaction with universities, business schools, colleges and other educational institutions with the resulting mutual benefits;
- expansion of the corporate training segment in the digital space due to greater flexibility and speed of decision-making, as well as greater availability of resources relative to traditional players in the educational market.

Regarding the last thesis, in the practice of corporate education, 70% of companies use both online and offline training.

However, according to the Ministry of Science and Higher Education of Russian Federation for 2020, out of all organizations that carried out educational activities under additional vocational education programs, organizations of the real sector of the economy—corporate universities, training centers of enterprises and others—accounted for only 11.5% [4].

According to analysts of the BusinesStat agency, the total number of additional vocational education programs in Russia in 2021–2025 will increase annually by 4.0–4.9% [4]. This growth will be associated with the transition of some programs to an online format. In addition, it is assumed that [21]:

- the population's attitudes will be redistributed from the goals of obtaining higher education to the format of shorter additional education programs that allow people to master new professional skills at lower cost;
- the number of programs for business and management will increase;
- the list of demanded specialties will change;
- new programs for working professions, as well as programs related to the digitalization of various processes will emerge.

6 Conclusion

It is obvious that the processes of digitalization and the development of Industry 4.0 will lead to numerous and unpredicted consequences in the economic and social spheres. However, the outlines of scenarios for future events are already being viewed. On the one hand, the multiple increase in productivity and liberation from heavy routine work, deforming the personality of employees, an increase in free time for their creativity and leisure are possible. On the other hand, there are obvious prospects for the narrowing of the labor market and employment opportunities, loss of livelihood of a significant part of workers and their families. In addition, digital technologies provide unlimited opportunities for social control, the thoughtless implementation of which will lead to an unprecedented violation of fundamental freedoms and human rights, depriving people of any privacy. The implementation of scenarios depends not directly on the requirements of Industry 4.0, but on the direction of socio-economic development, its humanistic orientation, aimed at the values of human development and justice, or increasing social polarization and strengthening social control. As human history demonstrated, new technologies turn out to be ethically neutral and the risks of their application will depend on the social structure of human society and progress (or regression) in this direction.

The revolutionary changes in the requirements for skills and training of workers during the transition to Industry 4.0 lead to an increasing mismatch, the gap between the constant changes (with ever-accelerating dynamics) of the needs of industry in the professional composition, qualities and characteristics of the workforce, on the one hand, and the inertial educational system, on the other. At the same time, new types of interaction are developing, innovative communications are being formed, connecting the demand from Industry 4.0 sectors and supply from the educational system. The present study examined their formation, identified existing trends and determined prospects for further development.

Thus, it can be stated that the processes of digital transformation of the economy dictate to companies the need to review the totality of skills demanded from employees, as well as the content and infrastructure of training and staff development.

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Priorities of Human Resources Policy in the Context of Digitalization and the COVID-19 Pandemic

Yulia Otmakhova and Dmitry Devyatkin

Abstract Digitalization has a global trend and has become a driver of competitiveness in the enterprise sector. The pandemic has forced governments and businesses around the globe to accelerate the transition to digital technologies. Due to those grand challenges, the labor market landscape and human resources policy priorities have undergone significant changes. New jobs, methods, and innovative practices have appeared under the influence of digitalization. In this research, we test how to apply large datasets of full-text documents (more than 1 million patents and Ph.D. theses) to find possible directions for transformation of working conditions and job-related changes. We have identified promising directions in terms of research and development and economy, which grew in 2020: agriculture machinery, pharmacology, diagnostic tools, logistics, and wireless technologies. Moreover, under those directions we have found some research and production centers, which we can consider potential producers and labour consumers. Russian federal and regional authorities might use results of our research to form personnel policies of regions and federal districts.

Keywords HR policy · Labor market · Digitalization · Big data analysis · Patent landscape · Text mining · COVID-19 pandemic

1 Introduction

Digitalization has a global trend and has become a driver of competitiveness in the enterprise sector. Pandemic has forced governments and businesses around the globe to accelerate the transition to digital technologies. Due to grand challenges, the labor market landscape and human resources policy priorities have undergone

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significant changes. Human resource management (HRM) is at the heart of these transformations, helping organizations navigate the vague present and unforeseeable future [4, 7]. New professions are being formed under the influence of digitalization. The COVID-19 pandemic has caused accelerating digitalization and led to the global health crisis and large-scale transformations in the economic situation of the population and business. The recent reports by international economic expert organizations show that the COVID-19 pandemic has led to a complex crisis in labor markets worldwide [22]. The OECD reports that unemployment peaks at 12.6% by 2020 and could still stand at 8.9% by the end of 2021 [13]. The Europe Commission concludes that the pandemic has already destroyed 6 million jobs in the European Union and hit young people the hardest [17]. Thus, the COVID-19 pandemic-induced lockdowns and related global recession of 2020 have created a highly uncertain outlook for the labor market and accelerated the arrival of the future of work. Companies have to restructure requirements and skills to workers in response to new technologies and new challenges.

The significant economic impacts of the crisis are particularly noticeable on global and local labor markets, including massive job losses, reduced working hours for employees, and measures taken by governments to financially support companies in a range of industries. Against the backdrop of a shrinking job market and rising unemployment, major structural shifts and innovative changes are expected, some of which will increase the efficiency of the labor market through the emergence of new professions, new methods, and work practices. However, in several business areas, many new vacancies are being formed, which will require additional training, deepening of specialization, and IT solutions.

In this paper, we set the following research question. Could the signs of the pandemic-driven transformations of the labor market be revealed from research and development (R&D) documents, such as patents and research papers? Besides, we study the applicability of text-mining methods and tools to assess the transformation and restructure of the workforce in response to new technologies due to COVID-19. We also test how large datasets of full-text R&D documents, popular scientific publications, and media news reports can be used to reveal possible directions of working conditions transformation and changes in professions.

2 Related Work

The consequences of the economic digitalization for the employment of the population in the context of the COVID-19 pandemic are considerable and have been directly affecting stock markets worldwide and authors of the paper evaluate the short-term impact of the coronavirus outbreak on 21 leading stock market indices in major affected countries including Japan, Korea, Singapore, the USA, Germany, Italy, and UK etc. [12]. The rapid spread of coronavirus (COVID-19) has dramatic impacts on global financial markets and lead to an unprecedented level of risk [2, 25].

These new challenges have become the object of new research, and the natural way to analyze that research is patent and research landscaping [3, 10, 11, 14, 21]. Recent studies in patent and research landscaping are devoted to the methods, which identify emergent topics with various types of features: lexis (keywords), citations, metadata (authorship, patent owners, etc.). Paper [9] validates the idea that influential authors suggest essential terms within a field and vice versa. The researchers combine both authors and terms in a graph-like structure and rank them jointly. They represent that output with phrasal embeddings and process them with a recurrent neural network to reveal research trends. The experiments show that the approach successfully detects past trends from the field, outperforming baselines based on text centrality or citation.

Förster with colleagues [6] used the number of cited references per year of a current research topic to solve the emerging research topic detection problem with a time series analysis method. The time series were analyzed stochastically. Namely, they proposed an approach to forecasting the emergence of a research topic using ARMA models. In [16], researchers identify keywords of a technological topic from patents. They layer the keywords, depending on the level of information. First, the features and types of technical information are analyzed by reviewing the patent law and investigating the description of patent documents. Second, the patents are structured using the information types, and the keywords in each type are layered through natural language processing. Consequently, the structured and layered keywords do not omit valuable terms.

The pandemic generates plenty of studies related to the patent and research landscaping of the virology-related fields and studies related to the impact of the pandemic on the markets. For example, in the papers [5, 24] the researchers analyze research papers and investigate collaboration relationships, research topics, and research trends on COVID-19. They retrieved COVID-related papers from the PubMed database and applied proprietary software tools to summarize bibliometric features. The results show that United States was the most productive and active country for COVID-19 research, with the largest number of publications and collaboration relationships. They also detected four key research topics, of which the topic of epidemiology and public health interventions has gathered the most significant attention. The topic of virus infection and immunity has been more focused during the early stage of the COVID-19 outbreak compared with the later stage. The topic popularity of clinical symptoms and diagnosis has been steady.

Regarding the patent landscaping research, it also primarily focuses on anti-virus treatment and vaccines. Paper [15] studies challenges in vaccine development for the pandemic, discussing issues related to pandemic preparedness and their implications for circular bioeconomy and sustainability. Paper [1] provides an extensive bibliometric analysis of COVID-19 research across the science and social science research landscape, using several ready-to-use bibliometric and text mining tools like VOS viewer and the Scopus database. The obtained results indicate the domination of health sciences in terms of relevant publications and total citations, while physical sciences, social sciences, and humanities are behind significantly. Nevertheless, there is evidence of research collaboration between different research areas, increasing the importance of non-health scientific disciplines. The researchers also revealed a need for an approach that considers various scientific disciplines to benefit evidence-based policymaking as part of efforts to respond to the pandemic.

However, those studies hardly consider how the COVID has affected all the technologies and how those technologies would change the working conditions and labor market. The supply and demand in the labor market are related to the different R&D databases. Namely, the demand is mostly reflected in the patents, whereas the supply should be presented in the databases of Ph.D. theses. Therefore, the documents from those databases related to the same technologies should be accurately linked together. The researchers usually utilize standard scientometric and patent databases, which do not support topical similarity searches for patents and research papers. Therefore, the accuracy of that research often depends on the granularity of the used classification system (IPC, CPC, etc.). In this paper, we tackle this problem with state-of-the-art text-mining methods to reveal exact topics and documents that emerged in the COVID era. Thus, the COVID-19 pandemic-induced lockdowns and related global recession of 2020 have created a highly uncertain outlook for the labor market and accelerated the arrival of the future of work, and companies have to restructure requirements and skills to workers in response to new technologies and new challenges.

3 Materials and Methods

In this study, we propose a text mining pipeline to reveal the growing topics in patenting, and; therefore, to identify employers and employees that can be positively affected by the pandemic. The pipeline has the following primary steps (Fig. 1).

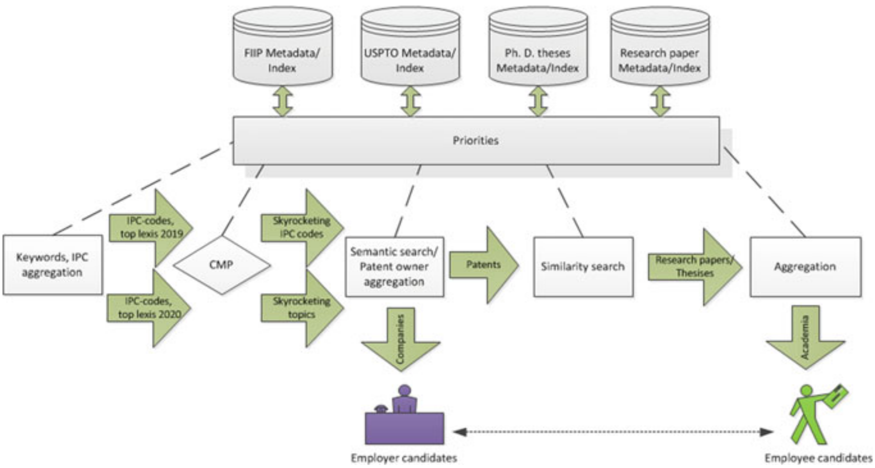

Fig. 1 Text mining pipeline to detect the impact of pandemic on the labor markets

1. Collect data corpora. The corpora contain Russian and US patents from 2019 to 2020 and Russian Ph.D. theses from 2005 to 2020 (More than 1 million full-text documents) [8, 23].
2. Detect the skyrocketing lexis and IPC codes.
3. Use the codes and lexis to extract R&D topics that have been transformed positively.
4. Reveal relevant Academia, R&D, and production centers. R&D and production centers can be considered as the primary potential employers, whereas universities are the primary sources of qualified labor.

We use the Priorities search and analytical system to perform the basic operations like collecting and indexing text databases, extracting the document metadata (authors, affiliations, etc.), extracting keywords of documents and collections [19]. The Priorities supports the topical similarity operation that helps to automatically link patents and other types of R&D documents [20].

We also utilize the approach from [18] to detect the lexis from growing patenting topics. Namely, we evaluate the *idf* score of each token *t* in the corpus. Also, we evaluated the *idf* score for each part of the corpus related to particular year *y*. Finally, we calculate the difference between those scores and rank the tokens regarding that difference multiplied on their frequency (*tf*) (Expression 1):

$$\Delta idf(t, y) = idf(t) - idf(t, y) \tag{1}$$

We generate the top-ranked lexis (keywords and phrases) for 2019 and 2020 related to the different high-level directions of patenting (A–H), and then we detect the difference between them. Therefore, we detect the emerging technologies. The reason for that emerging can be different from the pandemic; therefore, the extracted topics should be validated manually.

Finally, we use the topical similarity operation to collect the patents, similar to the obtained keywords for each emerged topic [20]. The owners of those patents can be considered potential employers. Then we apply the same method to find the Ph.D. theses, which are similar to those patents [20]. We consider affiliations of those theses as the potential education centers, which can provide qualified personnel to those employers.

4 Skyrocketing Topics

Acceleration of digitalization in the context of the COVID-19 pandemic led to opportunities for innovation and patenting new technology to help prevent the next one and respond to changes in consumer behavior and business practices due to travel restrictions and social distancing. In current circumstances, patents could create opportunities for exclusive rights and licenses in which investors and business partners participate. The COVID-19 pandemic has increased the need for and interest in

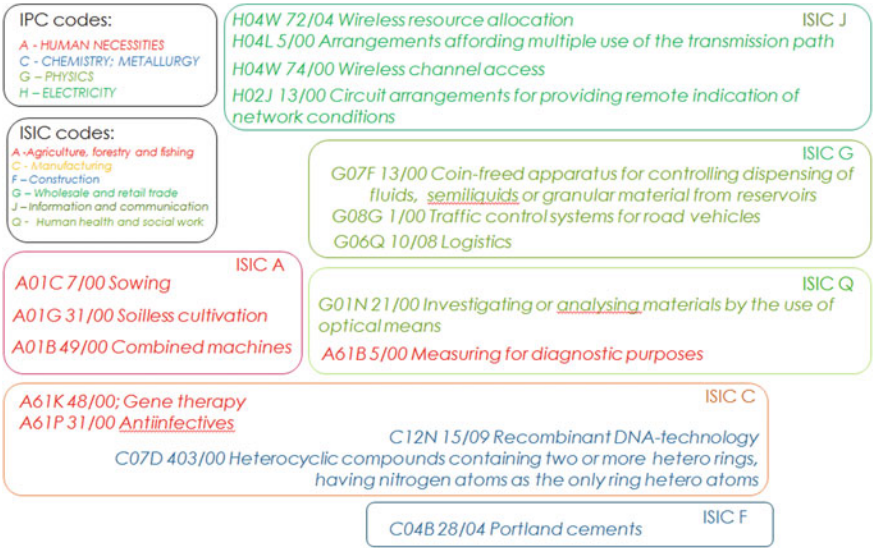

Fig. 2 Growing patenting topics, associated with the pandemic

innovations across a wide range of essential technologies, particularly in the fields of human health, retail trade, construction, agriculture, and digital technologies. The pandemic also increases demand for improvements in technology for work remotely, safer commerce, and social activities. Pandemic is coming up with ideas to meet new needs and improvements in a wide range of other technologies (Fig. 2).

The pandemic creates immediate needs for technology to prevent, diagnose and immunize against infection, and treat patients with COVID-19. According to our research, the most growing patenting topics of gene therapy and anti-infective became recombinant DNA technology and heterocyclic compounds construction. In the information and communication sphere, the most popular technologies were wireless resource allocation, wireless channel access, circuit arrangements for providing a remote indication for network condition.

5 Potential Employers and Educational Centers

The most significant number of patents on technologies related to human necessities is concentrated in four huge organizations: Rostselmash LLC, "National medical research center of radiology" Ministery of Health of Russian Federation, "MES" LLC, CJSC "Production Association "Specavtomatika" (Table 1a). Rostselmash is one of the largest developers and manufacturers of agricultural machinery and its innovation center, experimental base, modern production of a complete technological

Table 1 Primary potential employers and educational centers in human necessities, chemistry and metallurgy

Potential employers	Patents	Educational centers	Ph.D. theses
(a) Human necessities			
"ROSTSELMASH" LLC	18	South-Ural State Agro University	9
"NATIONAL MEDICAL RESEARCH CENTER OF RADIOLOGY"	16	Far-East State Agro University	4
"MES" LLC	15	Penza State Agro University	4
CJSC "PRODUCTION ASSOCIATION "SPECAVTOMATIKA"	13	Polzunov Altai State Technical University	4
"CHKZ" LLC	8	Nizhny Novgorod State Pedagogical University	3
"FARMINTERPRISES" LLC	5	Ural State Pedagogical University	3
"IQ VITAMINNAYA STUDIYA" LLC	5	Central Research Institute of Epidemiology	3
"ALTONIKA" LLC	4	Voronezh State University of Forestry and Technologies	2
"KHIMFARMTECH" LLC	4	Astrakhan State University	2
"VALENTA INTELLECT" LLC	4	Russian State Agrarian University	2
"FBK" LLC	3	Moscow State University for The Humanities	2
"GORODSKYE TEPLITSY" LLC	2	Herzen University	2
		Saint Petersburg State University	2
(b) Chemistry and metallurgy			
NATIONAL RESEARCH CENTER OF EPIDEMIOLOGY AND MICROBIOLOGY	16	National Research Center of Epidemiology and Microbiology	20
STATE RESEARCH CENTER OF VIRUSOLOGY AND BIOTECHNOLOGY "VECTOR"	10	Moscow State University	6
FARMINTERPRIZES LLC	4	Research Institute of Virusology named aft. D. Ivanovsky	3
INSTITUTE OF BIOORGANIC CHEMISTRY RAS	2	Russian Research institute of agrobiology	3
GENETIC DIAGNOSTICS AND TERAPY 21 LD	2	Moscow State Academy of Precise Chemical Technologies	2

(continued)

Table 1 (continued)

Potential employers	Patents	Educational centers	Ph.D. theses
REKOMBITECH LLC	2	Moscow State Academy of Veterinary Medicine and Biotechnology named aft K. Skryabin	2
CJSC "BIOCARD"	1	Russian Research Institute of Veterinary Virusology and Microbiology	2
"GENNAYA I KLETOCHNAYA TERAPIYA" LLC	1	Research Institute of Vaccines and Serums them. I.I. Mechnikov	2
VIRIDANCE LLC	1	Moscow State University of Applied Biotechnology	2
		State Research Center for Applied Microbiology and Biotechnology	2

cycle. Among the educational centers, we could single out the undisputed leader in the number of theses—South-Ural State Agro University (Chelyabinsk).

The analysis results showed that the two largest scientific centers of Russia in the field of chemistry and metallurgy are leading by a large margin in the number of patents. Those centers are the National Research Center of Epidemiology and Microbiology named aft N. Gamaleya (Moscow) and State Research Center of Virology and Biotechnology "Vector" (Novosibirsk). The absolute leader in the number of dissertations in this field is the National Research Center of Epidemiology and Microbiology (Table 1b).

The largest number of patents in the Physics belongs to YANDEX (Table 2a). Theses on this topic are most actively defended at two well-known Moscow universities—State University of Management and Bauman Moscow State Technical University.

The analysis showed that "Sozvezdie" has the highest patent activity in the Electricity area (Table 2b). Concern "Sozvezdie" is engaged in the development and production of high-tech intelligent control and communication systems, electronic warfare, and special equipment. All those products meet the needs of the Armed Forces and other special formations, modern systems, and tools, as well as civil and telecommunications products based on the latest scientific and technological achievements and innovative technologies. Three organizations demonstrate high patent activity: the company "National radiotechnical bureau", the 16th Central Research Institute of Communications, the company MTS. The company "National radiotechnical bureau" is actively involved in the modernization and creation of new air navigation systems, the development of automated control systems, technical and software tools for testing complex systems. The 16th Central Research Institute of Communications conducts applied scientific research in building systems, complexes, and military communication of strategic, operational, and tactical management units.

Table 2 Primary potential employers and educational centers in physics and in electricity

Potential employers	Patents	Educational centers	Ph.D. theses
(a) Physics			
YANDEX, LLC	7	Bauman Moscow State Technical University	2
FRESH MARKET, LLC	2	Moscow State University of Service	2
OBOZ, LLC	2	State University of Management	1
33rd Central Research Test Institute of Ministry of Defence	1	Izhevsk State technical University	1
IOFFELED, LLC	1	Moscow Technological University	1
NANO VISION, LLC	1	Vladimir State University	1
All-Russian Research Institute for Optical and Physical Measurements	1	Moscow State University of Applied Biotechnology	1
SKHOLKOVO INSTITUTE	1	Saint Petersburg State Technical University	1
VENDING TRADE, LLC	1	Peter the Great St. Petersburg Polytechnic University	1
GRAND GEKTOR, LLC	1	National Research University of Electronic Technology	1
GCC ENGINEERING SERVICE, LLC	1		
INNOVATIKA + , LLC	1		
LINKOR, LLC	1		
PLATFORMA, LLC	1		
YANDEXMARKET, LLC	1		
MONITORING, LLC	1		
(b) Electricity			
JSC CONCERN SOZVEZDIE	23	Moscow Technical University of Communications and Informatics	17
JSC NATIONAL RADIOTECHNIC BUREAU	7	Nizhny Novgorod State University	6
JSC MTS	6	Moscow Power Engineering Institute	3
16th Central Research Institute of Communications	6	Izhevsk State Technical University	3
JSC POLYUS Research Institute	5	Voronezh State University	3
JSC Television Scientific Research Institute	5	Novosibirsk State Technical University	2
RUSSIAN FEDERAL NUCLEAR CENTER	4	Vladimir State University	2

(continued)

Table 2 (continued)

Potential employers	Patents	Educational centers	Ph.D. theses
ROSATOM	4	Ryazan State Radio Engineering University	2
QANTUM A RUS, LLC	4	Bonch-Bruevich St. Petersburg State University of Telecommunications	2
JSC Omsk Scientific-Research Institute of Instrument Engineering	4	Kazan State Technical University	1
INTERCONNECT, LLC	3	MIREA—Russian Technological University	1
QANTTELECOM, LLC	2	Peter the Great St. Petersburg Polytechnic University	1
CIT, LLC	2		

MTS is the largest mobile network operator in Russia, operating on GSM, UMTS, and LTE standards. The strong leader on a number of theses is the Moscow technical university of communications and informatics.

6 Conclusion

Accelerating digitalization under the impact of the pandemic of COVID-19 is considerable. It has been directly affecting nationals and global markets and has led to large-scale socio-economic and technological transformations in different business areas worldwide. Large datasets of full-text R&D documents, popular scientific publications, and media news reports can be used to reveal possible directions of working conditions transformation and changes in professions.

Innovations spurred by the COVID-19 pandemic will advance public health, improve health care delivery, save lives, and improve industrial, medical, and consumer technology in general. Patent protection can help ensure that these technological improvements can be developed and refined to have their most significant impact.

The paper presents the results of a study of possible directions of transformation of working conditions and changes in the most popular professions based on the analysis of large arrays of full-text scientific and technical documents (scientific publications, dissertation abstracts, USPTO, and FIPS patents), popular scientific publications and media news reports, carried out with the search and analytical system "IAS Priorities". We have detected promising R&D directions and economic activities, which grew in 2020: agriculture machinery, pharmacology, diagnostic tools, logistics, wireless technologies. We have detected some Academia and production centers within those directions, considered potential producers and labor consumers. In future research, we will conduct this analysis, mainly based on Russian theses and patents to new stages, emphasizing the role of human resources in digital transformation and meeting the enlarged and new needs showed the pandemic.

These results can be used by federal and regional authorities to assess various restrictive measures in Russian regions and formulate priorities for supporting the population and business in the pandemic of COVID-19. The COVID-19 pandemic is forcing governments of all countries to turn toward digital technologies to respond to the crisis in the short term. Navigating through these challenging times requires governments and businesses to reinvent existing policies and tools of human resource management in the long term. Therefore, understanding the current state of science and technology using the scientific and patent landscape methods is essential for setting priorities in determining government tasks and topics of grant programs for research organizations and higher educational institutions.

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