

Similarities and Differences Between the Technological Paradigms “Production System”, “Cyber-physical System” and “Cyber-physical Production System”

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Abstract—This article examines the terms "production system", "cyber-physical system" and "cyber-physical production system". The paper is a scientific investigation for the similarities and differences between them. Through systematic analysis and synthesis of the main content and structural characteristics of the terms "production system", "cyber-physical system" and "cyber-physical production system" their definitions are upgraded and refined. Criteria are highlighted according to which similarities and differences are synthesized, and through analysis similarities and differences are synthesized, conditioned by the definitions of the studied concepts. The results of the analysis indicate that from the point of view of production engineering, the cyber-physical production system integrates in its content and in its structure the specificity of the real-time production process and provides more reliable cyber protection, flexibility, efficiency and added value, compared to the other two concepts studied.

Keywords—production system, cyber-physical system, cyber-physical production system

I. INTRODUCTION

The advance of the new technologies and the challenges of Industry 4.0, as well as the permanent need to achieve ever more perceptible adaptability, efficiency and efficacy, leading to a higher added value of contemporary production, require the search of new solutions, which should integrate the real-life physical production systems [1, 2] and the achievements of the concepts for the Internet of things, for the large bulks of data, for the blockchain and cloud technologies [3, 4]. This is related to the fast penetration of the digital technologies in the real-life production process and the differentiation of a new type of systems – cyber-physical production ones, the architecture of which is based on physical and cyber elements. This, however, requires in-depth study of the concepts “cyber-physical system” and “production system”, which are the fundament of the concept “cyber-physical production system” [5].



Fig. 1. Common model for organization of the production system

On Fig. 1 are shown the basic model of production system. The first block Inputs included raw materials, machines, labour and etc., which are used in working/production process – manual, mechanical or robotic operations. The block outputs include finished goods, services, which are ready for the market.

The concepts "cyber-physical system" and "production system" are engineering concepts that have long had their place in the organization of automated processes, in reengineering, in the planning and design of production. [6] Industry 4.0 calls for the upgrading of these concepts and their integration into a new production-technological terminology, which has its undisputed place today in the design of the new high-tech smart productions. The concept of "cyber-physical production system" is a term that is the foundation of production engineering in the design and construction of not only smart factories, but also in the design and organization of individual smart production modules and processes in production business organizations.

A. Definitions of the Concept “Cyber-physical System”

The definition of the concept “cyber-physical system” requires a theoretical analysis of numerous definitions, which, in their diversity, outline the core nature and purpose of those structures integrated between the physical and cyber reality. Some of the main definitions of the concept can be drawn on this basis:

- ✓ smart systems, which include designed interacting networks of physical and digital components [7];
- ✓ physical and engineering systems, which operations are monitored, coordinated, controlled and integrated by a computational and communication core [8, 9, 10];
- ✓ integration of digital with physical processes, which behavior is determined both by the cyber and by the physical parts of the system, whereby embedded computers and networks monitor and control the physical processes with feedback circuits, where the physical processes influence the computations and vice-versa, which makes the system architecture forming links incessantly changing [11];
- ✓ a special type of system of subsystems, where numerous subsystems with various degrees of autonomy achieve

common goals while it is adapting to the particular environment [12];

- ✓ systems of collaborating computational elements that control physical entities, generally using feedback from sensors they monitor. A cyber-physical system is characterized by a physical asset, such as a machine, and its digital twin; basically a software model that mimics the behavior of the physical asset [13];
- ✓ integration is also developed and on the basis excellence in informatics, as Artificial Intelligence [3, 13] and blockchain [4, 14, 15];
- ✓ integration between the computational models and the physical components, while, at the same time, offering interoperability and sustainability [16];
- ✓ it has a 5-stage architecture, and, therefore, it is assumed in the literature that its structure is laid on the basis of the 5C Model – connection, conversion, cyber, cognition and configuration. [17, 18].

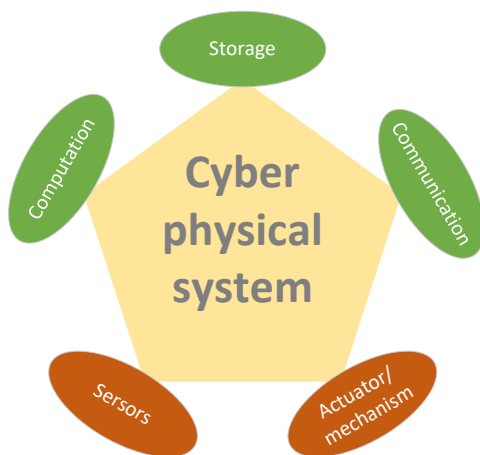


Fig. 2. Cyber – physical system

It can be summarized that the cyber-physical system comprises the cycle from gathering the raw data from the real-life production environment, through a multistage analysis and sending signals to real-life physical assets for carrying out physical operations in a specific temporal and spatial-physical aspect, to taking relevant to the reality management decisions and creating a sustainable value.

B. Definitions of the Concept “Production System”

The concept “production system” is widely popular in scientific literature. A brief theoretical review of its definitions shows that it is explicitly defined by the authors most often as:

- ✓ methods, procedure or arrangement which includes all functions required to accumulate (gather) the inputs, process or reprocess the inputs, and deliver the marketable output (goods) [19];
- ✓ manufacturing production in the form of goods from materials, resources, infrastructure and labour [19];
- ✓ organizational unity, having the task to bring the production process in line with the relevant organizational principles (forms), in view of achieving the best possible impact on the development of the economic effect;

- ✓ part of a business organization, determined by material and cash flow and subjected to the rational formation and organization of production through the activities: delivery of elemental factors, their transformation and the realization of a finished end product [20, 21].

On the basis of studying the definitions of the concept “production system”, it can be summarized that the production system:

- ✓ is a spatial arrangement of the workplaces in the production process, as well as structuring the production times and the organizational principle of timing. The spatial and temporal principles lay out the organizational forms in the production system;
- ✓ connects the rationality of the economic action with the value obtained at the output, which is higher than the one that entered at the input.

C. Definitions of the Concept “Cyber-physical Production System”

The concept “cyber-physical production system” has not been studied in depth yet. Nevertheless, there are some individual publications, where this concept is most often defined as follows:

- ✓ a technology, which has computational and physical capabilities, combined with the possibility for interaction between a human and a machine [22];
- ✓ implementation of elements from the technology of the cyber-physical systems into a production system [23];
- ✓ integration between a physical component – machines, tools, and a virtual component – a simulation model, data analysis, etc. into the production context, related to human resources [22];
- ✓ a system of subsystems of autonomous and cooperative elements, which connect with each other in respect to the situation on all the production levels – from processes through machines to production and logistic networks, whereby procuring the processes of decision making in real time, responding to unforeseen conditions and changes occurring over time [6];

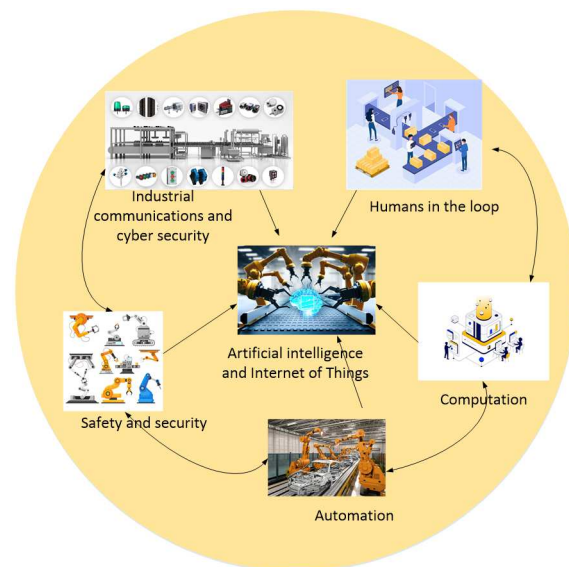


Fig. 3. Model for organization of the cyber-physical production system

- ✓ a system of simply isolated subsystems with complex interactions between them, comprised of autonomous and joint elements, including physical elements (robots, metal-working machines, etc.), cyber elements and people, which can be connected or independent from each other depending on the various situations, where the connection between the subsystems influences all the levels of the production life cycle, from the processes to logistics, and, therefore, the cyber-physical production systems are adaptable under unforeseen conditions and are able to autonomously take decisions or solve cognitive problems [24].

It can be summarized on the basis of the carried out theoretical review of the main definitions of the concept “cyber-physical production system” that this is a comparatively new term, the defining of which is still not definitive and standardized. Generally speaking, in larger terms, the cyber-physical production system can be defined as a cyber system and a real-life physical system connected with each other in a real-life production environment within a single and integral system.

II. METHODS

A. Main Objectives of the Study

Subject of analysis are the similarities and differences between them.

The objectives in the present article come down to:

- ✓ synthesizing upgraded and precisely specified definitions of the concepts, which are object of the analysis;
- ✓ systematic analysis and synthesis of the main content and structural characteristics of the concepts “production system”, “cyber-physical system” and “cyber-physical production system”;
- ✓ synthesis of the similarities and differences, determined by the definitions of the studied concepts.

B. Synthesis

On the basis of a systematic critical theoretical review of the most commonly used in literature definitions of the concepts “production system”, “cyber-physical system” and “cyber-physical production system” the definitions of those concepts are precisely specified and upgraded, and they become a working fundament of the analysis in respect to the similarities and differences in their content and structural nature.

On this basis, for the purposes of the present article, as working definitions are accepted the precisely specified and enriched definitions of the studied and analyzed concepts:

- ✓ The production system is a specific unity of interrelated and interdependent subsystems, methodology and toolset, which on the basis of automation of the production process, objectivize the nature of the production operations in view of achieving the strategic organizational goals. In a structural respect, the production system is based on the principles of the systematic approach and is mostly comprised of two subsystems (managing and managed – transforming one).

- ✓ The cyber-physical system connects into a network resources, information, objects and people. It is a specific unity between the real-life physical world and the digital one, while it is based on and integrates in itself the elements of the ecosystem “machine – human”, as well as of the blockchain technologies by interacting with the physical reality through the large data sets stored by it and their evaluation.
- ✓ The cyber-physical production system is a digital virtual-and-physical production model connecting the real-life production process like artificial intelligence, blockchain networks, strategic and production management, which controls the machines, sensor devices, robots, production capacities and etc..

C. Systematic Analysis

The examined concepts should be analyzed in respect to their content nature and architecture. Such an analysis will subsequently be a prerequisite for defining the particular similarities and differences between them.

Core aspects of the concept “production system”

The production system and its separate components should be in a state of dynamic equilibrium – to carry out precisely the planned production assignments. The choice of a product or service and the decisions for the scale of the capacity determine the nature and scale of the production system, while the synchronization between its separate subsystems depends on the maximum operability (the speed of implementing the decisions taken).

The production system, as a concept of production engineering, finds its expression in the relationship between the production factors – means of production, tools, staff and materials. This relationship is revealed through their designated parts in the value chain from manufacturing to freight forwarding.

The analysis of the adopted working definition indicates that the production system is inextricably linked to production engineering and determined by material and cash flows, and is subjected to the rational formation and organization of production through the activities: delivery of elemental factors, their transformation and realization of a finished end product. This, in particular, determines its resource aspect. It is expressed in the ceaseless delivery of material resources at the input of the engineering production system /input/, and, subsequently, in the transformation process of bringing out a product result with value /output/.

The main characteristics of the production system most generally find expression in:

- ✓ the object presented by the production process;
- ✓ the tasks, which should be solved in the subsystems of the production system;
- ✓ the methods enabling the solution of the problems and tasks in the engineering production system through creating and achieving organizational unity with the spatial structure during the running of the operations, and informational connection of the technical /technological – economic/ parameters;
- ✓ the results leading to achieving a better engineering design, technological and organizational structure of the

production processes, as well as to creating fully digital-aided assignments and smart manufacturing's.

From a manufacturing engineering perspective, the production system is a spatial arrangement of the workplaces in the production process, as well as structuring the production times and the type of the temporal running of the production process /the organizational principle of timing/. The spatial and temporal principles lay out the organizational forms in the engineering production system;

Pursuing an economic effect, the production systems connect the rationality of the economic action with the value obtained at the output, which is higher than the one that has entered at the input. A number of parameters determine the complexity of the engineering production systems, including:

- ✓ the quantity and assortment of the manufactured production;
- ✓ complexity of the production process;
- ✓ complexity of the external connections;
- ✓ probability characteristics and quantitative assessments of the input and output material flows.

Content-related specific features of the concept "cyber-physical system"

The content-related analysis of the concept "cyber-physical system" indicates that the hierarchical structural dependencies of the real-life production process are multiplied through it in a particular software model, based on connectivity and multilayer complex analysis. Thus, the cyber-physical system facilitates the designing in a digital environment of the authentic spatial and temporal structure of a particular object, as well as the simulation of processes typical for it.

From a engineering perspective, the cyber-physical systems enable connecting into a network resources, information, objects and people. There are based on and integrate in themselves the elements of the ecosystem "machine – human", as well as of the blockchain technologies by interacting with the physical reality through the large data sets stored by them and their evaluation.

In the cyber-physical system, the information about the strength, nature and intensity of the cycles, determining the object, is a raw data base, subject to monitoring, research and strategic analysis. Thus, on the basis of the incoming bits of information, drawn from the information bulk, there are control commands sent from the software model to the physical elements of a particular ecosystem.

On the basis of the global Internet network, the cyber-physical systems enable not only the identification of objects, production processes and capacities and organizational-and-production problems, but also their localization in real time. Moreover – they enable a permanent monitoring and management of the entire production and management process in the digital business organizations by facilitating the encompassing and closing of the complete cycle of the transformational process from the order to the delivery of a finished product.

Main characteristics of the concept "cyber-physical production system"

The analysis of the adopted working definition of the term "cyber-physical production system" indicates that, in its nature, it is:

- ✓ a engineering concept, where, most often, there are interacting physical components, blockchain networks, robotized systems and models based on artificial intelligence and sensor technologies;
- ✓ an innovative kind of engineering ecosystem of the type "human – machine – cyber device", which has its real-life physical manifestation, but also its virtual duplicate, corresponding to the real-life production system in respect to structure, organization, resource provision, goal setting, strategy;
- ✓ a production engineering system of a large amount of physical items, services and processes – on the one hand, and a system of sensors gathering data from the physical world, models and algorithms integrating various scenarios under revealed various conditions of the environment and interrelated cyber devices – on the other hand, unified in one single entity in view of fulfilling certain physical and cyber production assignments under particular prerequisites;
- ✓ a robotized model, which, through accurately described and simulated by machines algorithm, is capable of analyzing and assessing the surrounding environment, and of undertaking actions which enhance the possibility to achieve particular goals;
- ✓ a production engineering production process based on technologies, which rely on sensors, that try to reproduce human thinking through abstract symbols on a hierarchical, logical level, or which mimic the human brain through neurons and neural networks, organized in layers, connected with each other through simulated lines, where those neural networks have the capacity to upgrade the acquired knowledge by gathering experience and growing.

III. MAIN SIMILARITIES AND FUNDAMENTAL DIFFERENCES BETWEEN THE ANALYZED CONCEPTS

The synthesis of the similarities and differences between the concepts "production system", "cyber-physical system" and "cyber-physical production system" will be carried out according to criteria that are the same for the three concepts.

TABLE I. A COMPARISON OF STUDY CONCEPTS IN TERMS OF BENEFITS FOR MANUFACTURING ENGINEERING

Criteria	Production System	Cyber-physical System	Cyber-physical Production System
<i>Remote access</i>	+	+++	+++
<i>Cyber defence</i>	+	+++	+++
<i>Support Industry 4.0</i>	+	+++	+++
<i>Flexibility</i>	+	++	+++
<i>Digital sustainability</i>	+	+++	+++
<i>Just-in-time response</i>	+	+++	+++
<i>Efficiency</i>	++	++	+++
<i>Added value</i>	+	++	+++

^a. Legend: + Low; ++ Good; +++ Very Good

Highlighting the similarities and differences between the studied concepts requires their assessment from the point of view of critical criteria for production engineering. (Table I).

That enables the maximum possible objective analyzing of the concepts, and on that basis, synthesizing the respective common and diverse characteristics.

A. Main Similarities

The similarities between the studied concepts have been brought forward on the basis of the following criteria:

- ✓ nature;
- ✓ reasons generating them;
- ✓ factors determining them;
- ✓ interaction with the real-life environment;
- ✓ results.

In respect to their nature, the three concepts are interrelated and interdependent in the content-related aspect. All the three concepts are based on the principles of the systematic approach, they use a common toolset, with a certain data base, they are related to the implementation of certain processes, where objects of control are the main areas of management. That also determines their relationship with management as a process, moreover, that according to their definitions, subject to control are the resources, the internal and external environment, the management processes and the obtained results.

At the same time, the production system, the cyber-physical system and the cyber-physical production system pursue a common goal – the optimization of a particular physical system and achieving maximum efficient results. They are based on one and the same principles of the organization of the activities, where control plays the main role.

The production system, just as well as the cyber-physical system and the cyber-physical production system permanently upgrade and enrich the incoming information depending on the changes in the organizational system and its environment. They have at their disposal multipurpose, multi-aspect information available ahead of the change, containing a forecast about the future course of the processes, for justifying the goals, for elaborating plans for the development of a structural and functional organization.

All the three studied concepts set efficiency and efficacy as goals. In respect to the reasons, which generate them, the production system, as well as the cyber-physical system and the cyber-physical production system interact through their subsystems with a particular physical environment; they are focused on the fulfillment of particular tasks, serving the goal and are related to the dynamic changes in the environment. Therefore, as major reasons determining them can be synthesized:

- ✓ the physical environment;
- ✓ the availability of tasks for implementation;
- ✓ the unpredictability of the environment.

The factors determining the production system, the cyber-physical system and the cyber-physical production

system are the main factors of the environment, nevertheless whether the latter is a digital or a physical one.

According to the criterion interaction with the real-life physical environment, all the three concepts assume in their essential characteristics two fundamentals – calculation of a particular information basis and upgrading the qualitative characteristics of the processes in the physical space. In this respect, the specific manifestation of the relation of the analyzed systems with the real-life environment finds its expression in:

- ✓ obtaining information from the real-life physical environment, which is used for comparison with another type of information, or with data acquired in another time period;
- ✓ improving the processes in the real-life physical environment.

According to the criterion results, with all the three concepts the efficiency is based on regulation and control, where, if necessary, corrective measures shall be undertaken in respect to the goals, plans, strategies and operational work of the subsystems of the production system, the cyber-physical system and the cyber-physical production system, as well as of their organizational systems, processes and functional areas, investments and funds.

B. Main Differences

Just like the similarities, the differences are also studied, analyzed and synthesized on the basis of criteria that are the same for the three concepts. Quantitative, qualitative, functional and content-related differences are searched on this basis in the studied concepts.

In respect to the quantitative differences, the broadest concept is the cyber-physical production system, which contains elements from both the cyber-physical system and the production one.

The qualitative differences between the three concepts find their expression in their structural organization, characteristic and content.

The organization with the production system is determined by two subsystems – managing and managed. The cyber-physical system has architecture of five levels – a smart level, a level for converting the information, a cyber level, a cognitive level and a configuration level. The organizational unity of the cyber-physical production system includes six subsystems – a real-life production system, a sensor-smart subsystem, an informational subsystem, a cyber subsystem, a smart subsystem, a managing and feedback subsystem.

The three concepts have different essential characteristics. With the production subsystem the content-related aspect comprises only the real-life physical system, while with the cyber-physical and the cyber-physical production system there is integration of two spaces – a physical and a cyber one. At the same time, the cyber-physical production system contains in itself also the core elements of the production system, however, the cyber-physical system does not have that feature.

The functional differences are related to the designation of the three studied concepts. The main function of the production system is the transformation of the incoming

resource streams into a finished product. The cyber-physical system is focused on correlating a particular physical subsystem with the digital environment, whereby it influences and manages the physical one. The cyber-physical production system builds an image – twin of the real-life production system in a cyber environment, and, on this basis facilitates and manages the taking of specific decisions, according to certain parameters, criteria and goals.

The content-related differences are primarily related to the organization of the researched systems. The production system sets as a goal the transformation of the resources into finished production. The cyber-physical system interacts with the physical reality by storing large sets of data and their evaluation, while procuring that through the ecosystem “machine – human” and the blockchain technologies. The cyber-physical production system connects the real-life production process and its information flows with a simulated, virtual production model, which is identical with the real-life one.

IV. DISCUSSION

As a result of the conducted study can be summarize that the production system, the cyber-physical system and the cyber-physical production system are: social units, since they are purposefully structured systems with the active participation of the human resources; an organizational-and-economic unity, since they are tools, whereby certain economic results are achieved; a engineering technical unity, since they are logical systems and integrate in themselves technologies and innovations; determined by horizontal and vertical distribution of labour, since they determine a combination of activities with the task to replace the efforts and the knowledge of one single individual with the more specialized efforts and knowledge of a great number of people; they have a management unit, which has as an object: all the processes, which run in them.

The production system, the cyber-physical system and the cyber-physical production system: have primarily qualitative, functional and content-related differences, which results in the difference in their economic efficiency and added value; serve various hierarchical and functional levels of the socio-economic sector; require different investments and resources for their implementation.

V. CONCLUSION

Taking into account the specifics and requirements of production engineering, the author generates the following concrete main conclusions:

- ✓ An engineered production system does not provide reliable remote access, effective cyber defense and digital resilience options. In it, the possibilities to react to changes in the environment are less effective compared to the possibilities provided by the cyber-physical system and the cyber-physical production system.
- ✓ The cyber-physical system is a reliable tool in the conditions of Industry 4.0, but it does not reflect the specifics of the engineering-production process and its requirements. In this aspect, it can be said that it does not provide the flexibility, efficiency and added value needed for modern smart production.

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