Digitalization as a Driver of Innovation for Industrial Enterprises

I Ivanov¹, T Lukyanova¹, L Orlova¹
¹State University of Management, 109542, Ryazanskij prospekt, 99, Moscow, Russia

E-mail: ivanov-igor-nik@mail.ru, lukyanovat@inbox.ru, lorlo@mail.ru

Abstract. This paper systematizes the basics of digital economy and describes them as potential building blocks for manufacturing. It analyzes the state-of-the-art of digitalization in the Russian Federation as well as how it manifests itself in manufacturing. Analysis of industrial innovation identifies the reasons why the manufacturing sector lags behind with respect to digitalization; the paper further sets forth the objectives, accomplishing which will bolster industrial innovation. The present study has discovered the basic technological trends applicable to the digitalization of industrial enterprises; additive manufacturing is the crucial aspect here. The paper presents individual positive examples of how Russian enterprises have managed to put the Industry 4.0 concept into good use. Revolutionizing the whole structure of Russian manufacturing requires developing and implementing innovative business models, above all the next-gen digital platforms. To facilitate the innovative development of Russian industrial enterprises, this paper substantiates the need for their cooperation that is both catalyzed by, and results in, digitalization of processes and business processes. The article structure the innovative cluster as a complex of blocks for research, education, production, infrastructure, and coordination. What distinguishes a cluster is that is is innovation-focused, whereas end-to-end digitalization supports generating the value added for the enterprises in the cluster. The paper also presents a mechanism that an innovative cluster could use to keep running efficiently in the light of end-to-end digitalization.

1. Introduction

Switching to a novel, unprecedented digitalization-induced socioeconomic growth requires a foundation in the form of production breakthroughs and radical innovation that bring rapid and profound structural development of the today’s manufacturing while also being the key factor behind making cutting-edge innovative products (smart tech, unmanned aerial vehicles, human-computer communication tools, biotechnologica drugs, etc.) or even backing whole industries (post-silicon electronics, quantum communication, green chemistry, post-carbon energy, etc.).

To be part of this new global technological reality, to be relevant as a player in the global high-tech markets, Russia needs to innovate its industries; in the context of the today’s reality, such innovation must be based on digitalizing the traditional industries and creating new sectors and fields that are driven by top-notch manufacturing technology, digital and platform-based solutions [11].

Competitiveness requires innovation in all its forms. This means that, for instance, laser-focusing on cost-cutting alone will be less efficient that a strategy that implies innovative development [19]. Digitalization of the industry is a key driver of economic breakthroughs; as such, it induces the global, national, and local effects [20] while defining the innovative potential of Russian businesses.
Digitalization and intellectualization of manufacturing imples transforming the existing businesses into cutting-edge digital enterprises that gain competitive advantage from IT in any part of their business, be it production as such, business processes, marketing, or CRM. Digitalization of industry is the essence of Industry 4.0.

According to PwC, the world’s investment in Industry 4.0 will total 907 billion US dollars a year for until 2020. Such investment will primarily target digital technologies such as sensors and communication devices; another crucial target is software and applications such as production management systems. Businesses will spend considerably to retrain their staff and to make the organizational transforms come true. Over a half of PwC’s respondents believe such investments will pay off in two years or even loss, and that’s given that such companies invest 5% of their total annual revenue [6].

As for Russian companies, the actual state-of-the-art in the country’s industrial manufacturing is far below what is necessary for deploying corporate information systems (CIS) for production automation; naturally, such technologies as big data, digital models, and prototypes, all of them being the essentials of Industry 4.0, are out of question [21].

Still, Russia is projected to be able to have 1.3 to 4.1 trillion rubles in economic effects by 2025 thanks to Industry 4.0 alone [18].

Figure 1. Industry 4.0 effects projected for Russia.

However, such an outcome requires finding the most promising ways to use digital technologies to catalyze Russian industrial innovation.

With this in mind, the following objectives and goals were set forth for this research:
— analyze Russia’s economic digitalization processes, in particular those that concern manufacturing;
— identify the basic technological trends in the digitalization of the country’s manufacturing industry;
— find out what kind of role innovative platform-based business models might play in digitalized manufacturing;
— evaluate clustering as a factor of innovative development of Russian manufacturing industry in a digital world.
2. Background and methodology

Research was based on statistics reported by industrial enterprises and monitoring their plans and strategies; the results of statistics studied carried out by HSE, Center for Strategic Development, and Rostekh Corporation; data reported by McKinsey and PwC; theoretical and practical scientific sources, information resources, and official websites/annual reports on industrial innovation.

The methodology comprised system analysis, structural and functional method, and comparative analysis.

Analysis of economic actors shows the most advanced (in terms of digitalization) sectors are the service industry, software development, communications, trade, financial sector (banking and insurance), media business, transport, e-commerce, car-making, energy, public management, and healthcare. It is manufacturing, a sector prone to inertness, where businesses are often unwilling to abandon earlier adopted production and production management technologies, that has the lowest degree of digitalization [17]. What plays an important role is the sectoral specific, the unique historical experience an enterprise has accumulated so far, the conventional approaches it has inherited. Still, what analysts refer to as the definitive technological trends in a digital economy, will manifest or is already manifesting itself in manufacturing.

Overview of industrial digitalization research [23, 2, 19, 17, 21, 22, etc.] gives a brief summary of digital economy, see Table 1.

| A digital economy element | Description | Potential industrial use |
|---------------------------|-------------|-------------------------|
| Blockchain                | a decentralized electronic chain of chronologically ordered blocks of mathematical data stored on a chain of computers rather than on a single server | creating a protected database on production, transport, and support of products, in the form complex networks maintained by multiple interested parties; such a database would help quality assurance |
| Internet of Things        | a computer network that combines a virtual environment and real-world physical objects | every single device could be connected to a network to communicate with other devices as well as with the information systems |
| Big data                  | collection, processing, and storage of a variety of digitalized big data | data mining enables business to fully benefit from its historical experience, data on which updates and grows on a daily basis |
| Digital platform          | a combination of digital data, standards models, methods, and means that are technologically integrated and connected to form a single automated functional system | helps reduce transaction costs by using a suit of digital technologies and a modified labor division system; production and exchange processes become faster and cheaper thanks to lessmiddlemen |
| Cyberphysical system (CPS)| a system comprising various natural objects, artificial subsystems, and controllers to make a singular entity out of that | can automatically adjust the process, diagnose, optimize, or configure itself to ensure the flexibility this or that production task requires |
| “Smart” factory           | A suit of systems comprising a paperless office, production and process automations, engineering automations and dispatching, etc. to | each component becomes traceable for compliance with production procedures; automation as such makes an enterprise run smoother and more efficiently |
attain nearly 100% automation of production under total centralized control

Experts of Higher School of Economics, a National Research University studied the innovation efforts and projects of Russian industrial enterprises; their analysis indicated lack of any advancement in the sector, see Figure 2 [9].

Extraction and process manufacturing; production and distribution of electricity, gas, and water. %.

Digitalization is currently the driver and the catalyst of innovation in Russian manufacturing; it is defined herein in a narrower sense as substituting analogous data collection and processing systems with technological systems that generate, transmit, and process digital signals on their state; it is also meant in a broader sense as a process of digitalizing the functions and activities (business processes) that were formerly done by people or by companies.

Russian manufacturers face difficulties doing that. Prof. V.V. Akberdina, Dr. of Economics and Head of the Department for Regional Industrial Policies and Economic Security under the Institute of
Economics, the Ural Branch of RAS, notes, “The current state-of-the-art in manufacturing and the structural domination of low-tech, environmentally unfriendly sectors force us to be conservative about any forecasts of total industrial digitalization in the near future [1].

3. Discussion and results
Despite lagging behind in terms of innovation, the basic sectors of the Russian economy do show certain trends, see Table 2.

Table 2. Key indicators of traditional industries and sectors of the Russian economy in the context of technological revolution (a fragment)[12].

| Industries/sectors of economy: process manufacturing | Key challenges in the long term | Disruptive factors of the new technological revolution: digitalization and cutting-edge technology | Changes in market architecture, corporate structure, and business models | A temporary “window of opportunity” for industries/sectors to rebuild themselves |
|----------------------------------------------------|--------------------------------|--------------------------------------------------|---------------------------------------------------------------|--------------------------------------------------|
| GDP contribution in 2016: 11.9%. Share in the total employment in 2015: 14.3% | Revenue drop, approaching the productivity of traditional technologies. Ever greater competition between developed and emerging economies, mainly Asia. Limited resources. Environmental constraints. Overly complex systems unsustainable. ‘HR famine’. | Robotized and automated production. Industrial Internet; digital, ‘smart’ and virtual factories. Digitalization (computer analytics, artificial intelligence, digital modeling and simulation, digital twins, computer-aided engineering). Cutting-edge production technologies: additive manufacturing, atomically precise manufacturing; advanced materials (3D and self-recovering materials, etc.) as well as their processing/machining methods. | Transition to product platforms; rearrangement of supply chains on the basis of ecosystem models Whole-cycle management; services as an alternative to produce supplies. Predictive systems becoming the center of revenue. | 2024: scaling the digital manufacturing, i.e. implementing the concept of the ‘factory of future’. Transition to platform-based market organization in process manufacturing. 2035: transition to the next generation of cutting-edge production technologies, the nature-like technologies, bionics, bioengineering, synthetic biology, biomanufacturing, neural nets, etc. |
| Field                  | Issues                                                                 | Technologies and Processes                                                                 | 2024: Transition                                                                 |
|-----------------------|------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| Metallurgy            | Stronger competition against novel non-metallic materials. Strict environmental constraints. Limited resources. Greater requirements to metal efficiency and wear resistance. | Light metal. Metallic materials for additive manufacturing, meta and supermaterials. Nanotechnologies. Structural materials. Ongoing globalization of the industry and consolidation of assets. From metal supplies to material supplies. Services as a growing subsector. | 2024: Transition to integrated digital manufacturing; business transformation due to the advancement of digital platforms that unite producers, suppliers, and buyers. |
| Chemistry             | Stronger global competition in high-volume chemistry. Stricter environmental constraints. Ever more limited resources. | Digitalization: digital models for simulating and managing the processes; virtual chemical experiments; digital modeling of molecules and chemical reactions; prototype modeling and virtual testing. Biotechnologies for making chemical products. Services as an alternative to product supplies. Transition to product platforms; rearranging the supply chain to be in line with the ecosystem model. | 2024: Scaling the biotechnologies in special chemistry. Platform-based reorganization of markets. Closed-cycle economy in chemical industries. |

Cutting edge technologies are such technologies and processes (including any equipment they require) that are either computer- or microelectronics-controlled and are used to design, produce, or process products (goods and services). Typical applications include computer-aided design and engineering, flexible production centers, robotics, auto-piloted vehicles and transports, automated storage and retrieval systems.

Analysis of digital innovation identifies the following major technological trends in the digitalization of industry:
- large-scale deployment of smart sensors in equipment and production lines (industrial Internet of Things);
- transition to unmanned manufacturing and large-scale use of robotics;
- transition to cloud-based rather than PC-based data storage and computing;
- end-to-end automation and integration of production and managerial process in a single information system (‘from equipment to the ministry’);
use of the total structured and unstructured data massifs for analysis (big data);
transition to mandatory digitalized specifications and workflows (‘paperless office’);
digital design and modeling of processes, objects, and products throughout the lifecycle from conception to operation (use of engineering software);
use of additive rather subtractive technologies, including 3D printing;
use of services to automatically order consumables and raw materials for production, to automate delivery to the customer evading the middlemen;
use of unmanned transport, including the delivery of industrial goods;
use of mobile technology to monitor and control life and production processes;
switch to industrial e-commerce.

All of these could be connected by communication networks (local factory-based nets) into a single flexible production system, ultimately bringing about a single automated production facility. The currently ongoing industrial revolution is based on additive technologies (5, 12) that drive digital manufacturing; larger-scale application will be literally revolutionary.

Additive manufacturing comprises complex digital 3D modeling for further layer-by-layer application of the material (3D printing). In more conventional manufacturing, a billet/workpiece is reduced in size. In additive manufacturing, a new product is made up from the consumables. In home 3D printing, the consumable is a special plastic wire. More recently, 3D printing has become advanced enough to use metals.

Computer models can be instantly sent to any production site anywhere in the world. This redefines manufacturing as such, as a 3D printer not only makes the whole facility more portable, it also replaces multiple pieces of equipment at an ordinary factory and can help reduce the number of items needed to produce a part.

Another benefit of additive manufacturing is the ease of making parts in small batches. This explains why healthcare and aerospace industries are so interested in additive manufacturing, as these industries are often in need of small-batch production. For instance, PAO ODK-Saturn uses 3D printing to make gas-turbine engine parts of cobalt and titanium alloys as well as of stainless steel.

Some Russian companies have brought Industry 4.0 components into action. ODK-Saturn presents itself as a “smart factory” in action that successfully uses digital manufacturing in its operations and is steadily undergoing digitalization. PAO Sibur Holding has automated its manufacturing processes, which greatly reduced the costs; they have also improved their process management system (APC), the enterprise management system (8AP EKP), and the business process management system (BPM8). Evrazholding completed 19 digitalization projects in 2017 alone. Plus, a gold-mining company, has created a single computer-controlled circuit of 210 machines: drills, trucks, ore crushing rotors, flotation tanks, etc. However, these examples are more like exceptions. Most of the Russian companies are in neither technological nor in financial capacity to embrace the fourth industrial revolution. Many of them have yet to upgrade their assets; replacing any of them or installing sensors and newer actuators requires considerable investment. Besides, their managers often fail to understand when and why they’d need Industry 4.0 and how to manage a digitalized enterprise.

Return on innovation is a function of how well it is done [16]:
— businesses that make active use of novel technologies and management methods are on average 26% more profitable than their competitors;
— companies that invest actively but do not focus on management are 11% lower;
— companies that only tackle their management issues have their revenues rise by a mere 9%, although they could triple that increase;
— companies that do not have a development strategy in place underperform by 24% in monetary terms against other market players.

Technological innovation requires adapting the operational management, the lifecycle management, the production and sales management, the strategy, and the investment, as digitalization redefines a company in terms of how it is run; as such, it affects (‘smartens’) the range of products,
works, and services the company provides, which requires a new strategy and new business models [25]. The concept of Industry 4.0 is expected to transform the entire production structure, which will require innovative business models—a specific approach to the company’s and its actors’ decision making on the distribution of income and risks when commercializing and implementing innovation, with maximizing the return on investment in mind. In other words, it is a tool that brings together technical solutions and economic outcomes [7].

There is a novel business model that is exclusive to digital economy; it’s referred to as a digital platform and is designed to provide businesses and people with a specific service that consists in coordinating different market actors. The current agenda is to create and launch next-gen digital platforms that will cover numerous markets and enterprises [5] by providing hardware and software to enable communication on the basis of cloud, open data, apps, and services.

A state-of-the-art industrial business model uses a technology platform based on the innovations inherent in a particular ecosystem; at the core of such a platform is a unique technology based on permanent innovations undertaken by every agent in the network. Technology is herein understood as a set of methods and tools intended to help accomplish a specific objective in manufacturing, marketing, product distribution, etc. [13].

Industrial technology platforms seek to:
- enable efficient retrofitting of production lines for making complex technological products,
- enable Russia to enter new markets, and provide conditions for innovation in manufacturing;
- give rise to new high-tech companies, including joint ventures run in cooperation with international businesses, while also expanding, and creating better environment for, SMEs and finding new direction for IT advancement;
- raise extra private funds, including international investment, to develop cutting-edge technology while also employing IT to promote high-tech manufacturing;
- create technologies and a comprehensive system for specialist training, retraining, and professional development;
- solve the society’s economic and social problems by giving rise to high-tech manufacturing.

What is apparent today is the need for large-scale cooperation and network-based coordination of innovative actors that will maximize their benefit and competitive advantages [3]. In this respect, technology platforms are comparable to innovative clusters in role and focus. Clusters are also intended to initiate R&D; however, they focus more on manufacturing-related tactical objectives [14].

Digital economy entails the emergence of novel forms of cooperation, which helps businesses become part of the global economy while also promoting competition and innovation, contributing to the return on capital; the enabling factors digital economy is based on include the removal of barriers of trade as well as better management practices [10]. Upgrading the industrial sector and establishing digital networking of VR-based production equipment are on the national agenda of the US, Germany, etc. The integrated next-gen platforms will also emerge as part of international cooperation [2].

Effective development of Russian digital economy will first require clustering; encouraging investors, researchers, and universities to be engaged with such clusters; creating an efficient cluster management system [15]. What actors in a cluster share includes the production facilities, IT, HR, intellectual property, technologies, and business promotion institutes. Clustering enables innovative projects, import substitution projects, comprehensive consumer service, and full lifecycle support. It becomes possible to carry out joint upgrade and retrofitting projects based on the technologies brought by the fourth industrial revolution [21].

Universities become central to the technological and innovative development in regional ecosystems, as their individual research teams, armed with their mobility and flexibility, can provide knowledge transfer, training, social mobility, implementation of educational standards, novel guidelines, new knowledge, consulting, R&D for businesses, etc.

Thus, a cluster structurally comprises:
- a research and education unit (universities, business incubators, research centers and labs, research institutes and design offices, R&D companies);
— a production unit (enterprises in the cluster that supply intermediate and end products);
— an infrastructural unit (financial institutions, services, marketing, logistics, energy, etc.);
— a coordination unit (a coordination council comprising all the actors in the cluster, also involving consumers, regional authorities, and the general public).

Figure 3 shows how this works in practice.

The basic advantages of clustering are:
— lower costs of retrofitting, infrastructural development, training, R&D, certification, market entry, and consumer interaction;
— creating a common cluster brand, joint participation in events, competitions, and procurement;
— joint use of production capacities;
— pooling the effort to handle quick production launch, digital modeling and prototyping;
— receiving governmental and targeted support for innovative projects done by a cluster;
— joint implementation of cutting-edge technologies, including ‘smart’ manufacturing for Industry 4.0.

Being a complex of localized industrial enterprises, research centers, universities, and other economic actors, a cluster boosts the competitive advantages of its participants and of itself as a whole [15], which creates a synergistic effect that boosts the performance indicators within the cluster, see Figure 4. What distinguishes a cluster is its focus on innovation [8,24], while end-to-end digitalization of manufacturing and business models supports the creation of added value.

4. Conclusions

In Russia as an economy, innovation is backed by the digitalization of its traditional industries, including manufacturing.

However, single positive examples of Russian companies using this or that element of Industry 4.0 are rather exceptions. Most of the Russian companies are in neither technological nor in financial capacity to embrace the fourth industrial revolution. Meanwhile, Russian manufacturers face challenges when it comes to revenue, product quality, occupational safety, and environmental compliance, which means the need innovation that is enabled by using the fourth industrial revolution technology to modernize their production lines.

Enterprise digitalization must make use of as many technological options available, with an emphasis on additive manufacturing. Addressing this requires developing and implementing innovative business models, in particular the next-gen digital platforms that link the mechanisms of creative value, making money, and controlling the value chains.

Promoting the cooperation of all market participants in manufacturing is prerequisite to industrial innovation in the context of end-to-end digitalization of processes and business processes. One promising form of such cooperation consists in creating an innovative industrial cluster comprising a research and education unit, a production unit, an infrastructural unit, and a coordination unit. Such a cluster generates technical, technological, economic, research, educational, managerial, and environmental effects; it also has a synergistic socioeconomic effect. All these effects incentivize further innovation in manufacturing.

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Figure 3. Organizational and functional diagram of the LipetskMash Industrial Cluster.
Figure 4. Mechanism that an innovative cluster could use to keep running efficiently in the light of end-to-end digitalization.

Synergistic socioeconom effect

- cluster enterprises becoming more efficient: lower transaction costs;
- advancement of innovation, production, transport, logistics, and socioeconomic infrastructure;
- boosting investment attractiveness and innovation;
- forming a competitive cluster-wide brand;
- mitigating the issues of the regional labor market;
- higher standard of living in the community;
- sustainable development of the local economy.

LOCAL EFFECT TYPE

Technical and technological:
- greater technological convergence;
- better customization opportunities;
- more digital solutions for process optimization;
- better product quality.

Economic:
- more extra investment;
- saving resources;
- more efficient utilization of fixed assets;
- lower costs of consuming energy; lower costs of IT services and software; lower weight;
- higher competitiveness;
- lower R&D costs;
- greater "weight" of software and services in the structure of added value.

Scientific and educational:
- digital training;
- increased knowledge transfer, including "hidden" knowledge;
- investment in research and technology as part of end-to-end digital technologies;
- digitalization-based solutions;
- more efficient use of R&D; more concentrated meaningful competencies in implementing cluster development strategies;
- start incentivization and support.

Managerial:
- more efficient coordination in a cluster;
- expansion of outsourcing; faster business processes;
- implementation of organizational and managerial innovation to introduce digital technology;
- more efficient decision-making in marketing.

Environmental:
- greater extent of production waste recycling;
- less harmful emissions;
- better opportunities to apply IT to energy saving.

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UNIT'S OF AN INNOVATIVE INDUSTRIAL CLUSTER

Coordination

Research and development

Education and training

Infrastructural