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One MES model in Digital Manufacturing

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Abstract

Digital manufacturing is base for Industry 4.0, based on advanced digital-oriented technologies, smart products (advanced production mode and new characteristics), and smart supply - chain (procurement of raw materials and delivery of finished products). Bidirectional exchange of information in collaborative manufacturing, using it exchange also for digital platforms of design of the innovative products. In this paper we are show developed model of Serbian digital factory with selected examples for the MES area.

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Keywords: Digital manufacturing; Industry 4.0; MES.

1. Introduction

Manufacturing Execution System (MES) arose from the need of production organizations to meet market requirements in terms of reactivity, product quality (production without scrap), compliance with standards (ISO 9001 and other quality standards), reducing production costs and meeting delivery deadlines [1]. As such, the functions of MES are primarily focused on production activities, so it can be said that its make the main component of added value of the products of all production of the company. Historically, today it is well applied in the process industry (pharmaceutical, food and semiconductor industries) where MES systems meet the needs of traceability imposed by strict government regulations, as well as the requirements of standards (ISO 9001 and others), and today, it is used in virtually all manufacturing industries.

Industry 4.0 is a new model of automation of technological systems based on intelligent networking of its elements and processes, with decentralized decision-making and management. Manufacturing Execution System (MES) is a digital model in this concept, and represents a link between the engineering planning function (CAD / CAM / PDM) and the factory business functions and supply chain (ERP), as well as digital models. In this way we come to real-time production (plant), which is managed by MES, and it is an information hub of the intelligent factory, supported by industrial internet, as a standard interface (RAMI 4.0 model for Industry 4.0), where online activities are managed in plant , with their simultaneous optimization.

A MES is essentially a decision support system for managers (predominantly in workshop) and functionality covers the data collection and analysis of three aspects of manufacturing [2]: (i) in the past - storage and analysis of historical data of past process runs (CIM concept), (ii) present, by digital manufacturing - real-time open and closed loop control of the process, and (iii) finally of the future (Industry 4.0 model) – predicting planning of future process runs as well as early warning of process or quality deviations. This paper presents the results of our research related to the last two elements of the development of MES production models.

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The aim of the research presented in this paper is to develop a hybrid model for online work order management, as part of the MES system in the concept of digital production, and vertical integration, which is presented in this paper, in part three. The basic framework for this research is the Intermet of Things (IoT) model, as one of the key technologies of Industry 4.0. On this way, a "bridge" would be established between the digital ERP model and the MES Industry 4.0 model, bringing the production organization to the Industry 4.0 model from its most important element - real time plant production management.

2. Literature review

The basic concept of the MES reference model was defined earlier - Manufacturing Execution System Association (MESA) [3,4], so that today I would have three more in practice: ISA 95, VDI 5600 and NAMUR [2], which essentially have all the elements of MESA, and are based on it, as a base model.

Table 1 shows summary analyzes and comparisons of the MESA reference model and its relationship to the Industry 4.0 concept, which is defined by our research model.

Table 1. MES components according MASA model and I4.0 modeling in manufacturing (adapted from [3,4])

Function in workshop / factory (production management level)	Request for I4.0 approach in workshop	I4.0 add comment / MES connection in digital chain
Resource allocation and their status of maintenance	Manages resources information, providing detailed history and status on real time in workshop, and monitoring of staff, machines, tools.	Digital model from CAD/CAM/ERP
Operations / Sequences Scheduling - Fine planning of workflow	Optimal sequence planning regarding the relevant basic conditions based on the resources available and recognizing alternative and overlapping/parallel operations.	Digital model from CAM/PLM
Dispatching Production Units and Machines	Manages flow of production units and machines, based on orders, batches and plan adjustments.	Digital model from CAM/ERP
Document Control in Workshop	All information (records/forms) relevant to the production process is made accessible to the staff.	Digital model of Work order
Data Collection / Acquisition in Workshop	Obtains the intra-operational production and parametric data from the workshop.	SCADA digital model
Labour Management	Provides optimisation of the labour exploitation and recording and edition of staff working hours.	HR digital model
Quality Management	Provides real time information to assure product quality and be able to identify problems and weak points.	ISO 9001:2015 digital model (QMS)
Process Management	Monitors production and provides or corrects decision support to improve process activities, including alarm management functions and other features.	KPI digital model from QMS
Maintenance Management	Tracks maintenance activities and provides instance solutions.	Digital model of predictive maintenance (BDA)
Product / Lot Tracking and Genealogy	Provides the status information of work order activities. Also it may generate historical information for the products that have been produced, the entire production chain to ensure traceability.	MES model in connection with all I4.0 modul in factory
Performance Analysis	Presents the performance (i.e. KPIs) of the facility for more study and analysis:of the manufactured sizes to downtime, disruptions, piece counter and others in order to allow production efficiency assessments and detection of problems.	All KPI parameters from diferent I4.0 moduls, including QMS

In the Industry 4.0 model, the MES module is based on the following elements [5-8]: (i) decentralized management of intelligent resources in the plant (MESA elements from table 1), (ii) vertical integration allows MES to comply with business processes, which the ERP model is managed (scheduling, quality, procurement, sales, delivery, ...), (iii) connectivity and mobile devices enable connection and communication between entities at the plant level in the MES model, using IoT, and (iv) cloud computing and data analysis, provide computer resources and online management of big data sets, which in the MES model are obtained from different sources and from different sides. In this context, traceability of production, resource optimization and zero scrap are especially important.

According to [9], the current and future model of MES development in the Industry 4.0 concept can be analyzed through the following aspects: (i) horizontal integration (via CPS in plant), (ii) vertical integration (engineering design and planning (PDM) and ERP) , (iii) front-end integration (CRM / PLM / SCM), and (iv) full digital factory integration (CPM).

A particularly important aspect of the application of MES is for SMEs, so an example of open source [6], and the formation of a general knowledge base model for CPS production organizations [3,7], is a way to accelerate these processes.

For the second approach (vertical integration), the concept of cloud based distributed production supported by the distributed model of MES in SCM [10] is interesting, with (a) centralized ERP (problems arise in the exchange of SCM data at the MES level, due to different interface, which limits online operation), and (b) the development of a user interface for the connection between ERP and MES is required. The input to the MES in the vertical integration model consists of data collected by the SCADA system (process level) [11], so this aspect especially should be taken into account.

The concept of the third approach is presented in detail in [12], supported by the ontology, as a model for line integration: PLC - SCADA - MES - ERP - SRM, and the second example refers to [13] the integration of MES and PLM. This approach is especially favorable for SMEs of production organizations in the field of mechanical engineering, where there is a lot of engineering design (CAD / CAM / CAPP).

Finally, the fourth approach is given in [14, 15], where the MES model is given as part of the overall digital model of the factory, realized through the following phases: (i) CPS definition and data collection by PLC, (ii) development and implementation of a complete SCADA system, (iii) development and implementation of real-time system between shop floor and management levels, (iv) development and implementation of a total production operation management system, and (v) development and implementation of real-time reporting system.

3. Problem description and model formulation

The research presented in this paper comes from the company produces household appliances (enamel dishes, sinks, water heaters), with a production volume of six million units per year. It has digitalized its business and is an example of an 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 and application of new technologies, so it can be said that it is a national leader in the application of elements of Industry 4.0 at Serbia.

The digital chain of models and data flow in Metalac dishes is composed and realized through the model shown in Figure 1, which has a unique database of all business factors, updated on a daily basis - with the latest product versions and history of their changes.

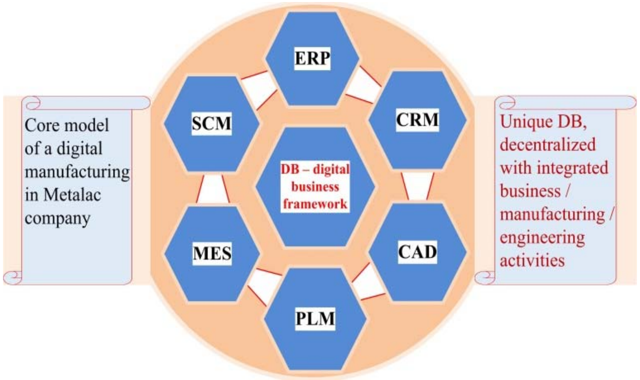

Figure 1. Digital model of Metalac Company

The total digital production model in Metalac company includes three wholes, Figure 2: (i) digital world (EBOM, MBOM, PDM, MES / ERP, digital twin CPS), (ii) real world or existing physical workshops, machines, tools, equipment and other resources, and (iii) hardware / software support, basically a cloud manufacturing model.

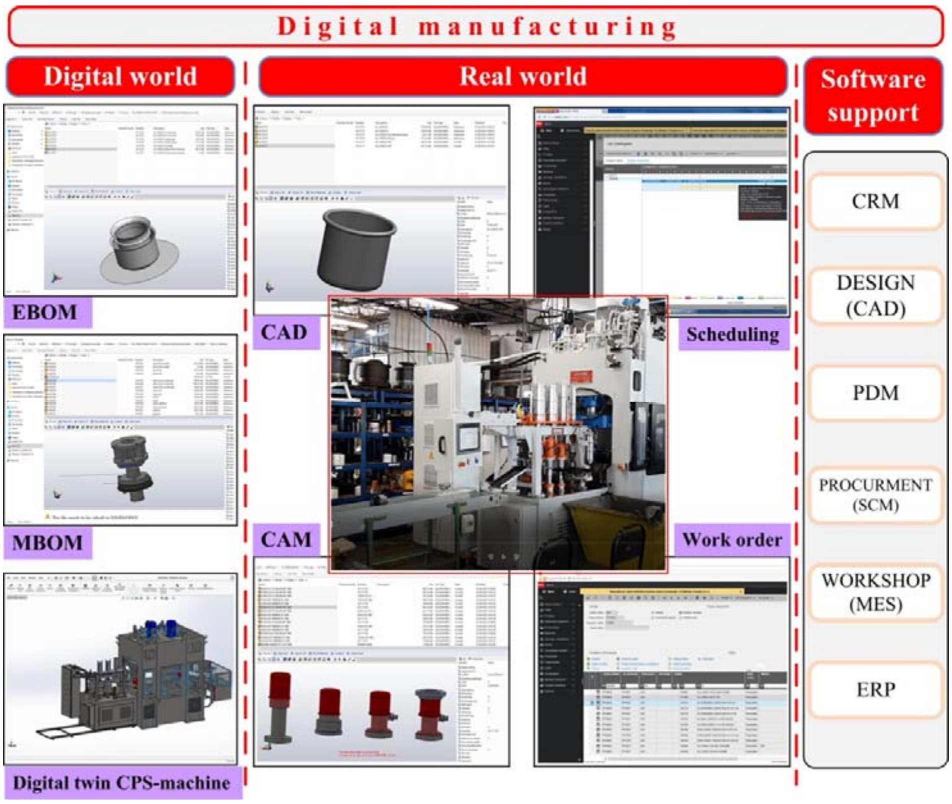

Figure 2. Layout of digital manufacturing in Metalac Company

Researches in the development and application of our MES model is aimed at achieving the following goals: (a) optimization of the entire supply chain by better control of the flow and steps of the production process, through real-time work order documentation, (b) provided higher quality data for quality assessment processes and products, through the visibility and transparency of data throughout the production process, which realizes the production of "zero" scrap, (c) reduction of material storage costs in progress (VIP) due to reduced delivery time, while same time reducing administrative work to maintain production documents, because everything is online, and (d) a better decision-making process, through easy access to current data and information for all critical operations and business cases in progress.

Technological factors determine the quality of the MES concept in application [16-19], and they are: (a) data and communication management (manufacturing data acquisition and exchange between MES and other systems (ERP, etc.). The main task is to efficiently collect the desired data about monitored entities in the production or supply chain, as well as their transfer to the MES. Today, RFID devices are the most widely used for this, increasingly supported by advanced localization algorithms. Data exchange is done via the cloud with the support of SOA architecture; (b) decision support logic (type and technique). Today, different models are used in practice for these purposes: rules, holons, agents, ANN; and (c) user interface (visualization and mobile device interfaces). The basic function of these elements is to facilitate application to user while providing the most important information for quick online decision-making.

3.1. Case study

This factory has in its plant several automatic machines for manufacturing of the products that work automatically and autonomously, such as CPS in CM environment. It has increased productivity, and brought quality to "zero defect".

A work order (WO) is generated with the following data: (i) general data - planning, production, storage, ordering data and calculation data (unit of measure, weight, surface), (ii) structural component (BOP), (iii) manufacturing component (MBOM), and (iv) the quantitative component (QBOP). When WO is defined in this way, the term production plan is generated. This is the framework of the MES model in the production conditions of this factory.

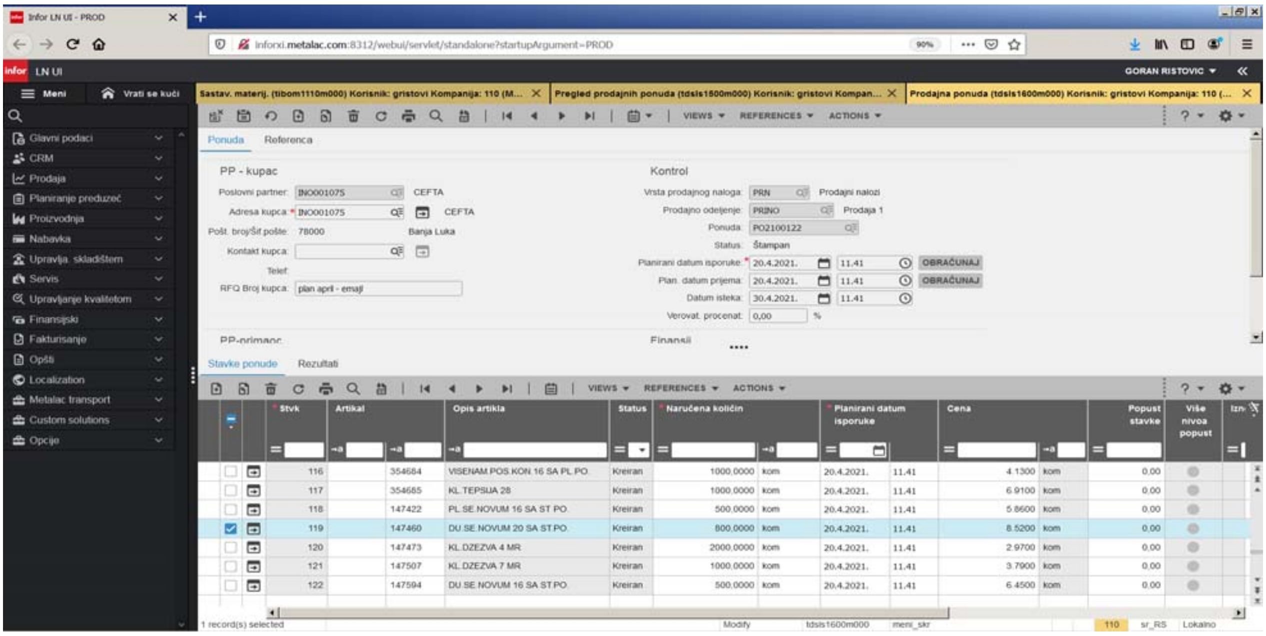

Figure 3. Work order plan for the product - completion date is 05/07/2021

In the following text, an example of managing a complete of work order, according to the above model, for a real product - 147460 - DU.SE.NOVUM 20 SA ST.PO is given. Its sales offer PO2100122 in the amount of 800 pieces, generated based on the customer's request is planned.

When the initiative is accepted, in accordance with Figure 3, the preparation of technical-technological documentation begins. The production of enameled ware takes place in two plants and is accompanied by the following work orders: (a) production in the plant of the finish machining where enamelling and packaging of products is performed. For this part, Figure 4 shows the work order for packaging this finished product and the necessary materials and semi-finished products for its realization. Packaging is not scheduled. The semi-finished products are marked (blue) and all work orders for their realization will be displayed.

By the same analogy, work orders are generating for second plant. The next phase is scheduling - which is done after generating work orders. The machining operation is performed first, followed by the enameling operation. The layout of the term map for a given example is given in Figure 5.

In addition to the required materials card listed in the above examples, each work order also contains a required operations card and material stock. For the enameling of the sphere from our example Figure 6 it shows.

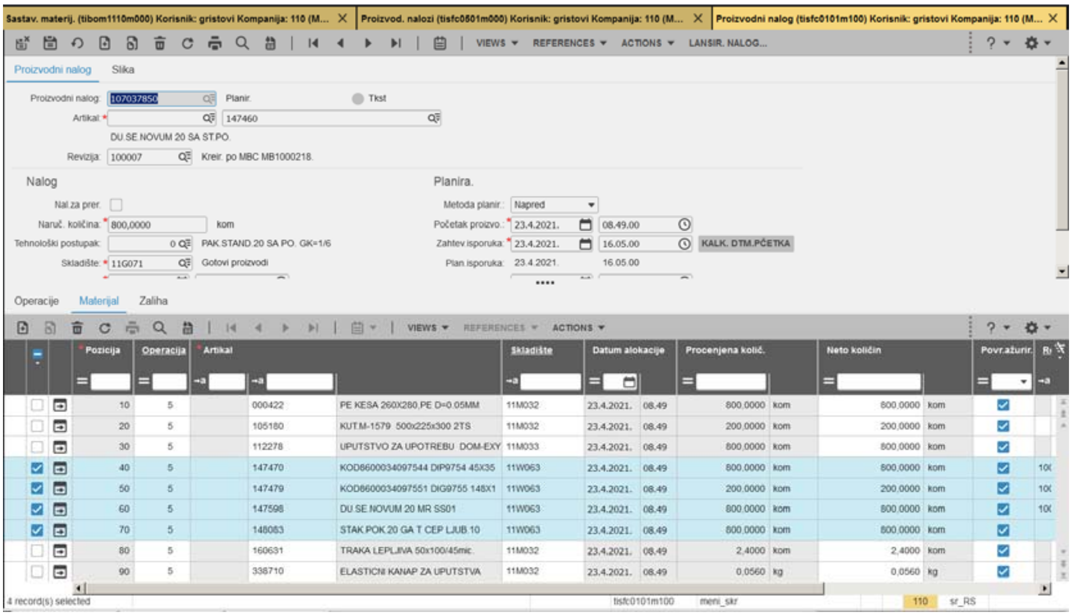

Figure 4. Work orders for the production of semi-finished products (set - a total of five)

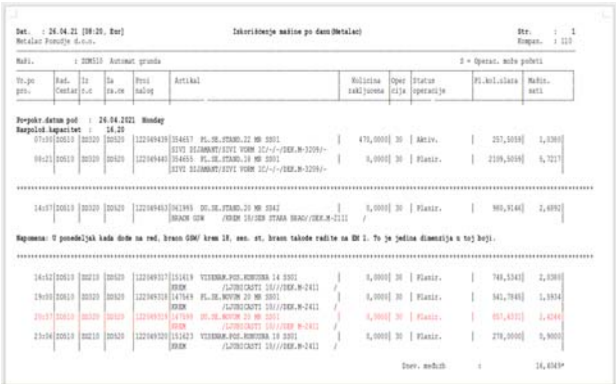

Figure 5. The term plan for enameling operations (red color - critical operation).

Check and determining the capacity is performed during the analysis and conclusion of monthly plans, where the workload of individual work centers is monitored and based on the workload, a decision is made on the required work dynamics on a monthly basis (work in 1, 2, 3 shifts ...). Figure 7 shows an example of the capacity required for April for a sheet metal machining plant.

After completing this documentation production begins, and through a hybrid model of the MES system, online monitoring of the above documentation is performed, as follows:

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

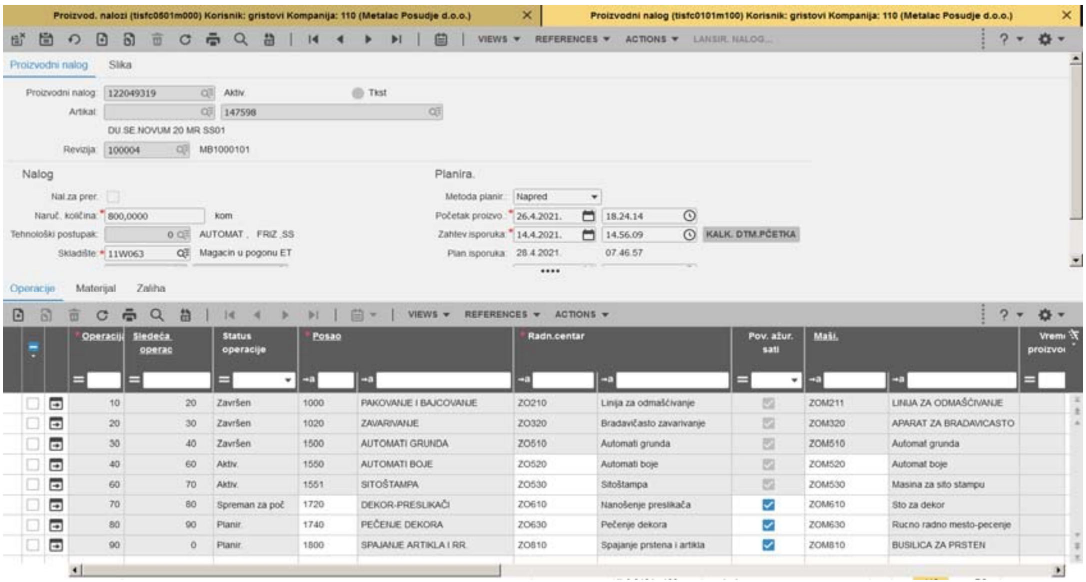

Figure 6. The card of required operations and materials stock

Datum : 27.04.2021 [15:34] Kapacitet iz razgradnje
Strana : 1

Metalac Posudje d.o.o.
Company : 110

Za period od 4 do 4

RC	Opis radnog centra	Vre.prip.	Vre.izr.	Ukupno vreme
MO1110	Hid.prese HVC-2-100	29,583	409,473	439,041
MO1120	Hidraulična presa HPC-2-63 V	17,634	224,976	242,609
MO1130	Hidraulična presa HS-100-GV	38,066	499,782	537,843
MO1140	Hidraulična presa HS-160-GV	34,600	444,869	479,469

Figure 7. A part of the capacity plan

- 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;
- 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.

In this way, this company has improved its digital production model by creating online collection and monitoring of work order data, noting that it has four CPS for deformation machining, thus building "cells" in production for the application of the Industry 4.0 model, because they are also covered by the above concept.

4. Conclusions and future work

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 [20,21]. On the other hand, from MES standpoint, its full integration into the online model of Industry 4.0 should be expected, which will mean that planning and scheduling at the plant level will be constantly updated. The proposed model in this paper can be one of the solutions. Further research in this area will focus on the development of a digital twin model for this example.

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