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The Digital Evolution of the PLM System based on the use of the Multicomponent Structure of Production Process Control

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This article is devoted to an analysis of the impact of digital transformation processes on change in the structure of the production processes, using the tools to manage the life cycle of products based on the concept of the 'Industry 4.0'. An integrated approach was developed based on the use of product lifecycle management (PLM), and manufacturing execution systems (MES) to optimise strategies, and technologies aimed at improving the quality of a number of modern business processes in high-tech enterprises. The authors consider the main components that should be part of modern MESs to improve the efficiency of the modified system of PLM.

Keywords: *Industry 4.0, Digital transformation, Integrated automatic enterprise management systems, Product life cycle management system.*

Introduction

The concept of the 'Industry 4.0' introduces global and difficult multifactorial organisational and technical systems, with the principle that the integration date from the difficult physical operations is put in a uniform informational field. In structure, the concept of the 'Industry 4.0' includes the following components: products life cycle management technology, technology of interpretation 'big dates', high-tech 'clever' production, cyber-physical systems, the industrial Internet of things (IoT), and also, interoperability to present time. They allow for enterprises to develop the most actual, and effective economical life. Efficiency, in this case, will depend directly on the degree and quality of use of the automation systems of production operations, as well as on the various additional processes included in the unified information area. The digital transformation of production is based on the process of continuous training for the personnel in the correct and effective application of information systems to allow, not only to process, but also to analyse the obtained data on the production and technological process.

A successful digital transformation requires the development of a technical infrastructure, and personnel competencies. This includes processes related to updating the current management system, and technologies for collecting, processing, and storing information necessary for making various management decisions. The development of digital transformation also proposes an effective and quality update to existing production and business processes, on a comprehensive introduction of advanced innovations. An important step in the development process is the need to adapt updated business processes to the requirements of the digital economy. Many technologies already have commercial products, but it is also clear to all participants that they will continue to develop rapidly, and the market for new products is only beginning to exist. In these conditions, many leaders are 'trying out' these new technologies. They want to do the following: gain experience using them, understand what competitive advantages they can give to the business, determine the direction and scale of transformation of the business, and assess the business risks associated with this transformation.

Business methods and management tools must also be transformed. Each method has its purpose and the conditions for its application. Under new conditions, old methods may turn out to be inadequate and become unnecessary or even dangerous for business. Digital transformation also requires the modernisation of the professional community's ideas about management, as well as the search for new, and modernisation of the existing management methods and tools.

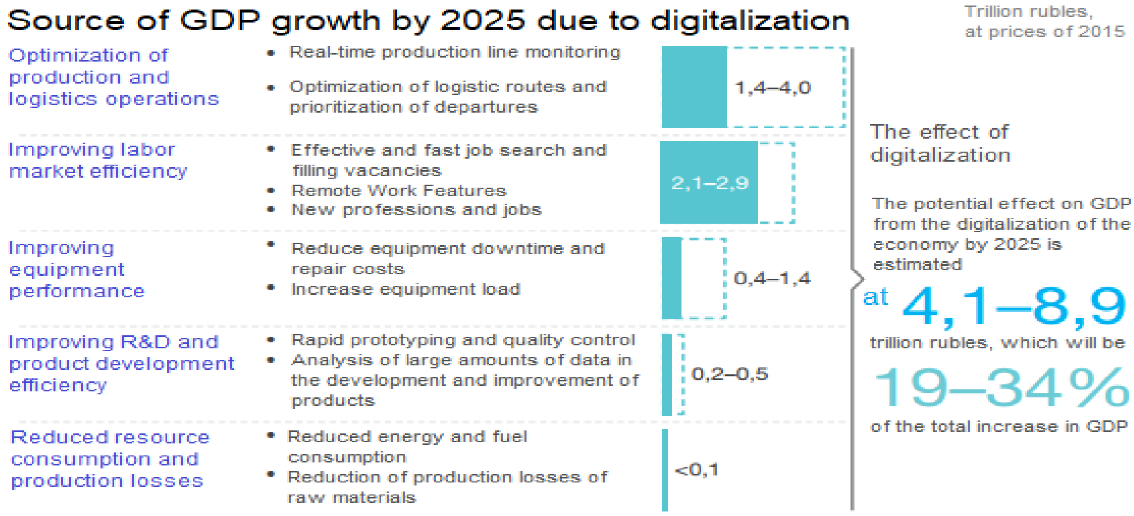
Theoretic Analysis

The concept of the 'Industry 4.0' was introduced by the German Federal Government as a strategic plan for the development of its industry. It was based on combining industrial equipment and information systems in a single information space, which will allow them to interact with each other, and with the external environment, without human intervention. The term, '4.0', means that this area of industrial development has such great potential that it will inevitably lead to the fourth industrial revolution. The Industry 4.0 has core four purposes: interoperability, virtualisation, decentralisation, and real-time operation. Interoperability is the ability of the mutual Internet connection and communication of people with cyber-physical systems and 'smart plants'. In such a system, sensors, equipment, and information systems are connected throughout the entire value chain, which goes beyond a single enterprise or business and can function almost without a person. The availability of finished products and equipment with a variety of sensors, the IoT, and cloud computing, make it possible for such a high level of decentralisation and to the degree that cyber-physical systems within the framework of smart plants can even make independent decisions. Therefore, the latest achievements in the development of artificial intelligence can also be a part of the Industry 4.0. In describing the fourth industrial revolution, real-time work is directly linked to cloud computing, big data, and the Internet. Thanks to these technologies, the virtual model of production of the smart plant is used in real time to control the operation of 'smart machines' and mechanisms to ensure the safety of those people who interact directly with robotic systems.

After the successful introduction of digital technologies, the management of the enterprise needs to maintain and develop the employees' competences in new production and technological spheres, as well as to increase their qualification level. It is a must for the enterprise to be competitive, and in their practices, be an advanced digital technology comparing with its competitors. Digital transformation allows the receiving of benefits at a stage when the personnel involved in the production process receive the necessary additional information for greater efficiency of the production process. For example, using augmented reality technologies. In the aviation industry, this technology is used by 'Boeing', which has introduced Google Glass-based augmented reality technology in the production process, reducing the production time by about a quarter, and the total number of errors by two times (Sacco, 2016). Another example is 'Lockheed Martin', whose specialists use augmented reality technology to obtain additional information when assembling the F-35 aircraft. The technology allows the capability to determine the optimal sequence of assembly, i.e. it is enough to take part and install it in the right place. According to the experts of the company, this technology reduces the total assembly time by 30 per cent, and increases the assembly accuracy by 95 per cent (George, 2015).

The digitalisation of the national economy in Russia should become a sustainable and reliable source of economic growth. Figure 1 shows the effect of the gross domestic product (GDP) growth from the digitalisation measures in the Russian economy by 2025 (PWC, 2019).

Figure 1. Forecast Sources of GDP Growth through Digitalisation Mechanisms



According to the authors of the report, the transformation of the 'classical industries' is irreversible. In 2017, the digital revolution entered a decisive phase, and digital transformation has become one of the main factors in world economic growth. According to the McKinsey estimates, Internet technology will experience up to a 22 per cent increase in GDP in China by 2025. In the United States, the expected growth in value created by digital technology may reach 1.6–2.2 trillion dollars by 2025.

By 2025, the potential economic effect of the digitalisation of the Russian economy will increase the country's GDP by 4.1–8.9 trillion rubles (in 2015 prices), which will be from 19–34 per cent of the total expected GDP growth, according to McKinsey. These forecasts are based, not only on the automation of existing processes, but also on the introduction of fundamentally new business models and technologies, such as digital platforms and ecosystems, in-depth big data analytics, 3D printing, robotics, and the IoT. According to McKinsey, until 2025, only the IoT will annually bring the global economy from 4–11 trillion dollars.

Several key areas and directions of transformation are recommended by specialists and experts within the framework of the concept of the Industry 4.0 (Kondratyev, Lyubimtsev & Merkulov, 2015; Top systems, 2019), as follows:

1. Updating the business model and digital strategy:
   - updating the general concept of digital enterprise.
   - reconsideration of the strategy and model of business.
   - optimisation of the portfolio of digital products.
   - development of new business thinking.

2. Changing the components of the digital operating model (structure, culture, and various processes):
    - development of a new unique digital structure.
    - creating a digital control model.
    - identification of place of digital business in the structure of enterprise.
    - reorganisation of the digital business management model.
    - optimisation of digital transformation mechanisms.

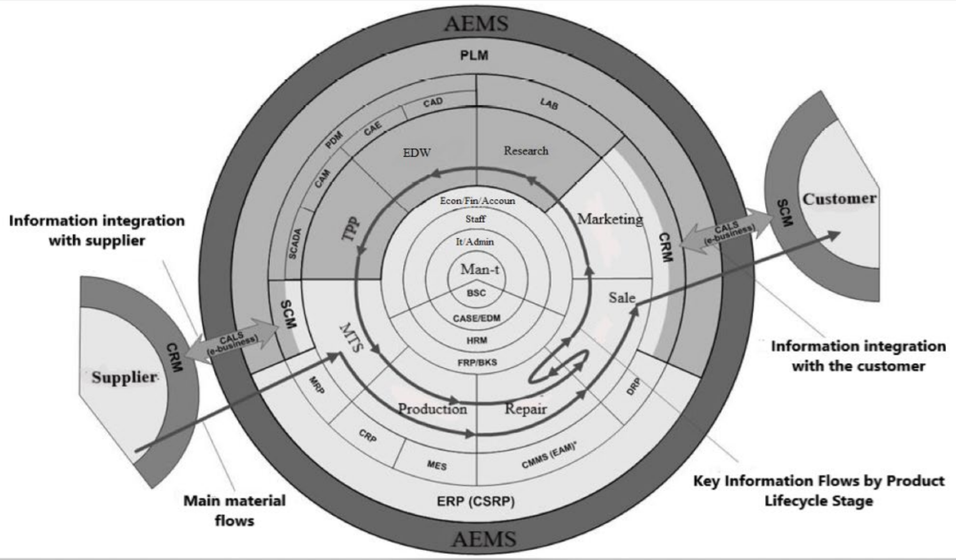
3. Changing technology infrastructure and digital manufacturing processes:
    - use of a bionic (toponymic) design for the purposes of a reduction of weight, and quality increase in the durability of products, as well as the application of ‘clever’ products.
    - carrying out the transformation of production and service support.
    - organisation of work with augmented reality technologies.
    - inclusion in the product process of ‘cloudy technologies’.
    - updating of the levels of technological readiness with the use of new components of the system PLM.

According to experts, the introduction of modern technologies can significantly improve the activities of enterprises in several areas. For example, in the area of production management, the Industry 4.0 technologies can help to optimise and automate basic production and management business processes, increase equipment efficiency by processing real-time data arrays, and identify hidden relationships, as well as improve the raw material consumption planning and graphics of finished products. In the field of equipment maintenance, modern technologies make it possible to build a preventive maintenance system that operates on the basis of prognostic models using real-time data that helps to assess the real equipment need for maintenance and repair and optimise these processes. These systems help to increase the coefficient of technical readiness of equipment and extend the life cycle of equipment due to more efficient maintenance. Digitalisation opens interesting prospects for companies to increase efficiency in the field of warehouse management and logistics processes. The introduction of automated supply chain management systems allows for the significant optimisation of stocks of finished products, raw materials, and spare parts stored in the company's warehouses. Digital tools also reduce logistics costs, help plan routes more efficiently, control traffic load, and more precisely, prioritise logistics operations across the enterprise.

Analysis of Research Multicomponent System of Automated Enterprise Management System (AEMS)

A key principle of organisation process digital transformation is the organisation of system interaction at three levels: preparation, management, and production automation. On the basis of the automated enterprise management system (AEMS), there are systems of PLM, and Enterprise Resource Planning (ERP). A structural composition of components included in the AEMS system is shown in the Figure 2 (Safronov & Barabanov, 2011).

Figure 2: A general overview of the systems in the structure of the AEMS



The control system is located in the centre. It includes the PLM module, which is in the main design bureau, and it allows the organization of the process of obtaining various data (including engineering) in real time about the products produced by the enterprise, as well as to obtain information about the product projects being developed (Gornostaev, 2008). One more component included in the structure of a core system of management is the ERP module, which is located in the main enterprise. Its direct functions include the organisation of the project management system, i.e. the tools for connecting the financial, and logistics areas. The ERP system uses a single program that performs many different functions from the management of processes to accounting. The maximum efficiency of an ERP system is achieved to use it with a CRM system, as well as a system control quality. The analysis of the structural components of the AEMS components from the Figure 2 shows that their efficiency depends on the quality of the continuous acquisition and life cycle support (CALS-technologies) used. Continuous acquisition and life cycle support technologies are aimed at optimising costs, imparting fundamentally new properties to products manufactured by the enterprise, and contributing to increasing the overall level of the after-sales service. In the aircraft industry, for example, the effective use of CALS-technologies is achieved due to the correct organisation of work within the framework of a single independent information model (Eltishev & Kulik, 2016).

The strategy for implementing CALS-technology is to develop a unified digital space that all participants in the life cycle will be able to use equally, which will reduce the 'information chaos' existing at the enterprise, and optimise communication between departments. Ultimately, this will have a beneficial effect on the quality of products. Using a unified digital space will optimise costs (time and materials) throughout the life cycle, which the needs of the customer will take into account. As a result, the overall competitiveness of the products will increase. A digital space created by using CALS-technology is based on the use of computer systems, which includes: systems of automatic modeling, including 2D, and 3D, as well as universal design systems (Bricscad, Autodesk Inventor, SolidWorks, etc.); software for the calculation of engineering, and engineering solutions (SCAD Office PC); and systems of automatic technological preparation of the production process, which in digital form, in real time, can show the necessary information about the current production process, and product quality control.

The most difficult and resource intensive transformation process is the organisational and technical system of PLM. The basis of this system is to find a sign of dualism, which can be represented by way of object operation and/or material information. The material and technical support, which includes the production itself, subsequent operation and utilisation or processing, as well as various related processes, occur in the physical environment, and they are fully accompanied by processes occurring in the information environment, which are implemented in the complex multifunctional computer environment. Therefore, in order to qualitatively improve the efficiency of the application of modern information technologies, it is necessary to transform the processes, which are carried out directly in the physical environment, into informational problems. In turn, they can also be converted back into a physical environment. The conversion process is necessary for the optimal design of the future life cycle of the product. In other words, it is necessary to achieve a full correspondence between the informational, and physical environments. To achieve this conformity, the gradual modernisation of the existing PLM structural systems into PLM+ systems is necessary (Pinkovtskaia, Balynin, Arbeláez Campillo & Rojas-Bahamón, 2019).

The structure of PLM, and the modernized PLM+ systems consist of the next complex consecutive works realised on a basis synthesis of different components within the created universal storage of data in a high-tech enterprise structure, including (Belov, Savich & Garichev, 2016):

- organisation of the process maintenance for electronic technical document flow in the enterprise; its key feature is the unity of design and technical data, including various accompanying information.
- office document flow in combination with unified document management. In other words, the possibility of the organisation of unified access to documents in the enterprise, as well as effective management of business processes, through the prompt coordination of documents.
- optimisation of the management technology in the organisation of relations with clients and at all stages of the life cycle (it is necessary not only to attract new, and retain old clients, but to also increase loyalty), in order to create, in the future, a stable and effective business on the basis of mutually beneficial relations.
- a modernised complex of operational and scheduling planning, which is based on MES systems. It is necessary, not only for effective organisation of the systems of production and technological processes control, but also for the simplification of the mechanisms of provision of initial design and technological documentation, as well as obtaining schedules of operation, and the loading of equipment in real time.
- using a single digital framework, the Microsoft .NET Framework, which is based on a unique common language runtime (CLR), which can compile different codes into a universal language that can be understood by the programming system.
- organisation of technological and design preparation of production based on the application of unified tools, with the purpose of qualitative improvement of basic components of automatisation.

Researching the Main Components of the System PLM+

As the main method of research, the article uses synthesized analysis of data presented by one of the Russian companies, a developer of complex solutions in the field of automation processes design and management of production spheres. Within the PLM+, a system of multicomponent program interaction is implemented and aimed at solving various tasks, beginning from development engineering and technical data, which is obtained from using computer-aided engineering (CAE), computer-aided design (CAD), manufacturing process management (MPM), computer-aided process planning (CAPP), and systems and finishing of the ability to manage this data with the product data management (PDM) system. The system, preferably on a permanent basis, conducts comprehensive data exchange with the ERP system, and system of project management, and in some cases, it is possible to interact with third-party information systems. For example, other enterprises or the customer.

The competent realisation PLM+ system will require leaders and managers to interact between the main structural components, which are the fundamental basis (Skoltech, 2018; CIMdata, 2019).

Organisation of document circulation

Through use of specialised software in enterprises, we can use all complexities of instruments to facilitate and speed up the registration of electronic documents, and also to organise a procedure for monitoring the implementation of current orders. The interface of the selected program should minimize pop-ups, including dialogue windows, and allow the user to focus on the direct performance of the tasks set by the leadership, which in turn will have a beneficial impact on the speed and quality of work. In a program, it is also desirable to have, not only ready universal templates — which, for example, can be used to create simple standardised office documents — but also, to have a mechanism for sending various orders and powers with the indication of direct performers and supervisors, which will allow to build work at the enterprise on the principle of 'Orders-Execution-Control'. For the enterprise management, an important aspect when choosing the program of specialised workflow management is the compliance of the program with the basic standards of office work and the possibility of fulfilling the function of maintaining register books. The program should be able to systematise the opened cases in the enterprise. In other words, create and work with multipurpose documents and perform various functions of nomenclature cases. For example, to carry out the procedure of indexing and storing various cases and documents.

Organisation of the client management system

The customer service management system is an effective strategy to perform business, at the heart of which is found a 'Marketing-Sales-Service' triangle. It concludes various individual characteristics and customer requests, including potential ones with the goal of creating mutually beneficial long-term relationships. At the enterprise, it is necessary to use a set of specialised programs, preferably Russian developed, in order to minimise the risks from new sanctions. This will allow leading specialists to develop a unique base for the storage of data, which meets individual requirements (Novikov & Veas Iniesta, 2018). A significant advantage of such a solution will be the maximum compliance with the various unique requirements for the structure of providing and storing all kinds of information. The best solution in this case, can be using the management system based on the 'T-FLEX DOCs' program, which was developed by the Russian company, 'TOP SYSTEMS'. The functionality included in the program will allow the monitoring of a significant amount of information. For example, on the number of contracts concluded, and entered accounts. The array of stored data can be presented for the interest of a particular user. In this case, it depends directly on his or her position and sphere of activity. It is also possible to highlight several mandatory tasks that the system for organisation client management must solve (Novikov, 2018):

- conduct mandatory systematisation in the sphere data processing of clients.
- contribute significant reduction in the costs of normal intra-production operations.
- influence the employees of the enterprise on purpose to increase their productivity.
- influence upon the organisation of processes related to the intra-production planning in an effective way.
- provide safe storage of data.

Use of a project management system with parameter definition of required resources and financial costs

The company's specialists should apply a project management system focussed on the capacity to provide, not only the maximum level of management of all ongoing processes within the project, but also to allow foreseeing the necessary resources and approximate completion dates for a particular project. In other words, a selected system should have a convenient tool for solving two main tasks: to carry out activities in the fields of planning, and control.

An important point is the ability to present data in the system, which would allow analysing the developed structure of the project, and immediately implementing it. At the same time, leading specialists and managers of the enterprise could watch the progress of the current design works. It is desirable for the system to contain data on past versions of projects, while keeping logs, and the changes made to them.

Using of the modernised system of operational and scheduled planning

The leadership of the enterprise needs to use a modernised system that would allow solving a wide range of tasks in the field of production systems planning, formation of planning, and reporting documents, as well as organisation of the procedures directly related to the integrated production process management. Therefore, it is possible to outline, most clearly, the possibilities that the system should have (Novikov, 2018):

- to perform calculations for the optimisation of the current production process.
- to optimise the production plan, taking into account the amount of time required for the complete production of the order, to consider the priority of the production of the order, and reduce the possible downtime of the equipment.

- to generate planning and reporting information according to any production schedule. For example, to prepare reports on completed orders and works, and show replacement and daily tasks.
- to control the course of performance of the established production tasks, and to reduce possible delay through the optimisation of working procedures.

The system PLM+ proposes the necessity to combine the functions of the MES, and PLM, which will enable eliminating the existing gaps in the production preparation by direct production. The following structural aspects will be involved: possibility to design products according to the established requirements; optimisation of the design of future products, considering current technological and production realities; application of unique technological processes, allowing increasing parameters of manufactured products in a qualitative way, and so on. Therefore, with an increase of the level integration of the development and production processes, the quality of the final product increases directly. The proposed integration improves the teamwork of engineers and designers, who can exchange additional information throughout the production process.

The affective use of the PLM+ is possible, only if it is based on an upgraded operational scheduling complex built on a modern MES system, which should include the following components:

- *Resource Allocation and Status (RAS*): the necessary tool for control of the general state and procedure distribution of resources in real time. If it is assumed that it is a machine park, using employees as resources, in this case, the system is automatically monitored for their condition, as well as analysis by considering the available resources.
- *Operations/Detail Scheduling (ODS*): allows the system to execute operational and detailed planning, in order to optimise the existing production schedule and organise parallel works at existing production capacities. These activities will significantly reduce the amount of time required to obtain the final product and reduce equipment downtime.
- *Dispatching Production Units (DPU)*: this is a procedure of system work organisations in the field of the production process of *dispatching*. It enables building production process information (at the shop floor level) in the most efficient order. In other words, to make adjustments in real time, which contributes to the effective organisation of the required range of works.
- *Document Control (DOC):* the document management system performs the necessary control over the content and flow of various documents, which are required to be present at each product manufactured by the enterprise. For example, drawings, regulations, and various technical documentation. It enables the issuing of shop

documents work orders, shift and daily tasks, etc., as well as allows changing the document templates.

- *Data Collection/Acquisition (DCA*): is a technology of collection and storage data. It saves all data required for system operation, including data that can be loaded externally. At the same time, it should be noted that the data warehouse is also used, as for all other systems included in the concept of the PLM+.
- *Labour Management (LM*): is a multi-module, multifunctional system of enterprise personnel management, which includes identification of current standards of activity, planning of resources use, and organisation of control over collective and individual activities, as well as the determination of procedures necessary for the management of the level of the professional training of employees. The system enables the ability to solve the following tasks: to determine the current productivity of employees of the enterprise, to consistently implement the complex of works related to procedures of operational planning, and to analyse parameters of planned works with the actual works performed.

Conclusion

The efficient digital transformation of the production process can be carried out only with the use of a universal and unified platform, which will allow creating a single independent digital system for the organisation of modern engineering.

The modern design process is a symbiosis of three multilateral subsystems, including the process of developing guidelines and requirements for the future product, the organisation of the product management system, and the direct design of the product, i.e. the definition of its future architecture (SEBok, 2019). The technological platforms being developed should qualitatively implement the process of designing the future architecture of products by considering their physical and logical structure, as well as fully using and developing technologies of functional interaction within the elements of the designed products. Therefore, we can create a triangle called the 'Requirement-Function-Object'. The multi-component system, PLM+, provides the capability to organise a single information space of a manufacturing enterprise, as well as provides information support for the life cycle of manufacturing complex high-tech equipment. This system integrates multi-vendor information systems of various functions and organises them on the basis of a service-oriented architecture by using web standards, which allows access to the combined data, and also significantly saves resources when expanding it. According to experts, the production efficiency implemented on the basis of the PLM+ is approximately 30–40 per cent higher than the efficiency of traditional production. The introduction of the PLM+ allows reducing:

- costs for the development and production of high-tech products by 25–38 per cent.

- costs associated with the marriage and elimination of product defects by 19–24 per cent.
- costs during the operation of the products by 26–29 per cent.
- time for launching new product samples on the market by 65–73 per cent.
- the global market completely rejects products that are not equipped with electronic documentation, and do not have the means of integrated logistic support for the post-production stages of the life cycle. Today, foreign customers of domestic products put forward requirements that cannot be met without the introduction of PLM+ technologies.
- submission of design and technological documentation in electronic form.
- submission of maintenance and repair documentation in the form of interactive electronic technical manuals (IETR) with illustrated electronic catalogues of spare parts, auxiliary materials, and means for remote ordering.
- organisation of an integrated logistics support system for products in the post-production stages of the life cycle.
- availability and operation of an electronic product cataloguing system.
- presence in enterprises of the requirements of ISO 9000:2000 quality management systems, etc.

Thus, the task of developing and implementing PLM technologies at industrial enterprises is becoming a State problem, the solution of which determines the efficiency of the economy. As the practice of informatisation shows, in the transition to an integrated information environment, the key point will be the availability of a sufficient number of qualified specialists.

REFERENCES

Belov, M. V., Savich, A. V., & Garichev, S. N. (2016). PLM-systems Designer. *large systems Management: proceedings*, *59*, 45-71.

CIMdata (2019). *Product Lifecycle Management (PLM) Definition.* Retrieved at http://www.cimdata.com/en/resources/about-plm.

Eltishev, D. K., & Kulik, V. D. (2016). Automation of Audit processes, accounting and distribution of electronic design documentation in PLM-system teamcenter. *Fundamental study*, *11*(3), 510-514.

George, A. (2015). Lockheed Is Using These Augmented Reality Glasses to Build Fighter Jets. *Popular mechanics.* Retrieved at https://www.popularmechanics.com/flight/a13967/lockheed-martin-augmented-reality-f-35/.

Gornostaev, S. A. (2008). *Development of methods and models for planning the activities of a defense concern in the field of civilian products' manufacture. Abstract of dissertation for the degree of PhD in Technical Sciences.* Moscow: Moscow State Technical University named after Bauman.

Kondratyev, V. V., Lyubimtsev, I. V., & Merkulov, A. V. (2015). Engineering and life cycle management of the object "enterprise management System". *Proceedings of the 18th Russian scientific conference "enterprise Engineering and knowledge management," 1*, 333-338.

Novikov, S. V. (2018). Russian Support for Innovation and Export Growth. *Russian Engineering Research, 38*(4), 305-308.

Novikov, S. V. (2018). The features of innovative processes in the Russian Federation: analysis of current practices. *Espacios, 39*(9), 2-8

Novikov, S. V., & Veas Iniesta, D. S. (2018). State regulation of the development of the connectivity of the Russian territory. *Espacios, 39*(45), 20-22

Pinkovtskaia, I. S., Balynin, I., Arbeláez Campillo, D. F., & Rojas-Bahamón, M. J. (2019). Small business development in Russia: results of the assessment of sectoral structure and number of employees. *Espacios, 40*(7), 6-17

PWC (2019). *An integrated approach to the transformation of manufacturing enterprises.* Retrieved at https://www.pwc.ru/ru/publications/PwC_Siemens_Digital_transformation.pdf.

Sacco, A. (2016). Google Glass takes flight at Boeing. *CIO*. Retrieved at https://www.cio.com/article/ 3095132/google-glass-takes-flight-at-boeing.html?page=2.

Safronov, V. V., & Barabanov, V. F. (2011). Methods of CAD and PLM systems integration. *Bulletin of Voronezh state technical University*, *10*(7), 61-64.

SEBok (2019). *Guide to the Systems Engineering Body of Knowledge (SEBoK)*. Retrieved at http://www.sebokwiki.org.

Skoltech (2018). Public analytical report on the development of new production technologies. *Skolkovo Institute of Science and Technology*. Retrieved at http://isicad.ru/ru/pdf/ReportSkolkovo2014.pdf.

Top systems (2019). *The concept of "PLM+"*. Retrieved at http://www.tflex.ru/plm/index.php.