Creation of cyber-physical systems based on basic structures in conditions of uncertainty

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Creation of cyber-physical systems based on basic structures in conditions of uncertainty

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Abstract. The article describes the processes of transformation of the basic structures of technical systems into cyber-physical systems based on the introduction of innovations. A distinctive feature of cyber-physical systems is the direct penetration of methods and means of cybernetics into controlled physical processes in order to intellectualize the system and minimize the influence of the “human factor”. The introduction of innovations occurs in conditions of insufficient information and is always associated with different types of uncertainty. Uncertainty disclosures are based on probabilistic models, fuzzy sets or using knowledge bases. The phased introduction of innovations allows for the reasonable allocation of resources. Basic structures are fundamental technological innovations, represented by functionally necessary and functionally sufficient structures of systems that control physical processes. The article describes the processes of transformation of the basic structures of systems into cyber-physical systems used in various physical environments - solid, liquid and gaseous. As examples, the automatic assembly line of printed circuit boards, the locating system for monitoring thermal networks by the method of monitoring insulation dampening, the system of catalytic neutralization of vehicle exhaust gases are considered. In these examples, the objects of activity are primary physical processes. An in-depth study of primary physical processes made it possible to obtain new informational possibilities for analyzing, interpreting and regulating the key parameters of the above systems based on computing resources.

1. Introduction
The processes of transformation of the basic structures of technical systems into cyber-physical systems (CPS) in accordance with the concept of "Industry 4.0" significantly change the methods of material production. Here, the basic structures are understood as the primary fundamental technological innovations, which are represented by the functionally necessary and functionally sufficient structures of the systems that control the physical processes. The basic structures are functionally necessary (FNS) and functionally-sufficient (FSS) structures [1]. The structure of the SFS is designated as a functionally necessary structure (FNS), designed to perform a defined class of the same purposes, functions, tasks, in which there is no kind of redundancy, and the minimum values of quality indicators from a given set forming an integral quality criterion are achieved. Functionally-sufficient structures (FSS) are characterized by the presence of some redundancy, which is permissible within the limits of given constraints, in this connection, the study of structures based on the coefficients of significance of its constituent elements acquires great importance. A distinctive feature of CPS is the direct penetration of methods and means of cybernetics into controlled physical processes in order to intellectualize the
system and minimize the influence of the “human factor”. The introduction of innovations, including the well-known components of Industry 4.0, takes place in conditions of insufficient information and is always associated with different types of uncertainty [2]. The basic concept of uncertainty comes from physics. Applied concepts related to the uncertainty of information are necessary for the formation and selection of innovations. Available or forecasted information is described in terms of probability theory. However, the fundamental difference between innovation activity lies precisely in the fact that probabilistic distributions of necessary quality indicators may be absent. This means that in some cases the use of probabilistic models will not be justified. This situation is described in the well-known work of FH Knight [3], where the main and fundamental difference between the concepts of risk and uncertainty lies in the fact that in some cases “risk” means a certain amount available for measurement, while in other cases it is something completely different. Further considerations of F H Knight and his numerous followers are reduced to the ability to conduct business in the context of disclosing uncertainty using probabilistic and related models at stages where information can be taken as reliable. At other stages, the disclosure of such uncertainty (it is called uncomputable) requires other approaches. The article assumes that the disclosure of uncertainties is performed on the basis of probabilistic models, fuzzy sets or using knowledge bases. Based on the justifications, a gradual introduction of innovations in the CPS and the allocation of resources are carried out. The article does not address the issues of classification of CPS. However, it was interesting to consider the processes of transformation of the basic structures of systems in CPS used in various physical media - solid, liquid and gaseous. As examples, an automatic line for the assembly of printed circuit boards [1], a locating system for monitoring thermal networks using the method of monitoring insulation dampening [4], a system for catalytic neutralization of vehicle exhaust [5] are considered. In these examples, the objects of activity are primary physical processes. An in-depth study of primary physical processes made it possible to obtain new informational possibilities for analyzing, interpreting and regulating the key parameters of the above systems based on computing resources.

2. CPS automatic assembly line of printed circuit boards

The basic structure for this example is defined by the SMEMA [6] standard. In-depth analysis of the processes of applying solder paste, installation of components, the soldering process revealed significant causes of non-conformities. The quality of electronic products is ensured by the introduction of 2D and 3D inspections at the stages of screen printing, control of soldered joints, 3D X-ray inspection. Interaction in the rank of M2M using IoT reduces the negative impact of the “human factor”. Problem issues under uncertainty are solved using DB and KB in the “Design for manufacturing” and “Production” stages. The mathematical model of processes based on Markov chains and the Kolmogorov equations [1]. All the probabilities of states on the basis of this model are as a functions of time, the volume of the batch produced and the intensity of the equipment loading. In terms of quality, these probabilities determine the estimates of non-conforming products when performing individual operations and final defect. Analysis of the causes of final defects is the basis for the introduction of technological innovations from the well-known components of Industry 4.0. For some indicators of quality, the determination of the required probability densities is unattainable. In this case, fuzzy estimates of quality indicators are used in the context of their dynamic changes in the tolerance field [7]. The combination of probabilistic and fuzzy estimates allows us to uncover uncertainties when achieving the quality of electronic products in a chain of life cycle processes.

3. CPS monitoring of heat networks

The basic structure of the heating network monitoring systems using the insulation dampening method with integrated signal conductors was developed by EMS A/S (Denmark) [8]. The introduction of innovations into the hardware and software has created conditions for more thorough monitoring of the parameters and the shape of the reflected signal of the reflectometer on the state of wetting of the metal of the heat pipe, leading to an accident. Formation and transmission to the operator of discrete signals on the status of heat networks ensures the up-to-date information about the state of facilities, databases.
and knowledge, support for management decisions. IoT, M2M, large amounts of data, cloud computing are used there. End-to-end digitalization of the system and work in real time when monitoring the processes of liquid penetration into the thermal insulation of the heat pipe create the conditions for taking into account all possible consequences. Controlling the dynamics of the pulse amplitude change in the tolerance field provides for the disclosure of uncertainty in the prediction of accidents on thermal networks.

4. CPS platinum catalyst
The basic structures of platinum catalysts are used to neutralize harmful vehicle emissions by converting oxides of nitrogen, carbon and residual hydrocarbons into nitrogen, harmless carbon dioxide and water [5]. The effectiveness of the neutralization process is achieved by controlling the heating of the catalyst depending on the concentration of harmful emissions [9]. The dependence of the concentration on temperature, the dynamics of the neutralization process and the consumption of platinum on the catalyst was estimated. The introduction of sensitive sensors, the Internet of things and optimal control allows to create CPS at the level of one car. Further development of CPS is provided in the M2M and MnM machine-to-machine interaction system in a stream of vehicles. The satellite system resources application creates the conditions for solving global nature-technogenic problems [10].

5. Phased optimization when creating a CPS in the face of uncertainty
Experience in creating the above examples of CPS showed the effectiveness of the step-by-step transformation of the basic structures by introducing methods and tools of cybernetics into controlled physical processes. Intellectualization of systems is achieved by introducing knowledge and technological innovations while assessing the effect and risks.

The disclosure of uncertainties at each stage of the life cycle depends on the availability of a priori information. Such information can be the probability distribution density. In this case, step-by-step optimization models [11] and Markov chains can serve as the basis for modeling process chains [12]. These models are applicable to the sequence of processes for collecting and processing analytical information in liquid and gaseous media.

Probability densities may not be known in case of technological innovations, introducing. In this case, fuzzy regulators with learning and self-learning become necessary. The addition of technological chains with an inter-machine interaction with IoT components and feedback allows to correct the values of critical parameters and increase the effectiveness of CPS. These processes are described by refined step-by-step models with feedbacks. A field or model experiment and analysis of the functioning of the basic structure are carried out. The values of critical parameters in the tolerance field are described in terms of fuzzy sets. To estimate the optimality, a multilinear function [11] can be used, which takes the form of an additive or multiplicative function depending on the set and interdependence of the indicators. Optimization seems to be purposeful phased implementation of technological innovations.

For uncertainties that are not computable according to [2], decision making is based on knowledge bases, where a “vector” is formed, suggesting the right choice. In essence, such a knowledge base is a model of a structured problem domain. The filling, structuring and training of such a DB is performed in the process of its constant updating [10].

6. Conclusion
The use of innovative methods and tools, including components I4.0 and computing resources, provides more advanced types of interaction between subsystems, self-tuning, adaptation, minimization of the human factor. Of particular importance is the deeper study of primary physical processes in a broad sense. The use of highly sensitive sensors based on nanotechnology in combination with IoT creates new opportunities for the analysis of liquid and gaseous media. In the field of electronic manufacturing, components and installation tools are constantly being improved. The examples considered in the article do not claim to cover the whole problem. A variety of options complicates the task of formation and selection. The article does not specifically address multi-criteria models that require special attention.
The use of such models will be directed:

- to optimize the structure of the CPS,
- to create a KB,
- to support management decisions.

Mathematical models and criteria are provided for assessing risks and new opportunities in comparison with basic structures in the conditions of insufficient information and statistical uncertainty. For the description of processes, Markov chains, fuzzy models of behavior of parameters, database were used. Estimates of the introduction of cyber-physical systems are based on a multi-criteria model with constraints.

References
[1] Korshunov G, Petrushevskaya A 2018 Modeling of digital manufacturing of electronics production and product quality assurance CEUR Workshop Proc. 2258 150-9
[2] Korshunov G 2018 Assessment of Risks and Capabilities in an Innovative Project Quality Managing Int. Scientific Conf. "Far East Con" (ISCFEC) Advances in Economics, Business and Management Research 47 657-60
[3] Knight F 1921 Risk, Uncertainty and Profit (Boston MA: Hart, Schaffner and Marx; Houghton Mifflin)
[4] Aleksandrov A and Korshunov G 2006 A device for determining the location of a defect in thermal insulation of a product pipeline Patent number 2287108 (RU)
[5] Korshunov G and Solnitsev R 2017 System catalytic neutralization control of combustion engines waste gases in mining technologies IOP Conf. Series: Earth and Environmental Science 87 657-60
[6] IPC-SMEMA-9851 http://www.ipc.org/html/IPC-SMEMA-9851.pdf
[7] Korshunov G, Smirnov V and Milova V 2019 Multi-criteria fuzzy model for system technical condition estimation at the life cycle stages IOP Conf. Series: MSE
[8] European monitoring systems http://www.ems-as.dk
[9] Solnitsev R, Korshunov G and Baranova O 2015 Closed System for Car Exhaust Emission Neutralization Control Information and Control Systems 2 (75) 37-42
[10] Solnitsev R, Ryzhov N, Korshunov G, Cho D and Paranichev A 2017 The Nature-Technogenic Control System. Design Information Maintenance 2017 XX Int. Conf. on Soft Computing and Measurements (SCM) pp 662-665
[11] Keeney R and Raiffa H 1976 Decisions with multiple objectives: Preferences and value tradeoffs (New York: Wiley)
[12] Korshunov G, Petrushevskaya A, Lipatnikov V and Smirnova M 2018 Development strategy and process models for phased automation of design and digital manufacturing IOP Conf. Series: Materials Science and Engineering 327 (2)