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Smart Manufacturing as a framework for Smart Mining

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Abstract

Based on the analogy between manufacturing and mining (i.e. ore 'production'), smart mining has four dimensions: (i) advanced digital-oriented technologies (such as Cloud computing and the Internet of things) with automated Cyber-Physical Systems (CPSs), adaptable production processes (dependent on working conditions) and production volume control (with optimal resource consumption); (ii) smart maintenance of CPSs; (iii) new ways for workers to perform their activities, using advanced digital-oriented technologies; and (iv) smart supply-chain (procurement of materials and spare parts / products delivery). This paper presents a case study on the smart mining approach implemented at a coal mining system in Serbia.

Keywords: Smart manufacturing; Smart mining; Analogy; Case study;

1. Introduction

Industry 4.0 (I4.0) is an intensive digital transformation, initially of production (since 2011) and other industries nowadays in a connected environment of data, people, processes, services, systems and the Internet of Things (IoT) – with the generation and utilization of information that can be applied as a way and means for achieving smart industry and ecosystems, based on industrial innovation and online cooperation of producers, buyers and suppliers. Nowadays, I4.0 is spreading to almost all areas of industry and science, but also to the non-industrial sector, i.e. medicine, dentistry, food production, entertainment industry etc. Taking into account that green energy and efficient power production are among key priorities of the 21st century science, the implementation of I4.0 principles in mining is very important as it can achieve higher reliability of mining machinery, lower ore production costs, higher efficiency and significant decrease of environmental pollution. That is why the concept of 'Smart mines' (SM) is being developed and constantly improved – with its place among other smart ecosystems shown in Figure 1 [1]. In the same figure, the relations between smart ecosystems as well as the main principles and levels of operability of I4.0 are also presented – in order to provide a better understanding of SM in the context of I4.0.

The main goal of this paper is to present one of the ways for successful implementation of the I4.0 in mining and related industries. In order to achieve this goal, the authors have developed three models which could be used as a basis for further implementation of I4.0 in mining: the Condition maintenance I4.0 model, the Cyber-Physical model of surface machinery exploitation management (control) and the Enterprise Resource Planning (ERP) model architecture – which is already implemented at the open-pit coal mine 'Drmno', Serbia.

I4.0, a German strategic initiative, is aimed at creating intelligent factories in which production technologies are

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upgraded, transformed, and connected into Cyber Physical Systems (CPS), IoT and Cloud Computing (CC) [2-5].

The essence of the I4.0 concept application is work on four levels of operability (operational, system, technical and semantic/virtual) and five principles, realizing smart models: factories, networks, cities, open pit (surface) mines, etc., using technologies which support I4.0 in practice [5], encompassing six areas and 42 elements that today make up the full concept of I4.0. On the other hand, our research in the area of application of the I4.0 concept in Small and Medium Enterprises (SMEs), shows that for them this concept contains between 18 and 24 elements, depending on its activity.

If we look further at the I4.0 model, it can be concluded that it is a methodology for generating the transformation of production (even in surface mines), dominated by machines (excavators) into digital production (mining), using CPS, CC, Big Data Analysis (BDA), Machine-Machine interface (M2M), ERP and Business Intelligence, IoT, Augmented Reality (AR), simulation, virtual manufacturing and intelligent robotics.

All this enables additional functions: system monitoring and diagnostics, environmental sustainability, resource saving and system efficiency [6], which is extremely important for the application of this concept in mining [7-10].

Taking into account the previously listed facts, in the following chapters, the developed I4.0 model for open-pit (surface) mining is presented in detail, with focus on the three developed submodules: the Condition maintenance I4.0 model, the Cyber-Physical model of surface machinery exploitation management and the ERP model. The main conclusions and guidelines for future research in the relevant field of science are presented in the final Chapter, as well as the important remarks regarding the current state of the I4.0 at the local and regional level (in the Republic of Serbia).

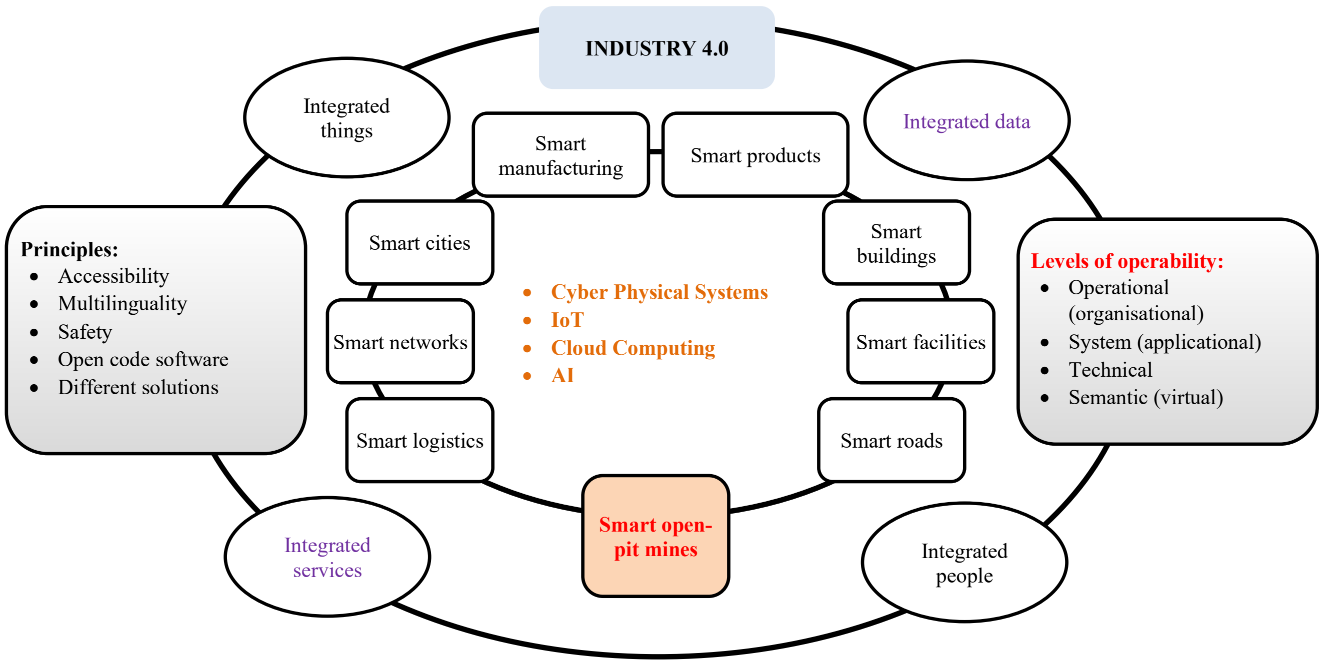

Fig. 1. Framework and structure of the I4.0 concept (adapted according to [3])

2. Industry 4.0 model for open-pit (surface) mining

Starting from the current level of the computer-based model for planning and managing the operation of auxiliary machinery at the surface coal mine "Drmno" [11], the research model according to the I4.0 concept for this particular case is shown in Figure 2 [3]. It includes two approaches: (i) development and implementation of maintenance models for heavy machinery, such as CPS, and (ii) planning and management of maintenance resources using the ERP model for I4.0.

Thus, like in the example in Figure 2, the condition maintenance is shown as the most vital module of this concept. It is designed and developed based on the model of engineering problem solving in this area, giving answers / solutions to the following questions: why (parameters of normal operation) – what (deviation from the prescribed value) – where (machine structure) – how (maintenance technology).

The answer to the last question is the application of the I4.0 model, which is shown in Figure 2, through four levels. The essence is at the last level – processes, on the line following the elements of machine systems of auxiliary mechanization machinery in operation, which creates an automated system for planning and monitoring its operation.

The scientific contribution of this approach is that the general I4.0 model based on the integration and connection of CPS, IoT and CC, methods of analogy, analysis and synthesis, for surface mining, is designed and applied in order to improve processes in a new way, in comparison to previous approaches based on the application of computer-based information systems (which, as a rule, work off-line, with the assistance of engineers / maintenance planners).

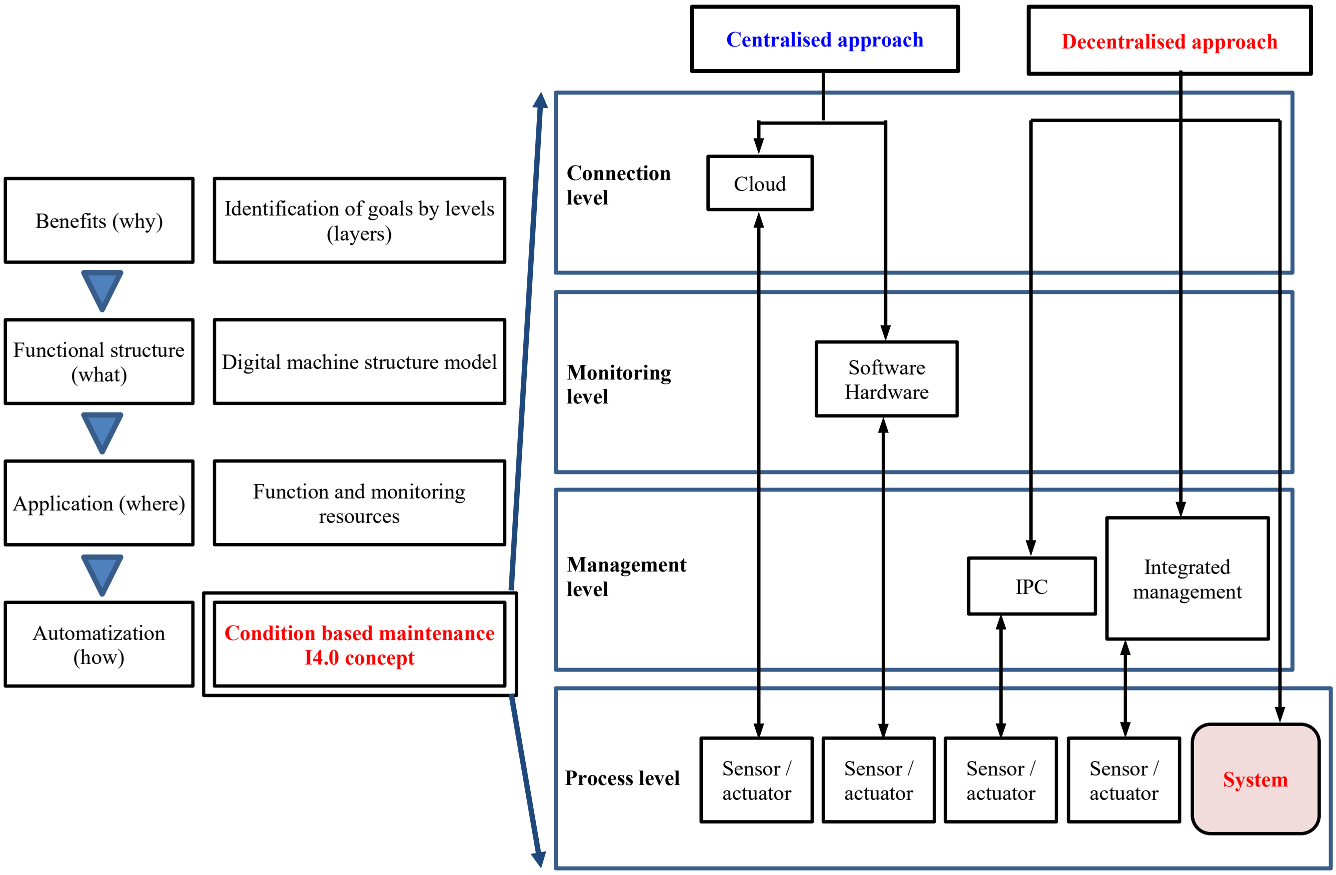

Fig. 2. Condition maintenance I4.0 model (adapted according to [3])

In this way, this model for surface mines includes the following main elements of the I4.0 concept: CPS, industrial IoT, CC, BDA, horizontal and vertical integration, and simulation. All the above facts refer to the application of the concept of I4.0 in one technological system, i.e., open pit mining. When these issues are extended to supply or sales chains or product life, new problems and challenges are posed to the table, covered by the ERP model. This approach, with the elements listed above, was the basis for designing the I4.0 model for the Drmno surface coal mine. A cyber physical model for controlling the operation of surface machinery is shown in Figure 3.

It has two levels: physical (includes machine and computer-based systems for execution and control of processes in this mine) and virtual part, which includes software systems and applied models for planning and control of processes that perform the physical elements of the model. The whole system includes four modules: M1 – knowledge base for operation and maintenance, M2 – intelligent analysis and synthesis based on the application of Schell intelligent agent for these purposes, M3 – machine system of auxiliary machinery with its HW / SW structure (M3.1), and M4 – large data set analysis and reporting agent.

According to the developed Cyber-Physical model of surface machinery exploitation management, in the module M1, the Data and Instructions, supported by the Information system and SaaS, are delivered to the Knowledge base, where availability and readiness of data must be provided in order to secure successful planned maintenance, spare parts delivering in time and appropriate machine maintenance. Based on the knowledge base (module M1), reasoning and conclusions could be made in module M2, based on Machine learning models (intelligent data analysis and synthesis) and the support of SaaS. M3 module provides management of auxiliary machinery at the open pit mine – where decisions could be made based on the conclusions of module M2. Module M3 is connected with the physical part of the Cyber-Physical model of surface machinery (sub-module M3.1) by the Machine system structure and Control units, where different sensors monitor values of variables important for maintenance quality assessment (such as: wear of machine parts, the level of fuel and oil, state of mechanical parts etc.), allowing maintenance afterwards (if and when necessary). Data from module M3 are transferred to module M4 where methods for Big data analysis are implemented in order to provide relevant information for the preparation of Reports, supported by the Cloud computing and SaaS.

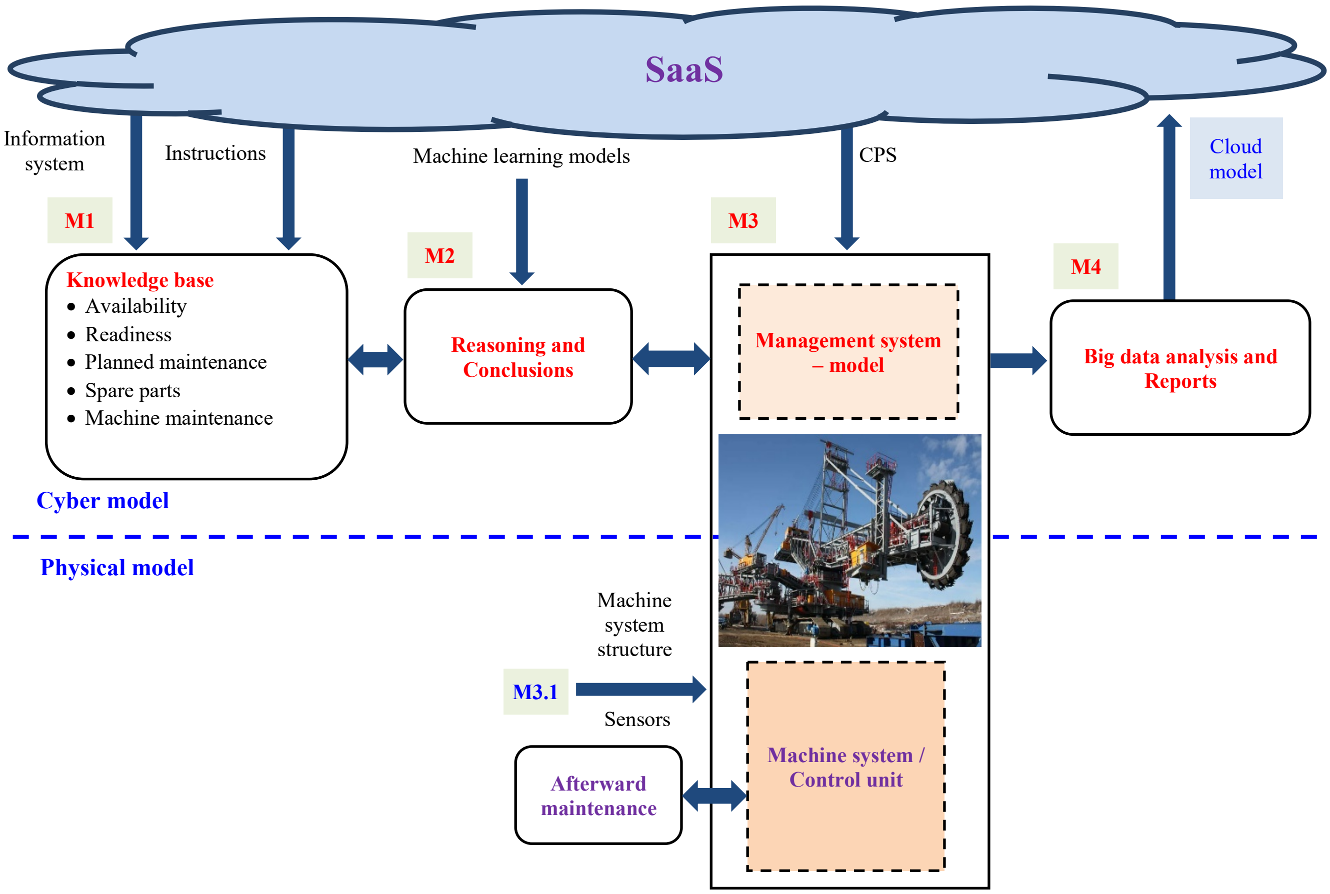

Fig. 3. Cyber-Physical model of surface machinery exploitation management (control)

2.1. ERP model for surface mining

Planning and management of maintenance resources at the surface mine in this concept is performed according to the ERP model [13]. The model was tested in this research and represents an upgrade of the existing information and communication system (ICSIS/ICT), applied at the surface mine 'Drmno', as shown in Figure 4. Real production at the surface mine, data on operation and maintenance are generated, through work orders, downtime maps, maintenance plans, inspection of spare parts stocks, etc. Based on the digital twins' model, which is connected to the real world through agent technology, for each agent the following aspects were defined: identification, authorization, configuration, capacity, status and metadata.

The data warehouse on the cloud (Service as a Software model – SaaS model) is an information center that stores and exchanges all production data from the mine. The Data Analysis Center creates, stores, retrieves, and investigates the uncertainty model, using machine learning models, statistical, or stochastic concepts, based on the mathematical functions needed to create data-driven models, provided by the ERP model concept. Each agent takes such models through intermediaries and decides on predictive operations and controls, based on the results that the models give.

The production application at the mine could include, as appropriate, applications such as Computer-Aided Design (CAD), Computer-Aided Quality Assurance (CAQ) and ERP systems. These applications communicate with the platform through their application interfaces, as they ultimately monitor and manage all activities and events taking place at the surface mine. An agent manager seeks out the right agents and manages them throughout their life cycles.

The data manager manages the master data as well as the life cycle and quality of the raw data. The work manager controls the workflows of the automation of the tasks performed on the platform, manages the rules designed to adequately manage the workflow and is involved in the presentation of the model. The security controller protects against computer viruses and hacking, and also controls electronic authorization and authentication, because data and the models that contain production experience and knowledge are valuable and, therefore, must be protected.

Some base concepts and technologies such as IoT and Big Data have been introduced in TE-KO to a certain extent in the last decade, bringing closer the idea of Smart Mining. More specifically, a system collecting data such as machine positions, engine operating time, fuel level etc. from machine sensors via GPS/GPRS has encompassed all machinery for auxiliary operations (e.g., bulldozers, backhoe loaders, graders, etc.) and some of the machinery for basic operations (e.g., bucket-wheel excavators, dragline excavators).

As for the environment-related data, PM10 was measured in several locations. Other environment-related data such as temperature, SO2 and P2.5 were collected and analyzed both outdoor and indoor (in a machinery maintenance workshop) only within an independent case study.

In addition to the data collected automatically from machine sensors, Big Data involves digital records from Mining Execution System (MES) (e.g., work schedules, work orders, maintenance orders, etc.) and ERP (e.g., inventory management records).

Analytics based on Big Data is still basic. In other words, various independent reports and the reports comparing analytics based on sensor data and digital records were provided (e.g., fuel consumption, working hours, maintenance time, etc.). Furthermore, basic geo-analytics in terms of route analysis, route visualization and geofencing, were also enabled within an online geo tool for monitoring machinery in real time and/or within the MES. Basic analytics allow for tracking the Key Performance Indicators (KPIs) that were defined for the established business processes (e.g., resource savings, readiness, availability, etc.).

Opportunities from the consolidation of the base technologies in terms of productivity and energy efficiency have been recognized. Even limited efforts to this end have led to substantial savings in terms of fuel consumption and working hours.

the remaining machinery and to expand and improve the data set collected via the IoT (status data, engine parameters, etc.).

Still, the renewal of some of the machinery might be necessary since only newer machinery has sensors that allow for collecting a richer and more reliable data set. Such substantial investment cannot be made all at once.

Although there is less risk to human safety in an open pit mine than in an underground mine, such risk does exist and can even lead to tragic outcomes (e.g., machine overturns, conveyor belt accidents, etc.). Base technologies of Smart Mining could improve human safety by alerting of dangerous situations such as proximity detection and collision warnings, or of health risks such as the increased concentration of pollutants in air.

Therefore, the MES supports planning and monitoring of end-to-end business processes in the sector for auxiliary operations such as: annual/daily planning of operations and scheduling of workers/machines, resource management (fuel and technical fluids), maintenance (preventive, intervention, and overhaul/investment), KPIs-based analytics, etc. It is integrated with the geo-tool for monitoring machinery in real-time and the branch-level ERP (inventory management, labeling, requiring a spare part and a receipt from the warehouse). Due to complexity and limited resources, it has been introduced in multiple phases over the period of several years, yet with a positive outcome in terms of KPIs. Likewise, the transition to Smart Mining can be gradual.

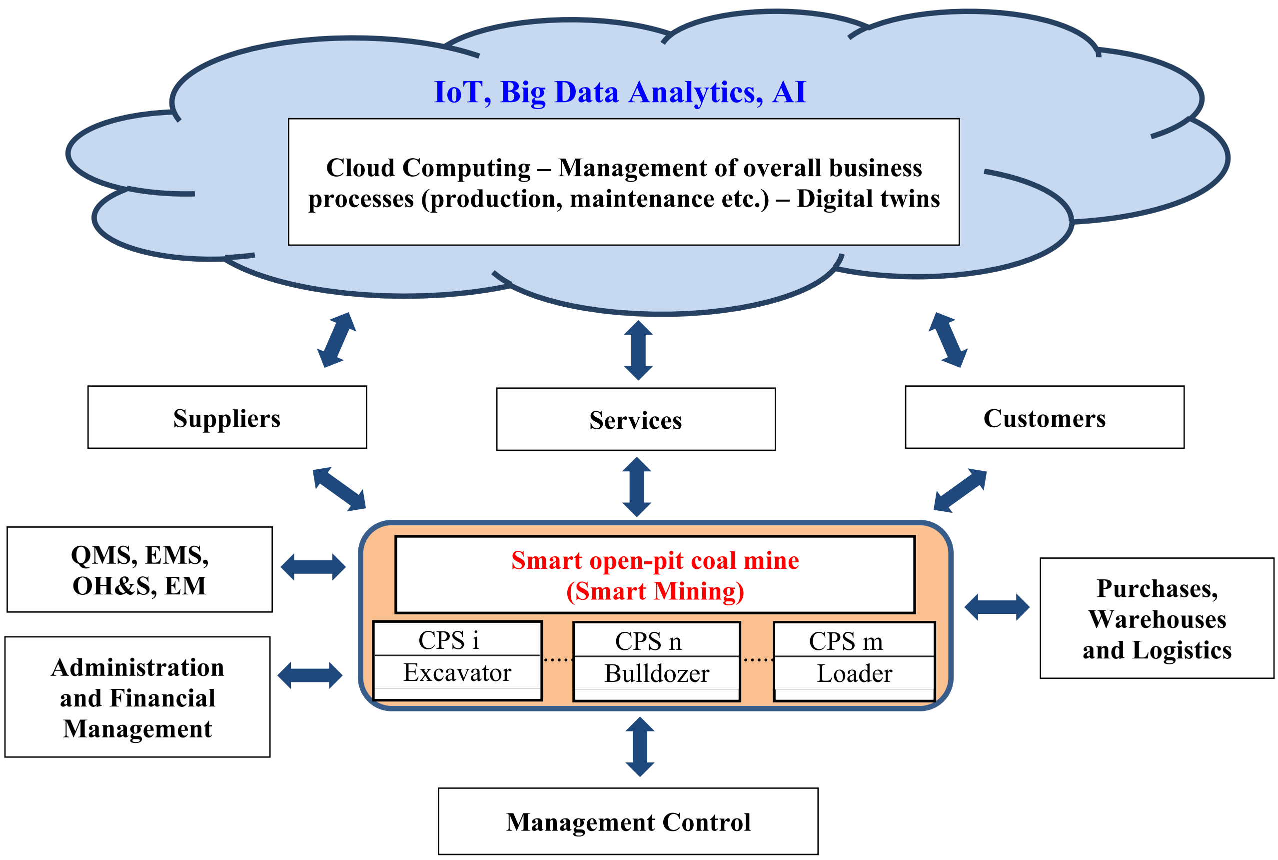

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Fig. 4. ERP model architecture for the open-pit coal mine 'Drmno'

3. Conclusion and guidelines for future research

Serbia has been approaching the program and application of the I4.0 model in practice in a systematic way since 2015 [14], and in 2019, a National Platform for I4.0 was adopted, as in other 38 countries all over the world. In this paper, using analogies with production [15-17], a model of smart mining is presented, with some elements developed and applied, and they refer primarily to the elements of ERP in I4.0. Future research and development of this model in practice will go in the direction of developing the CPS concept for an excavator, as a basic machine system in smart mining. For this particular machine, the concept of smart maintenance will be developed and applied, as a part of the I4.0 model. At the beginning of future research, the following steps will be followed:

- introduction of a shared/integrated digital platform connecting the sector for auxiliary operations with the sector for basic operations, as well as,
- a technological upgrade to support additional smart mining features such as smart analytics,
- ERP extended board or a single board for monitoring smart and analytics in general based on Big Data coming from various connected systems.

Besides excavators, other systems in mining industry will be also taken in consideration, for example, production systems which support mining maintenance, such as CNC machines for the production of spare parts [18] or adaptive shop-floors [19]. Some work in this direction is already being done (i.e. experimental research of conveyor idlers and their key components – rolling bearings [20-22]).

References

[1] Lu, Y., et al., Industry 4.0: A survey on technology, applications and open research issues, Journal of Industrial Information Integration, 6 (2017) 1-10, https://doi:org/10.1016/j.jii.2017 .4.5.

[2] Zhong, R., et al. Intelligent Manufacturing in the Context of Industry 4.0: A Review, Engineering 3 (2017) 616–630, https://dx.doi.org/10.1016/J.ENG.2017.05.015.

[3] Lee J., et al.: A cyber-physical systems architecture for industry 4.0-based manufacturing systems. Manufacturing Letter, 2015;3:18–23. https://doi.org/10.1016/j.mfglet.2014.12.001.

[4] Zezulka, F., et al., Industry 4.0 – An Introduction in the phenomenon, IFAC-Papers On Line 49-25 (2016) 008–012. https://doi.org/10.1016/j.ifacol.2016.12.002.

[5] Recommendations for implementing the strategic initiative INDUSTRIE 4.0, Securing the future of German manufacturing industry Final report of the Industrie 4.0 Working Group, April 2013. (https://www.din.de/blob/76902/e8cac883f42bf28536e7e8165993f1fd/recommendations-for-implementing-industry-4-0-data.pdf - Accessed, April 2020)

[6] Oztemel1, E., Gursev, S., Literature review of Industry 4.0 and related technologies, Journal of Intelligent Manufacturing - 2018, https://doi.org/10.1007/s10845-018-1433-8.

[7] Yun, C., et al., Digital Coal Mine Integrated Automation System Based on Control Net, J China University Mining & Technology 2007, 17(2): 0210-0214.

[8] Chaowasakoo, P., et al., Digitalization of mine operations: Scenarios to benefit in real-time truck Dispatching, International Journal of Mining Science and Technology, Volume 27, Issue 2, March 2017, Pages 229-236. https://doi.org/10.1016/j.ijmst.2017.01.007.

[9] Guofa Wang et al., Intelligent and ecological coal mining as well as clean utilization technology in China: Review and prospects, International Journal of Mining Science and Technology, Volume 29, Issue 2, March 2019, Pages 161-169. https://doi.org/10.1016/j.ijmst.2018.06.005.

[10] Barnewold, L., Lottermoser, B., Identification of digital technologies and digitalisation trends in the mining industry, International Journal of Mining Science and Technology, Volume 30, Issue 6, June 2020, Pages 747-757. https://doi.org/10.1016/j.ijmst.2020.07.003.

[11] Simeunović, V., et al., Development of Industry 4.0 Model for Open Pit Coal Mine (in Serbian), 26th YU INO conference, Procedia YU INFO 26 (2020) 279-284. http://www.yuinfo.org/ZBORNIK_YU_INFO_2020.pdf.

[12] Karre, H., et al., Transition towards and Industry 4.0 of the Leanlab at Graz UofT, Procedia Manufacturing 9 (2017) 206-213. https://doi:10.1016/j.promfg.2017.04.006.

[13] Olson, D., et al., Open source ERP business model framework, Robotics and Computer–Integrated Manufacturing 50 (2018), 30–36. https://doi:org/10.1016/j. rcim.2015.09.007.

[14] Majstorovic, V., et al., Program - Advanced Industrialization of Serbia and Industry Policy, horizon 2020/2030, Mechanical Engineering Faculty, 2016.

[15] Stock, T., Seliger, G.: Opportunities of Sustainable Manufacturing in Industry 4.0, 13th Global Conference on Sustainable Manufacturing - Decoupling Growth from Resource Use, Procedia CIRP 40 (2016) 536 – 541. https://doi:10.1016/j.procir.2016. 01.129.

[16] Schumacher, A., et al., A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises, Changeable, Agile, Reconfigurable & Virtual Production, Procedia CIRP 52 (2016) 161 – 166. https://doi:10.1016/j.procir.2016.07.040.

[17] Landherr, M., et al., The Application Centre Industrie 4.0 - Industry-driven manufacturing, research and development, 49th CIRP Conference on Manufacturing Systems (CIRP-CMS 2016), Procedia CIRP 57 (2016) 26 – 31. https://doi.10.1016/j.procir.2016.11.006.

[18] Dimitris Mourtzis, Nikolaos Milas, Nikolaos Athinaios, Towards Machine Shop 4.0: A General Machine Model for CNC machine-tools through OPC-UA, Procedia CIRP, Volume 78, 2018, Pages 301-306, DOI: https://doi.org/10.1016/j.procir.2018.09.045

[19] Dimitris Mourtzis, Ekaterini Vlachou, A cloud-based cyber-physical system for adaptive shop-floor scheduling and condition-based maintenance, Journal of Manufacturing Systems, Volume 47, 2018, Pages 179-198, DOI: https://doi.org/10.1016/j.jmsy.2018.05.008

[20] Miskovic, Z., Mitrovic R.,, Tasic Mi. and Tasic Ma.: Determination of the Wing Conveyor Idlers' Axial Loads Using the Finite Element Method, Lecture notes in Networks and Systems - Experimental and Numerical Investigations in Materials Science and Engineering, Lecture notes in Networks and Systems - Experimental and Numerical Investigations in Materials Science and Engineering, 54 (2018) 174 – 192. https://link.springer.com/chapter/10.1007/978-3-319-99620-2_14

[21] Miskovic Z., Mitrovic R., Maksimovic V., Milivojevic A.: Analysis and prediction of vibrations of ball bearings contaminated by open pit coal mine debris particles, Technical Gazzete (Tehnicki Vjesnik), Josip Juraj Strossmayer University of Osijek, 24 (2017) 1941 – 1950 https://doi.org/10.17559/TV-20151203140843

[22] Mitrovic R., Atanasovska I., Soldat N., Momcilovic D.: Effects of operation temperature on thermal expansion and main parameters of radial ball bearings, Thermal Science, Institut za nuklearne nauke "Vinča", 40/58 (2015) 1835 – 1844 http://www.doiserbia.nb.rs/Article.aspx?id=0354-98361500091M