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PILOT STUDY OF INDUSTRY 4.0 AND DIGITAL TECHNOLOGY PREVALENCE IN RUSSIAN MANUFACTURING COMPANIES

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Abstract
The spread of digital technologies dramatically changes production processes. The fourth industrial revolution opens up new opportunities for the introduction of technologies, having a significant impact on the production cycle, starting with highly automated production lines and ending with the large-scale implementation of technological solutions designed to improve productivity, optimize costs, quality and reliability. Defining digital transformations, primarily in the manufacturing industry, as a strategic imperative for the entire economy based on opinions and intentions of entrepreneurs (short and medium-term), key aspects of the digitalization process in Russian medium, high-tech and low-tech manufacturing industries are revealed. A set of tendencies in the development of digital technologies by their main types is presented, the level of industry participation in digital transformation is shown, as well as many other important digital transformation processes in enterprises that are not measured by quantitative statistics.

Keywords
Industry 4.0, digitalization, digital technologies, business tendency observations, manufacturing.

Introduction

The current stage of digital transformation is in the active phase and is characterized by breakthrough dynamics of the spread and the implementation of new technologies, changing global markets and the social sphere. Over the following 10 years, the gross value of digitalization in various sectors may amount to more than 100 trillion dollars for society and industry [1].

It should be noted that the current stage of digital transformation is also characterized by a deep penetration of digital technologies into the value chains in manufacturing, which is reflected in the concept of Industrie 4.0 [2]. The Fourth Industrial Revolution in manufacturing is a top priority for many business enterprises around the world, as it becomes the driving force of economic growth, opening up opportunities that could not be achieved and realized during the previous revolutions.

IoT technologies play a key role in these changes [3]. Manufacturing industry relies on technologies of Industrial IoT (hereinafter – IIoT), undoubtedly playing a leading role in their implementation [4].

In addition to IIoT, among the technologies, playing an important role in digital transformation of manufacturing, cloud computing, edge computing, machine learning and big data analytics, artificial intelligence, mobile computing, data communication and network technologies, enterprise resource planning (ERP, i-ERP), robotic complex, virtual and augmented reality, blockchain, additive technologies and 3D-printing can be mentioned [5].

As various studies show, the manufacturing industry is one of those industries that have been moving relatively slowly so far in terms of engaging in

digital transformation process [4, 5]. Like many other economic activities, in different countries manufacturing is represented by large and small local producers, developing with different potential and speed. In most enterprises, digitalization initiatives are still fragmented, a holistic picture of change is still missing, although the adjustments are obvious [4].

At the same time, it is worth noting that, apparently, it is the digitalization of the manufacturing industry that largely determines the leadership of some countries in the field of the digital economy. International experience shows that the higher the level of digitalization, the higher the competitiveness of national economies. The leading countries are already implementing a whole range of large state programs in the field of advanced technologies in manufacturing and other sectors of the economy, designed to launch a new technological revolution [6].

The ever-growing number of studies and practical work on this topic evidences the importance and necessity of measuring the level of digital development. Large studies on digitalization are produced by the UN [7], OECD [8], World Economic Forum [1], IMF [9], ITU [10], etc. At the same time, regular information is provided as part of expert studies of major international consulting companies, including market leaders such as McKinsey & Company, PwC, Deloitte, Forrester, which produce reports on the digitization of the economy as a whole and its various industries (for example, manufacturing) [4–6, 11, 12].

Along with international, national organizations and consulting companies, the scientific community is actively researching the economic aspects of digital practices and technologies [13–18].

Due to the fact that successful transition to digital technologies largely depends on the scale and capabilities of information content, the development and harmonization of methods for measuring the digital development of enterprises is currently in an active stage in Russia. The importance of research on industrial phenomena related to digitalization, contributing to inclusiveness and sustainability of economic growth, noticeably increases every year.

However, the complex of key technological solutions, which serve as the foundations in manufacturing transformation, is currently not fully covered in quantitative statistics in Russian statistical practice. The insufficiency of quantitative statistical accounting is especially noticeable in the lack of assessments characterizing the growth dynamics of digital solutions. The main processes of the measured digital economy mainly affect the services sector (healthcare, government, financial services, trade).

In this regard, for the operational and large-scale measurement of the level of penetration of digital technologies into the Russian business environment, such a method for estimating the existing level of digital activity was used as business tendency observations based on the opinions of the direct participants in the industry-specific events – entrepreneurs. Against the background of the prevalence of quantitative assessments, the system of primary qualitative indicators of the business tendency monitoring of digital activity in manufacturing can significantly complement and expand the analytical capabilities of the official standard practices for measuring the digital economy.

At the international level, there is sufficient number of studies based on a similar empirical basis [19–21]. This paper continues their line using Russian data.

In particular, based on the results of the "Digital activity of enterprises in the manufacturing industry" business tendency monitoring, the assessments of managers characterizing various aspects of digitalization in general and the level of prevalence of certain digital technologies at Russian manufacturing enterprises in 2018 were analyzed, presenting opportunities that expand the identification of short-term trends. The set of primary indicators of such observation, characterizing more than 1200 Russian enterprises, concentrated in 30 regions of the Russian Federation, undoubtedly, can significantly fill the existing information content. The object of the study consisted of manufacturing industries, representing the medium and high-tech, as well as low-tech manufacturing.

Based on the data obtained, a set of tendencies characterizing important processes of digital transformation in enterprises that are not measured by quantitative statistics has been visualized. To achieve this purpose, the following tasks were identified:

- To study the level of diffusion of Industry 4.0 technologies in manufacturing industries.
- Compare the indicators of digital activity of enterprises with their strategy in the field of digital technologies.
- Analyze the involvement of digital technologies in business processes and the digitalization of labor.

The choice of these tasks was determined both by the specifics of the available data, and by the desire to reflect many aspects of digital transformation. In addition to the direct diffusion of technology, it seems important to study the organizational, managerial and other aspects of digital transformation, which, as the literature shows [13], are often no less important.

The empirical base of research

The results of the monitoring, containing short and medium-term assessments of the level of digital activity (prevalence of digital technologies) at large and medium-sized Russian industrial enterprises in 2018, became the empirical base of this study. The specially organized business tendency observation was conducted by the autonomous non-profit organization "Russian Statistics" commissioned by the Institute for Statistical Studies and Economics of Knowledge of the National Research University Higher School of Economics. For the first time in Russian statistical practice, tendencies based on the opinions and intentions of managers of manufacturing enterprises, characterizing the dynamics and scale of digital technologies introduction by main types of technologies, level of industrial readiness for digital transition and actual participation in the process, investment potential, as well as barriers to realization of digital transformation, were detected. The monitoring was performed by self-filling in questionnaires by respondents (directors or managers of enterprises) who have the necessary level of competence regarding the questions asked in the questionnaire.

The territorial bodies of state statistics did the selection of organizations for conducting business surveys independently. In the survey, the total set of units of observation is represented by 1230 enterprises registered in Russia, included in sections B, C, D up to the second level of OKVED 2 classification.

In this paper, the object of study is the manufacturing sector in accordance with the classification of industries and their ranking by technological level. In our opinion, given the specifics of digitalization processes at Russian enterprises in order to monitor digital transformation and the level of digital activity in the manufacturing industry, it was necessary to differentiate the units of observation and the resulting information at the level of separate groups of manufacturing enterprises according to their technological level.

In order to solve the tasks and obtain more detailed results of the business tendency survey, it is sensible to use the classification developed by UNIDO and recommended for use in the CIS countries [23–25]. It is based on the International Standard Industrial Classification (ISIC) and the Standard International Trade Classification (SITC), as well as the version of the OECD classification adapted to the characteristics of the countries of the region, linking industry expenditures on research and development with value added and production. The classification includes the following technological categories: raw materials processing, low-tech production, medium and high-tech production.

Table 1
Classification of types of economic activity of the manufacturing industry by the level of technology in accordance with the all-Russian classifier of economic activity OKVED2 (2017–2018).

Medium- and high-tech production		Low-tech production	
20	Manufacture of chemicals and chemical products (*abbreviated: "Chemicals and chemical products"*)	13	Manufacture of textiles (*abbreviated: "Textiles"*).
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations (*abbreviated: "Pharmaceuticals"*).	14	Manufacture of wearing apparel (*abbreviated: "Wearing apparel"*).
26	Manufacture of computers, electronic and optical equipment (*abbreviated: "Computers, electronic and optical equipment"*).	15	Manufacture of leather and leather products (*abbreviated: "Leather"*).
27	Manufacture of electrical equipment (*abbreviated: "Electrical equipment"*).	19	Manufacture of coke and refined petroleum products (*abbreviated: "Coke and refined petroleum products"*).
28	Manufacture of machinery and equipment not elsewhere classified (*abbreviated: "Machinery and equipment n. e. c." or "M&E n. e. c."*)	22	Manufacture of rubber and plastic products (*abbreviated: "Rubber and plastic products" or "Rubber and plastic"*).
29	Manufacture of motor vehicles, trailers and semi-trailers (*abbreviated: "Motor vehicles, trailers and semi-trailers"*).	24	Manufacture of basic metals (*abbreviated: "Basic metals"*).
		25	Manufacture of fabricated metal products, except machinery and equipment (*abbreviated: "Fabricated metal products"*).
		31	Manufacture of furniture (*abbreviated: "Furniture"*).

Note: Equivalent nomenclature in English for the names of the industries is partially based on NACE Rev. 2 [22].

The processing of raw materials consists of activities with a low level of technology, labor-intensive production processes and low capital intensity. Possible competitive advantages of such industries are mainly determined by the presence of local natural resources in the country or by the fact that the skills and technologies used in production can attract capital and promote new technologies.

Low-tech production includes low-tech industries that have fairly simple skill requirements, but are more capital-intensive. In developed countries, the assembly operations of such industries are often transferred to countries with cheap labor and raw materials, while complex production and technological functions are retained within the country.

According to the recommendations of UNIDO, medium-tech and high-tech manufacturing industries for Russia are combined into one group characterized by complex technology and high requirements for personnel qualifications. Medium-tech industries include enterprises with moderately high level of scientific research and development, requiring complex skills, continuous training, adopting "best practices", improving equipment and optimizing composite processes. High-tech industries use advanced technologies that require large investments in research and development, technological infrastructure and the level of special technical skills.

In our study, industries representing medium- and high-tech, as well as low-tech manufacturing were embraced. Table 1 presents the distribution of economic activities regarding the technological structure of manufacturing in accordance with the classification of OKVED 2. The set of industries in the technological categories "low-tech production" and "medium- and high-tech production" corresponds to the recommendations of UNIDO.

Methodology

The construction of the digital activity monitoring program in the format of obtaining reliable data, that is, comprehensive, high-quality and comparable in terms of economic activity results of business surveys, was based on international experience in generating and measuring digital progress. The underlying sources in the design of the survey program were:

- the relevant practice of the European Commission (EC) regarding the methodology for creating and implementing a unified digital agenda in Europe aimed at ensuring sustainable economic and social benefits from market digitalization, as well as conducting annual surveys of the information society;
- EC core strategy and platform for digitalization of the European manufacturing industry to achieve the full benefits of a single digital market and digital innovations;
- EC guidelines and plans to assist European manufacturing, small and medium-sized businesses, researchers and government agencies in maximizing the use of digital technologies;
- composite performance indicators combined into the European Digital Economy and Society Index (DESI) (key blocks, construction methodology and results analysis practice).

The survey of heads of manufacturing organizations was conducted on a specially designed questionnaire – "Survey of business tendencies and digital activity of manufacturing", containing 15 integrated thematic blocks of questions corresponding to different qualitative parameters of activity.

In general, the system of indicators and the structure of relevant issues in the survey program are based on the following standard methodological principles going from the recommendations of the Organization for Economic Co-operation and Development (OECD) and the Statistics Department of the European Commission (EC):

- questions relate to the characteristics of the activities of the organization directly surveyed;
- questions reflect the dynamics of indicators for the year;
- on all issues related to the assessments of the dynamics (tendencies) of indicators, a three-category graduation is used: the number of respondents indicating growth (improvement) (+), no change (=), decline (deterioration) (−), respectively;
- all information obtained in the process of business tendency survey is of a qualitative nature.

Business tendency observations are a method of collecting information from a certain number of units or individuals that make up a sample in order to make sensible conclusions about main tendencies in a change of the statistical population. An objective advantage is the ability to receive answers from the economic community to many key questions related to short-term features of industrial functioning, which are often not reflected in official quantitative statistics. Traditional quantitative statistics shows changes in objective conditions, while qualitative survey data show how economic agents interpret and evaluate these changes.

Consequently, the analysis of the results obtained consisted of the measurement and ranking of the intensity of development or the prevalence of one or another aspect of the observation (indicator). Analytical interpretation of the digitalization processes

of manufacturing enterprises was represented in the visualization, which in real time characterizes the current and expected business tendencies in terms of changes in digital activity.

Considering that now there are many alternative methodological approaches to measure and present the results of measuring the effects and processes of digitalization, authors decided to use some of them additionally for our tasks, adapting them for the Russian practice of measuring digital activity. In particular, along with the traditional methods of the analysis of nonparametric information, authors used the McKinsey & Company approach to measure the level of real use of digital technologies in business processes and the level of digitalization of labor [26]. Authors found an interesting the approach in which they divide the digital activity indicators into three categories: "digital assets", "digital use" (digital technologies use in business processes) and "digital labor". They proposed this classification within the framework of the MGI digitalization index methodology for 22 sectors of the US economy [26]. Due to the fact that authors are working with qualitative nonparametric indicators, the indicator of "digital assets" was decided to be excluded, for an adequate measurement of which data are necessary in quantitative form. One of the results of the McKinsey & Company study was that it is the digital use and the digital labor that are key to the digital transformation of industries, so excluding this category seems acceptable. Authors decided to rely partially on this division method, adapting it for the Russian practice of measuring digital activity. The study of digital transformation in this differentiated form turned out to be important for identifying specific aspects of digitalization that need additional attention from business and government.

The prevalence of digital technologies in the manufacturing industries

In this section, digital technologies for the current level of prevalence at Russian manufacturing enterprises in 2018 were examined. The results of the analysis are presented in accordance with the industry classification and the division by technological level (Figs 1 and 2).

On the basis of the survey questionnaire, the following nine technologies were identified, the implementation of which in the production was stated by the respondents interviewed: intellectual robotic complexes; 3D printing (includes only fused deposition modeling); additive technologies (includes additive manufacturing technologies besides fused deposition modeling, such as selective laser sintering, laser stereolithography etc.); open manufacturing technologies (digital instruments allowing the use of networks of geographically dispersed manufacturing facilities); cloud computing; manufacturing analytics technology; IIoT; big data processing technologies; Radio Frequency Identification (RFID).

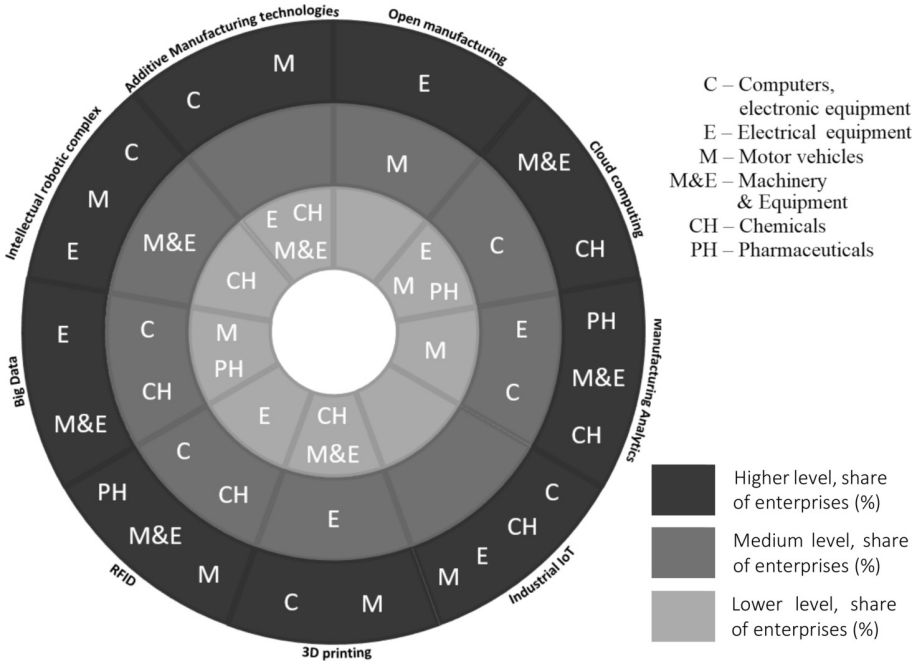

Fig. 1. Ranking of medium and high-tech industries by the level of prevalence of digital technologies.

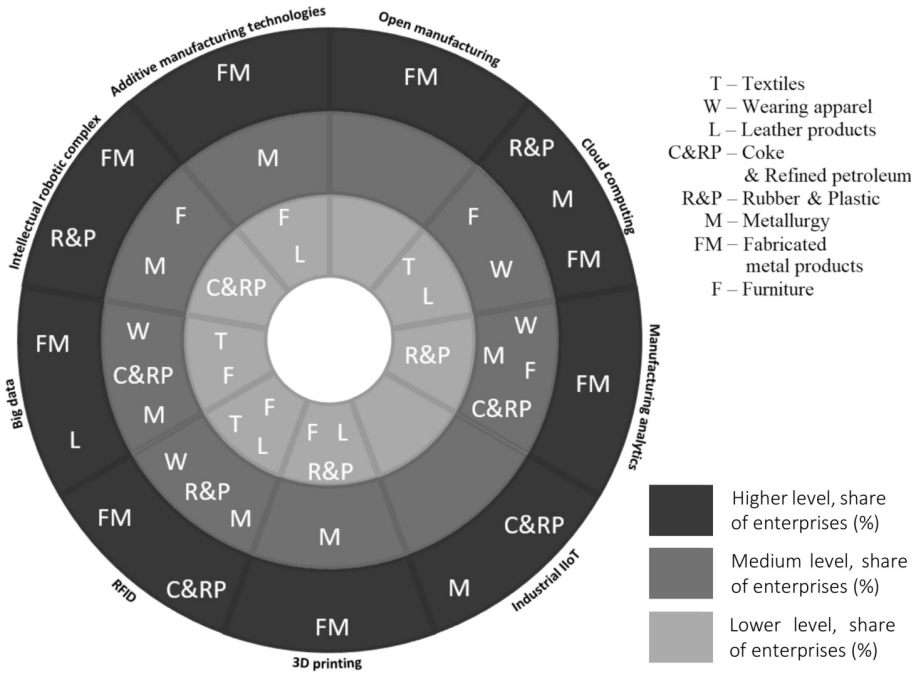

Fig. 2. Ranking low-tech industries by the level of prevalence of digital technologies.

Within each studied technology, the industry samples were divided into three segments, according to the "high", "medium" and "low" level of prevalence. The principle of this division was the ranking of the sample by the size of the share of respondents who indicated the implementation of a particular technology. The industries with the highest coverage received a "high" level of the technology prevalence, with the medium coverage – "medium", and with the low coverage – respectively, "low".

According to the presented visualization (Fig. 1), in the medium and high-tech industries, the leading technology in terms of a high level of presence in the industry was IIoT. It was within this technology that the largest number of industries were concentrated, among which were computers, electronic and optical equipment, electric equipment, chemicals and chemical products, motor vehicles, trailers and semi-trailers.

In addition to IIoT, the technologies that accumulate a great number of industries in the high-level segment should include intellectual robotic complexes, the manufacturing analytics technology and RFID.

It should be noted that intellectual robotic complexes, as well as IIoT, were most prevalent in enterprises producing computers, electronic and optical products, motor vehicles, trailers and semi-trailers and electrical equipment.

Pharmaceuticals, the motor vehicles industry and the production of machinery and equipment n. e. c. became industries with a high level of the RFID technology prevalence. In the case of the pharmaceutical industry, the observed tendency is largely determined by government policy. Since 2014, when the decision was made on the need to create a unified labeling system to control the movement of goods in the territory of the Eurasian Economic Union (EAEU) member countries, government projects are implemented annually to introduce product labeling in various industries using RFID [27]. The pharmaceutical industry has become one of the industries most affected by these projects.

Further differentiation of industries within the segment of high involvement of the remaining technologies shows that additive technologies and 3D printing were common in the motor vehicles industry and the computers, electronic and optical equipment production. This result is consistent with existing studies on the use of additive production in various industries [28].

Let us move to the level of the digital technologies prevalence among a group of low-tech industries (Fig. 2). Cloud computing has become the most common in the low-tech segment. As shown by the results of the survey, this technology was used at a relatively high level in three sectors at once – the production of basic metals, fabricated metal products and rubber and plastic products.

The following relatively common technologies were intellectual robotic complexes, big data and RFID, which were present at a high level in the

industries of fabricated metal products, rubber and plastic products, leather, as well as coke and petroleum products.

As the analysis showed, the manufacture of fabricated metal products in the low-technology segment has become the industry that is most susceptible to digital technologies. At the low level, industrial enterprises for the production of textiles, furniture and leather were mainly concentrated.

Digital activity of enterprises and the presence of a strategy in the field of digital technologies

The business tendency survey program also allows to measure the level of digital activity, as well as the presence of a strategy in the field of digital technologies in enterprises. Taking into account the analysis of the level of the digital technologies prevalence on production, authors considered it important to identify and demonstrate in detail the characteristics of the distribution of industries in accordance with their digital activity and the digital strategy.

To do this, two sets of the survey results were identified, the first of which includes industry-wide assessments of managers characterizing their own digital activity as "high", and the second – the proportion of respondents who stated about the presence of digital technology strategy. The analytical interpretation of the results is visualized in Fig. 3. Accordingly, the abscissa axis reflects the assessments of respondents with a "high" level of digital activity, and the ordinate axis represents the shares of enterprises that had a strategy in the field of digital technologies.

The group that included the maximum shares of both enterprises with high digital activity and the enterprises with the developed digital strategy consisted of computer production and production of fabricated metal products, which is quite consistent with the results of the ranking of industries by the level of digital technologies prevalence. A slightly lower concentration of such enterprises was represented by manufacture of machinery and equipment n. e. c., chemicals and pharmaceuticals. The electrical equipment industry stands alone, where, against the background of a fairly high level of digital activity, the concentration of industries that operate on the basis of a digital strategy is only at a medium level. Finally, the group that accumulated the smallest share

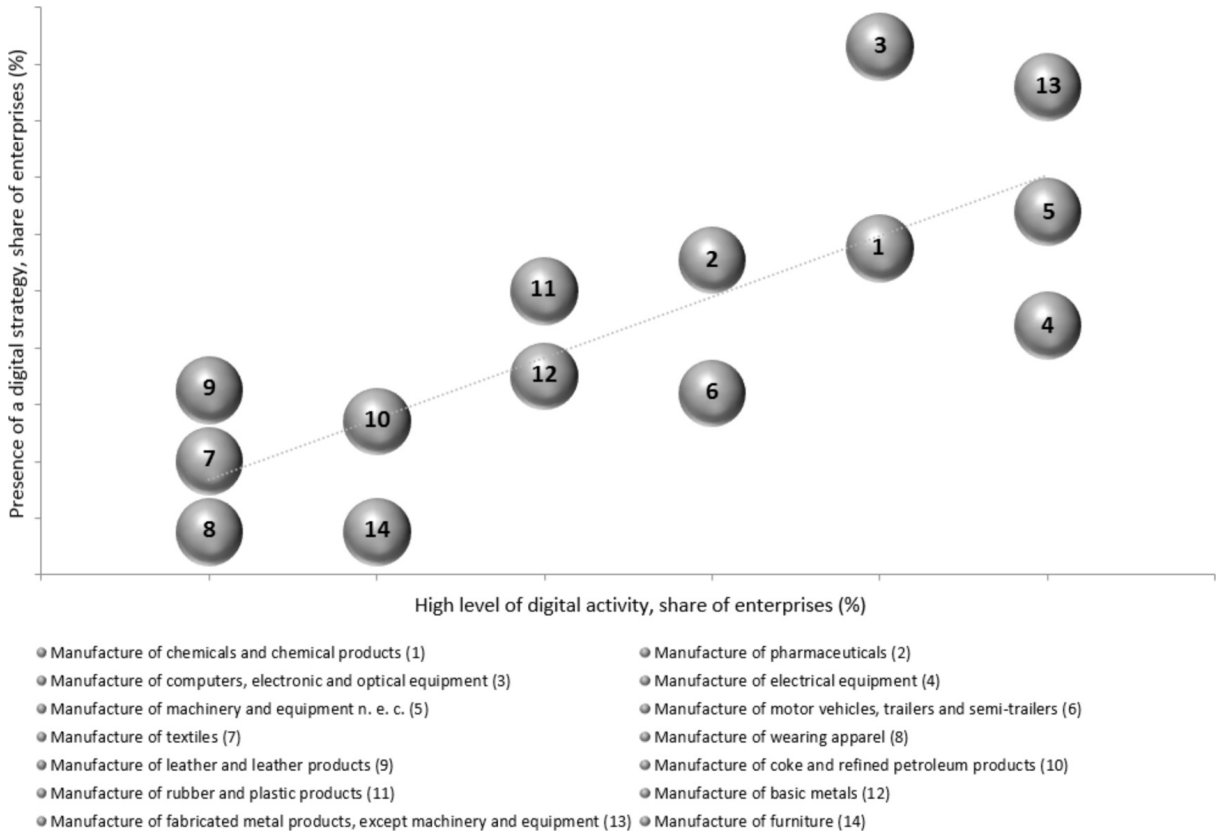

Fig. 3. Distribution of manufacturing industries in accordance with the level of digital activity and the presence of a strategy in the field of digital technologies.

of enterprises with a high level of digital activity and a relatively small share of enterprises that had their own digital strategy included the production of leather, textiles, wearing apparel, furniture, as well as coke and petroleum products.

In general, the existing distribution partially overlaps with the tendencies represented by Figs 1 and 2, although there are some exceptions. It can be assumed that the directors' perception of their own digital activity depends largely on their general understanding of the situation and the strategy for further development. The number and variety of digital technologies being introduced can sometimes be less significant, as can be seen, for example, in the case of pharmaceuticals: in the previous section, this industry was among those with the least amount of digital technologies at high and medium levels, but this did not negatively affect directors' perceptions in terms of their digital activity.

The use of digital technologies in business processes and the digitalization of labor

Because of the topicality of these issues it was important for us to find out, on the basis of the obtained survey results, what criteria for digital transformation and to what extent determined the use of digital technology in business processes at the moment, and which of them became significant to digitalization of labor in manufacturing in 2018 (to solve these problems, the McKinsey & Company approach, described in detail in the methodology section was used [26]. In particular, to solve each of the tasks, we focused on the criteria, expertly selected from the survey questionnaire, the most relevant to two categories – "digital use" and "digital labor".

The following indicators were selected as the criteria for the "digital use", the level of which the managers rated "above the normal level" (see Table 2). Some criteria come into contact with the digital technologies from the first section (Figs 1 and 2), but it is worth noting that here authors are considering the same technologies through another prism. If in the first section authors relied on data on the number of enterprises, where at least to some extent there was experience in implementing a particular technology, then in this section the data on the number of enterprises indicating high intensity of technology use or widespread use of certain digital practices were used.

Table 2
The use of digital business processes in manufacturing sectors.

	Criteria / Sector	*Cloud services*	*Digital information exchange inside a firm*	*Digital information exchange outside a firm (with consumers/contractors)*	*Electronic invoicing*	*Electronic commerce turnover*	*Using PCs, laptops, tablets and other portable devices*	*Internet access and its use for business purposes*
Medium- and high-tech manufacturing	Chemicals	■	▪	▪	▪	▫	▪	▪
	Pharmaceuticals	■	▪	▫	▫	▪	▫	▪
	Computers, electronic and optical equipment	▪	▪	▪	▪	■	▪	▪
	Electrical equipment	■	▪	▫	▪	▫	■	■
	Machinery and equipment n. e. c.	■	▪	▪	■	■	▪	▪
	Motor vehicles, trailers and semi-trailers	▫	▪	▪	▪	■	▫	▪
Low-tech manufacturing	Textiles	▫	▪	▪	■	▫	▪	▪
	Wearing apparel	▫	■	▪	■	▫	▪	▪
	Leather	▫	▫	■	■	▫	▪	▪
	Coke and refined petroleum products	▫	▪	▪	■	▫	▪	▪
	Rubber and plastic products	▫	▪	■	▫	▪	■	▪
	Metallurgy	▫	▪	▫	▫	▫	▪	■
	Fabricated metal products	▪	■	■	■	▪	▪	▪
	Furniture	▫	▪	▪	▫	▫	■	▪

■ High level within a sector, share of enterprises (%)
▪ Medium level within a sector, share of enterprises (%)
▫ Low level within a sector, share of enterprises (%)

The visualization shows that medium and high-tech industries differ from low-tech ones by a higher level of cloud services use, emphasizing a certain level of the digital gap. The only exception here is the motor vehicles industry, where the intensity of use of cloud services is relatively low. A similar tendency is observed with the criterion of electronic commerce turnover, although there are more exceptions among medium and high-tech industries that are the chemical industry and the production of electrical equipment.

In the production of electrical equipment, the relative levels of the use of digital devices and the Internet are the highest among medium and high-tech industries, although this industry is lagging behind in the exchange of information in digital form with consumers and contractors. In the production of machinery and equipment n. e. c., the most important criterion is electronic invoicing.

In the pharmaceutical industry, relatively less intensive use is demonstrated in such criteria as the exchange of information in digital form with consumers and contractors, electronic invoicing and the use of digital devices.

Low-tech industries are primarily distinguished by the fact that, unlike medium- and high-tech industries, they are focused on the criterion of electronic invoicing. Such feature occurs in the production of textiles, wearing apparel, leather, coke and petroleum products and fabricated metal products. However, in the other low-tech industries this criterion shows a low level of intensity.

In addition, technological processes associated with the criterion of the exchange of information in digital form with consumers and contractors are important for the low-tech segment. By this criterion, a high intensity is demonstrated by the leather, rubber and plastic products and fabricated metal products industries.

In general, in both medium, high-tech and low-tech segments, the use of digital technologies in business processes is fairly evenly distributed among various criteria, with the exception of those that show lagging behind for all industries of the particular segment.

Let us move to the indicators of the "digital labor" now (see Table 3). Here there is a somewhat greater variation in the emphasis of criteria among the industries.

Table 3
The features of digital labor in manufacturing sectors.

Sector	Criteria	*Number of ICT specialists employed*	*Centralized ICT education programs for employees*	*ICT training courses for employees*	*ICT vacancies that are difficult to fill*	*carried out by employees*: *Support for ICT infrastructure (servers, computers etc.)*	*Office software support*	*Development of management systems and software*	*Support for management systems and software*	*Development of corporate web portals*	*Support for corporate web portals*	*Digital security and data protection*
Medium- and high-tech manufacturing	Chemicals											
	Pharmaceuticals											
	Computers, electronic and optical equipment											
	Electrical equipment											
	Machinery and equipment n. e. c.											
	Motor vehicles, trailers and semi-trailers											
Low-tech manufacturing	Textiles											
	Wearing apparel											
	Leather											
	Coke and refined petroleum products											
	Rubber and plastic products											
	Metallurgy											
	Fabricated metal products											
	Furniture											

High level within a sector, share of enterprises (%) — Medium level within a sector, share of enterprises (%) — Low level within a sector, share of enterprises (%)

As expected, the manufacture of computers, electronic and optical equipment and the manufacture of electrical equipment became the leaders in the number of ICT specialists employed. By the development of centralized educational programs in the field of digital technologies, all sectors were divided between the two groups with a large gap between them: in the chemical production, the production of electrical equipment, machinery and equipment n. e. c., coke and refined petroleum products, rubber and plastic, and fabricated metal products, such programs were conducted with relatively high intensity, and in other industries – with a noticeably lower. At the same time, third-party ICT skills training courses receive attention at least at an average level in almost all industries, with the exception of the wearing apparel production and the furniture production, which means that employers understand the need to invest in digital human capital of their employees, at least at a basic level. In many industries, there is a shortage of ICT specialists to fill existing vacancies, which also demonstrates the awareness of the need for digital transformation and employees with advanced knowledge in the field of digital technologies.

As for the implementation by the company's own employees of various functions in the field of digital technologies, the distribution is relatively even. In the computer industry, due to its specifics, there are more enterprises where their own employees are engaged in the development of software and corporate web portals. In the production of machinery and equipment n. e. c., according to the results obtained, the functions associated with the development and support of corporate web portals are also carried out by employees to a big extent. Of the individual industries, car manufacturing stands out here, where a significant number of criteria for the digitalization of labor indicate a lag. The motor vehicles industry stands out from the majority of other industries, having low levels for many digital labor criteria. Along with this, the criterion of the number of ICT specialists is low in the chemical production, basic metals, textiles and leather.

Conclusions

Defining digital transformations primarily in manufacturing activities as a strategic imperative for the entire economy, the paper presents and analyzes the results of business tendency monitoring, which characterize important industry tendencies and phenomena occurring as part of digital transformation of manufacturing. Our work is the first step in the study of entrepreneurial assessments of tendencies in the digital economy. Reliable measurements of the effects of such economic phenomena have not yet been conducted in the country. The results of the business tendency monitoring improve the quality of information flows on the positive economic impact of digitalization. As a result, the novelty of the study in terms of completing the gaps in statistical information about economic events and tendencies related to the spread and growth rate of industry digitalization consisted of generalized assessments of opinions and intentions of entrepreneurs regarding the introduction of breakthrough business models and digital technologies in manufacturing enterprises.

In general, the survey revealed significant differences in entrepreneurial judgments regarding most aspects of digitalization of production. This tendency emphasizes the multi-structural nature of the Russian manufacturing industry, when its various segments operate in fundamentally different economic conditions, primarily in terms of access to development resources, and, accordingly, have fundamentally different potential for digital development. However, on the other hand, despite the fact that the transition to Industry 4.0 takes place within the relatively unfavorable business climate, the obtained opinions allow us to state that the level of immersion of the manufacturing enterprises into digitalization processes is not yet deep, but the progress is obvious. Interest in Industry 4.0 is gradually being transformed into concrete investments and real results, contributing to the ever-increasing growth of the level of digitalization and integration in large and medium-sized industrial enterprises. This is largely manifested in the level of prevalence (presence) of technologies in each of the studied industries.

The most important features should be considered the following:

- the digital agenda was a sufficient priority in the industrial development of the studied set of enterprises in 2018, but many technologies were still under development, requiring serious investments and improvements;
- the observed differences in the opinions of the management of manufacturing enterprises are fairly objective and indicate a significant level of heterogeneity in the development of certain types of activity in manufacturing enterprises;
- IIoT, intellectual robotic complexes and manufacturing analytics are most common in the medium and high-tech segment; 3D printing technologies and RFID tags are presented at different levels of distribution in a large number of industries, which may indicate an active dynamics of their introduc-

tion and development in Russian manufacturing;
- the use of cloud services had become one of the main markers for the high intensity of the use of digital technologies in business processes in the mid- and high-tech segment, while in the low-technology segment it was electronic invoicing;
- the issue of labor digitalization had received considerable attention in the vast majority of manufacturing industries. Many enterprises in various industries invest in the organization of educational programs and pay for training courses in the field of IT for their employees.

We can try to trace further ways to address the problem. One of them is associated with the further expansion of the business tendency observation program by the inclusion of other industries outside manufacturing, the study of new digital technologies and new forms of digital activity.

The additional important step is the development of composite indicators. Such indicators may be, for example, a digital transformation indicator, compiled on the basis of entrepreneurial assessments of the level of digital technologies and practices of the digital economy prevalence; a labor digitalization indicator based on relevant criteria; an indicator of digital investment activity, etc.

Another possible direction of research can be an in-depth cross-analysis of the relationship between the economic performance of enterprises, such as profit or labor productivity, and generalized assessments of their managers regarding the digitalization of their own production. This kind of research can be conducted in a sectoral context too. The results of such a study will allow a better estimation of the economic effect of digital transformation through the use of alternative indicators from business tendency surveys.

In addition, business tendency monitoring can be used to predict the pace and quality characteristics of digital transformation in the framework of foresight research. Several studies can be devoted to analyzing the effectiveness of using the composite digitalization indicators to predict various economic and technological quantitative indicators.

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