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Digital Manufacturing as a basis for the development of the Industry 4.0 model

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Abstract

The digital manufacturing (DM) is base for Industry 4.0, that have following dimensions: (i) digital manufacturing based on advanced digital-oriented technologies, (ii) smart products (advanced production mode and new characteristics), and (iii) smart supply - chain (procurement of raw materials and delivery of finished products). Bidirectional exchange of information in collaborative production, using it exchange also for digital platforms of design of the innovative products. This paper presents developed model of Serbian digital factory with selected examples, specifically for the Manufacturing Execution System (MES) area.

Keywords: Digital manufacturing; Industry 4.0; Case study.

1. Introduction

The rapid market changes and strong product individualization create the need for great flexibility of production management on new foundations, such as the Industry 4.0 model. Thus the National Institute of Standards and Technology (NIST), USA, defines: “A smart manufacturing system as fully-integrated, collaborative manufacturing systems that respond in real time to meet changing demands and conditions in the factory, in the supply network, and in customer needs ” [1]. This definition represents today's Industry 4.0 framework.

Starting from the above framework, the paper presents an example of a digital factory [2,3] where mass production is realized as way that some individual requirements of customers are met, because these are products for home use. It means that a specially developed segment of the link between MES - Enterprise Resource Planning (ERP) system is updated on a daily basis, and from other side means that real - time work order management is a key element of this approach. For these purposes, an Internet of Things (IoT) application has been developed here, used for that, as it is stated in the paper.

At the beginning of this paper, we started from the definition of Industry 4.0, as a framework for the development of this model in an industrial company. The literature review provides elements of MES, as part of the Industry 4.0 concept from the aspects of production information flow (IIP), DT / DS and business information management (ERP). In the most important part of the paper, the structure of the DM model for the company Metalac is given with the elements of production management, as the most important part of MES. There is also an example of CPS in workshop for which on-line MES was developed and applied according to the Industry 4.0 model - point 3.3. Finally, the basic messages in the further development and application of this model in the mentioned company are given. Thus, the basic contribution of this paper is a presentation from the practice of the MES model that

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works online, as a basis for the same ERP model in the concept of Industry 4.0.

2. Literature review

The industrial internet is one of the most important links in the development of the intelligent manufacturing systems, which connects the physical and cyber components in a technological system, creating the IoT. For these purposes today is the latest approach: development and application of the Industrial Internet Platform (IIP) [4], as a part of the research presented in this paper and relates to the development of the IIP for the MES platform and the work order within it.

The cyber-physical manufacturing (CPM) represents a vision of the future of competitive production, capable of facing the complexity of internal (requirements for new products) and external (supply and sales chains) real-time management structure, decentralized entities [5]. The problem of managing the requirements of the individual customers in serial production is an element of the model in research, presented in this paper.

Industry 4.0 enables new types of the operator-machine interactions, based on a paradigm shift - from independent automated and human decision, to human-AI symbiosis, based on the collaboration of artificial intelligence (AI) and human intelligence [6]. Smart manufacturing (SM) uses big data sets for intelligent decision making, and cyber-physical systems (CPS) play a key role in digitizing production and integrating its processes. Digital Twin (DT) is an accurate digital copy of the physical system, including its properties and relationship with the environment, as well as an important element of smart manufacturing [1]. DT is constantly synchronized with its physical system and gives its realistic picture with continuous control over it. The latest research directions in this area are the development of reference models for the product level, which is the framework of our research presented in this paper - DT application programming interface (API).

A particularly important segment of the application of DT in smart manufacturing is the real-time work order management (MES) [7,8]. The real-time work order management essence is to get feedback on the status of the elements of the work order (MES) from the plant, in this model achieved using the model Digital Shadows (DS). The DS is a DM with one additional automated flow of information between the state of an existing physical object and the digital model, which means that if the state of a physical object changes, then the state of the digital object automatically changes, but not vice versa, Figure 1 [7]. The starting from these facts, this paper specifically tests the work order model as part of the MES.

The SM presents a fully integrated collaborative technology system, real-time feedback responds, to meet changing requirements and conditions in the factory, customer needs and supply chain requirements [9]. The MES is the basis for Industry 4.0 model management in real production, because it forms the hub of the planning function from which the production management model grows. Regard to this, for the Industry 4.0 model, it has been shown that the application of agents for modeling the management of MES is not adequate for industrial application. At this level of development and application of IT in production, currently the solution is given as software-defined control (SDC) [9]. This model coexists with the applied architecture model ISA-95, where MES and ERP are mutually integrated and logically centralized. (Particularly, Figure 4 in section 3.2 shown context of application in Metalac Company) Work in Progress (VIP) - example.

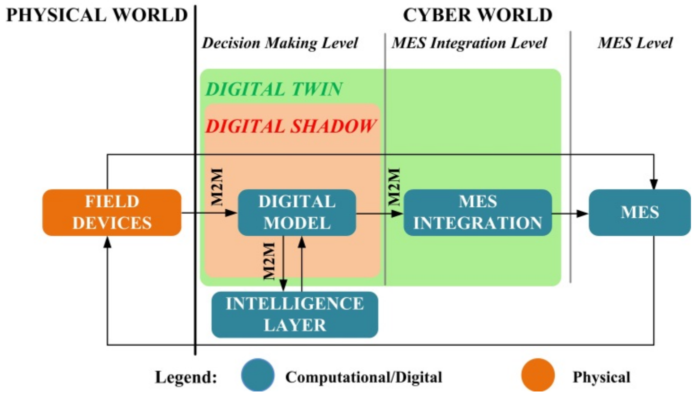

Fig. 1. DT vs DS model basic architecture [7]

The monitoring of production data is essential for high-level control of the production process in the Industry 4.0 model, achieved by using the MES system [10]. The DT for workshop in the MES model collects information about parts, technologies, tools, machines and processes on different platforms (android, tablet, control unit etc.) and through cloud technologies generates a model of decentralized smart production management where MES is the center of this model. Regarding to this, research has the same approach. (Particularly, Figure 4 in section 3.2 shown context of application in Metalac Company) Work in Progress (VIP) - example.

The MES generates the big data set. By using AI learning techniques this set should be used for online management of technological processes, based on predictive production planning (operation planning and resource allocation) [11-14].

3. A digital manufacturing model for metalworking industry

The company Metalac produces household appliances (cookware, sinks, boilers, etc.), six million units production volume per year. It is an example digitalized manufacturing organization in Serbia, which has products that are a brand on the world market. For these reasons, it invests a lot in research and development as well as application of new technologies, so it can be said that it is a national leader in the application of elements of Industry 4.0 in Serbia.

3.1. Model of digital manufacturing

The digital chain of models and data flow in Metalac cookware is composed and realized through the model shown in Figure 2, has a unique database of all business factors, updated on a daily basis - with the latest product versions and history of their changes.

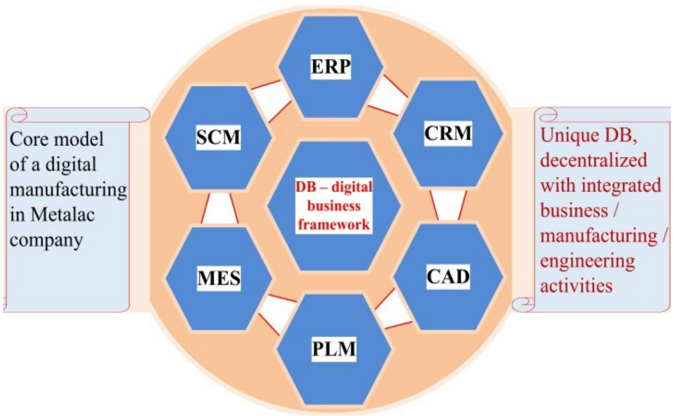

Fig. 2. The digital model of Metalac Company

How is the digital chain established and functioning in this organization? The product offer request is generated in the customer relationship management (CRM) module. After accepting, the customer need is transformed into requirements for production and planning orders as part of the business information system (CRM module (purchase order / delivery note created directly in ERP)). Thus, it becomes part of a unique database system (DB), so the designer, based on the standard dimensional parameters, automatically generates a typical CAD model (3D model of the part and components (structural, quantitative and modular)) - EBOM. In the next phase, the designer generates a typical CAM technology for the CAD model, which includes: sequence of manufacturing operations + extraction tools + machines (3D machine model - digital twin). After creating CAM documentation (MBOM), the system in the next phase generates a quality control plan (CAQ) for the 3D part, as a part of the ISO 9001 model). In the next step, the ERP forms a complete of the work order (WO): degreasing sheet, sheet for enameling, quality control sheet, calculates the cost of operation in workshop, forms a packing list, gives a final inspection plan. The SCM module defines the procurement and quality control plan of the input materials and raw materials. Thus forms an unique system of digital chain model for the product that will be made in the planned quantity with a defined deadline, which is included in an unique system of classification of business factors. The PDM system is now fully implemented and it is on the cloud. Also, it is considering the expansion of the PLM system from the level of the product description at this moment to the level of the digital production program, also stored on the cloud. The ensuring traceability and tracing the errors is done backwards, through delivery requests and work orders, through ERP, because it connected through levels (higher and lower). The MES system works online, because a digital chain of production monitoring is provided. This means that the ERP system is monitored online, so the business plan is made on an annual basis, the production and delivery plan on a monthly basis and the production scheduling on a monthly basis, Figure 3.

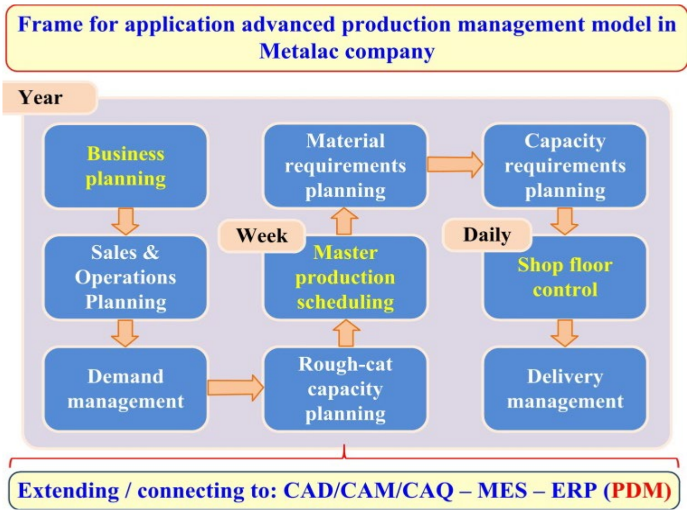

Fig. 3. The digital model of production management in Metalac Company

3.2. Example of applications

The overall digital production model in Metalac Company includes three wholes, Figure 4: (i) digital world (Engineering bill of materials (EBOM), Manufacturing bill of materials (MBOM), Product data management (PDM), MES / ERP, digital twin CPS), (ii) real world, which consists of the existing physical workshops, machines, tools, equipment and other resources, and (iii) hardware / software support, which is basically create a cloud manufacturing model.

The product design (CAD) is run as a completely new customer request or the existing product is adapted to the customer request. Parallel to this, as needed a CAD model (for example handles) is used for 3D printing. In the next step, this model is sent to the customer for approval (shape, color, etc.), after it becomes a request for the production and purchase order. The product design is done according to typical geometric features, which creates the families of the parts with standard dimensions. For these reasons, the customer, as the first response to his request, is sent an offer with a standard product (shape, color), and if he has special additional shape requirements, which require the development of new special tools, then he is notified in advance due to the higher price of such product. If he accepts that, parallel with the development of the CAD product model, the CAD model of the tool is also developed. The material is standard carbon steel for enameling EN10209, which exists in the PDM knowledge base, which use for automatically obtained the weight and surface of the part. The output of this module is BOM products and / or BOM tools, if it is a special tool, as well as their 3D models that become part of DB PDM.

The development of technology includes defining the sequence of the product manufacturing operations and the necessary tools for it, as well as the machines on which they will be performed (MRP II). Manufacturing operations include plastic deformation processes (sheet metal cutting, bending, extraction, deep extraction, edge trimming), as well as 3D printing. In these processes, the designer takes into account the technological limitations: min enamelling radius and checking the tangency and curvature of the enamelling surfaces.

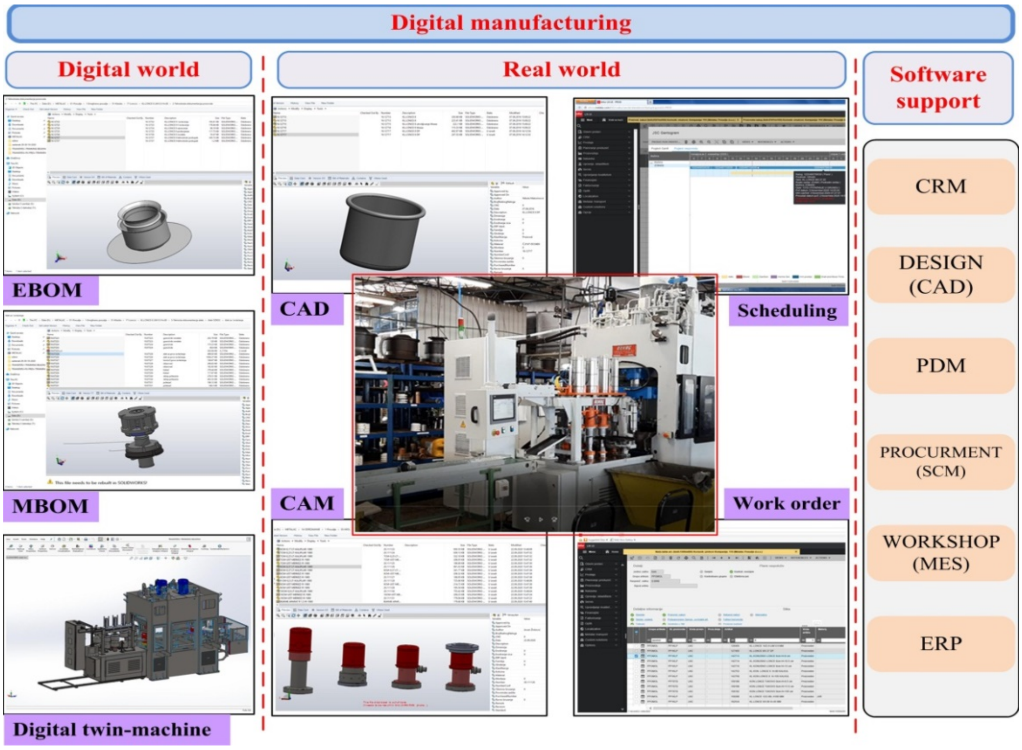

Fig. 4. Layout of digital manufacturing in Metalac Company

The manufacturing of the deep extraction disc is done on an automatic line with the optimization of the material strip based on the CAD model of the disc, by efficiency from 90%. The number of deep extraction operations is from 3 to 5, but there are tools for 11 deep extraction operations. As concerned to the tools for deformation processing, they are connected via the ERP system into a unique BP, among other things prescribes the maintenance of the tool, the service life, the moment of ordering a new one, etc. All reports are signal and automatically generated. The output of this module is MBOM, in the format PRT, DRV, ASM, DWG, PDF, linked to the ERP system of classification by production companies, programs and product families, which gave a unique connection ERP - BP (business planning) - WO (work order).

This factory has several automatic machines for machining of the products in its workshop that work autonomously, such as CPS in a CM environment. It has multiplied productivity and brought quality to "zero defect".

The work order is generated with the following data: (i) general data - planning, production, storage, ordering data and calculation data (unit of measure, weight, and surface), (ii) structural components, (iii) technological components (MBOM), and (iv) quantitative components. When the HE is defined, the production scheduling is generated. This is the framework of the MES model in the production conditions of this factory.

The CU CPS screen from the photo (Figure 4) is shown in Figure 5.

On the left side of the screen are the parameters of the cutting strip (width, length, thickness, diameter of the disc, the distance between the edge of the disk-disk, the distance between the edge of the disk-edge of the strip as well as angle of strip position to the machine). The left side shows the arrangements of the disc on the strip, and the green color means that the disc number 4 is currently being cut.

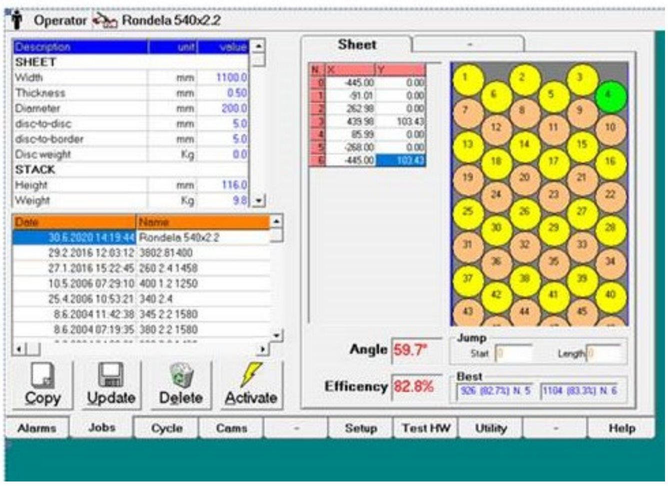

Fig. 5. Part of MES model on CPS in workshop

The CPS is through cloud connected to ERP, so it automatically generates feeder coordinates, number of rows and recalculates the efficiency of strip/roll, which directly gives the material norm for a particular disc, which is returned online to the ERP's material components by the formula: ratio - disc weight (SW-3D) / strip efficiency (0.828 from Figure 5) gives / controls the material norm for some disc. Here it is important to note that the width of the roll strip can be changed, and the system is set-up according to it at the beginning of the process, so that today the factory works with standard and dedicated strip widths (for example boiler disc). On this way it is close the MES system of this CPS, and big data about the process for each WO is generated.

3.3. Work order (WO) management

Since the factory currently has a CPS that operates according to the Industry 4.0 concept at the MES level, for other not interconnected machines, WO management is performed according to the classic ERP model. In order to improve this concept and adjusted to the Industry 4.0 model in this area, the development and application of the IoT model for WO management was approached.

The physical challenges of the Metalac Company production of cookwares, sinks, boilers as finished products and packaging are as following:

- The absence of large and optimal series, stochastic appearance of purchase orders due to unstable market;
- The need for daily scheduling of the equipment capacity and professional workforce reservations for the period until the customer accepts the estimated delivery dates;
- The need for constant scheduling of production of multi-level components, i.e. stocks of semi-finished products with over stocks due to planned losses due to frequent adjustments of the production process of small series;
- The need to motivate employees and the millennial generation to be variably rewarded and each day reported on how much they have earned;
- The need to provide a digital guarantee for each product separately - unique labeling and traceability of process parameters for each product.

The cloud mobile solutions are implemented in the production monitoring process, used to have the continuity of the accurate real-time information for the real-time scheduling and planning of production.

The consequence of the having real-time information is the gain of precise scheduling of the production process and accurate offers to customers.

Metalac Company implements its own developed IoT and mobile software solutions for production monitoring such as:

- Each product are labeled with a unique mQR code that allows interaction;
- Each work order, production equipment and signals for communication are labeled with unique mQR codes;
- Every worker are enabled to have mobile phones and a RECi Review application to communicate with the process;
- The basis of employee interaction with the process is a mobile phone camera and RECi Review application that scans a QR code, that bridges the gap between data on equipment, on paper, on a computer screen (ERP) with the worker and his need to easily and instantly without walking to the nearest terminal provide information when the event takes place;
- The employee motivation is obtained on the basis of variable rewards based on mobile data that they share in order to determine their participation in the earnings from the produced series;
- Verification of compliance of the given information by the employees is done with the help of IoT machine learning signals from mobile IoT vibration sensors on the production equipment;
- The RECi Review mobile application is a platform integrated with the Camunda BPMN business process machine, which orchestrates and integrates digital processes with other processes - and a special advantage for NoIT experts, which can quickly draw process diagrams, install and change within minutes if needed;
- The RECi Review presents a flexible MES that allows real-time inflow of information by workers and cross-linking of traceable data located in separate data buffers and with different update frequencies (ERP, PDM, external suppliers, equipment repairers).

The results of information collecting are:

- The current mobile information on the real-time availability of equipment (OEE) and the availability of (professional) manpower in the resource calendar;
- NoCode and NoIT advantages the ease of setting up your own developed MES mob. RECi Review applications for NoIT professionals (typically production technologists);
- High productivity in providing and reviewing information by employees in the production process;
- The data collected from the realization of the production process enable variable rewarding and increased motivation of employees to provide information on the basis they earn additionally;
- The calculation of direct and indirect costs on individual products;
- The integration of sales RECi Review ratings and customer's satisfaction that have after-sales interaction with the product is done by mQR codes that uniquely mark each Metalac Company product.

4. Conclusions and future research / development / application

In Serbia, the National Platform for Industry 4.0 has been adopted, which means that in the triangle: decision makers (government, ministries, associations of economy) - scientific community (faculties, institutes) - industry (primarily SMEs) organized systematic efforts to implement Industry 4.0 [15, 16]. On the other side, since 2015, the Faculty of Mechanical Engineering in Belgrade has organized five international Conferences on the Industry 4.0 Model for Advanced Engineering / Manufacturing - Industry 4.0 and Smart Manufacturing and held 28 Panels on Industry 4.0. This has led to the fact that digitalization is an imperative of the moment in the development of the Serbian industry, and Industry 4.0 is the goal to be pursued. The model in this paper is one of example that provide best practice. Future research in this example will relate to the further establishment of the CPS in manufacturing, for example for enameling, as well as the extension of the MES IoT model to other processes where WO operates.

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