Concept of engineering as a basis for development cyber-physical system

Violetta N. Volkova[1[0000-0001-9658-5135]], Valery. I. Karpov[2[0000-0001-6338-0467]]. Alla E. Leonova[3[0000-0002-2124-0295]], Aleksandra V. Loginova[4[0000-0002-7783-7795]], Elena Vl. Romanova[5[0000-0002-4933-9422]]

[1,4] Peter the Great St. Petersburg Polytechnic University,
St. Petersburg, Russia, saiu@ftk.spbstu.ru
[2] AO «NICEVT», Moscow, Russia, vikarp@mail.ru
3 AO «NICEVT», Moscow, Russia, alla.leonova.nicevt.ru
5 Plekhanov Russian University of Economics, Research Institute "Voskhod" Moscow, Russia
romanova.ev@rea.ru

Abstract. The purpose of this article is to substantiate the role of engineering as the basis for the development of the cyber-physical system. The proposed concept is based on the laws of the theory of open systems and the source sense of the concept of "engineering". In the near future, it is planned to widely introduce cyber-physical systems in industrial enterprises, which combine advanced industrial (industrial) and digital (information) technologies, which ensures the development of systems.

To research of enterprise development process, the article proposes to use the theory of open systems L. von Bertalanffy and substantiates the role of engineering, understood in the original sense of the term: (engineering from lat. ingenium - ingenuity, invention, knowledge), which arose in Europe in the XVI century, which should be understood not only computer engineering (software for design, engineering analysis, consulting), but primarily the use of scientific and technical knowledge for the adaptation of innovative technologies, organization of production processes and management in a particular enterprise, taking into account its purpose features.

Section 1 describes the accepted concept of a cyber-physical system. In section 2, to substantiate the role of engineering in cyber-physical systems, the features of open systems with open elements, the class of which includes CPS, are considered. Section 3 addresses the challenges of sustainable CPS development.

Keywords: engineering, innovations, innovative technologies, Cyber-physical system (CPS), methods of organizing complicated expertise, industrial enterprise, industrial revolutions, systems theory, technologies, emergence.

Proceedings of the XXII International Conference "Enterprise Engineering and Knowledge Management" April 25-26, 2019, Moscow, Russia

1 The concept of Cyber-physical Systems in Industrial Enterprises

Now there is no uniquely standard identifying of a cyber-physical system (Cyber-Physical System - CPS).

In a number of works (for example, [1, 2]) there is information that the term "cyber-physical systems" was offered in 2006 by Helen Jill, at that time the director of the built-in and hybrid systems in National scientific fund of the USA, wishing to underline distinctive feature of the seminar of NSF CPS Workshop organized by it, to review a role of the built-in systems. The term CPS is offered for designation of the complexes consisting of the different natural objects, artificial systems, and managing controllers integrated into a whole and including real-time embedded systems, distributed computing systems, automated control systems for technical processes and objects, wireless sensor networks.

Active use of the term began within the project of the German government Industry 4.0 on industry computerization. Broad application of cyber-physical systems in different spheres of human activity, including industrial production, the transport, power, military systems, civil infrastructure, life support systems from medicine to smart houses and the cities is predicted.

Now in a general view, the cyber-physical system is defined as the information and technological concept meaning integration of computing resources and physical processes. In such system sensors, the equipment and information systems are connected to the help of standard Internet protocols for forecasting, self-adjustment, and adaptation to changes. At this CPS are developed a network of rather autonomous interacting technologies, but not as the separate self-contained unit [2].

In a number of works [3–12, etc.], CPS is understood as various classes of automatic control systems for natural and artificial objects of animate and inanimate nature. Within the framework of a fairly widespread terminology, CPS treats as geographically distributed automatic systems for collecting, processing, analyzing data and information about the state of the respective physical objects and processes or a system of coordinated management decision-making. In the applied aspect, CPS are presented as a set of automatic systems for collecting, processing, analyzing data, including geographically distributed. By application, CPS classifies sensor-based systems, data acquisition systems, wireless sensor networks that control some aspect of the environment and transmit the processed information to a central site. The CPS also includes the process control systems, distributed robotics, and avionics. In the future, some researchers associate cyberspace with physical processes [13–15 and others] to the CPS class.

Common to various interpretations is only the fact that CPS uses phenomenal (as they are called by E.A. Lee and S.A. Seshia [3]) information technologies. The dominant role of the cybernetic component in CPS is often emphasized, interpreting the "cyber" in the initial sense - "control", which can be realized both automatically and automatically, i.e. with the participation of man. At the same time, the key element of electronic maintenance (e-maintenance) is web-technologies that provide remote administration, monitoring, testing, diagnostics, prediction of the condition of the products in use, reconfiguration of their structures in the event of emergency and abnormal situations and the absence of necessary reserves [6, 16 - 22 and others].

The most significant application of the concept of cyber-physical systems is industrial production. Many works provide examples of the use of individual innovative technologies in industrial enterprises, which provide monitoring and diagnostics, automatic reporting on the state of monitored equipment, and data on malfunctions; about consumables resources; loading equipment, etc., while the ideologist of the modern industrial revolution K. Schwab [23] believes that the most unpredictable result will come out with the integrated introduction of interacting technologies.

Given the diversity of interpretations of the concept of CPS, this article proposes to adopt a concept based on combining industrial and information technologies with a physical element (decision makers on the choice and implementation of innovations), which can be considered the development of human-machine systems, i.e. relevant classes of automated systems for managing objects and processes. For example, a cyber-physical system for a manufacturing enterprise may include the following complex of technologies: CAD / CAE computer-aided design system, industrial robots and computer vision systems coordinating their interaction, 3d printing for prototyping and manufacturing small batches of products, virtual (AR) technology and augmented reality (VR) to create visual "instructions-hints" in the workplace, as well as to promote and sell products, a "big data" analysis tool to support online decision making, the integration of supplier-customer pairs into a single loop for managing end-to-end business processes and data exchange, and other technologies. At the same time, CPS should be developed as a network of interconnected technologies that are included in the life cycle of a production enterprise, and not as separate autonomous devices.

Such treatment corresponds to the definition of CPS which is accepted by the deputy CEO of Ruselprom concern, the Dr. экон. sciences, professor S.A. Masyutin: "The Cyber-physical system is an organizational and technical concept of management of information flows, integration of computing resources into physical processes of production. In such system sensors, controllers and information systems are united in a single network throughout all life cycle of a product. The cyber-physical network can be, both within one enterprise and within a dynamic business model as a part of which several enterprises. Operations throughout all life cycle interact with each other with the help of standard Internet protocols for management, planning, self-adjustment and adaptation to changes. The Internet of things cannot exist without cyber-physical systems as CPS is the infrastructure of the Internet of things[24].

A similar understanding of CPS is given by E.A. Lee и S.A. Seshia[3]. On the example presented in a graphic form they explain that they in CPS network integrate: first a "physical" part of a cyber-physical system which is not implemented by means of computers or digital networks and can include mechanical parts, biological or chemical processes, or people operators; secondly, there are one or several computing platforms which consist of sensors, actuators, one or several computers and (perhaps) one or several operating systems; and thirdly, there is a network structure which provides mechanisms of communication of computers. Together platforms and network create "cyber" - a part of CPS. Network platforms have own sensors and/or actuators.

Action taken by actuators influences the data provided by sensors which measure processes at the physical enterprise. Implementation of the law of management with use of a feedback loop is provided in model.

The given example, certainly, primitively displays the predicted GPS as new technologies for CPS (see, for example, [25]) which become more and more fantastic, will lead to qualitatively new automatic intercomputer exchange (M2M) of all with all, to models of the common information space of the enterprise (CISE) creating almost simultaneous information support of all components of a system that will lead to constant conversion of structures, to use of the decentralized principles of management of network-centric type.

At the same time, it can be predicted that the joint use and interaction of industrial and information technologies in accordance with one of the basic laws of the theory of systems proposed by L. von Bertalanffy [26] – the laws of emergence, will lead to the appearance of the effect of a new quality, new properties that are absent in the scattered application of technologies, i.e., the effect of emergence, and therefore, CPS in the adopted concept ensures the development of the enterprise, and it can be attributed to the class of open systems.

Therefore it is useful for research and development of CPS to apply patterns and models of this theory.

2 Justification of the Role of Engineering in a Cyber-physical System

Organismic approach and concept of an open system were offered L. von Bertalanffy as on the basis of studying of live organisms he found out that the mechanical concept which is the cornerstone of classical science relying on theoretical physics and laws of thermodynamics cannot explain the surprising order, the organization, regulation, continuous changes observed in live organisms and new understanding of problems of controllability and sustainable development of systems is necessary.

In open systems unlike closed (isolated from Wednesday) thermodynamic regularities which contradict the second beginning of thermodynamics are shown. According to this beginning, the general course of physical events in the closed systems occurs in the direction of an increase in entropy and achievement of a condition of the maximum disorder. At the same time in open systems in which there are a transfer and transformation of substance according to L. von Bertalanffy 's concept "… input of a negentropy", i.e. decrease in entropy is quite possible; and "… similar systems can keep the high level and even develop towards increase in an order of complexity" [26, page 42].

L. von Bertalanffy actually found new regularity which in open systems with active elements resists to the second law of thermodynamics – "ability to resist entropy (destroying a system) to trends and to show negentropy trends".

The open system unlike closed (isolated) under the corresponding conditions reaches a condition of mobile balance in which its structure remains to a constant. But unlike usual balance this constancy remains in the course of continuous exchange and the movement of a substance ([26], page 42).

One of the fundamentally important for understanding the process of development of systems is the fundamental nonequilibrium, discovered by E. Bauer [27], i.e. the desire to maintain a stable imbalance and use energy to maintain themselves in a dis-equilibrium state. E. Bauer explains this by the fact that all structures of living cells at the molecular level are pre-charged with “extra” excess energy, as compared to the same non-living molecule, and the organism receives external energy not for work, but for maintaining its non-equilibrium structure [27].

Due to these features, the system exhibits: the ability to resist entropic (system-destroying) tendencies, to show adaptability, i.e. the ability to adapt to changing environmental conditions and interference, both external and internal, the ability to develop behaviors and change its structure (if necessary), while maintaining the integrity and basic properties; ability and pursuit of goal setting.

The cited features have a variety of manifestations that can sometimes be identified as independent characteristics. Most of them are due to the presence of active elements that stimulate the exchange of material, energy and information products with the environment and exhibit their own "initiatives", so that such systems do not follow the pattern of increasing entropy (similar to the second law of thermodynamics, acting in closed systems, the so-called "second the beginning ") and even there are negentropic tendencies, that is, self-organization itself, development.

The features are contradictory. In most cases, they are of a dual nature, are both positive and negative, desirable and undesirable for the social system. On the one hand, among them, there are properties that are useful for the existence of the system, its adaptability to changing environmental conditions, but at the same time, these features cause uncertainty, non-stationarity of parameters, instability of the functioning of the system, unpredictability of behavior.

Features of open systems and explaining their regularity are due to the presence of active elements that stimulate the exchange of material, energy and information products with the environment and show their own "initiatives", an active principle. Due to this, in such systems, the regularity of entropy increase is violated and negentropic tendencies are observed, i.e. self-organization and development proper.

Thus, studies of open systems have shown that their development occurs: 1) on the basis of exchange with the environment of information, energy, material innovations (ie, openness of the system) and 2) through active elements that initiate their own innovations and ensure the interaction of innovations.

Understanding the features of open systems allows us to understand that the term “design” is not fundamentally applicable to living objects and systems that we refer to as open systems. A living system, the study of which became the basis of L. von Bertalanffy’s organismic approach, cannot be “assembled” from parts. It can only “grow”, develop, adjust, influence the process of moving towards the desired state by controlling this process.

A number of works on CPS emphasize the special importance of the cybernetic (managerial) component, which should provide a new quality of production management, a transition to a qualitatively new automatic machine-to-machine exchange of all with everyone in the framework of CPS projects, which is provided by new technologies - intelligent sensors and wireless communication etc.

Taking into account the peculiarities of cyber-physical systems, they can be considered as an opportunity to get the effect of emergence, that is, the appearance of new quality of production processes, and at the same time resist undesirable results when introducing emergent technologies, since CPS combines new technologies and physical an element (of a human being), nevertheless, is developed not as isolated technologies, but as systems in which it is supposed to manage a complex of technologies, and it is possible to hope that the management functions will retain it is the physical element, that is, the decision makers on the choice and implementation of technologies.

Researches of open systems have shown that their development occurs: 1) on the basis of exchange with the environment of information, energy, material innovations (ie, openness of the system) and 2) through active elements that initiate their own innovations and ensure the interaction of innovations.

At the same time, the most promising form ensuring the development of an enterprise is engineering in the original understanding of this term, which arose in Europe in the 16th century (engineering, from the Latin *Ingenium* - ingenuity, invention, knowledge), i.e. not only computer engineering (software for engineering analysis and design) [27], and first of all - the use of scientific and technical knowledge to create systems, devices, materials and the organization of production processes and management of production processes and activities of enterprises in general.

In this understanding, engineering can be considered as the similarity of living cells containing some “excess energy” according to E. Bauer, and in socio-economic systems - information, which initiates innovations for the development of the “organism” of an enterprise, realizing the organismic approach of L. von Bertalanffy.

E. Bauer formulated the principle of sustainable imbalance of living systems: “... living systems are never in equilibrium and perform, due to their free energy, constantly work against the equilibrium required by the laws of physics and chemistry under the existing external conditions” [28, C. 43].

This principle serves to fundamentally distinguish between a working living system and a working mechanical system or machine, which is expressed in the inequality of potentials, in the created electrical gradient, whereas in a non-living closed system any gradients are distributed according to the entropy rule -dimensionally. This "extra" energy that exists in living cells at any level, Bauer calls "structural energy" and understands as deformation, disequilibrium in the structure of the living molecule.

The meaning of the principle of sustainable imbalance lies in the bio-physical aspects of the direction of energy movement in living systems. E. Bauer argues that the work done by this living cell structure is performed only by disequilibrium, and not by energy coming from outside, while in a machine the work is performed directly from an external energy source. The body uses the energy coming from outside not to work, but only to maintain the "excess energy" in living cells.

“Therefore, in order to preserve them, that is, the conditions of the system, it is necessary to constantly renew them, that is, to constantly expend work. Thus, the chemical energy of food is consumed in the body to create a free energy structure, to build, renew, preserve this structure, rather than directly turning into work "[28, p. 55].

Bauer made this conclusion based on specific observations, which gives some grounds for analogies in open systems, the main laws of which were obtained on the basis of observations of biological objects and were confirmed by subsequent studies of socio-economic systems.

With regard to enterprises, E. Bauer's conclusion can be interpreted as the need to constantly maintain the redundancy of energy, or more precisely, information, in certain structures, constantly spending relevant work on this, which is the task of engineering, which should i.e. scientific and technical knowledge to create devices, materials, organization of production processes and management of production processes and the activities of the enterprise as a whole.

Moreover, engineering should be provided not just by some kind of subdivision such as the former design bureaus (design bureaus), but be the ideology of development at all levels of production and enterprise management.

3 Problems of Sustainable Development of the Cyber-physical System

The development of intelligent technologies will lead to the fact that more and more functions that previously only a person could perform would be transferred to artificial intelligence systems. At the same time, as a result, unpredictable consequences can arise, including those that can be both positive and negatively affecting the development of the enterprise, or even dangerous. K. Schwab predicts that technologies open up new opportunities, but at the same time predict the opposite effect of the introduction of technologies, especially in the conditions of their combination and the emergence of an emergent effect.

According to K. Schwab, in its scale, volume and complexity, "The fourth industrial revolution have no analogs in the previous experience of mankind. New technologies unite the physical, informational and biological worlds, capable of creating, on the one hand, enormous opportunities, and on the other, a potential threat "[23]. At the same time, K. Schwab predicts that initially innovative technologies will be used separately, but "the turning point will soon come when they begin to develop, stratifying and strengthening each other, representing the interweaving of technologies from the world of physics, biology and digital realities" [23 , with. 9]. "Technologies will help to find solutions to many problems that we face today, but they themselves exacerbate some of these problems" [29, p. 273].

Despite the projected development of intelligent technologies, there are management functions such as targeting, planning, developing a system of values and criteria that ensure the sustainable development of an enterprise that currently cannot be automated, and some researchers who originally hoped to automate such intelligent functions, begin to doubt the possibility of their automation and in the future.

This allows us to hope that a person will keep control over the development of CPS, i.e. persons who develop management actions for the development of the enterprise.

A particular problem is the preservation of the sustainability of an enterprise when introducing technologies that are a special kind of “disruptive innovations” by K. Christensen [30], creating a situation of “creative destruction” by J. Schumpeter [31] and V. Zombart [32]. Therefore, they develop models for managing sustainable development of enterprises and organizations in the context of the introduction and use of emergent technologies (for example, [33, 34] and others).

It is also important to take into account that from the point of view of R. Akoff's classification [35, p. 33] in open information systems, both user elements and the system as a whole are targeted aspirations. The goals of creating such systems both at the network level as a whole and at the level of its elements are the desire to achieve the maximum increase in the integration of all types of resources and freedom of information exchange. In this case, there are various relationships between goal-oriented elements and between the elements and the system as a whole. Therefore, in a normally functioning organism, the purposefulness of individual components is subordinated to the purposefulness of the organism as a whole. At the same time, at the level of socio-economic systems, both the system as a whole and its elements are targeted, which leads to the problem of resolving contradictions between active elements (components) and the system as a whole.

Considering the development of CPS of enterprises (organizations) considered in managing the development of comparative analysis and selection of innovative technologies, taking into account their features, capabilities, usefulness and consequences of their implementation. This is beginning to be realized and models are being developed for the selection and management of the introduction of innovative technologies (for example, [36-38]), the training of personnel for work in the conditions of the new information environment [39]. When developing these models, methods and models of systems theory are used (for example, [40–43, etc.]).

4 Conclusion

The article presents the concept of engineering as the basis of the enterprise's cyber-physical system, understood in the original sense of the term engineering, i.e. not only as computer engineering (software for design, engineering analysis, consulting), but primarily as the use of scientific and technical knowledge to adopt innovative technologies, organization of production and management processes, taking into account the purpose and characteristics of a particular enterprise.

To substantiate the concept, a study is conducted on the development process of an enterprise when creating CPS. The concept of a cyber-physical system of an industrial enterprise has been adopted as a means that can: 1) ensure the emergence effect of the joint introduction of information and industrial technologies; 2) to resist undesirable results that may arise as a result of the interaction of technologies, based on the control of the physical element - man, persons, producing control actions for the development of the CPS enterprise.

The concept is based on the fact that the cyber-physical system of an enterprise is developed not as the use of disparate technologies, but as a system in which the inclusion of new technologies in the life cycle of an enterprise, integration of technologies and a physical element (decision makers on the choice and implementation of innovations) and is focused on the fact that it is the physical element that will retain the control functions, i.e. person.

Further development of the presented work involves the study of the forms and methods of using the idea of engineering, ensuring the development of the production process and the enterprise as a whole, based on scientific and technical knowledge, the development of criteria for assessing the effect of emergence as a result of integrating information and advanced industrial technologies. from the point of view of product quality, which significantly depends on the specific types and conditions of production processes.

For citations of references, we prefer the use of square brackets and consecutive numbers. Citations using labels or the author/year convention are also acceptable. The following bibliography provides a sample reference list with entries for journal articles [1], an LNCS chapter [2], a book [3], proceedings without editors [4], as well as a URL [5].

References

1. Chernyak Leonid. The Internet of Things: New Challenges and New Technologies // Open Systems. DBMS. 2013. No. 4. P. 14–18. URL: URL Electronic resource: http://www.osp.ru/os/2013/04/13035551
2. Cyber-physical system https://ru.wikipedia.org.
3. Lee E A. and Seshia S.A. Introduction to Embedded Systems. A Cyber-Physical Systems Approach, LeeSeshia.org, 2011.
4. Colombo A., Bangemann T. Industrial Cloud-based Cyber-physical Systems: The IMC-AESOP Approach. Cham Springer International Publishing, 2014. 45 p.
5. Kupriyanovskiy V.P., Namiot D.E., Sinyagov S.A. Cyber-physical systems as the basis of the digital economy // International Journal of Open Information Technologies ISSN: 2307-8162 vol. 4, no. 2, 2016. C. 18□25.
6. Dobrynin A.P. et al. Digital economy - various ways to efficiently apply technologies (BIM, PLM, CAD, IOT, Smart City, BIG DATA, and others) // International Journal of Open Information Technologies. 2016. Vol. 4. No. 1. P. 4□11.
7. Namiot D. On Big Data Processing Stream // International Journal of Open Information Technologies. 2015. Vol. 3. No. 8. S. 48-51.
8. Lee E.A. The Past, The Present and the Future of Cyber-Physical Systems: A Focus on Models. URL: https://citeweb.info/20150013436 (appeal date 2.04.2018) /
9. Lee, Edward (January 23, 2008). Cyber Physical Systems: Design Challeng-es. University of California, Berkeley Technical Report No. UCB / EECS-2008-8. Retrieved 2008-06-07.
10. Wolf W. Cyber-physical systems // Computer. - 2009. - no. 3. - pp. 88-89.
11. Heng S. Industry 4.0: Upgrading of Germany's Industrial Capabilities on the Horizon // Available at SSRN 2656608. - 2014

12. "NSF Workshop On Cyber-Physical Systems". Retrieved 2008-06-09.
13. Zhuge H. Cyber-physical Society, "The 1st Workshop on the Cyber Physical Society, in conjunction with the 6th International Conference on Semantics, Knowledge and Grids, Ningbo, China, 2010.
14. The Cyber-Physical Society website, http://www.knowledgegrid.net/~H.Zhuge/CPS.htm.
15. Zhuge H. Socio-Natural Thought Semantic Link Network: A Method of Semantic Networking in the Cyber Physical Society // Keynote at IEEE AINA 2010. , Australia, April 20–23, 2010.
16. Hu J. et al. A review of stimuli-responsive polymers for smart textile applications // Smart Materials and Structures. - 2012. - Т. 21. - №. 5. - p. 053001.
17. DRAFT NIST Big Data Interoperability Framework: Volume 4 April 2015.
18. Cyber-Phisical System. Driving force for innovation in mobility, healthy, energy and production. ACATECH 2011.
19. Living in networked world. Integrate research agenda Cyber-Physical Sys-tems (agenda CPS). ACATECH 2015.
20. German Indian Partnership for IT Systems. ACATECH 2014.
21. Industry 4.0 and Urban Development. The Case of India. ACATECH 2015.
22. Smarch service weilt. Recommendations for Strategic Initiatives web-based service for Busines. ACATECH 2015
23. Schwab K. The Fourth Industrial Revolution: Translation from English. M .: Publishing house "E", 2017. 208 p.
24. Masyutin S.A. Enterprise strategy in the transition to Industry 4.0 // PLM.pw ›2016/09 / The-6-Factors-of-Industry-4.0.html.
25. Atmojo, U.D., Vyatkin, V.A. Review on Programming Approaches for Dy-Namic Industrial Cyber-Physical Systems // Proceedings - IEEE 16th Inter-national Conference on Industrial Informatics, INDIN 2018.
26. Bertalanffy L. von. The general theory of systems: a critical review // Research on the general theory of systems. M .: Progress, 1969. P. 23-82.
27. Bauer E.S. Theoretical Biology. M. - L .: Izd. WIEM, 1935. - 206 p.
28. Schwab K., Davis T. Technologies of the Fourth Industrial Revolution. M .: Publishing house "E", 2018. 320 p.
29. Computer engineering: studies. manual / A.I. Borovkov [et al.]. - SPb. : Publishing House Polytechnic. University, 2012. - 93 p.
30. Christensen K. Innovator Dilemma: How do strong companies die because of new technologies? M .: Publishing house: Alpina Business Books, 2004.
31. Schumpeter J. Theory of Economic Development / Trans. from English M .: Progress, 1982.
32. Sombart V. Collected Works. Volume 3. Luxury and capitalism. War and capitalism. M .: Publishing House Vladimir Dal, 2008.
33. Problems of Sustainable Development of Socio-Economic Systems in the Implementation of Innovations / V.N. Volkova, A.V. Loginova, L.V. Cher-nenkaja, E.V. Romanova, Y.Y. Chernyy,. V.E. Sys-tems and Environments, Ergo 2018 3. 2018. P. 53-56.
34. Volkova V.N., Lankin V.E. The problem of sustainability of the socio-economic system in terms of the introduction of innovations of the fourth industrial revolution // Scientific and practical journal "Economics and Management: Problems and Solutions. 6, t. 7 (77). May 2018 Pp. 25 - 29.
35. Ackoff R.L. Management in the 21st Century: Corporate Transformation / R.L. Ackoff; per. from English F.P. Tarasenko. - Tomsk: Izdvo Tomsk University, 1006. 418 p.

36. Approach to comparative analysis and selection of technological innovations of the third and fourth industrial revolutions / V.N. Volkova, A.V.
37. Volkova V.N., Kudryavtseva A.S. Models for the management of innovative activities of industrial enterprises // Open Education. 2018; 22 (4): 64-73. https://doi.org/10.21686/1818-4243-2018-4-64-73.
38. Kudryavtseva A.S. Models for the management of industrial enterprises in the implementation of technological innovations // System analysis in design and management: Proceedings of the Intern. scientific and practical conf. Part 1. SPb .: Publishing house of the Polytechnic University, 2018. P. 389 - 398.
39. The impact of NBIC-technology development and engineering personnel management training. V.N. Volkova, V.N. Kozlov, A.E. Karlik, E.A. Iakovleva. Strategic Partnership of Hi-Tech Branches ...
40. Classification of methods and models in system analysis / V.N. Volkova, V.N. Kozlov, V.E. Mager, L.V. Chernenkaya // Soft Computing and Measuring (SCM), 2017 XX IEEE International Conference. P. 183-186.
41. Volkova V.N., Kozlov V.N., Efremov A.A. The contribution of the school "System Analysis in Design and Management" to the development of informatics, information systems and technologies // Scientific and practical journal "Applied Informatics" / Journal of applied informatics. Volume 13. Number 2 (74). 2018 March - April.
42. Modeling systems and processes: Practicum / V.N. Volkova, G.V. Gorelova, A.A. Efremov et al. / Ed. V.N. Volkova. M .: Yurayt Publishing House, 2016. 295 p.
43. Volkova V.N., Denisov A.A. Methods of organizing complex examinations. SPb .: Polytechnic University Publishing, St. Petersburg, 2010. 128 p.