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ERP in Industry 4.0 Context

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Abstract. Industry 4.0 (I4.0) is a new 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 the basis of distributed control. This approach has brought unprecedented opportunities to manufacturing systems, especially in the fields of planning and control, from resource to supply chains levels. For this reason, enterprise resource planning (ERP) is being researched and developed, which is based on the use of I4.0 elements: internet of things (IoT), big data analytics (BDA), AI and cloud computing (CC), which in this paper show.

Keywords: Industry 4.0, ERP, Smart factory, Smart ERP.

1 Introduction - the Need for New ERP Paradigms for Industry 4.0

Industry 4.0 is today and strategic national program of scientific and technological development of the most developed countries around the world, which has been implemented since 2011. Today, thirty-seven countries have this program, whose primary objective is to increase the competitiveness, productivity and efficiency of national industries [1], [2]. On the other hand, this model is the basic framework for research, development, designing and implementation of the next generation of technological systems, smart factories. One of the most important elements within them is the ERP model, which is considered in 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. 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.

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 databases used to plan and manage at the plant, factory and supply chain levels [5], [6], [7], from the perspective of the six technologies on which this production is based, and which containing elements of the ERP model. This overview is given in Table 1, with special reference to additional characteristics related to Industry 4.0.

Table 1. Characteristics of data in smart manufacturing (adopted according [6])

	Nature of data	Data type	Data volume
Automation and manufacturing technology	Prediction technology	Numerical, string, bits, symbolic	Medium. (Very large – big volume) ¹
Data storage technology	Status and history of production equipment	Numerical, symbolic, string, time series, text	Very large. (Cloud computing) ¹
Digitization technology	Artifact characterization, status	Numerical, symbolic, text	Large. (Digital twin) ¹
Cloud computing technology	As-is data, transformed data, integrated data, models, algorithms	Potentially data of types determined by the cloud design	Very large. (SaaS) ¹
Agent technology	Application specific	Application specific	Low. (AI) ¹
Prediction technology	Application specific	Numerical, categorical, time series	Medium. (Intelligent Maintenance) ¹

Note: ¹Add characteristics of I4.0 approach.

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. 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.

The planning of production and technological resources in the production control model (MRP / ERP) has a long history, and this development has taken two directions: (i) business aspect (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 (from the software package to the client server architecture). An overview of the development of this model is given in Table 2 [3], [9].

Table 2. History of ERP model development [3], [9]

Year / model / Level	Characteristics of MRP/ERP model	Aspects of function
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

Information system for control the appropriate level of stock in a warehouse (material, spare parts) was been the first level in this area [9]. 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) and quantity. 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, 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 in Industry 4.0 model.

2 ERP Model for Industry 4.0

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 [10]. 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. 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 [11]. 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 2.

Table 2. Framework of ERP model for Industry 4.0 (extended approach according [11])

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-MES1-PLC2) 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: ¹MES – Manufacturing execution system; ²PLC - Programmable logic controller.

The ERP model for smart factories is used to manage all business and technology processes in real time across the whole supply chain, based on a fast and flexible response to its customers' requirements. For the first time the Industry 4.0 model allows us to do this, and the ERP model permeates the infrastructure of the entire model shown on Figure 1 [8].

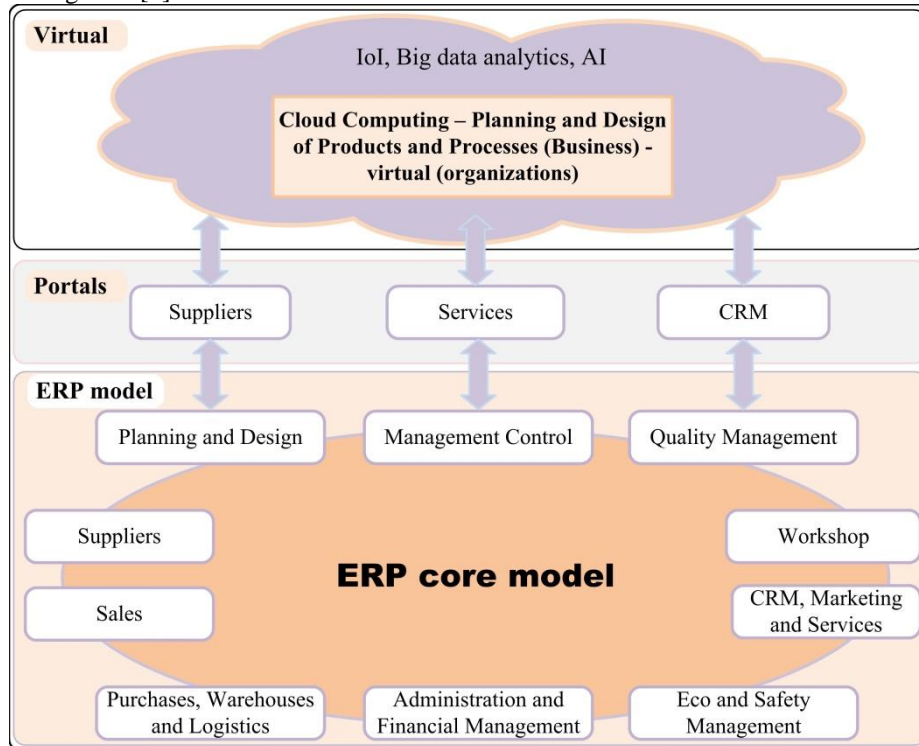


Fig. 1. ERP Industry 4.0 model (adopted according [3])

The model has three parts: (i) virtual whole, which is based on the cloud computing (SaaS) model. It contains a virtual model of an ERP system, linked through IoT all business (procurement, sales, management, finance), production (workshop) and technological (designing) processes, with large databases that are generating. Their analysis, optimization and decision making are performed using AI and machine learning techniques; (ii) interfaces (suppliers, services and CRM). Their function is to provide to user the on-line user necessary information related to procurement, sales and other services (for example maintenance) that help us track the dynamics of smart manufacturing, and (iii) core model, which includes the business-technological and managerial functions of the organization as well as the production itself, a total of ten units.

In the smart factory model, the following functions are realized using an intelligent ERP system [4],[7],[12],[13]: (i) *management of customer requirements*. Real

time creating the information content of request or offer using: Electronic Data Interchange (EDI) tools, web portals, forecasts and customer MRPs. Also managing the “Master Production Schedule” (MPS), with open orders and framework agreements, the procurement activities can be scheduled (purchases and production of finished or semi-finished goods); (ii) *production planning (MRP 1)*. The model calculates the needed quantities of raw materials to be procured for the accepted requirements from the previous point, taking into account: accepted offers, existing stock, quantities reserved for production orders in progress and sales plans; (iii) *manufacturing scheduling (MRP 2)*. Production resource planning for MRP 1 orders, taking into account: machines capacity, labor force, maintenance plans, delivery times. Technology documentation (machining operations, tools and controls plans) are elements of this module; (iv) *management production (Manufacturing Execution System – MES)*. Monitoring and managing the complete work order at all stages of production, both at the manufacturing plant and at the subcontractors, including planned maintenance orders; (v) *integration and communication between technical departments and customers*. This is related for connecting and integrating about a product (in the factory) – PDM (Product Data Management) and product (along lifecycle) – PLM (Product Lifecycle Management), for all stages of product planning and designing (bills of products) from all aspects of defining and reconsidering; (vi) *Quality Management System (QMS), EMS and OH&S*. These models manage quality information (quality management and traceability), ecology and health protection; (vii) *management warehouses and stock, logistics management*. All changes to the storage are monitored online via bar code or RFID, and the ERP model takes care about required / planned quantities. Likewise, internal transport as well as all shipments of finished products, are monitored in the same way, and (viii) *administration and financial management*. Production accounting management to determined all costs and productivity parameters, by different areas and bases.

In Serbia, intensive work is being done to develop and implement ERP models for SMEs [17], through the national Platform for Industry 4.0 [1]. 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 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.

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 [14].

3 Conclusions

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 [15], [16], 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 on the project [17] 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.). The limitations on the development and application of this model in SMEs primarily relate to the lack of resources in them, and in particular finance (ICT infrastructure and cloud services) and experts knowledge from SMEs for the used of ERP.

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