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DIGITAL TRANSFORMATION IN MANUFACTURING: DRIVERS, BARRIERS, AND BENEFITS

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DIGITAL TRANSFORMATION IN MANUFACTURING: DRIVERS, BARRIERS, AND BENEFITS[3]

This paper investigates the drivers, barriers, and benefits that can be associated with management decisions regarding the implementation of digital technologies in Russian manufacturing enterprises. The empirical basis of the study is the results of the business tendencies surveys for 2018 and 2019. Potential factors for the introduction of digital technologies were divided into three groups: drivers of business activity (production and economic parameters), drivers of digital activity (parameters characterizing the level of enterprise involvement in digital processes) and barriers, preventing the enterprise from transitioning to digital transformation. In the first part, regression analysis is used to identify the relevant factors among the drivers and barriers. In the second part, the benefits expected by enterprise managers from the implementation of individual digital technologies are revealed. Significant drivers are the number of specialists working in the enterprise in the field of information and communication technology (ICT), the presence of a developed strategy in the field of digital technologies, involvement in the government's digital agenda, and a positive perception of the economic situation at the enterprise by its management. Among the expected benefits, the most important are the optimization of production and logistics operations, increasing the level of customer service and expanding the customer base.

JEL Classification: L60, M15, O14, O33

Keywords: digitalization, digital economy, digital technology, digital transformation, manufacturing, business tendency surveys

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1. Introduction

In recent years, the digital economy has become one of the central topics of discussion in research literature and the expert community. In the world, more and more attention is paid to the study of digital processes, which are supposed to be able to become drivers of the growth of competitiveness of enterprises, to solve the problem of slowing productivity growth and economic stagnation in developed countries (Sorbe *et al.* 2019; Bersch *et al.* 2019), as well as accelerate economic growth in developing countries (Zhang & Chen 2019; Hawash & Lang 2019; UNCTAD 2019). In this regard, it becomes important to identify the reasons for the introduction of digital technology in enterprises.

In the manufacturing industry, the current stage in the development of digital technologies is closely connected with the concept of Industry 4.0. In our interpretation, it is the broad and multifaceted process of integrating physical objects, human actors, intelligent machines, and production lines into a single automated information system (Oztemel & Gursev 2020; Agostini & Filippini 2019). Distinctive features of manufacturing based on the advanced Industry 4.0 technologies are both high efficiency and a deep level of customization of the manufactured product (Ghobakhloo & Fathi 2019; Idrisov *et al.* 2018).

The need for measuring digitalization processes both in manufacturing and other types of economic activity has been increasing over the past decade, causing a high demand for prompt, regular and reliable statistical estimates. However, in international practice, a fully harmonized conceptual framework for the digital economy has not yet been developed. Leading international organizations, making independent attempts to measure digital phenomena, offer their own definitions and approaches that emphasize various aspects of this multifaceted phenomenon: dependence on digital technologies, intangible assets, massive use of data, the emergence of new business models, social implications etc. (OECD 2015; World Bank 2018).

In current research, it is customary to separate processes such as digitization, digitalization, and digital transformation (Mergel *et al.* 2019; Vial 2019; Gobble 2018; Osmundsen *et al.* 2018). Although the established definitions of these concepts in the literature have not yet been developed, and many authors use them as synonyms, nevertheless, there is a tendency to understand digitization as the transition to digital information storages, while digitalization is associated with changes in socio-technical structures caused by the implementation of digital technologies. At the same time, digital transformation is focused more on managerial aspects of digitalization, being linked to a large-scale process of implementing digital technologies and the corresponding organizational transformations.

Digital transformation is the concept now widely popular not only in the scientific literature, but also in the expert and business community (McKinsey 2019; Deloitte 2019). In the literature there are various approaches to the classification of its factors (see, for example, Machado *et al.* 2019; Wolf *et al.* 2018; Osmundsen *et al.* 2018; Liere-Netheler *et al.* 2018).

In the theoretical aspect, the existing literature on digital transformation largely inherits the research tradition of "diffusion of innovation" (Rogers 2003; Gokhberg *et al.* 2016). Indeed, corporate decisions related to digital transformation fit into the wider context of innovative technological development. However, at the level of company management practice, it turns out to be necessary to separate innovation and digital strategies: the concept of digital transformation describes a broad, long, and unified process of internal changes that can have multiple goals at the same time and result in scale reorganization of the whole business model (Gobble 2018). Covering all aspects of the enterprise's activities, digital transformation requires a wide range of participants, as well as following a clear and coherent roadmap, and, as a result, special metrics become necessary for its assessing, which may be irrelevant for the development and implementation of individual innovations (Gobble 2018; Agostini & Filippini 2019).

At the same time, we surely agree with the position (DeStefano *et al.* 2017) that the economic consequences of the introduction of various digital technologies can vary significantly, and therefore the identification of drivers, barriers, and benefits should be carried out separately

for digital technologies. Nevertheless, in our opinion, taking into account the specifics of the digital transformation process described above, we can talk about both general drivers and barriers to its implementation, studying the introduction of digital technologies in an aggregated form, as well as about the expected benefits and economic consequences of implementing specific digital technologies.

Based on the data array of the results of market surveys of industrial corporate managers available to us, we considered it appropriate to propose our own classification of general factors of digital transformation. In the framework of our study, such factors are understood as a set of parameters characterizing various aspects of the industrial enterprise, which are able to demonstrate a stable positive or negative relationship with the processes of digital technology implementation. Potential factors included drivers of business activity (economic parameters), drivers of digital activity (parameters associated with the level of enterprise involvement in digitalization), and barriers preventing the enterprise from successfully continuing digital transformation. In addition to general factors, we examined specific benefits that encourage enterprises to introduce certain digital technologies.

Accordingly, in the framework of this article we consider two research questions. The first can be formulated as follows: what are the drivers of business and digital activity, as well as barriers associated with the level of digital transformation of manufacturing enterprises in the current phase of digital development in Russia? At the same time, the second question concerns the level of individual technologies: what benefits do industrial enterprises expect to receive from the introduction of digital technologies?

In the current research practice, the study of digital transformation factors is dominated by methods of qualitative analysis, such as case study (Nissen *et al.* 2018; Wolf *et al.* 2018; Machado et al. 2019), bibliometric studies (Osmundsen *et al.* 2018; Liere-Netheler *et al.* 2018), in-depth interviews with industry representatives (Liere-Netheler *et al.* 2018), as well as analysis of survey data using statistical methods (Agostini & Filippini 2019; Kokolek *et al.* 2019; Mhlungu *et al.* 2019; Zomer *et al.* 2018; DeStefano *et al.* 2017). Studies based on quantitative statistics are a relative minority, although the examples are also found in the literature (Andrews *et al.* 2018).

For the most part, this is due to the lack of available quantitative data. For instance, in Russia, official statistical monitoring of the use of digital technologies in business so far has mainly included only the "first wave" technologies: computerization, process automation, telecommunications (Kitrar & Lola 2019). Among relatively more advanced technologies, only cloud computing has been taken into account.

In such circumstances, surveys of entrepreneurs become powerful potential informational content for studying digital transformation using statistical methods. In our work, we continue this line of research, based on data obtained as part of a pilot project of the Centre for Business Tendencies Studies at the Institute for Statistical Studies and Economics of Knowledge of the Higher School of Economics, launched in 2018 and aimed at measuring digital activity of Russian enterprises (Kitrar & Lola, 2019). The monitoring results for 2018 and 2019 were used in descriptive studies of digital transformation of the manufacturing industry (Lola & Bakeev, 2019; Lola 2019, 2020). In the framework of this work, the results of two observations for 2018 and 2019 were used to identify factors of the introduction of digital technologies in enterprises.

At the first iteration of the study, for general factors, using correlation and regression analysis, we tried to identify attributes of the presence of causal relationships, using variables for 2018 as explanations for the variable reflecting the level of digital technology adoption in 2019. This allows you to reduce the possible impact of the problem of simultaneity and the likelihood of reverse causality. The analysis performed in this way, due to the limited nature of the available data set, does not allow us to unequivocally state the existence of causal relationships, however, it may indicate their possible presence for certain variables, thereby showing the direction for further research.

Thus, the aggregate indicator, reflecting the number of recorded cases of digital technology introduction, is an explained variable at the first iteration of the study. A list of technologies was

formed on the basis of available indicators in the questionnaire and included, first of all, advanced digital technologies related to the Industry 4. 0 concept: Internet of Things, additive manufacturing (3D printing), open production technologies, "cloud" and "edge" computing technologies , end-to-end automation and integration of production and management processes, big data and manufacturing analytics. In addition to these technologies, robotic production / automated lines, a digital workplace and the use of radio frequency identification technologies (RFID) were included in the list as constitutive elements of digital transformation.

The second iteration of the study involves identifying the specific benefits expected from the implementation of the technologies mentioned above. Here we focus only on the observations results for 2019, exploring them using regression analysis. In this iteration, we are interested in characterizing enterprises that implement certain digital technologies.

It should be noted that our work, based on Russian data, is primarily aimed at identifying the drivers of business and digital activity that are specific to Russia. They may differ significantly from the results obtained for other countries due to gaps in the level of dissemination of digital technologies and the characteristics of national economic and technological development.

Existing studies reveal the national specifics of digital transformation for a number of countries. For example, in Germany, the main expected benefits from the introduction of digital technologies in manufacturing are the reduction in the share of production defects, the improvement of labour conditions and labour productivity, and the business drivers are the demand from consumers and the need to integrate within the production chain (Liere-Netheler *et al.* 2018).

The digital transformation in Hungary, as evidenced by existing research, is mainly at the experimental stage (Feher *et al.* 2017). It is characterized, firstly, by the large role of IT knowledge and skills not only at the implementation stage, but also at the stage of raising awareness and generating ideas; secondly, the lack of a clear vision and organizational capabilities as one of the main barriers; thirdly, the increased difficulties of enterprises that have already embarked on the path of digital transformation, resulting from a lack of experience and the necessary skills.

Among the features that are characteristic of Russia in the context of digital transformation, the literature particularly emphasizes the increased level of heterogeneity in the level of development of manufacturing enterprises (Tolkachev & Morkovkin 2019; Nissen *et al.* 2018). Authors pay attention to the fact that there is a significant gap between the companies in terms of financial capabilities, the level of competitiveness in international markets, affordable infrastructure and management practices.

As a result, there are prerequisites for a serious gap in the level of digital transformation between the two groups of enterprises (Nissen *et al.* 2018). The first includes leading companies with a high level of competitiveness and significant development budgets, while the second includes other companies that do not fully see the opportunities of digital development and do not have the necessary budgets for its implementation. They need tried and tested practices, because; unlike the companies from the first group, they cannot work by trial and error when implementing digital technologies.

When describing the problems of enterprises from the first group regarding the introduction of digital technologies, the authors mention biases in assessing the outcomes of implementing digital projects (re-evaluation of benefits and underestimation of costs), focusing on short-term goals, lack of performance metrics, and an ad-hoc decision-making manner (Nissen *et al.* 2018), a large dependence of the launched initiatives on state funding in the absence of a unified system for evaluating government support programs (Idrisov *et al.* 2018). A common problem for the prospects of Russian manufacturing in the implementation of digital technologies is the lack of specialists with the necessary qualifications (Nissen *et al.* 2018; Zozulja 2018).

In general, authors give low assessments of the current state of digital transformation in Russian manufacturing (Idrisov *et al.* 2018; 2018; Tolkachev & Morkovkin 2019). At the same time, the majority indicates the presence of development potential, including due to the low base effect (Korovin 2019; Akberdina 2018).

In recent years, Russia has created a system of state support for the national innovation system, and in particular, sectoral strategies for manufacturing industries (Idrisov *et al.* 2018). State support for the introduction of digital technologies in manufacturing enterprises in Russia may become a factor of significant productivity growth, but studies show that this requires a policy aimed at narrowing the gap between a small share of technologically advanced enterprises and others.

Thus, the results of our paper may be useful primarily for studying the experience of developing and transition economies, which are often characterized by catch-up innovative development and the large role of state innovation policy. In particular, our findings may shed light on the specifics of digital transformation in developing countries as opposed to developed ones.

2. Data and Variables

The data source for this study was the results of two surveys containing short- and medium-term estimates of the level of business and digital activity at large and medium-sized Russian manufacturing enterprises in 2018 and 2019, respectively. The surveys were carried out as part of a specially organized business tendencies studies program conducted by the autonomous non-profit information and publishing centre "Statistics of Russia," commissioned by the Centre for Business Tendencies Studies of the Institute for Statistical Studies and Economics of Knowledge of the Higher School of Economics. The questionnaires were filled out by respondents (directors or managers of enterprises) with the necessary level of competence in relation to questions asked.

The companies for the surveys were selected independently by the regional bodies of the state statistics system. Each of the two surveys as observation units included more than 1,100 enterprises, geographically concentrated in the same thirty regions of the Russian Federation[4]. For the analysis in the framework of this study, manufacturing enterprises were selected (section C of the OKVED 2 economic activities classifier). The sample population is representative of all units of observation, multidimensional, stratified, and representative of the main economic indicators of the thirty regions of Russia.

The main objective of the pilot survey was to fill in the incompleteness of statistical information on economic events and trends related to the industrial digitalization by obtaining generalized entrepreneurial opinions and intentions regarding the introduction of new business models and digital technologies in the activities of manufacturing enterprises. The pilot survey program included indicators characterizing the development of the market of digital technologies, the level of digital integration in the production process, prevailing digital skills of employees and the main factors that impede the spread of these technologies in the manufacturing industry.

The construction of the program of digital activity monitoring was based on international experience in the measurement of digital progress. The pilot survey program is harmonized with international standards and, in the aspect related to methodology for building the indicators, is based on the European system for studying business tendencies (European Commission 2016, 2019).

Let us turn to the description of variables based on the results of the business tendencies research. As mentioned above, our study involves two iterations. As part of the first, we study digital transformation as a single process, trying to identify common factors for the introduction of digital technologies among manufacturing enterprises. At this iteration, we use the results of two surveys for 2018 and 2019.

[4] Krasnodar krai, Krasnoyarsk krai, Primorsky krai, Stavropol krai, Khabarovsk krai, Arkhangelsk oblast, Vladimir oblast, Volgograd oblast, Vologda oblast, Nizhny Novgorod oblast, Irkutsk oblast, Tver oblast, Kemerovo oblast, Samara oblast, St. Petersburg, Leningrad oblast, Moscow , Moscow oblast, Novosibirsk oblast, Rostov oblast, Sverdlovsk oblast, Smolensk oblast, Tula oblast, Tyumen oblast, Chelyabinsk oblast, Republic of Bashkortostan, Republic of Dagestan, Republic of Tatarstan, Udmurt Republic, Republic of Sakha (Yakutia).

The explained aggregate variable reflects the number of recorded cases of the introduction of 10 digital technologies in 2019 at least at some level. The list consists of the following technologies: Internet of Things, additive manufacturing (3D printing), open production technologies, "cloud" and "edge" computing technologies, end-to-end automation and information integration of production and management processes, big data, manufacturing analytics, as well as robotic production / automated lines, digital workplace and RFID.

Explanatory variables were divided into three groups: business activity drivers, digital activity drivers, and barriers. The choice of such a wide range of factors is due to the multidimensional and complex nature of the digital transformation process, which depends on the general economic characteristics of the enterprise, on the development of the enterprise in the field of digital practices and knowledge, and on various kinds of specific internal and external barriers. A complete list of selected factors is presented in Table 1. The variables related to business and digital activity drivers reflect the respondents' answers to the question of whether the indicator increased (improved) this year compared to the previous one. The exception here is only one of the digital activity drivers – a variable reflecting the respondent's assessment of the positive impact on the enterprise's activities of the Digital Economy of the Russian Federation state program adopted in 2017[5]. The inclusion of this variable allows us to analyze the role of the state in the process of implementing digital technologies in Russian manufacturing. "Barrier" variables reflect the respondent's assessment of the presence or absence of relevant barriers to the implementation of a digital technology.

For the statistical model in the first iteration, it was impossible to detail observation units to the level of individual respondents participating in the survey. For this reason, subsectors differentiated to the third level of the OKVED 2 classifier were considered as units of observation in it. Accordingly, the explained variable reflected the number of recorded cases of the introduction of digital technologies in the subsectors, and the explanatory variables show the shares of enterprises in the subsectors with positive answers according to the indicators in Table 1.

Table 1 – General factors for implementing digital technology

Presence / absence of increase (improvement) in the current year compared to the previous year		***Expectation of positive impact / lack of expectation or difficulty in answering***	***Presence / absence***
Business Activity Drivers	**Digital Activity Drivers**		**Barriers**
• *Demand for products* ***(DEMAND)*** • *Primary product output in kind* ***(OUTPUT)*** • *Production investment* ***(INVESTMENT)*** • *The economic situation at the enterprise* ***(SITUATION)*** • *Competitiveness of the main product* ***(COMPET)***	• *The number of ICT specialists in the enterprise* ***(SPECIALISTS)*** • *Presence of a digital technology strategy* ***(STRATEGY)***	• *State program "Digital Economy of the Russian Federation"* ***(PROGRAM)***	• *Lack of sufficient budget* ***(BUDGET)*** • *Infrastructure restrictions* ***(INFRASTRUCTURE)*** • *Low digital literacy* ***(COMPETENCE)*** • *Low payback* ***(PAYBACK)*** • *Lack of favorable and stable economic conditions in the country* ***(CONDITIONS)***

Figure 1 presents a distribution of the explained variable used in the first iteration of the study. In total, we identified 84 subsectors, for which the graph shows the ratio of the number of cases of the introduction of digital technologies to the total number of enterprises included in the subindustry as part of our survey.

[5] URL: https://digital.gov.ru/ru/activity/directions/858/ (In Russian).

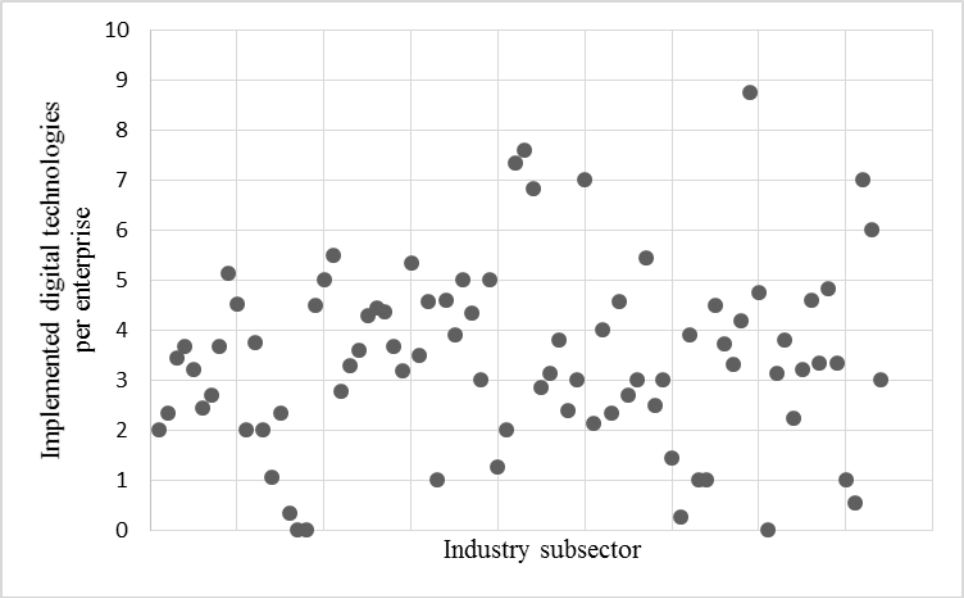

Figure 1. The number of digital technologies implemented in manufacturing subsectors per enterprise (2019 г.).

In the second iteration, instead of the explained count variable, binary variables were formed that reflected the fact of the introduction of individual digital technologies. Since only the survey results for 2019 were included in this iteration, using individual enterprises as the observation units was possible. The explanatory variables represented the respondents' answers recorded in binary form, reflecting their assessment of the presence or absence at the “high,” “moderate” or “low” level of certain benefits that the company receives from the implementation of digital technologies. We considered the following list of benefits:

- Increase in labor productivity;
- Increase in equipment productivity;
- Optimization of production and logistics operations;
- Production growth;
- Reduction in costs and production defects;
- Improving customer service;
- Improving competitiveness;
- Increase in profit;
- The expansion of the customer base;
- Optimization of the number of employees due to the robotization of low-skilled personnel.

Figure 2 describes the distribution of the variables being explained in the second iteration. In total, our sample included 1163 enterprises. The figure shows the shares of enterprises from the general sample, in which the introduction of a certain type of digital technology is recorded at least at a low level.

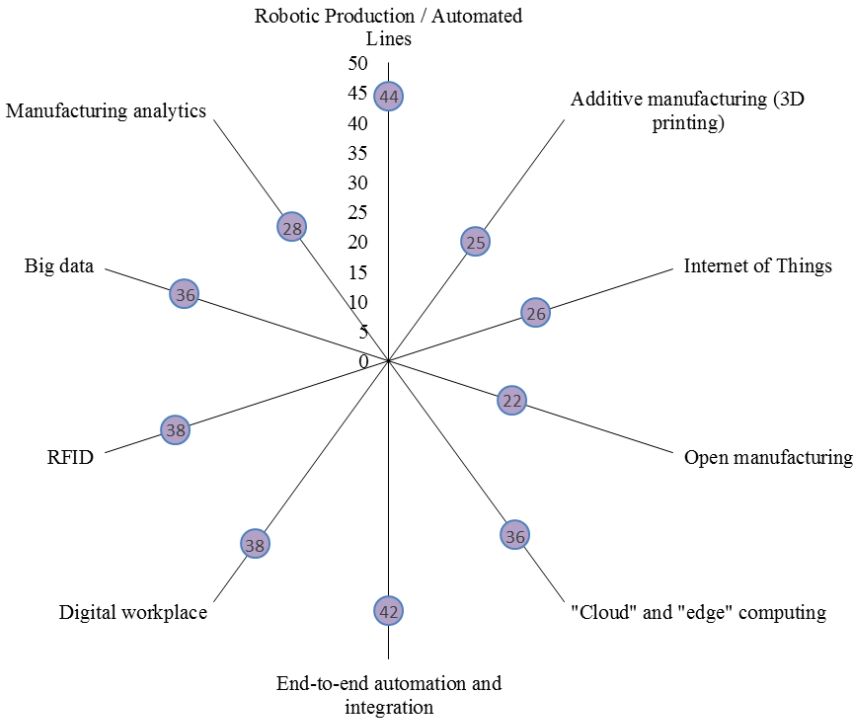

Figure 2. The share of enterprises from the total sample of 2019 that introduced a certain digital technology (%)

3. Methods

At the first iteration, the explained variable takes the form of count data, reflecting the number of recorded cases of the introduction of digital technologies in enterprises. This led to our choice of a negative binomial regression model, which is widely used when working with count data (Agostini & Filippini 2019; Baggio *et al.* 2018; Zhou & Carin 2015; Pedersen & Skagen 2014; Li 2010). Our decision in favor of the negative binomial model compared to the Poisson model that is traditional for count data was due to overdispersion found in the data. Negative binomial models, unlike Poisson models, allow a situation in which the variance significantly exceeds the average value in the distribution. An offset variable was included in the model, representing the number of enterprises based on which aggregated data on subsectors were generated.

This model, which separates the explained and explanatory variables in time, can weaken the effect of the problem of simultaneity and point out potential causal relationships between the analyzed variables. It is true that here we can only talk about possibilities for causal relationships, since to prove their existence it is necessary to fulfill the condition for the absence of dynamics among unobservables, which we cannot provide with our research design and the available data. However, the results obtained may highlight the factors that can be given more attention in further research in order to verify their potentially important role in the process of digital transformation in developing countries at its initial stage.

Before the regression analysis, as part of the first iteration, we performed a correlation analysis for the initial screening of variables. In this case, we used Spearman's rank correlation coefficients, selected due to the high skewness of the distributions of the variables, which we identified. Then the variables were sequentially included in the final models based on the Akaike information criterion (AIC).

Let us move on to the second iteration. In it, the explained variables are in binary form, which led to the choice of logistic regression for the analysis. For the digital technologies we chose, we determined the optimal model of logit regression, which allows us to characterize the digital technologies that we are considering from the point of view of the benefits gained from their implementation. As mentioned above, we have data on respondents' assessment of the presence of

benefits at high, moderate and low levels. Accordingly, we considered three variables for each benefit as possible components of the models. Models were also compared based on the Akaike information criterion (AIC).

4. Findings

At the preliminary stage of the study, as part of the first iteration, we conducted a correlation analysis of potential factors for the introduction of digital technologies, the results of which are presented in Table 2. The analysis showed a statistically significant correlation for most variables with moderately weak correlation coefficients. For two variables "demand" and "payback", no significant correlation was found. The results of the correlation analysis for barriers showed counterintuitive results, when a stronger perception of the barriers by respondents was weakly positively correlated with the general level of implementation of digital technologies.

Then we conducted a regression analysis, the results of which are presented in Table 3. Our study showed that the optimal explanatory model includes the following variables: the economic situation, the number of ICT specialists, the presence of a digital technology strategy, and a positive perception of the Digital Economy of the Russian Federation program.

Table 2 – Spearman's rank correlation analysis results (general factors)

A group of factors	*Variable*	*Spearman's ρ*	*p-value*
Business Activity Drivers	**DEMAND**	0.141	0.202
	OUTPUT	0.275	0.011**
	INVESTMENT	0.245	0.025**
	SITUATION	0.337	0.002***
	COMPET	0.235	0.031**
Digital Activity Drivers	**SPECIALISTS**	0.495	1.681e-06***
	STRATEGY	0.484	3.045e-06***
	PROGRAM	0.456	1.288e-05***
Barriers	**BUDGET**	0.195	0.076*
	INFRASTRCTURE	0.359	0.001***
	COMPETENCE	0.216	0.049**
	PAYBACK	-0.019	0.857
	CONDITIONS	0.238	0.0293**

Note: *, **, *** are significant on levels $p < 0.1$; $p < 0.05$; $p < 0.01$ respectively.

Table 3 – Regression analysis results (general factors)

Variable	*Coefficient*	*p-value*
SITUATION	0.833	0.003***
SPECIALISTS	1.183	0.026**
STRATEGY	0.603	0.0792*
PROGRAM	0.978	0.002***

Note: *, **, *** are significant on levels $p < 0.1$; $p < 0.05$; $p < 0.01$ respectively.

The results of the study in the framework of the second iteration in a generalized form are presented in Figure 3. For each digital technology, we evaluated the best model of logistic regression, considering as explanatory variables certain benefits from the introduction of digital technologies at a high, moderate and low level. Each technology sector in the figure is divided into three areas, corresponding to the presence of the benefits at one of the three levels, which were revealed in the array of enterprises that we studied in 2019. In the case of robotic production / automated lines, it was impossible to establish the optimal model on these data, so this technology was excluded from our consideration.

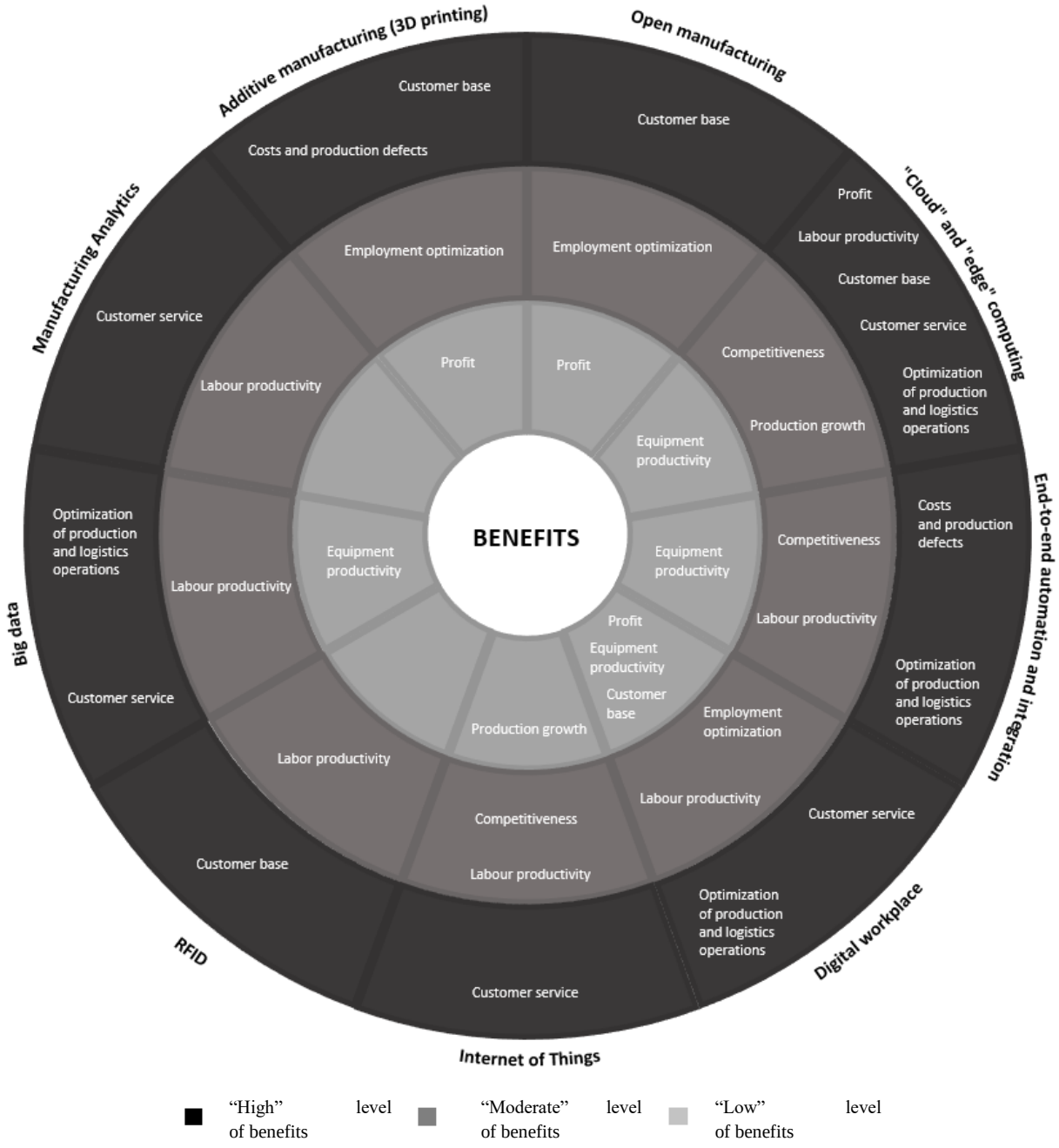

Figure 3 – Benefits relevant to the implementation of certain digital technologies

A visual analysis of the results shows that the respondents associate the greatest benefits from the introduction of digital technologies with the area of interaction with customers – in the form of increasing the level of customer service and expanding the customer base. In addition, for many technologies, benefits in the form of optimization of production and logistics operations are indicated at the high level. Benefits in the form of increased labor productivity were identified for most digital technologies, but only at a moderate level, and in the form of increased equipment productivity for fewer technologies and only at a low level. Benefits in the form of cost reduction and reduction of production defects correspond to the implementation of the additive manufacturing technology and end-to-end automation, while for other technologies, no relationships were identified at any of the three levels. In general, moderately weak expectations are associated with such benefits as increased competitiveness, increased profits and optimized

number of employees. The benefits in the form of production growth had the most weakly expressed perception.

As for individual digital technologies, the clear leader in terms of perceived benefits is cloud and edge computing. Along with them, the benefits of end-to-end automation and information integration, digital workplace and additive manufacturing are relatively well understood. For other technologies, the revealed benefits are more likely to be sporadic and more difficult to interpret, which indicates less stable results.

5. Dicsussion and Conclusions

Based on the results obtained, we can draw a number of conclusions regarding the factors of digital transformation, which are currently the most active in the Russian manufacturing industry, and try to describe in general terms the current stage of the ongoing digital transition.

One of the main common factors of digital transformation in our sample is the number of hired ICT specialists at the enterprise. This result is in good agreement with the available literature on the close relationship between technology use and employee skills (Andrews *et al.* 2018; Bartel et al. 2007; Autor *et al.* 2003). Our results are likely to be similar to the conclusions obtained in the framework of the analysis of digital transformation in Hungary (Feher *et al.* 2017): the role of human capital in the field of IT knowledge and skills at the initial stage of digital transformation is especially important because of raised general awareness and generated ideas related to the possibilities of introducing digital technologies at the enterprise. ICT specialists act precisely as the initial drivers of digital transformation, influencing decisions about the need to implement digital technologies.

Along with ICT specialists, the digital technology strategy and the positive perception of the impact of the Digital Economy of the Russian Federation program turned out to be significant drivers of digital activity. These results, respectively, saying about the important role of the organizational, managerial component of the enterprise and government policy, are also understandable. At the initial stage of digital transformation, the introduction of digital technologies is not yet an urgent need, but rather appears as one of the possible unique development strategies. Therefore, under these conditions, the activities of the company's management become an important independent driver, since it is not entirely determined by the pressure of the external economic and technological environment. As for government policy, its large role in the initial stages of technological transformations in developing countries is also a rather known fact, and its decisive importance for digital transformation in Russia is currently noted in the literature (Idrisov *et al.* 2018; Nissen *et al.* 2018).

If we discuss the business activity drivers, then the indicators that directly affect the economic parameters of the enterprise, such as sales or profit, turned out to be relatively insignificant for decisions on the introduction of digital technologies on the general data set compared to a more general indicator reflecting the respondents' assessments of the economic situation at the enterprise. As can be seen, for respondents, what was important was, first of all, a stable and steadily improving economic situation and the absence of crisis phenomena. In such favorable stable economic conditions, managers were more likely to pay attention to the possibility of introducing digital technologies in their enterprises.

The counterintuitive result, which is that respondents' assessments of the presence of certain barriers to digital transformation (for example, the lack of an adequate budget, infrastructure constraints, low literacy of ICT specialists and the lack of favorable economic conditions in the country) positively correlates with the introduction of digital technologies, can also be explained by the high impact of awareness in the initial stages of technological transformation. Business leaders who have not yet embarked on the path of digital transformation are not enough informed and cannot adequately assess existing barriers. At the same time, enterprises that have already launched the process of implementing digital technologies, at first

are faced with increased difficulties (Feher *et al.* 2017). As a result, they are more likely to indicate the presence of certain barriers, while being relative leaders in terms of digital transformation.

The second part of the study, concerning the benefits of the introduction of digital technologies, allows us to more deeply characterize the current stage of digital transformation in Russia. Firstly, it shows that digital technologies so far mostly act as a tool for optimizing individual operations and more efficient work with clients. To a lesser extent, benefits are expected from digital technologies in the field of increasing productivity and optimizing the number of employees, which implies a fundamental restructuring of business models. In this sense, the situation in Russia is similar to the situation in most countries of the world and has not yet fully approached the level of the most developed industrial countries (Castelo-Branco *et al.* 2019; Liere-Netheler *et al.* 2018). It can be expected that with the spread of advanced technologies of Industry 4.0, such as the Internet of Things, manufacturing analytics and additive manufacturing, the tendency to deeply transform production based on digital technologies in Russia will intensify.

In addition, our results regarding benefits from the introduction of digital technologies partly shed light on the discussion about the role of digital technologies in a wider context of increasing productivity growth (see Goldfarb *et al.* 2019). At present, we cannot draw definitive conclusions about the impact of digital technologies, since most enterprises have not yet fully mastered digital technologies in their business models. As a result, the economic effect of the introduction of digital technologies can actually be significant, but may be delayed and not fully appear at the first stages of digital transformation.

In general, our results show that the state of digital transformation in the Russian manufacturing industry coincides with existing evidence on digital transition in developing countries and, in many respects, in developed countries. We are witnessing the initial stage of digital transformation, which, most likely, determines the large role of human capital, company management and the overall stability of the economic situation as the most significant factors in introducing digital technologies, and also explains the increased difficulties of the enterprises involved in digital transformation.

Once again confirmed in our study, the important role of government policy indicates the need for close attention to the principles of its implementation. In order for digital transformation to become a serious driver of economic development, it is necessary to reduce the existing gaps in the level of digital development, which the authors point to (Tolkachev & Morkovkin 2019; Nissen *et al.* 2018). In this direction, further studies are possible, for example, regarding the role of public-private partnerships in the context of the dissemination of digital technologies, the differences between public and private enterprises in terms of digital transformation (see, for example, Kokolek *et al.* 2019).

In the near future, a study of a substantial transition to the use of digitalized business models from the stage of individual experiments and sporadic initiatives in the field of digital technology will be getting increasingly important. As these trends grow, researchers will be able to more deeply characterize the features of the current digital technological transformation in order to compare it with previous industrial transformations. In this sense, longitudinal business tendencies research is of great importance, which allows us to conduct micro-level timely analysis. Our paper shows the great potential of such survey programs in the context of technological problems, revealing the relevant characteristics of the initial stage of digital transformation of the manufacturing industry. Further updating the survey program in order to increase the scope of measurement of processes and digitalization effects will expand the potential set of statistical tools and measurement methods that can be used to study the spectrum of previously unexplored phenomena of the digital economy.

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