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ANALYSIS OF POTENTIAL OPPORTUNITIES AND RATIONALE OF CYBER-PHYSICAL SYSTEMS FOR MINING AND METALLURGICAL COMPLEX

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Abstract. Overview of general Cyber-Physical Systems (CPS) and technologies, analysis of potential possibilities for their application in the field of mining and metallurgical enterprises in Ukraine. The research objective is to analyze the possibilities of modern cyber-physical systems and other innovative approaches in the structure as a part of the concept "Industry 4.0" to improve the efficiency and competitiveness of domestic enterprises of mining-metallurgical complex (MMC). By applying the system analysis are investigated the main process stages and TP of domestic enterprises, identified promising areas for the implementation of the "unmanned production" on the basis of CPS. The obtained results can be applied for the implementation of projects intellectual production control. Showed the modern tendency of creating a "smart production", "smart products'', ''smart production methods" based on the concept of "Industry 4.0". Presented a number of business processes and technological processes, automation of which is widely highlighted in the concept of "Industry 4.0". It is primary and secondary production, logistics, marketing, procurement, maintenance control. Studied the implementation of intelligent maintenance control system on the basis of CPS and other promising approaches to the concept of "Industry 4.0" in terms of large mining companies (such as Mining Enterprise and steel company "Metinvest Ukraine", "Arcelor Mittal Kryvyi Rih", etc.).

Key words: Cyber-Physical Systems (CPS), Industry 4.0, Smart Factory, Key Performance Indicator (KPI).

Introduction. Mining and metallurgical complex (MMC) in Ukraine is the leading branch of Ukrainian economy, which provides more than 20% of GDP and about 30-40% of export revenues of the country [1]. It is expected this trend to be continued in the future in the short and medium term. However, in this industry in recent decades has accumulated a number of problems that negatively affect the competitiveness of domestic enterprises in the world market. These are primarily obsolete assets (depreciation sometimes up to 7090%), technology, features of a raw-material base, ecology, and extremely low energy efficiency. So, for example, in terms of specific energy consumption per unit of finished product is spent on average 2-3 times more energy than European enterprises, USA, Japan, South Korea, etc. [2]. So in order to correct the negative tendencies of development of domestic MMC is needed highly effective innovation.

The analysis of industrial development strategies of the most developed countries of the world shows the modern tendency of creating a "smart production" (smart factory, Fig.1), "smart products'', ''smart production methods" based on the concept of "Industry 4.0" (or the 4th industrial revolution, Fig.2). The idea of this concept was formulated in 2006 in Hannover (Germany), and after several years became a promising program of industrial development in Germany to 2030 approved by the government of that country [3]. To date, most of the world's largest corporations (e.g. Siemens, Bosch, Schneider Electric, RollsRoyce, Trumpf, Dassault Systèmes, etc.) have declared their active participation in the implementation of this concept in their projects [4].

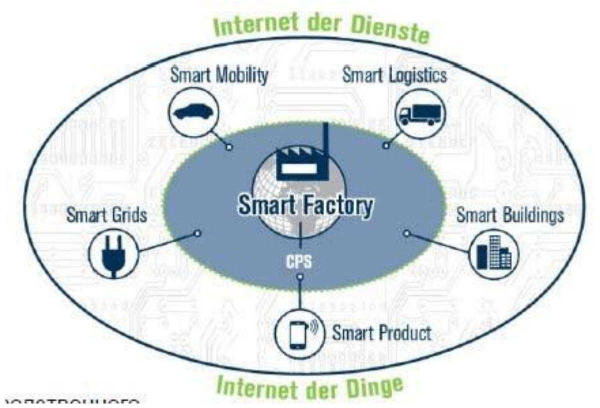

Figure 1. Typical structure of Smart Factory

It is believed that the first industrial revolution (Fig. 2) took place thanks to the steam engine, dramatically increasing labor productivity in the 19th century. The second one was marked by mass production in the early 20th century through the use of electricity. The third revolution can be considered as intermediate and attributed to it industrial robots and automation since the information technology and industry. This early 1970s. Respectively, the fourth industrial dramatically increased labor productivity and, revolution means the emergence of a fully digital consequently, production efficiency, industry based on mutual penetration of competitiveness, etc.

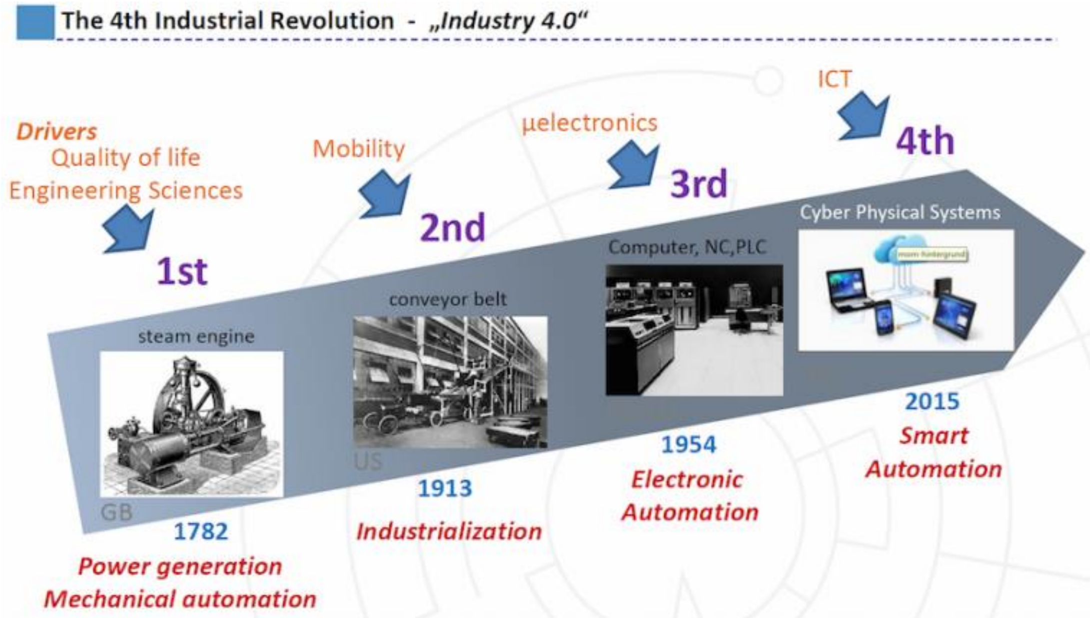

Figure 2. Evolution of scientific and technological progress

Cyber-physical systems (CPS) also belong to the fourth industrial revolution (Fig. 2). It is believed that in the future such intelligent systems will completely replace human labor. This is especially true of hazardous industries, which are in the fullest extent can be attributed to MMC. Our country has a fairly large industrial and scientific potential, and, therefore, cannot be outside this process. Therefore, the aim and objectives of this article are analysis of possibilities of modern CPS and other innovative approaches in the structure of the concept "Industry 4.0", to improve the efficiency and competitiveness of domestic enterprises of mining and metallurgical complex (MMC). Objects of research are the basic limits and the technological processes as a perspective area of the implementation of "unmanned production" on the basis of CPS [5-7].

Materials and Methods. You can list key technological trends underlying cyber-physical systems (fig. 3). Isolated they are already used in different areas, but being integrated into a single unit, they change existing relationships between producers, suppliers and customers and between man and machine.

Big data and Analytics. A collection and a comprehensive assessment of data from different sources will become a standard for decisionmaking in real-time.

Autonomous robots. Industrial robots can already perform quite complex operations, but the computer vision systems will allow robots to interact with each other and automatically adjust their actions, and people can sit next to them, to influence them and it will be safe.

Modeling and simulation. Engineers have already been using 3D modeling in the design stage of products or processes. In the future, big data technologies allow to use different simulators in real time. For example, in the production stage the operator will be able to virtually simulate the physical process taking into account the available raw materials and people, and thereby to reduce the setup time of equipment and increase quality.

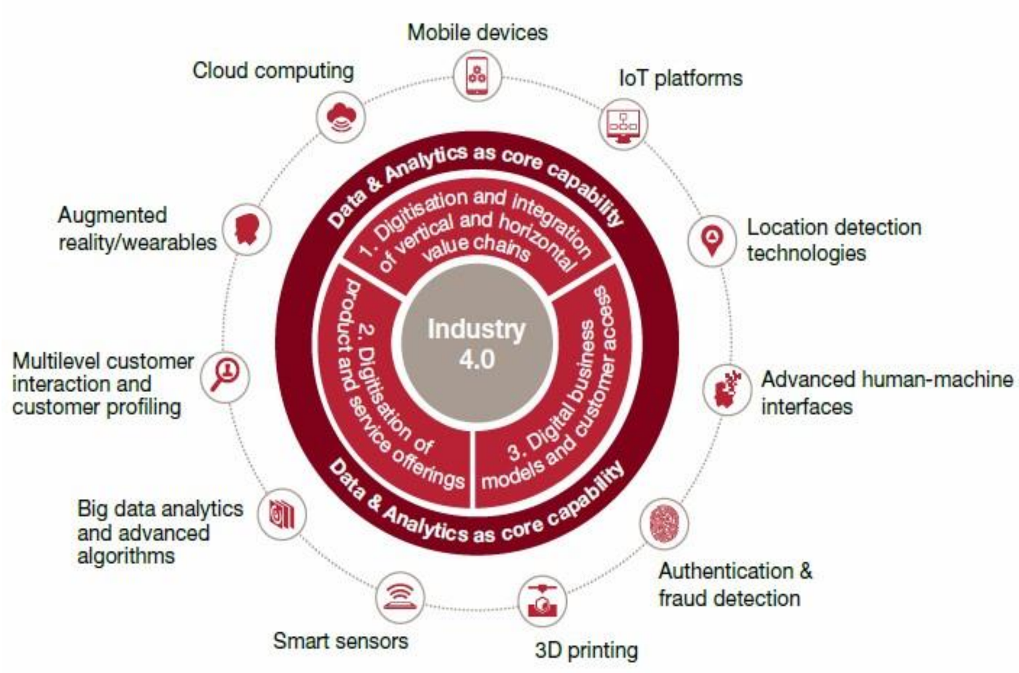

Figure 3. Technologies of Industry 4.0

Cloud computing will require a better system integration, both horizontal between suppliers and customers, and vertical between various functions and operations. To create a platform for collaboration and data exchange between geographically distributed partners enable cloud technology.

Internet of things. Sensors and sensor readings generally fall into the central control system of the production process, and even at this level are taken decisions. In the future, the possibilities, offered by embedded systems, will allow devices to communicate with each other and decentralize decision -making. For example, you can use RFID (Radio-frequency identification) tags for semi-automated production line, reading the label to decide for itself (in real time), what operation to apply to one or the other semis.

Information security. Many companies use the system of management and production based on traditional technology or not having access to the Internet. However, the expansion of relations with partners, the use open standards and protocols dramatically increase the risk of information security. For the protection of industrial systems are required not only highquality and secure communications, but system account management and access control (Identity and Access Management).

3D printing. 3D printers are mainly used for prototyping or individual components. In the future, a 3D printer can be widely used for the production of small batches of specialized products. Its design advantages and the decentralized nature of production will reduce transportation costs and warehouse stocks.

Augmented reality. Technology is at the early stages of its development, but in the future will allow employees to accelerate the adoption of solutions. For example, an employee can receive instructions on how to repair or replace a broken part in a production system, when he looks at it through the glasses of augmented reality.

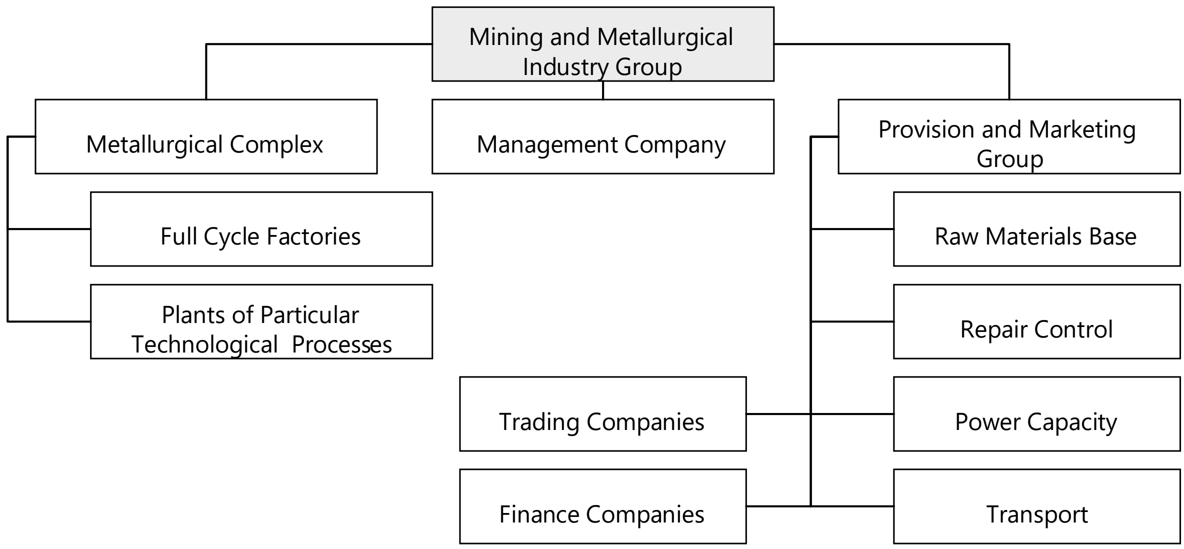

Figure 4. Typical organizational structure of enterprises and industrial holdings of mining and metallurgical industry in Ukraine

Let us analyze the prospects of application of the above approaches in the context of domestic mining companies. The basis of the latter is mining and processing enterprises (MPE) and the steel mills. Fig.4 shows a typical organizational and production structure of these enterprises and holdings in Ukraine.

Analysis of this organizational structure shows the presence of a number of business processes and the technological processes, automation of which is widely represented in the concept of "Industry 4.0". First of all, it is primary and secondary production, logistics, marketing, procurement, maintenance control etc. Let us make a feasibility study for the implementation of intelligent maintenance control system on the basis of CPS and other promising approaches to the concept of "Industry 4.0" in terms of large mining companies (such as Mining Enterprise and/or steel company "Metinvest Ukraine", "Arcelor Mittal Kryvyi Rih", etc.). For the calculations we use a common methodology based on KPI (Key Performance Indicator) [8]. According to this method in order to calculate the performance indicators for the enterprise or production, it is necessary to analyze these items:

1. The consumption of raw material per day.

2. The volume of raw materials in warehouses and in an incomplete form.

3. The actual productivity.

4. The cost of storing finished products.

5. The amount of other expenses.

6. The required funds for the repair and maintenance of equipment.

According to the method described in ISO 22400 [9], in the process of further calculations should be used the following dependencies for the above indicators:

$$IndexKPI = \frac{Fact - Base}{Plan - Base} \quad (1)$$

$$KRes(\%) = \sum_{i=1}^{N} IndexKPI_i W_i \quad (2)$$

where IndexKPI - the value of the efficiency index for the selected random process stages; Fact, Plan, Base - the corresponding values of the adopted indicators on the articles 1-6 (actual, planned, base); KRes - final calculation index of the innovation efficiency; i - number of process stage; N - the number of analyzed stages.

Results. The calculations of Key Performance Indicators of the intelligent maintenance control project with the use of CPS [10] on the example of a private enterprise "ArcelorMittal Kryvyi Rih" (AMKR). Estimated by experts each of the components of this project provides some savings (Fig. 5).

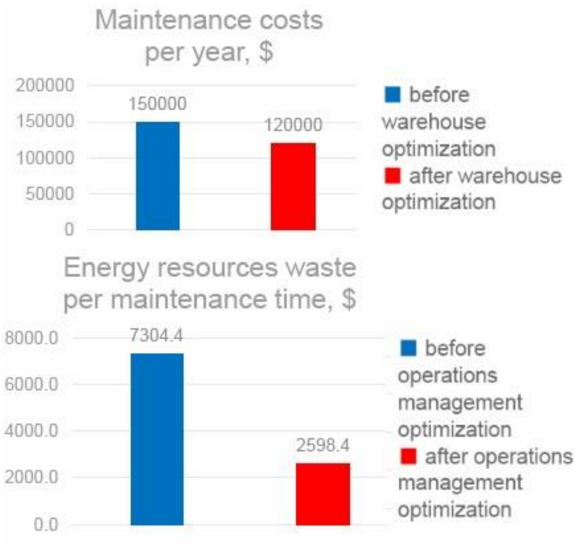

Figure 5. Expected economic benefits in the implementation of intelligent maintenance control in terms of AMKR (A – savings on the purchase of spare parts due to optimization of the warehouse; B – reducing idle resources through streamlined work processes and faster maintenance of measuring equipment)

The main components of such a system include:

1. "Smart warehouse" is an intelligent CPS to optimize the assortment of parts, number of parts and devices. Implementation will reduce the number of required warehouses from 10% to 5%, therefore, will decrease the storage costs. To calculate the efficiency, we use KPI – "Storage and transport relation of the loss" (paragraph 8.28 ISO 22400).

2. Workplaces, operations management and intelligent CPS transportation will reduce the time of maintenance and repair to 24 hours. For example, to date, in AMKR this time is 170 hours. To calculate the efficiency of the use of KPI "Efficiency" (paragraph 8.9 of ISO 22400).

Fig. 6 shows the expected estimate indicators of economic efficiency by the above procedure. Similar results can be obtained for other technological processes.

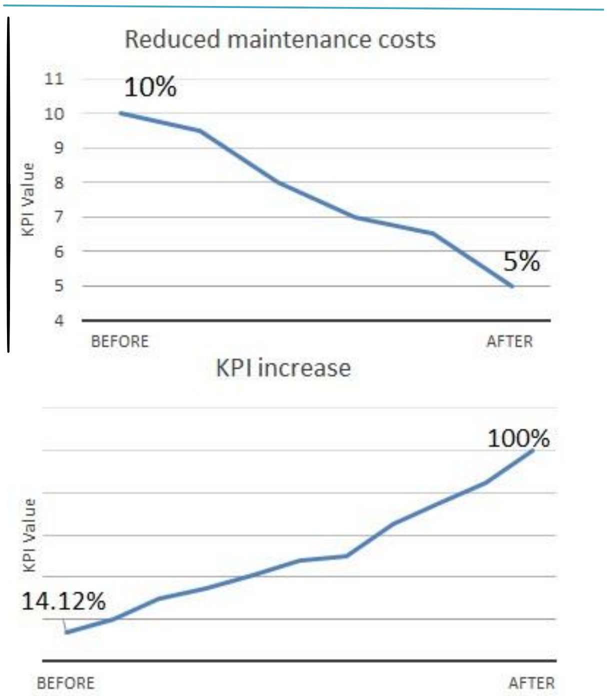

Figure 6. Expected economic performance after project implementation

Conclusions. On the above we can conclude that the implementation of innovative projects "smart'' (Smart Factory) with CPS based on modern scientific concept of Industry 4.0 has significant potential for growth of the competitiveness of domestic mining companies. So produced estimates of key performance indicators for such enterprises based on the ISO 22400 methodology demonstrate the reserves for optimization of KPI values in the range of 5-80%.

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