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ERP MODEL FOR INDUSTRY 4.0 CONCEPT

Vidosav MAJSTOROVIC[1,*], Slavenko STOJADINOVIC[2]

[1)] PhD, Prof., Faculty of Mechanical Engineering, Laboratory for Production Metrology and TQM, University of Belgrade, Serbia
[2)] PhD, Assistant Prof., Faculty of Mechanical Engineering, Laboratory for Production Metrology and TQM, University of Belgrade, Serbia

Abstract: *Industry 4.0 as advanced model of technology systems automation, based on the convergence of technologies that make up the concept of intelligent manufacturing, integrated with information and communication technologies that have been applied in a new way (cloud computing, big data analytics and AI), and based on distributed management. This approach has brought unprecedented opportunities to technology systems, from resource levels to supply chains, which are becoming more flexible, responsive to customer demands, and product quality is without defects. On the other hand, planning and control production in this model must have a specific concept that defines it. Also, model has its own development, and the subject of this paper is the analysis and synthesis of the follow two models: Industry 4.0 (I4.0) and enterprise resource planning (ERP), as a whole of intelligent manufacturing. The paper also provides ours research model for the ERP model developing the Industry 4.0 concept, for Serbian manufacturing SMEs.*

Key words: *Industry 4.0, ERP, Smart factory, Smart ERP.*

1. INTRODUCTION

Industry 4.0 model is today the basic framework for research, development, designing and implementation of the next generation of manufacturing systems, which we commonly call, smart factories. Very important part of this concept is the ERP model. It is used for intelligent planning and control of all factory-level resources in the I4.0 concept.

This paper from the following aspects: (i) historical development of the concept of planning and production control in the context of automation of manufacturing systems and the nature, type and volume of data in them, (ii) ERP data management and integration model in I4.0 concept, (iii) structure of the smart manufacturing model I4.0 with the place of the ERP model in it, and (iv) modeling with case studies for SMEs in Serbia. Finally, some aspects of the future development of the ERP model for the I4.0 concept are given, especially from the perspective of new paradigms such as designing and production control.

2. PARADIGMS FOR ERP 4.0

Industry 4.0 concept is so far the best model of manufacturing system for managing the relationships between supply and demand of customers from the following aspects: quantity, variety, time of market appearance, price, quality and design [1, 2], because it gives a model of analysis and synthesis the information during product life cycle, using cloud computing and big data analytics. This approach makes it possible to individualize each customer's requests, which has become the smart manufacturing paradigm.

Industry 4.0 model is based on data-driven technology which is networked and decentralized, and realized in cyber space. Therefore, it is very important for the smart manufacturing model to explore nature, the type and size of data bases used to plan and manage at the workshop, factory and supply chain levels, from the perspective of the six technologies on which this production is based, and which containing elements of the ERP model [3, 4]. This overview is given in Table 1, with special reference to additional characteristics related to Industry 4.0.

Table 1

Basic paradigms of smart manufacturing for ERP 4.0 (adopted according [3])

Technology	Nature of data	Type of data	Data volume
Automation of manufacturing technology	Prediction technology	Numerical, string, bits, symbolic	Medium. (Very large – big volume)[1)]
Data storage technology	Status and history of equipment	Numerical, symbolic, string, time series, text	Very large. (Cloud computing) [1)]
Digitization technology	Artifact characterizatio, status	Numerical, symbolic, text	Large. (Digital twin) [1)]
Cloud computing	Integrated data, models, algorithms	Potentially data of types determined by the cloud design	Very large. (SaaS) [1)]
Agent technology	Specific application	Application specific	Low. (AI) [1)]
Prediction technology	Specific application	Numerical, categorical, time series	Medium. (Intelligent Maintenance)[1)]

[1)] Add characteristics of I4.0 approach.

[*] Corresponding author: Kraljice Marije 16, 11120 Belgrade PF34; Tel.: + 381 (0)11 33 02 407;
E-mail addresses: *vidosav.majstorovic@sbb.rs* (V. Majstorović), *sstojadinovic@mas.bg.ac.rs* (S. Stojadinovic).

Table 2

History of ERP model development [5, 6]

Year/model/ Level	Characteristics of MRP/ERP model	Main functions
1960s/**IC**/ I level	Inventory management and control	Warehouse control
1970s/**MRP I**/ II level	Material Requirements Planning	Bill of product
1980s/**MRP II**/ III level	Manufacturing Resources Planning	Bill of manufacturing process
1990s/**ERP**/ IV level	Enterprise Resource Planning	Integrate business activities across organization units
2000s/**ERP II**/ V level	Enterprise Resource Planning by Internet	Services Oriented Architecture (SOA)
2010s/**Cloud based ERP**/ VI level	Cloud based ERP	ERP as software a service (SaaS) model
2020s/**I4.0 ERP**/ VII level	ERP of Industry 4.0 model	I4.0 concept introducing

The planning of production control manufacturing resources in the manufacturing (MRP / ERP) has a long history, and this development has taken two directions: (i) business aspect of manufacturing (from stock planning at the plant level to the whole chain (request for offer - delivery of the finished product) at the company level, and (ii) technological aspect of manufacturing (from the software package to the client server architecture). An overview of the development of this model is given in Table 2 [5, 6].

Information system for control the appropriate level of stock in a warehouse (material, spare parts) was been the first level in this area [5]. Material requirement planning (MRP I) used software applications for scheduling manufacturing processes and for operations raw material purchases, level two. Now, for the first time, they are introducing into production planning and control bill of structure, materials (BOM), product (BOP), and quantity product (BOP). Manufacturing Resource Planning (MRP II) used software for coordinating manufacturing processes from product planning, parts purchasing, inventory control to product distribution, level III. Enterprise resource planning (ERP) uses a multi-module application software system, for improving the performance of the internal business processes, based on integrate business activities (planning, purchasing and distribution) across functional departments (marketing, design, accounting, HR), level IV. ERP II using internet web-browsers, with Services Oriented Architecture (SOA) and mobile devices were made possible, is level V. Cloud ERP, level VI are business applications are delivered as a service (SaaS) model [7], suitable for SMEs as well. Finally, the last seventh level refers to the ERP model for Industry 4.0.

The previous analysis shows that the development of the first four levels of the ERP model was based on the development of information systems, and after that IT technologies involved in the development of this model. The latest model is an internet-oriented networking concept, based on cloud computing and AI tools and techniques in Industry 4.0 model.

3. ERP 4.0 MODEL

Information content and level connectivity in smart manufacturing is high and is implemented through 2M (man-machine) – computer communication, which is monitored by AI algorithms. In the smart manufacturing model, information flows are realized through cloud and physical layers [7, 8]. Cloud layer includes models and algorithms related to: operations and configuration management, process and service models and condition monitoring. ERP covers this last layer. The physical layer includes equipment and sensors. In this way, divided virtual-physical systems through cloud computing perform resource sharing, managed through the ERP model.

Digitized and networked technology systems, with Internet of Things as per Industry 4.0 concept, have the ability to assign production control tasks to "intelligent" objects: machines, products and parts [9]. In this way, greater flexibility and adaptability of the manufacturing system itself, through the ERP model, is achieved. This approach defines new paradigms of production planning and control, which is based on a hybrid model of transition at centralized to a decentralized management concept [10]. On the other hand, the optimization of ERP parameters is performed at a centralized (supply chain) and / or distributed (part) control level, which means that decisions regarding production planning and control are made globally or locally, according to Kanban (pull) or holon model.

Data became the key elements in planning, control and executing all activities along supply chain in I4.0 model. For these reasons, an organization must carefully treat and properly use all data to create an effective basis for decision making [6]. The main challenge is innovative data management on the Industry 4.0 platform, which includes storage, exchange and use of data. The development and implementation of such concepts must be stimulated because only data that is error-free, up-to-date, accessible and usable can contribute to the success of the company, Table 3.

Industry 4.0 is building smart factories in deployment that have four dimensions [11, 12, 13]: (i) smart manufacturing based on advanced digital-oriented technologies (Additive manufacturing, Cloud computing and Internet of things). It has automated flexible lines that adapt production processes with changed conditions to the type of product, while sometime maintaining high quality, high productivity and flexibility, as well as production volume, with optimal consumption of resources; (ii) smart products (advanced production mode and new characteristics). They generate and send to the manufacturer exploitation feedback information, which is used primarily in the field of customer service. On this way increases the value added of the product, and the manufacturer develops a new business model (product + service); (iii) new ways workers perform their activities, based on advanced digital-oriented technologies (smart working), and (iv) smart supply-chain (procurement of raw materials and delivery of

Table 3

Framework of ERP model for Industry 4.0 (extended approach according [6])

Characteristics / I4.0 challenge	Desirable features of an ERP systems	Example	Goals	I4.0 approach
Data storage / balance centralized and decentralized approach.	Simplification of data model.	Simple table structures for the logical data model.	Data on time.	Cloud computing
	Decentralized data management	Distributed storage of data in different systems.	Bidirectional (ERP-MES[1]-PLC[2]) loading of data.	
Data flow / the connection of the ERP system in two directions – horizontal and vertical.	Linkage to previous systems	Exchange data (vertical and horizontal) and processing of different systems.	Integration of systems for a flexible planning and control.	Interoperability
	Speed of data access	ERP system should deliver requested data within short response times.	Fast reaction to changes.	
Data used / virtual and real models of intelligent products.	Visualization	The user interface of the ERP systems should display information adequately.	Improvement of human-machine interaction.	Big data analytics, AI
	Integration and Intelligence	ERP system should connect data from different sources and hence create new information	Generation of new information.	
	Automation	ERP system should use the data to trigger automated processes.	Reduction of errors and increase in efficiency.	

Note: [1]MES – Manufacturing execution system; [2]PLC – *Programmable logic controller.*

finished products). Bidirectional exchange of information in collaborative production, using it exchange also for digital platforms of design of the innovative products, Fig. 1 [17].

This framework of a smart factory is also based on four dimensions of basic technologies for Industry 4.0: (i) cloud manufacturing, (ii) internet of things for manufacturing, (iii) big data (for manufacturing), and (iv) analytics (for manufacturing).

For our analyses, relate to the ERP model, the dashed line marks elements of both structures. On the other hand, the smart supply chain in the I4.0 concept has a special function – to create added value for the customer, which gives them digital platforms for planning and designing of product and production, procurement and sales, creating a management framework product over the life of the product. This creates a new business model for the organization in the circular economy – eco sustainable smart production [14, 15]. In this concept, the ERP model is a key element of the vertical integration model, but is also whole part of the smart chains and core technologies for Industry 4.0, as it shown in Fig. 2.

There are three integration concepts in the Industry 4.0 model that apply [16, 17]: (i) vertical integration (from process – sensor, to organization (corporate planning) – ERP). The center of integration at this level is the cyber-physical system, which production is realized; (ii) horizontal – from request for offer to delivery note of finished product (marketing, designing, production, delivery). Integration center is an intelligent product, with added value; and (iii) supply chains and sustainable production with a customer relationship management (CRM) integration center. Thus the organization builds a new business model of its Industry 4.0 concept, the center of which is a large database and its reporting. The ERP model plays a key role in this.

4. RESEARCH AND DEVELOPMENT OF ERP 4.0 MODEL FOR SMEs

The Industry 4.0 model currently has forty five elements that make up its full structure applicable in large organizations. Our research shows that this model for SMEs should have between fourteen and twenty two elements depending on the type of production that the SME is engaged [18]. But one of the basic elements without this model cannot be applied is modeling - the virtual part.

Modeling is one of the most important elements of the I4.0 model, especially for the digital twin. This aspect is particularly expressive in the smart manufacturing model, where knowledge modeling is the most important element. In the digital era, the management of technological systems including their elements, encountered in the following forms [20–22]: (i) centralized hierarchical model, where we have an integrated computer system of production and management; (ii) distributed heterarchical model, which builds the symbiosis of the two models (computer-aided manufacturing and management) on the principles of biologically inspired models; (iii) CPS based distributed control [22], and (iv) IoT based distributed control [23, 24].

The last two models are important for our research, and they are realized in the I4.0 concepts through the models: agent based, multi-agent based and holonic based, type of control. The ERP model in these concepts builds as an innovative model on new paradigms, such as: collaborative control, product-driven agents, IoT agents, which makes the infrastructure of the model itself. In Serbia, intensive work is being done to develop and implement ERP models for SMEs [25], through the national Platform for Industry 4.0 [17, 18], Fig. 2. On the smart workshop where real production takes place as the creating point of manufacturing data. Virtual shop floor of a physical one using agent technology, where

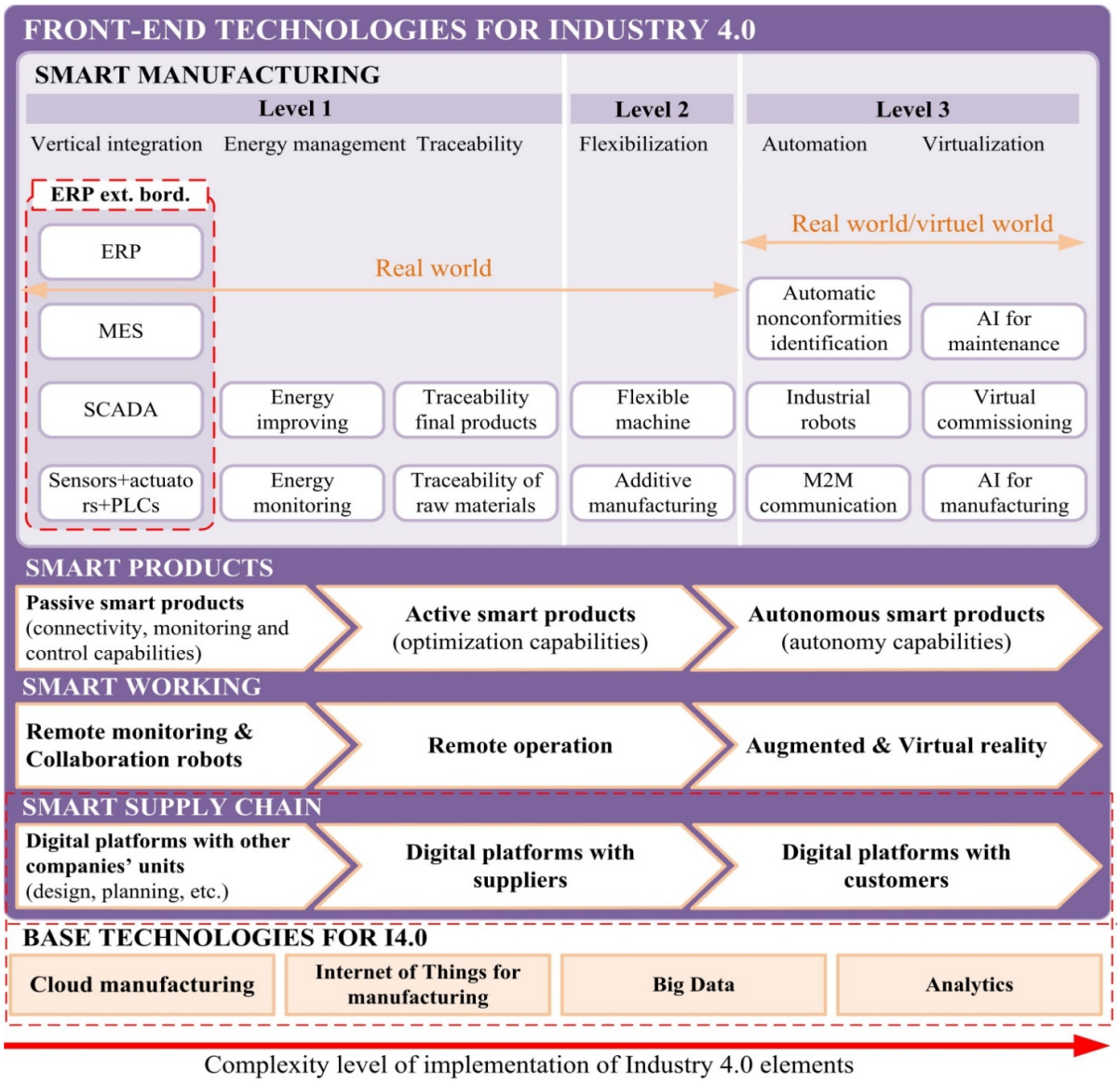

Fig. 1. Framework for Industry 4.0 model (adopted according [17]).

each agent has: identification, authorization, configuration, capability, operation and status data, and transmits them and their metadata.

Data warehouse is an information hub that stores and exchanges manufacturing data. Data analytics center is the model creation, storage, retrieval and uncertainty which provides machine learning, statistical, or stochastic based models that build on mathematical functions needed to create data driven models. Each agent retrieves such models through a broker agent and decides predictive operations and controls, based on the results that models output. Manufacturing application include applications, such as CAD, CAM, CAQ, ERP systems. These applications communicate with the platform through their application interfaces because they eventually supervise and manage all activities and events occurring on the physical workshop. Agent manager searches adequate agents, and manages them during their lifecycles. Data governor manages master data as well as the lifecycle and quality of raw data. Workflow manager controls workflows to automate the tasks performed on the platform, manages the rules designed to handle workflow appropriately, and engages in model representation. Security controller protects against computer viruses and hacking, and controls electronic authorization and authentication, because data and models that incorporate manufacturing experience and knowledge are valuable and, thus, must be protected.

For SMEs, the integral model of smart manufacturing and ERP is researched and defined, based on the base elements of Industry 4.0: Cyber physical systems (CPS), M2M – Man-machine communication / MMI – Man-machine interaction, Operation management for I4.0, Digital Twins, Horizontal & Vertical Integration, Using Light Signals, Smart / Mobile Maintenance, Condition Monitoring, VR – Virtual Reality, QR Code, Data Security, Open Communication Protocols (OPC-UA), IoT – Internet of Things (IIoT – Industrial Internet of

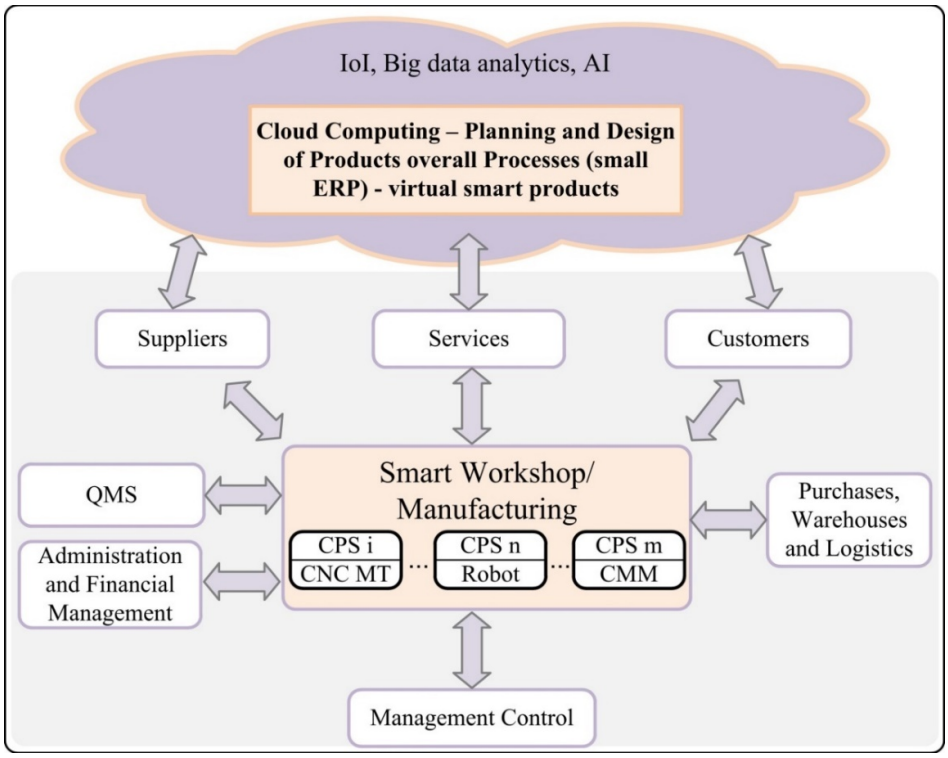

Fig. 2. Framework of a smart manufacturing system for Industry 4.0 in SMEs.

Things)), Real-Time Communication, Big Data, Cloud, Automation Pyramid, Resource Planning (ERP), Work Order Management (MES), Supplier Relationships, Intelligent Logistics, Customer Relationships, WWW [18].

The SMEs for which this project is implemented are from the field of metal industry and produce parts, subassemblies and assemblies for factories from Italy, Switzerland, Austria, Germany and the Netherlands.

5. CONCLUSIONS AND FUTURE WORK

Today, we can say that the concept of Industry 4.0 has a special place and role for the design engineer and production planner, which is still irreplaceable, but now has a different role, namely a new paradigm. It is particularly reflected in the construction and management of the digital twin model of the smart factory, and thus of the ERP module.

In [23,24], this approach is explored in detail, and a five-level model of the pyramid of the industrial internet is proposed: (i) smart object (physical objects and embedded intelligence), (ii) industrial internet of things (level 1 and network, (iii) cyber-physical production system (level 2 and integration previous levels), (iv) service-oriented digital twin (ubiquitous knowledge and level 3), and (v) smart factory (manufacturing employees and level 4). From an ERP perspective, the specificities of executives monitoring CPSs, facility managers and engineer resource planners are specifically referenced and used here, as outlined in Levels 4 and 5. One of the future directions of ERP development is the open source model.

Research in the project [18] in the forthcoming period will focus on the development of demonstration models for individual I4.0 segments for SMEs (designing - digital twin, procurement, customers, MES, etc.), as a part whole model ERP for SMEs.

REFERENCES

[1] Y. Yong, S. E. Kathryn, L. Dongni, *The evolution of production systems from Industry 2.0 through Industry 4.0*, International Journal of Production Research, Vol. 56, No. 1–2, 2018, pp. 848–861,

[2] S. Bonnaud, C. Didier, A. Kohler, *Industry 4.0 and Cognitive Manufacturing, Architecture Patterns*, Use Cases and IBM Solutions, available at: https://www.ibm.com/downloads/cas/ M8J5BA6R, accessed: March 2020.

[3] A. Kusiak, *Fundamentals of smart manufacturing: A multi-thread perspective*, Annual Reviews in Control, Vol. 47, 2019, pp. 214-220.

[4] L. Monostori, P. Valckenaers, A. Dolgui, H. Panetto, M. Brdys, B. C. Csáji, *Cooperative control in production and logistics*, Annual Reviews in Control, Vol. 39, 2015, pp. 12–29.

[5] N., N., *A Brief History of ERP – since 1960 and the future of ERP*, available at: https://www.erp-information.com/history-of-erp.html, accessed: March 2020.

[6] C. A. Hochmuth, C. Bartodziej, C. Schwägler, *Industry 4.0 Is your ERP system ready for the digital era?*, available at: https://www2.deloitte.com/ content/dam/ Deloitte/de/Documents/technology/Deloitte_ERP_Industrie-4-0_Whitepaper.pdf, accessed: Feb. 2020.

[7] D. Ivanov, S. Sethi, A. Dolgui, B. Sokolov, *A survey on control theory applications to operational systems, supply chain management, and Industry 4.0*, Annual Reviews in Control, Vol. 46, 2018, pp. 134–147.

[8] G. Morel, C.E. Pereira, S.Y. Nof, *Historical survey and emerging challenges of manufacturing automation modeling and control: A systems architecting perspective*, Annual Reviews in Control, Vol. 47, 2019, pp. 21–34.

[9] S. Erola, W. Sihna, *Intelligent production planning and control in the cloud – to-wards a scalable software architecture*, Procedia CIRP, Vol. 62, 2017, 571 – 576.

[10] J. P. U. Cadavid, S. Lamouri, B. Grabot, A. Fortin, *Machine Learning n Production Planning and Control: A Review of Empiricl Literature*, 9th IFAC conference on Manufacturing Modeling, Management and Control, Dmitry Ivanov et al. (Ed.), pp. 385–390, Berlin, Germany, August 28-30, 2019.

[11] D. Zuehlke, *Smart Factory - Towards a factory-of-things*, Annual Reviews in Control, Vol. 34, 2010, pp. 129–138.

[12] P. Barber, *Industry 4.0 and the Digital Factory*, available at: https://www.weforum.org/agenda/2019/07/factories-lead-fourth-industrial-revolution-automation-jobs, accessed: March 2020.

[13] L. D. Xua, E. L. Xu, L. Lia, *Industry 4.0: state of the art and future trends*, International Journal of Production Research, Vol. 56, No. 8, 2018, pp. pp. 2941–2962.

[14] P. Osterrieder, L. Budde, T. Friedli, *The smart factory as a key construct of industry 4.0: A systematic literature review*, International Journal of Production Economics, Vol. 211, 2019, pp. 35–51.

[15] J. Bendul, H. Blunck, *The design space of production planning and control for Industry 4.0*, Computers in Industry, Vol. 105, 2019, pp 260-272.

[16] László Monostori, Paul Valckenaers, Alexandre Dolgui, Hervé Panetto, Mietek Brdys, Balázs Csanád Csáji, *Cooperative control in production and logistics*, Annual Reviews in Control 39 (2015) pp. 12–29, https://doi.org/10.1016/j.arcontrol.2015.02.001.

[17] A. Frank, L. Dalenogare, N. Ayala, *Industry 4.0 technologies: Implementation patterns in manufacturing*, International Journal of Production Economics, Vol. 210, 2019, pp. 15–26.

[18] V. Majstorovic et al., *I4.0 for SMEs*, Project, Faculty of Mechanical Engineering, Belgrade, 2019.

[19] V. Majstorovic et al., *Cyber-Physical Manufacturing in Context of Industry 4.0 Model*, 3rd International Conference on the Industry 4.0 model for Advanced Manufacturing, Jun Ni et al. (Ed.), pp. 227–238, Serbia, June 2018, Springer, Belgrade.

[20] C. Emmanouilidis, P. Pistofidis, L. Bertoncelj, V. Katsouros, A. Fournaris, C. Koulamas, C. Ruiz-Carcel, *Enabling the human in the loop: Linked data and knowledge in industrial cyber-physical systems,* Annual Reviews in Control, Vol. 47, 2019, pp. 249–265.

[21] Michele Dassisti, Antonio Giovannini, Pasquale Merla, Michela Chimienti, Hervé Panetto, *An approach to support Industry 4.0 adoption in SMEs using a core-metamodel*, Annual Reviews in Control 47 (2019) pp. 266–274, https://doi.org/10.1016/j.arcontrol.2018.11.001.

[22] C. Fallera, D. Feldmüllera, *Industry 4.0 Learning Factory for regional SMEs*, Procedia CIRP, Vol. 32, 2015, pp. 88 – 91.

[23] N., N., *Industry 4.0 – Opportunities and Challenges of the Industrial Internet*, available at: https://www.pwc.nl/en/assets/documents/pwc-industrie-4-0.pdf, accessed: March 2020.

[24] H. Y. K. Lim, P. Zheng, C. Chen, *A state-of-the-art survey of Digital Twin: techniques, engineering product lifecycle management and business innovation perspectives*, J Intell Manuf, Vol. 30, 2019.

[25] D. Olson, B. Johansson, R. Carvalho, *Open source ERP business model framework*, Robotics and Computer–Integrated Manufacturing, Vol. 50, 2018, pp. 30–36.