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THE DEVELOPMENT OF DIGITAL ECONOMY TECHNOLOGIES AND IMPLEMENTATION OF MANUFACTURING EXECUTION SYSTEMS

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Abstract

Modern production is aimed at maximum productivity and manufacturability. The latter is a decisive factor in the competition for sales markets and, as a consequence, for the profit and enterprises development. In a post-industrial society, which every economy of the 21st century must build and accept, the most important advantage is the use of high technologies to manage modern manufacturing systems. The article is devoted to the problem of digital economy technologies for managing modern manufacturing systems. A theoretical analysis of the patterns of using digital technologies in managing manufacturing systems is carried out. Based on the results of the expert survey, new functionality and potential effects of the use of digital economy technologies for managing manufacturing systems are identified. A hierarchy model of managing a manufacturing system using digital technologies is presented.

Keywords

Digital technologies – Manufacturing systems – Government policy – Government support

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Introduction

Considering the digital economy genesis as the main component of the fourth industrial revolution made it possible to analyse the interconnection of such an economy with the modern stage of information technology development, at which the use of the Internet and mobile telecommunications in all spheres of management became objectively necessary. The pattern of the digital economy genesis allows us to conclude that it is becoming a driver of the development of the productive forces[1].

The technological advances of the fourth industrial revolution had a significant impact on both the business environment and its participants, who completely switched to the use of digital technologies, combining industrial technologies with the digital ones[2]. According to C. Matt, T. Hess and A. Benlian, digital transformation is mandatory for the companies that want to improve efficiency in a rapidly changing global competitive environment[3]. Yet, before companies can reap the rewards and benefit from digital changes, they must make a series of investments. Analysts from leading companies who perform market analysis are sure that it is worth it. The so-called Industry 4.0 caused the significant changes that the manufacturing industry is facing and will continue to influence the work of enterprises in the future[4]. A study of the development and future of Industry 4.0[5] shows that industrial companies expect that the implementation of Industry 4.0 initiatives will lead to annual cost savings of 3.6% over the next five years. This will happen due to internal improvements and close collaboration across the production and distribution chain. It is also expected for revenues to increase by 2.9% annually due to digitalization of products and services. Companies expect to benefit from the development and launch of new digital services, including platforms for hosting industrial ecosystems. Thus, expectations for the benefits that Industry 4.0 will bring are high[6].

[1] R. Bukht y R. Heeks, “Defining, Conceptualising and Measuring the Digital Economy”, International Organisations Research Journal Vol: 13 num 2 (2018): 143–172; M. A. Afonasova; E. E. Panfilova y M. A. Galichkina, “Social and Economic Background of Digital Economy: Conditions for Transition”, European Research Studies Journal Vol: XXI num Special 3 (2018): 292-302 y K. K. Rikhter y N. V. Pakhomova, “Tsifrovaya ekonomika kak innovatsiya XXI veka: vyzovy i shansy dlya ustoichivogo razvitiya”, Problemy sovremennoi ekonomiki num 2 (2018): 22–23.

[2] B. Carlsson, “The Digital Economy: what is new and what is not?”, Structural change and economic dynamics Vol: 15 num 3 (2004): 245–264; D. R. Schallmo y C. A. Williams, “Digital Transformation of Business Models”, Digital Transformation Now! (2018): 9–13 y G. I. Avtsinova; O. A. Blokhina; N. V. Gubanova; E. E. Konovalova y J. A. Semenova, “Socio-Economic Effects of Small Business Development in The Hospitality Industry in the Context of The Digital Economy”, Revista Turismo Estudos & Práticas num 4 (2020): 1-7.

[3] C. Matt; T. Hess y A. Benlian, “Digital transformation strategies”, Business & Information Systems Engineering Vol: 57 num 5 (2015): 339–343.

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[6] G. V. Kalabukhova; O. A. Morozova; L. S. Onokoy; E. Yu. Chicherova y I. G. Shadskaja, “Digitalization as a Factor of Increasing Investment Activity in the Tourism Industry”, Journal of

Recently, the theory and practice of manufacturing execution systems (MES) have acquired new development[7]. High-performance computers, GRID-systems, information and computing networks and modern programming technologies created conditions for reaching a completely different qualitative level of automation of managing manufacturing systems using MES. Therefore, the possibilities of using MES in manufacturing systems attracted the close attention of scientists and managers for several years.[8]

MES are special application software systems designed for the computerization of production management, which connects the tasks of analysing production processes at various levels of managing, synchronizing, coordinating and optimizing these processes. MES function in real-time, providing control of all the production system's components, inputs, outputs, personnel, material and financial resources, technological equipment and technological processes[9].

The main functions of MES include the transmission of technological information to the administrative level and back. MES implement this function by ensuring the interaction of business logistics and planning software applications, such as ERP (enterprise resource planning), with process automation systems (PAS), such as SCADA (supervisory control and data acquisition systems) or batch solution[10].

The article is aimed at studying the possibilities of digital economy technologies for managing modern manufacturing systems.

Research hypothesis: The management of modern manufacturing systems based on the use of MES will ensure the continuity of information flows both in the horizontal and vertical directions "process control – manufacturing operations management – business process management".

Environmental Management and Tourism Vol: 11 num 4 (2020): 883-889; A. A. Fedulin; I. V. Chernaya; E. Yu. Orlova; G. I. Avtsinova y T. V. Simonyan, "Formation of Approaches to Environmental Policy under Conditions of Digital Economy", Journal of Environmental Management and Tourism Vol: 11 num 3 (2020): 549-554 y M. Ya. Veselovsky; M. A. Izmailova; I. V. Bitkina; N. L. Krasyukova y A. A. Stepanov, "Enhancement of government innovation policy in digital transformation of Russian Companies", Revista Inclusiones num 3 (2020): 306-319.

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[10] R. Y. Zhong; X. Xu; E. Klotz y S. T. Newman, "Intelligent Manufacturing in the Context of Industry 4.0: A Review", Frontiers of Mechanical Engineering Vol: 3 num 5 (2017): 616-630.

According to the results of the study, it can be concluded that the goal set in the study was achieved.

Methods

To solve the tasks set in the work, general scientific methods were used:

a) theoretical methods: analysis of the reviewed scientific sources on the research problem to clarify the features of digital economy technologies for managing modern manufacturing systems;

b) empirical methods: a survey of experts in this area of research.

The experts were assigned to identify new functionality and potential effects of the use of digital economy technologies for managing manufacturing systems and to characterize the hierarchy model of managing manufacturing systems using digital technologies.

The survey was conducted among 33 experts, IT specialists, as well as representatives of industrial enterprises, whose activities were related to the automation of production for more than 5 years.

All participants were warned about the purpose of the survey, as well as about the fact that the organizers of the study planned to publish the results of the study in the form of summary.

Results

According to the experts, the introduction of digital economy technologies in managing manufacturing systems creates new functionality and achieves corresponding results (Table 1).

No.	Functionality	Results
1	Full automation of technological process control	Reduction of equipment failures and energy losses
2	Reliable and safe operation of production equipment	Reduction of economic and social losses, increasing customer confidence
3	Production equipment optimization	Increasing the social and economic efficiency of enterprises
4	Optimal management of maintenance and use of enterprise assets	Reduction of investment needs and operating costs
5	Possibility to obtain information about the consequences of the decisions in real-time	Reduction of equipment failures and energy losses

Note: compiled based on the expert survey

Table 1

New functionality and the results of the introduction of digital economy technologies in managing manufacturing systems

Presented in Table 1 potential effects of the use of control systems (the systems with an inherent connection between the computational and physical elements with the built-in technology of interaction between them and the environment, which minimizes human participation in production processes) can further detail their real types concerning particular industrial enterprises.

According to the experts, for the digitalization of the management of modern manufacturing systems in general, it is necessary to create conditions for the development and introduction of MES.

Applying a five-level model of the functional hierarchy of the production system[11,12], considering the availability of digital technologies that can be used at various levels of management and based on the expert survey, we will present a hierarchy model of managing manufacturing systems as a set of tools that operate at different management levels from the first one to the fourth one, information networks for data transmission within each level and channels for the exchange of information between levels (Table 2).

The data that is transferred between neighbouring levels from the bottom to the top is consolidated according to the temporal characteristics of information processes that are processed at the highest level. The information descended from the upper levels to the lower ones is detailed following the information needs of the lower level.

Level	Characteristic
Process level (zero level)	The technological process is formed by a certain set of physical (chemical, biological) processes that are implemented in a certain sequence. As a result, materials, components, energy, effort and people's intelligence are transformed into the final product. The technological processes implementation takes place using technological equipment, the functioning of which and, consequently, the parameters of physical processes, can be changed, and regulates the parameters of technological processes.
Process control level (first level)	Direct control of physical processes and primary control of their parameters. It uses the end devices of automation and telemechanics (actuators), converters of physical quantities (sensors) and input/output devices. Actuators respond to incoming signals from the second level and determine the operating modes of technological equipment, which provide the parameters of physical processes required for the implementation of certain technological processes. Primary converters (sensors) that operate at this level transmit their output signals to the second level of the functional hierarchy. These signals contain objective data about the parameters of physical processes, characteristics of the manufactured product, the

[11] P. A. Bernus y L. Nemes, "Framework to define a generic enterprise reference architecture and methodology", Computer Integrated Manufacturing Systems Vol: 9 num 3 (1996): 179-191.
[12] O. S. Sivash; D. D. Burkaltseva; I. V. Kurianova; D. V. Nekhaychuk; A. A. Stepanov; A. S. Tyulin y S. Niyazbekova, "Trends and consequences of introduction of automation and digitalization of enterprises, industry, and economy", Revista Inclusiones Vol: 7 num Especial (2020): 15-31.

	state and operating modes of technological equipment and the parameters of the state of the environment. The processes of the first level take place in real-time of physical processes; in other words, their parameters change within seconds or less.
Control and monitoring of parameters of zero-level physical processes, operating modes and condition of technological equipment, product characteristics, environmental conditions, etc. (second level)	Intelligent systems are used to process data from the first-level sensor layer and to generate control signals for actuators of this level. These are programmable logic controllers (PLC), distributed control systems (DCS), SCADA and batch automation systems. The hardware and software of the second level produce control signals for technological equipment following the operational control commands that come from the third level. These signals control the executive devices of the first level, which, in their turn, send the feedback signals to the second level. Second-level processes are characterized by time intervals of hours, minutes, seconds and less.
Manufacturing operations management (MOM) (third level)	Several types of computerized systems are used, which are called manufacturing operations management systems (MOMS). They provide support for four groups of MOM-level operational management functions (production, maintenance and quality and inventory management). In addition to MES, these include laboratory information management systems (LIMS), warehouse management systems (WMS) and computerized maintenance management systems (CMMS). The duration of the third-level processes is determined by days, work shifts, hours, minutes and seconds. This level is intermediate between the first and second levels and the fourth level. At this level, algorithms for controlling technological equipment, parameters of technological processes, production personnel, material resources, energy and finished products are formed.
Business logistics and planning (fourth level)	This level covers the management of business processes that govern the production activities of the entire enterprise. Several types of application programs are used. These are product lifecycle management (PLM) systems, enterprise resource planning (ERP) systems, customer relationship management (CRM) systems and human resources management (HRM) systems. Corporate-level management aims at long-term (strategic) and short-term (tactical) planning of production, supply, sales, management of modernization and development of production, etc. The processes of the fourth level operate within months, weeks, days.

Note: compiled based on the expert survey

Table 2

Hierarchy model of managing manufacturing systems using digital technologies

In addition to ERP, PLM, CRM and HRM systems, process development execution systems (PDES) can also be referred to the fourth-level management systems. PDES are specialized software and hardware systems designed for the development of high-tech manufacturing processes. They emerged as a means of design automation in such high-tech industries as semiconductor and nanotechnology, the production of microelectromechanical systems (MEMS) and biomedical equipment, etc. These systems are connected, on the one hand, to PLM systems and, on the other hand, to MES.

Discussion

One of the main functions of MES as software and hardware systems is the automation of information transition between the second and the fourth levels. At the levels of production (the first and the second levels of the hierarchy model of managing manufacturing system) and business processes (the fourth level), their information is significantly different by its nature, origin, temporal parameters and forms of presentation. Therefore, one of the main functions of the level of operational management of an enterprise is the transfer of information between the levels of production and business[13].

The third and fourth levels exchange information about production capacity, definition of operations, operational plans and production productivity. Production capacity data determine the available resources and free production capacity (personnel, production equipment, assets, etc.) available for the use in manufacturing. Here, the definition of operations is understood as detailed algorithms for the manufacture of products. Operational plans determine the schedule for all types of production activities (production processes, warehousing, supply, sales, etc.). Productivity is determined by data about the volume of production of a product for a certain period and about the resources that were used for this.

The production plan formed at the upper management level is transmitted from the fourth level to the third one. Based on the received plan, at the MOM level, operational production plans are formed; technological schemes and modes necessary for the implementation of the production plan are determined; parameters for setting up technological equipment and algorithms for controlling the parameters of physical processes are selected; algorithms for controlling equipment are formed to create the necessary parameters for implementing technological processes and for the transmission of the control command to the second level.

The information about the equipment configuration, technological schemes that ensure the manufacturing of a product following its definition, commands for the operational control of the equipment and process parameters is transmitted from the third level to the second one. In response to operational control commands, feedback data from the second level is received by the third level, as well as data on the state of equipment and parameters of technological processes.

MOM is divided into four fields: 1) production process management; 2) maintenance and repair of equipment process management; 3) quality management; 4) inventory management.

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[13] I. N. Lukiyanchuk; S. V. Panasenko; S. Y. Kazantseva; K. A. Lebedev y O. Y. Lebedeva, “Development of online retailing logistics flows in a globalized digital economy”, Revista Inclusiones Vol: 7 num Especial (2020): 407- 416 y E. N. Muraya; V. R. Roganov; E. I. Skiteva; I. V. Evgrafova y I. L. Daudov, “Digital Entrepreneurship and Education: Support for Innovative Projects”, International Journal of Advanced Trends in Computer Science and Engineering Vol: 8 num 6 (2019): 3304-3311.

Management within each field involves certain activities (sequences of actions) of manufacturing operations management, which determines the functions of MES. MES function in eight functional areas:

1) product definition management. Here, product definition is a detailed description of the sequence of actions, the implementation of which allows one to obtain a product. Product definition management can be viewed as a part of product lifecycle management;

2) resource management. Resource management involves the collection and accumulation of data, their analysis and exchange of information about resources (personnel, technological equipment, materials, finished products) and the development of commands for their management. This function provides real-time control of resources and the preservation of a detailed history of their movement in the production process;

3) production process planning. Production process planning is the determination of the sequence of work (schedule) according to the production requirements, formed at the fourth level. Typically, the enterprise resource planning systems such as ERP are used to form these requirements;

4) dispatching of production. Dispatching includes managing the real-time flow of tasks, orders, teams, etc. Its goal is to strictly adhere to the work schedule, respond to unforeseen circumstances, control labour costs, etc.;

5) production control. Since the main functions of management and control of technological processes are implemented at the second level, where systems of the PAS class operate, the role of MES in this functional area can be reduced to informing other systems about the production process;

6) production data selection and accumulation. It includes the collection, accumulation and distribution of data about monitoring the progress of technological processes, parameters of physical processes, the state of equipment, material resources, etc.;

7) production performance analysis. During the production performance analysis, performance indicators are formed, such as overall equipment effectiveness (OEE), key performance indicators (KPI), etc.[14]

8) product tracking.

Within the comprehensive automation of management of modern manufacturing systems, an approach known as totally integrated automation (TIA) has emerged[15], which means that the tasks of automation of various control levels are considered to be interconnected. Therefore, a corporate management automation system is considered to be an integral software and hardware complex that provides automation of management

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[14] R. K. Singh; E. J. Clements y V. Sonwaney, "Measurement of overall equipment effectiveness to improve operational efficiency", International Journal of Process Management and Benchmarking Processes Vol: 8 num 2 (2018): 246–261 y M. Bernard; S. Gianni y A. Neely, "Intellectual capital-defining key performance indicators for organizational knowledge assets", Journal of Business Process and Management Vol: 10 num 5 (2004): 551–569.

[15] J. Schmidt, "Totally Integrated Automation", IFAC Proceedings Vol: 33 num 1 (2000): 1-3.

functions along the entire vertical direction: from the level of technological process management to business process management. That is why the continuity of information flows both in the vertical and horizontal directions at each level is naturally achieved. With this approach, information is transmitted in digital form and is automatically transformed when moving from one level to another following the needs of users of this level.

Conclusion

The digital economy is a modern type of management, which is characterized by the predominant role of data and methods of managing them as a defining resource in the field of production, distribution, exchange and consumption.

The current state of production systems is characterized by information incompatibility of individual technological objects caused by the lack of coordination of actions. Elimination of information heterogeneity and the creation of a centralized information system with the possibility of remote access to the data of its control subjects at various levels of the functional hierarchy will make it possible to increase the controllability of the system and, hence, improve the efficiency of its work.

The application of the approach of integrated automation of manufacturing systems management requires significant investments. Therefore, the modernization of the management of manufacturing systems must be carried out in stages. It is important to preserve the already existing automation tools for individual objects and processes by introducing electronic data exchange channels and creating a centralized data warehouse and an information and analytical system that carries out thematic processing and analysis of information following the needs of users at all levels of management and provides them with remote access to this information at their request. This can be achieved by creating a computerized dispatch control system for production systems using the MES methodology and web technologies.

Thus, the results of the study confirmed the hypothesis that the management of modern manufacturing systems based on the use of MES will ensure the continuity of information flows both in the horizontal and vertical directions “process control – manufacturing operations management – business process management”.

We see the research prospects in the development of a system for integrated automation of manufacturing systems according to the TIA approach. The results of this research will make it possible to develop a scientifically based vision of the state of the problem, formulate a strategy for the MSE and, on this basis, optimize approaches for the stage-by-stage automation.

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