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Strategy of digital transformation of industrial enterprises: The effects of the introduction of smart manufacturing technologies

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Abstract

The socio-economic effects from the introduction of smart manufacturing technologies are of significant interest in terms of their generalisation and systematisation at the current stage of the digital transformation on industrial enterprises, as well as the objectives in the context of industrial modernization and new business model development. The proposed systematisation is based on the allocation of three groups of socio-economic effects according to the main direction of their action. The first group of effects primarily leads to reduction in the costs of industrial enterprises. The second group of effects leads mainly to an increase in revenues: some effects to a greater extent in the short and medium term, others in the long term, including through the creation of long-term distinctive capabilities, unique competencies, and sustainable competitive advantages for industrial companies. The third group of effects includes social and economic effects that are broader in focus and have a multiplicative effect, as well as the character of positive externalities (external effects).

As a result of systematisation, the author identified in three groups, respectively, 12, 8 and 13 effects from the implementation of the complex of smart manufacturing technologies. The author stresses the particular importance of studying the socio-economic effects from the implementation of smart manufacturing technologies, since many improvements at the intersection of production and social transformation are currently insufficiently studied. It contrasts to the core production effects, many of which have been studied in sufficient detail by the scientific and expert communities. Systematisation, classification, differentiation and quantitative assessment of various socio-economic effects of the complex of smart manufacturing technologies can and even in a certain sense should (in the context of the tasks to modernise the economy and industries of the Russian Federation) become a separate subject area at the intersection of performance management and smart production.

Keywords: smart manufacturing, industrial enterprises, industry, digital technology, digital economy, digital transformation, Industry 4.0, cyber-physical system, business models, digital twins.

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Introduction

The smart manufacturing system has become one of the most significant technology complexes within the framework of the general trend of the formation and development of the digital economy. As defined by the US National Institute of Standards and Technology (NIST), Smart Manufacturing is "fully integrated enterprise manufacturing systems that are able to respond in real time to changing production conditions, supply chain requirements, and meet customer needs" [Merzlikina, 2021]. The concept of "smart manufacturing" can also be defined as the intelligent management and optimisation of business, production and digital processes along the entire value chain in real time [Geerts, 2016]. In another definition, the focus is on the potential for increased productivity: smart manufacturing is a combination of big data processing technologies, artificial intelligence and advanced robotics, interconnected machines and tools used to increase enterprise productivity and optimise energy and workforce [Phuyal et al., 2020a]. The complex of smart manufacturing technologies in the most extensive and enumerative interpretation combines digital product design, analytics, production process, inventory and supply chain system, product customisation, real-time operational process blocks, product delivery system and end customers using cloud computing, which allow to increase production to order and make product customisation and the overall maintenance of the supply and demand ecosystem more efficient [Phuyal et al., 2020b].

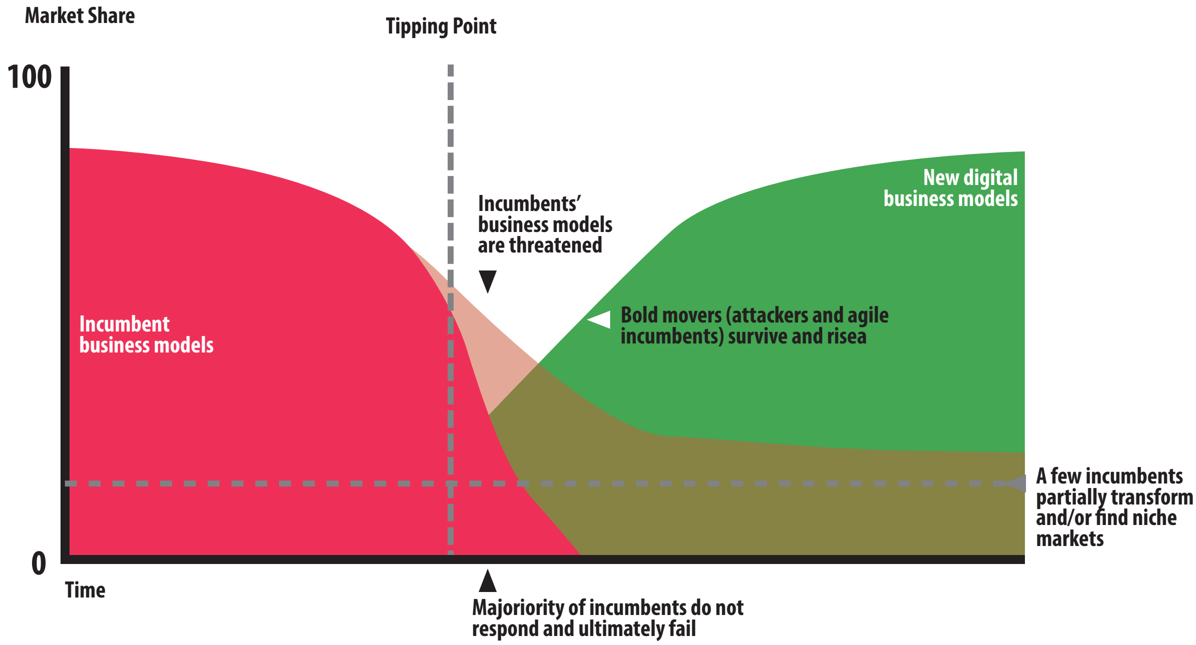
A very similar concept (which, in the context of this study, it is advisable to use as a full analogue for the term "smart production") "smart factory" refers to a factory that has reached a level that makes possible the functions of self-organisation in production and in all processes associated with it. The main advantage lies in the mutual complementarity of diversified areas of the production ecosystem, from smart production to smart logistics networks [Strozzi et al., 2017]. Powerful capabilities allow you to perform operations with minimal manual intervention and high reliability in various aspects of the ecosystem, including high values of automated workflows, asset synchronisation, improved tracking and scheduling, optimised energy consumption inherent in a smart factory to increase productivity, uptime and quality. The key capabilities of a smart factory are highly interconnected, transparent, proactive and flexible. This helps in the overall efficiency of the ecosystem supply chain [Odważny et al., 2018].

At the same time, there is a point of view that it is more expedient to consider two sets of technologies - "digital design" and "customised product" as separate components of the development of digital transformation of industrial enterprises beyond the scope of smart production in a narrower sense. The isolation of these two sets of technologies is justified primarily by autonomy (both software and process and organisational), as well as the distinctive features of their implementation and the specifics of the technology commercialisation logic, as well as those specific effects that were identified separately for customisation in the context of the digital transformation of industrial enterprises [Titov, Titova, 2022]. Based on these considerations, in this paper preference is given to a narrower definition of smart production, since it also seems appropriate from the point of view of describing and systematising the entire set of socio-economic effects from the introduction of a set of smart production technologies. A narrower interpretation of smart manufacturing allows us to more accurately define and delineate its effects in the context of the digital transformation of industrial enterprises.

It is also very important to understand the relationship between different sets of technologies and the choice of specific, niche business models by industrial enterprises. So, a monograph edited by A. Trachuk "Transformation of industry in the context of the fourth industrial revolution" presents three distinctive business models: a smart automated plant, a customer-oriented plant, a mobile plant [Trachuk et al., 2018]. It is logical to assume that industrial enterprises focused on the implementation of a set of "smart production" technologies will gravitate towards the "smart automated plant" business model. The success of the business of an industrial enterprise fundamentally depends on the degree of complementarity of the complex of digital technologies and the business model, since inconsistencies will affect the stability and effectiveness of both individual blocks of business processes and the entire strategy.

In industry, value creation processes are changing as information and communication technologies are integrated with manufacturing processes. This change could lead to efficiency gains and new business models. The digital disruption embodied in smart manufacturing is already here and happening faster than many companies thought. Numerous studies have shown that the use of intelligent manufacturing technologies provides the first mover advantage. For example, mid-sized companies that are more digitally advanced grow significantly faster than lagging companies. Producers can get ahead of the curve, capitalise on new opportunities. Studies also show that the relationship between investments in smart manufacturing technologies and the fourth industrial revolution, the results of innovation and productivity growth are non-linear and have a stable positive relationship only after a certain critical mass of investments has been reached [Trachuk, Linder, 2020]. Most companies that do not adapt their business models to the opportunities created by digital technologies will fail

Fig. 1. New digital business models are replacing old ones



Source: [Bughin et al., 2018].

[Bughin et al., 2018]. Figure 1 shows a tipping point where there is a sharp decline in the market share of traditional companies that have failed to respond to the challenges of the digital economy. This is partly due to an insufficiently structured understanding by companies of how to relate digital transformation tasks to the transformation of business models [Schallmo et al., 2018]. However, some companies manage to adapt primarily due to the rapid reorientation to niche markets.

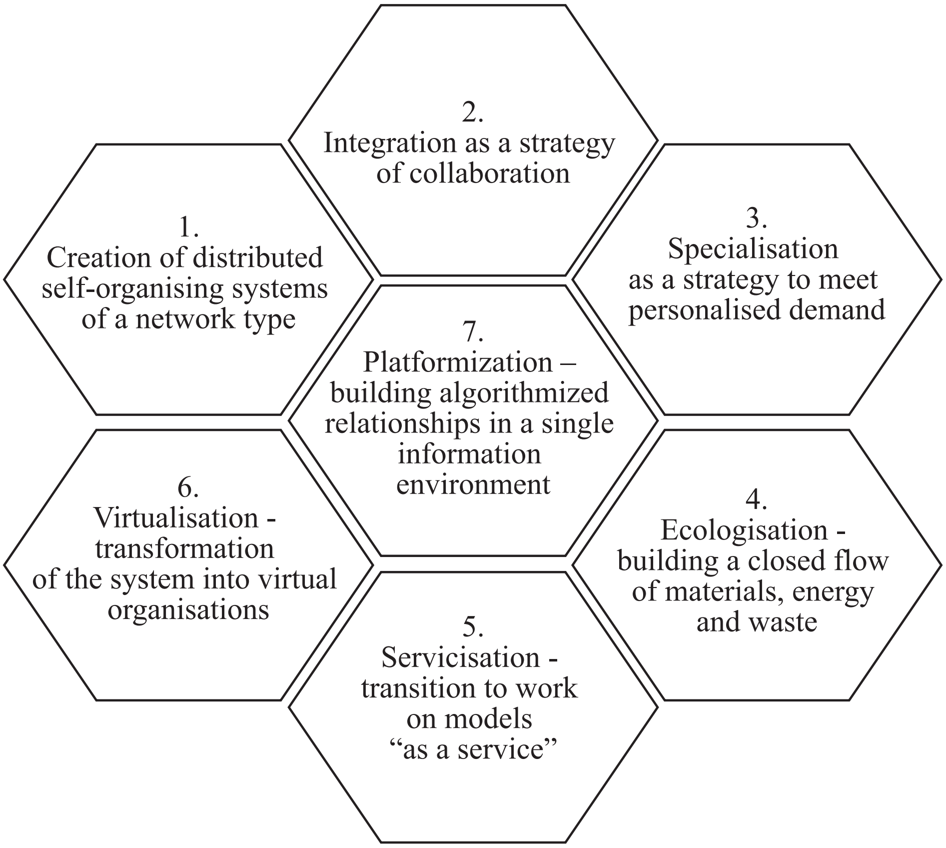
The intensive development of production systems based on the implementation of the Smart Production Complex of Technologies at the current stage is mainly carried out by innovative companies, as is supposed to be a model of Rogers's innovation: innovators (2.5%), the first users (13.5%), early majority (13.5%), late majority (34%), conservatives (16%). Of course, the model of diffusion of innovation is more emphasised by the user aspects from the consumer, and not organisational and informational. Nevertheless, according to the sum of the shares of innovators and early users (16%), this model can be relatively accurately, although in a general sense characterise the current stage of the use of smart production technologies in Russian industry. This

Table 1
Use of digital technologies in organizations by type of economic activity in 2020 (% of the total number of organizations)

Undustry	Cloud services	Big Data	Digital platforms	IoT	AI	Robots
Mineral extraction	19.0	21.8	13.2	14.6	2.5	4.2
Manufacturing industry	27.1	26.5	16.0	15.8	3.6	17.2
Energy supply	19.4	23.7	16.6	15.9	3.3	2.0

Source: compiled by the author based on [Digital economy.., 2022].

Fig. 2. Trends in the development of production and logistics systems



Source: [Myasnikova, 2020].

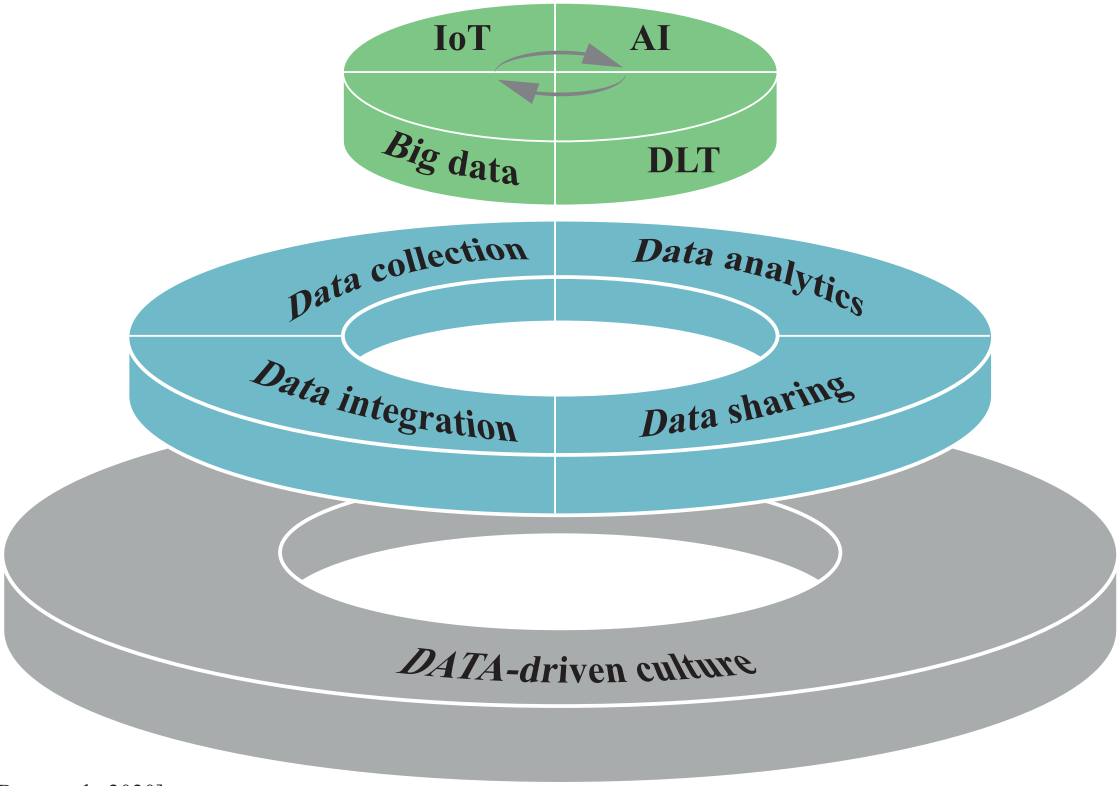
is quite well correlated with the data of the study “Digital Economy 2022”, presented in Table. 1 In the context of the use of digital technologies in organisations according to the type of economic activity [Digital economy .., 2022]. Particular importance and interest now are the speed and completeness of the exit to the areas of the early and late majority of Rogers curve. At the same time, the studies noted that the development directions of Russian industrial companies correspond to global trends, however, the pace of implementation of digital initiatives is noticeably lag behind the pace of leading countries - according to various estimates, from 5 to 10 years [Digital transformation of industries .., 2021]. This explains the severity and urgency of modernisation tasks facing Russian industrial enterprises.

The concept of smart production is based on a whole range of advanced and promising technologies of the fourth industrial revolution (industry 4.0), among which, first of all, virtual modeling, big data, cloud computing, artificial intelligence (AI), Internet of things (IoT), connected robotics, predictive analytics, additive manufacturing, etc. [Digital transformation of industries.., 2021]. The diversity of a large conglomerate of smart manufacturing technologies to a large extent predetermines the variety of socio-economic effects from their implementation.

The generalisation of the main trends in the development of production and logistics systems based on the introduction of smart production technologies, proposed by O. Myasnikova (Fig. 2) is a bright example.

However, it is important to note that the pace of digitalisation depends not only on the development of technologies themselves. L. Berg and colleagues pay attention to the aspect of cultural and social transformation, speaking about the pyramidal structure of the digital economy (Fig. 3), where the fundamental layer is a data-based culture, or data-driven culture, which is understood as a culture of willingness to create and share data throughout the value chain [Berg et al., 2020].

Fig. 3. Structural representation of the digital economy



Source: [Berg et al., 2020].

1. Three groups of effects from introducing a complex of smart production technologies

The overall socio-economic effect from the introduction of a complex of smart production technologies in industry and in the economy as a whole is characterised by a large and rather diverse set of effects leading to an increase in the efficiency of enterprises, a reduction in many cost groups and an increase in demand for products and revenue, which ultimately affects growth of profitability. The scientific and expert communities have already developed a fairly mature and evidence-based understanding of a number of central effects of smart manufacturing. At the same time, a number of specific and broader socio-economic effects are still receiving insufficient attention even in the leading publications on the digital transformation of industrial enterprises.

Among the socio-economic effects of a complex of smart production technologies, it seems most appropriate to single out three enlarged groups of effects. The first on the main vector of action leads to cost reduction. The second leads mainly to an increase in revenue: some effects to a greater extent in the short and medium term, others in the long term, including through the creation of long-term distinctive abilities, unique competencies, and sustainable competitive advantages for industrial companies. The third group of effects is the wider socio-economic effects from the use of a complex of smart production technologies, which can be generally characterised as having a multiplier effect for the entire economy and the properties of positive externalities (external effects). Such a division into three groups of effects seems appropriate from the point of view of the main focus of effects, however, at the same time, it should be noted that in many contexts, the use of a set of smart manufacturing technologies directly or indirectly affects both costs, and the future sales potential of companies, and multipliers for industry and economy level. The boundaries between individual effects can be somewhat blurred.

The importance of systematising the effects in terms of dividing into three groups of effects lies in a more complete and broader understanding of the potential of a complex of smart manufacturing technologies, which can positively influence the dynamics of the implementation and scaling of both the technologies themselves and the business models interconnected with them. This is important from the point of view of the readiness and speed of decision-making both by the industrial enterprises themselves and by other stakeholders, including those influencing the innovation, technology and industrial policies of the state.

2. Group of cost reduction effects at industrial enterprises

To the group of effects of a smart production technology complex can be attributed the following:

• *Reducing the cost of control and monitoring of production processes.* Industrial production engineers can directly monitor and control industrial processes via the Internet, which allows to control engineers to access the production system from anywhere through cloud computing. The cyber-physical system links computational objects to the physical world and its ongoing processes using data processing services available directly on the Internet. An example is microchip and microelectronics company Micron, which has built one of the most advanced integrated platforms for the Internet of Things and analytics. This platform helps the company to monitor processes in real time and identify production anomalies and non-value-adding losses, as well as perform automatic analysis of the causes of such inconsistencies and anomalies. As a result, a number of central operational metrics improved by tens of percent. In particular, the launch of new products accelerated by 20%, and the reduction of unplanned downtime was 30% [Lage, Filho, 2010].

• *Reducing the cost of parts and components.* Additive manufacturing, also known as 3D printing technology, opens up new horizons for smart manufacturing technologies. Additive manufacturing technology is extremely flexible for customisation, rapid prototyping and rapid production of spare parts. It also reduces lead times and machine replacement costs [Lu, 2017]. There is also a reduction in material consumption and a reduction in the weight of parts. Modern products in smart factories are produced using artificial intelligence. An AI-based system can be given initial conditions, and it will work through many options and produce ready-made solutions.

• *More efficient use of production capacity through the ecosystem integration of all elements, including machinery.* Thanks to the integral and synergistic configuration of smart production devices within a single digital technological ecosystem, the success of a production task is determined by the overall availability of all equipment. In addition, thanks to ecosystem integration, a high level of production adaptarion to emerging unforeseen situations is ensured [Kasyanenko et al., 2020].

• *Reducing downtime, losses and waste.* Included in a single digital technological ecosystem, an enterprise has a clear understanding of bottlenecks, machine and equipment performance, and other inefficient operations. With this data, the manufacturer can make adjustments to processes to reduce losses and waste, as well as reduce downtime.

• *Reducing the costs associated with the failure of equipment.* The principle of Predictive Maintenance (predictive maintenance of equipment) is to anticipate problems and failures, and eliminate them in a timely manner [Carvalho et al., 2019]. Setting up a digital twin and using a large number of sensors for machines, machine tools, equipment and devices [Kanawaday, Sane, 2017] makes it possible to recognise faults in time and carry out repairs, as well as to calculate the estimated stock of repair kits with smaller errors [Kasyanenko et al., 2020]. A more advanced tool for predicting equipment activity can reduce the time and material costs of repairs and maintenance, prevent unplanned emergency interruptions in operation, and reduce capital costs in the long term.

• *Reducing reverse engineering costs.* Additive manufacturing facilitates the reverse engineering of any part or product through 3D scanning and allows to design reconfiguration and rapid reproduction for testing and validation [Kang, 2016]. In terms of objective unit costs, additive technologies turn out to be less expensive than traditional ones [Barvinok et al., 2014]. For example, in the aircraft industry, the creation of a rapid simulation platform can reduce the time of design and design development by 20% [Kheifets, Chernova, 2019].

• *Optimisation and information integration of supply chains*. Currently, the concept of open supply chain management (Open Supply Chain Management, OSCM) has particular promise as a new paradigm in the evolution of SCM. Companies can benefit from integrated physical and conceptual resources to improve the efficiency and agility of core supply chain processes, including sourcing, manufacturing, distribution and marketing [Rahmanzadeh et al., 2022]. Deliveries are becoming more flexible as suppliers communicate with warehouses, autonomous or semi-autonomous vehicles and drones in real time. The chains also include mobile robots and cobots (collaborative robots) to automatically perform delivery tasks [Rovito, 2022].

• *Reduced electricity consumption.* A number of studies show a very significant reduction in electricity consumption during the transition to smart manufacturing [Kumar et al., 2021]. For example, industrial companies in Germany were able to reduce electricity consumption by 24% by implementing a program to automate protection on the CSF server [Kasyanenko et al., 2020]. At the same time, it should be noted that smart manufacturing systems will require huge data centers to implement and support their networking needs. Data centers consume a lot of energy, and the resources needed to generate energy have a negative impact on the environment. The following example demonstrates what data center capacity may be required in the future.

The flow of data generated by engines and aircraft is also changing the service and support offerings that jet engine manufacturers can provide. Engines produce a huge amount of information. A single Boeing 737 engine produces 20 terabytes of data every hour in flight. Thus, an eight-hour flight from New York to London in a twin-engine aircraft can generate about 320 terabytes of data [Mathai, 2015].

• *Reduction of the training cost highly qualified engineers and workers.* Virtual reality and augmented reality are already widely used in the production systems of leading international companies to train young engineers and graduates of technical universities who are not very well prepared to work with production processes. The experience of industry leaders shows that through smart manufacturing, graduates and novice professionals are successfully introduced to the production process, mechanisation processes, troubleshooting and maintenance systems. And this form of instruction and training turns out to be even more useful in a number of core competencies than theoretical training in a more academic context [Moon et al., 2019]. For a number of parameters, training new employees and testing the product with demonstrations of various conditions in the augmented environment turned out to be more efficient and time-saving. You can also expect greater involvement and loyalty of employees in the context of using smart manufacturing technologies, increasing their creativity [Gajdzik, Wolniak, 2022], as well as the ability to solve more complex tasks using digital competencies [Paelke, 2014; Ivanov, 2016].

• *Reduction of time and cost in R&D.* Rapid assembly of prototypes helps speed up the production of new products, products of various modifications [Barvinok et al., 2014]. Fast and short communication with customers helps to quickly respond to changes in their preferences and test new products. This makes it possible to reduce unproductive costs in the course of innovation [Hinz, 2013; Guneshka, 2021].

• *Reduction of sunk costs, since the adaptability of production reduces the importance of the factor of specific assets.* Often, specific capital investments associated with interaction with certain customers and suppliers are characterized by a limited ability to reuse the results obtained. The equipment used for smart manufacturing provides a higher level of organization of flexible lines and provides the ability to quickly and efficiently distribute production tasks between individual universal devices depending on the load and level of readiness [Kasyanenko et al., 2020].

• *Reducing the need for working capital.* The reduction in the need for working capital is primarily due to the reduction in inventories and the expansion of opportunities for receiving full or partial prepayment of products from the buyer [Matulik, 2008].

3. Group of effects from increasing the revenue at industrial enterprises

The group of effects that mainly lead to an increase in revenue can primarily include:

• *Improved understanding of shopping habits and requirements.* In today's environment, manufacturers want their customers to share their feedback and personal opinions about products or usage plans. Based on this information, manufacturers tend to focus their product design on meeting the needs of a relatively wide range of customers [Ren et al., 2019]. The processing of large amounts of data helps the manufacturer to determine the current state of the product and the causes of failures, encouraging customers to buy its products, since their purchasing habits and requirements have been taken into account in the design and manufacture. Big data analysis allows you to use the potential of data-driven marketing in the context of production activities to full extent.

• *Better customer satisfaction.* After analysing data from different stages of the technological process, using machine learning and artificial intelligence, manufacturers become more flexible and can quickly change their business models in response to changes in the external environment. Thanks to additive manufacturing and reverse engineering, a quantum leap is being achieved in a number of high-tech industries. For example, in medical manufacturing, additive manufacturing and reverse engineering technologies are used for implants in dentistry and orthopedics to replace damaged body parts. Similar technologies are also used for prototyping, design and testing of structures in civil engineering to ensure cost-effectiveness and customer satisfaction. In this case, modeling and additive technologies make it possible to understand how to provide the best zoning of premises [Negi et al., 2013]. Another example is shoe makers Nike and Under Armor, who are exploring how additive manufacturing can revolutionise shoe manufacturing, ultimately allowing them to tailor sneakers to every athlete's foot.

• *Fast adaptation of products to customer requirements due to production flexibility.* Virtual and augmented reality help in the digital manufacturing process to visualise and test products in a simulated environment for end customers, which enhances the ability to customise a product based on a simulated environment for end customers [Berg, Vance, 2017]. This leads not only to a reduction in a number of costs [Riemer, Totz, 2003], but also increases future sales and profitability. The flexibility of production implies the technical and organisational ability to change equipment quckly within the framework of new tasks, taking into account the requirements of customers and consumers of the final product [Glazkov, 2016].

• *Ability to manufacture small series of specific modifications of products and parts.* Increasing adaptability to changing demand and the speed of launching a new product range into production provides new marketing opportunities and benefits for both large and small and medium-sized innovative enterprises [Barvinok et al., 2014]. Evolving distributed manufacturing systems that replace classical hierarchical control modes are very important for realising an intelligent manufacturing system that can handle growing customisation needs, sudden fluctuations in the supply chain, and is also suitable for small production batches [Lu et al., 2016].

• *Improving the quality of products, reducing manufacturing defects.* All equipment that monitors and controls the production works in real time. Big data is actively used to improve the quality of manufactured products and search for defects in the production process. The presence of such a tool as monitoring of work operations can improve the efficiency of employees. Operations and process monitors have the ability to view data automatically at set intervals on key indicators and control panels to improve process control and product quality, reduce materials for production, reduce resource usage time, and more. It is also important that the standardization of data collection will also make it possible to compare the efficiency of various production facilities, divisions, and assembly lines [Baurina, 2020].

• *Increase in prices and margins of products due to the factor of monopolistic competition.* The economic nature of smart manufacturing from the point of view of the sectoral economy consists in a more pronounced market structure of monopolistic competition. This, in turn, means that more and more industrial companies, thanks to the introduction of a set of "smart production" technologies, can secure such differentiation that will be recognised by the market both in terms of increasing sales growth potential and in terms of achieving high profitability of business lines.

• *Reducing the total cost of ownership of complex technical products for consumers at the stage of product maintenance (digital service).* By streamlining the engineering change process, especially in the context of complex product manufacturing, and by using digital services in the maintenance phase, the total cost of ownership can be reduced. In both B2B and B2C segments, this becomes one of the central competitive advantages and can be used in the course of marketing campaigns. At the same time, the components of a digital service in many industries can turn out to be higher marginal than the supported product. This approach in some cases changes the landscape of entire industries. Probably the most famous and large-scale example of this kind is Apple, whose share of revenue and profit from services (within the software ecosystem) has been growing in recent years, while the "hardware" component has been declining.

• *Increase delivery lead time by providing a more innovative product.* Customers who order an innovative product to fit their specification are willing to wait longer on average, which leads to lower revenue losses, as well as to a reduction in supply chain errors caused by accelerated product assembly [Piller et al., 2004].

4. Group of effects of multiplicative action and positive externalities from the introduction of smart manufacturing technologies

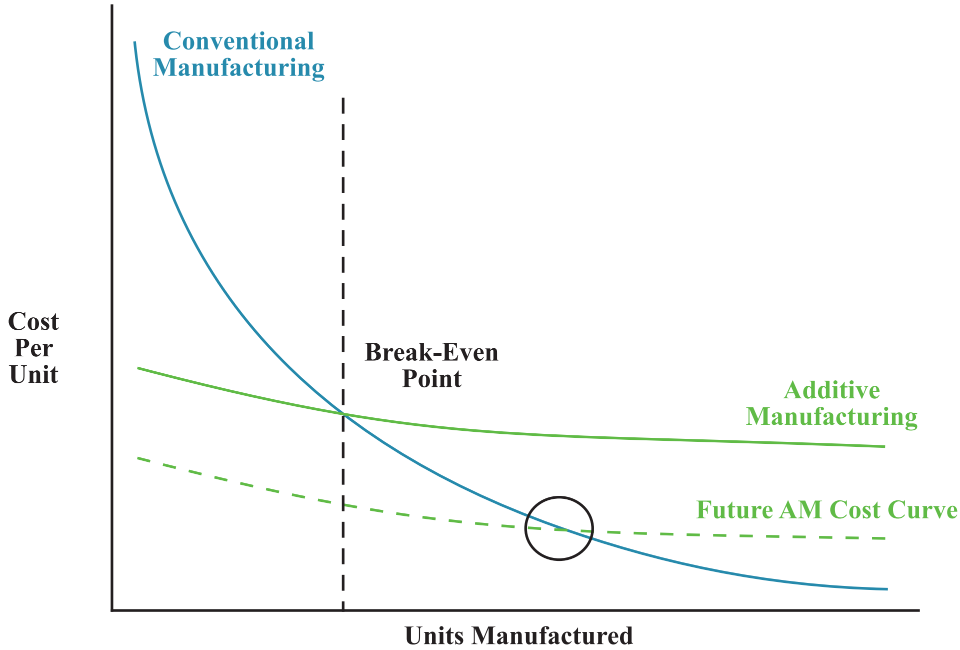
The group of broader socio-economic effects from the use of a complex of "smart production" technologies, which can be generally characterized as having a multiplier effect for the entire economy, as well as the impact as positive externalities (external effects), can primarily be attributed to:

• *Growth of the semiconductor electronics and industrial equipment market.* This growth is accompanied by the development of technologies based on the use of semiconductor electronics. At the same time, imbalances and sectoral crises arise due to a shortage of electronics or equipment, as happened in the automotive industry in 2020–2022 due to a chronic shortage of microelectronic components [Shcherbakov, 2022].

• *Increasing the level of science intensity and manufacturability of products and services in related industries.* The introduction of a complex of technologies "smart production" becomes a driver of scientific and technological development not only in leading industries, but also in related ones [Digital Russia: new reality, 2017], and leads to a higher level of production efficiency, which is characterised by such indicators as the level of innovative activity , the share of high-tech products in GDP, the share of R&D expenditures in GDP. Moreover, the integration model of end-to-end digital transformation of industry based on matrix and industry models allows to build an integration inter-industry digital network in the conditions of the digital economy, within which end-to-end digitalisation of all sectors of the national economy takes place based on common segments of the digital infrastructure and the organisation of functional interactions between them [Zubritskaya , 2018].

• *Intensification of applied science development, especially technical and engineering.* A more complete system of integration of scientific, technical and industrial

Fig. 4. Prospects for reducing the unit costs of small and medium-sized manufacturers through the reduction in the cost of additive manufacturing technologies



Source: [Mahoney, Kota, 2020].

subsystems becomes necessary for the innovative development of the country and industry 4.0. Smart manufacturing, according to a number of researchers, is one of the most suitable landscapes for introducing open innovations [Rahmanzadeh et al., 2022].

• *Changing the structure of employment from low-skilled to highly skilled jobs.* The main effect in terms of the quality of human capital of industrial enterprises is that automation allows manufacturers to start and complete projects with a minimum number of low-skilled workers. Faster access enables higher-skilled employees to focus only on their core tasks. This allows manufacturers to introduce innovative technologies faster without spending additional resources on it. Undoubtedly, the question of the extent to which smart production will generate highly skilled jobs in order to cover the retirement of a large number of professions that become unnecessary in smart production is of great scientific and practical interest and of particular socio-economic significance. Despite the considerable controversy of the issue and various estimates, including conservative and pessimistic ones, the average estimates are encouraging [Jagannathan et al., 2019; Grenčíková et al., 2020; Anackovski et al., 2021], especially if we consider the overall reduction in man-hours in high-tech industries as part of the general economic trend towards a shorter workweek. In countries that have already institutionalised a shorter workweek to varying degrees (for example, in Germany, Austria, France, where the working week in industrial enterprises is about 33 hours), automation is not perceived with hostility, but with an understanding of its long-term benefits in terms of the quality of life of the personnel of enterprises.

• *Increasing demand for IT professionals.* This professional group in the broad definition should be singled out separately, since its increase in the last few years has become an extremely significant priority of state policy in the field of employment, education and retraining of personnel in many countries, including Russia. Further development and implementation of intelligent manufacturing systems will create additional demand for information technology specialists. The information technology sector will need skilled people to design, develop, run and maintain network programs. Thus, the number of jobs in the field of information technology will grow. However, in manufacturing plants, unskilled operators and other workers are at risk of losing their jobs.

• *Increasing labor productivity in industry and the economy as a whole.* This effect is largely a product of the shift in smart industry employment towards a more highly skilled workforce and a sharp decline in the employment of low-skilled workers. However, it is necessary to note other components, due to which this effect is more pronounced and systemic within the framework of the smart production paradigm. Enterprises create separate performance

Table 2
Systematization of the socio-economic effects from the implementation of smart production technologies

Cost reduction effects	Revenue increase effects	Multiplier effects and positive externalities
Reducing the cost of control and monitoring of production processes	Improved understanding of shopping habits and requirements	Growth of the semiconductor electronics and industrial equipment market
Reducing the cost of parts and accessories	Better customer satisfaction	Increasing the level of science intensity and manufacturability of products and services in related industries
More efficient use of production capacity through ecosystem integration	Fast adaptation of products to customer requirements due to production flexibility	Intensification of the applied science development, especially technical and engineering
Reduce downtime, losses and waste	Ability to manufacture small series of specific modifications of products and parts	Changing the structure of employment towards highly skilled jobs
Reducing the costs associated with equipment failure	Improving the quality of products, reducing manufacturing defects	Increasing demand for IT professionals
Reducing reverse engineering costs	Increase in prices and margins of products due to the factor of monopolistic competition	Increasing labor productivity in industry and in the economy as a whole
Optimisation and information integration of supply chains	Reduction for consumers of the total cost of ownership of complex technical products at the digital service stage	Reduction of economic and social damage from non-compliance with safety regulations
Reduced electricity consumption	Increase delivery lead time by providing a more innovative product	Broader transition of industries and sectors of the economy to PaaS business models
Reducing the cost of training highly qualified engineering and working specialists		Increasing the share of medium and small enterprises in the volume of industrial production
Time reduction and cost in R&D		Increasing the investment activity of enterprises
Reduction of sunk costs by reducing the importance of the factor of specific assets		Improving the quality and transparency of management
Reducing the need for working capital		Improving corporate governance and ESG factors in industrial companies
Increasing the environmental sustainability of production		

Source: compiled by the author.

management systems [Bagautdinova, Bagautdinova, 2018].

• *Reduction of economic and social damage from non-compliance with safety regulations.* A number of smart manufacturing technologies, in particular computer vision, allow not only to optimise processes, but also to control the actions and operations of personnel at a new level in terms of meeting safety requirements [Tarasova, Shparova, 2021; Rovito, 2022]. However, the point is not only in effective control, but also in the fact that the complex of "smart production" technologies allows, already within the framework of workplace design, to ensure the highest prioritisation of safety in the workplace. Research on the effect of reducing worker injuries and improving their overall well-being and quality of life is of particular interest. In the context of the activities of Russian industrial enterprises, this is especially important, since so far in most industries the levels of injury to workers and working conditions in terms of health hazards can hardly be called satisfactory, given the already existing potential for the use of high technologies. Here are some examples of private smart manufacturing technologies that have taken workplace safety to a new level. The first example is the progress in the robotic environment, where, thanks to a number of technologies, the biometric data of the operator is also included in the control loop. Thanks to this, it is possible to implement a personalised security strategy based on the role of a person, physical condition, speed, and other parameters [Wang, Wang, 2020]. A second example is that a number of smart technologies, especially augmented reality, are improving the quality of safety training [Deac et al., 2017]. As a third example, dynamic self-organising security systems are being developed to help an engineer working in a smart manufacturing facility discover all security-related devices and automatically generate a suitable security configuration. This configuration will be automatically deployed to the system after adaptation and verification by a safety engineer. The proposed self-organising security system simplifies security configuration in a dynamic environment. Therefore, this not only improves workplace safety, but also reduces engineering effort and equipment downtime, which in turn improves profitability [Etz et al., 2020].

• *Wider transition of industries and sectors of the economy to PaaS (Product as a Service) business models.* At first glance, this may seem somewhat counterintuitive, but the complex of smart manufacturing technologies stimulates not only innovative technological and product components in the industry itself, but also a more integral and holistic inclusion of service components in a common product shell, especially services with a high level of digitalisation. This is especially important both for the competitiveness of Russian industrial enterprises and for the marginality of their business. Service components are on average more cost-effective. Smart manufacturing creates a much greater variety of niches for building new business models, such as paying monthly subscriptions instead of hardware sales (also known as "product as a service").

• *Increasing the share of medium and small enterprises in the volume of industrial production.* This effect largely depends on the contexts of individual industries, and in most cases it should not be an end in itself. Nevertheless, many experts point out that many sectors of Russian industry are characterised by a high concentration of large-scale industries and that it does not correspond to the parameters of a progressive sectoral structure. Increasing adaptability to changing demand and the speed of launching a new product range as one of the central advantages of the "smart production" technology complex provides new marketing opportunities and benefits for both large and small and medium-sized innovative enterprises [Barvinok, Smelov, Kokareva, Malykhin, 2014]. Graphically, the advantage of introducing digital technologies (primarily additive manufacturing) for small and medium-sized industrial companies is shown in Fig. 4. As AM technology becomes more versatile in terms of materials, part sizes, and reliability, and as more companies enter the 3D printer market, prices are falling. Small hobby 3D printers from companies like MakerBot are available for less than $3,000. Industrial-scale printers using polymers or ceramics cost less than $95,000, and printers using metals around $400,000. However, new machines from Desktop Metal and HP promise to cut price levels significantly [Mahoney, Kota, 2020].

• *Increasing the investment activity of enterprises, including small and medium ones.* Investment growth can be expected in all types of fixed assets (3D printing machines), intangible assets (software, licenses, patent), research and development. However, empirical studies of small and medium-sized enterprises show that they have unsustainable behavior in terms of investment in information and communication technologies and need external support to integrate digital transformation into the overall strategy of the firm [Ulas, 2019]. However, it is not only about support, but also about understanding the potential of smart manufacturing technologies, including for assessing the investment feasibility of various solutions. Digital twin technologies are especially useful in this regard. Digital twin technologies are used to gather information for a realistic economic evaluation of full automation solutions, to support and encourage investment to realize the potential of digital transformation of manufacturing. Technologies include modeling, data analysis, and behavioral models that are used to assess impact, implementation scenarios, eliminate the need for physical prototypes, reduce development time, and improve quality [Caccamo, 2022]. Also, in a recent study, taking into account the problems of the activities of small and medium-sized enterprises in conditions of high uncertainty of digital transformation processes, a modification of the value stream mapping method (VSM) was proposed to evaluate intelligent production decisions, in which the emphasis is on information flows and integration required key performance indicators [Martin, 2020].

• *Improving the quality and transparency of management.* Technological and organisational innovations occur both sequentially and simultaneously and complement each other in the context of the transition to smart manufacturing. The interaction between the two types of innovation is complex. Most manufacturers have old systems for collecting and processing information. New systems must be upgraded to the next generation of performance. Based on these new ideas and a better understanding of the business, it becomes possible to develop new strategies [Baurina, 2020].

• *Improvement of corporate governance and ESG factors in industrial companies.* Despite the importance of corporate transformation towards industry 4.0 (Corporate Transformation Toward Industry 4.0, CTTI4.0), to date, research on how companies report CTTI4.0 information in their annual reports and how this affects financial performance is scarce. However, recent pioneering work [Alkaraan et al., 2022] in this area found that CTTI4.0 disclosure has a positive impact on the financial performance of industrial companies. In addition, environmental, social and governance (ESG) practices have been found to favorably influence the relationship between CTTI4.0 disclosures and financial performance.

• *Increasing the environmental sustainability of production.* By intelligently managing the entire manufacturing process, smart manufacturing systems reduce waste, overproduction and energy consumption. The manufacturing system automatically orders material or parts from its suppliers when needed. In times of lower sales volumes, fewer raw materials are ordered. Another example of environmental sustainability is that manufacturing companies are connected to power plants and can schedule energy-intensive tasks with the natural overproduction of energy from wind or solar energy. Surplus energy can be used by other companies or private households in the immediate surroundings. Thanks to intelligent energy management systems and network technologies, renewable energy sources can be used more efficiently.

5. Systematisation of socio-economic effects of the introduction of smart manufacturing technologies in tabular form

It seems appropriate to present the socio-economic effects of the introduction of smart manufacturing technologies identified above for three groups in tabular form (Table 2.). Some of the extended effect titles have been shortened for tabular presentation.

6. Conclusions and possible directions for further research

As a result of the study, 12 cost reduction effects, 8 revenue increase effects and 13 multiplier effects and the nature of positive external effects from the introduction of a set of smart production technologies in industrial enterprises are summarised and highlighted. Of particular importance at present are the areas of research on the socio-economic effects of the introduction of smart manufacturing technologies, since some improvements at the intersection of production and social transformation are currently insufficiently studied, in contrast to the actual production effects, many of which have been studied in sufficient detail by the scientific and expert communities.

It seems that the systematisation, classification, differentiation and quantitative assessment of the various effects of the "smart production" complex can and even in a certain sense (in the context of the tasks of modernising the economy and industry of the Russian Federation) should become a separate subject area at the intersection of performance management (Performance Management) and smart production (Smart Manufacturing). The question of the feasibility and prospects of building a certain composite index of the level of maturity and / or the effectiveness of the introduction of smart manufacturing technologies at the level of industry or individual industries and sectors may deserve special attention.

From the point of view of the state industrial policy, it is important to understand the priority of ensuring the wider use of a set of smart manufacturing technologies. State industrial policy instruments and a favorable institutional environment can help with the rapid scaling of a set of smart manufacturing technologies across a wide range of enterprises in various industries and sectors of the economy.

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