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MANAGEMENT OF RESOURCES IN SMALL AND MEDIUM-SIZED PRODUCTION ENTERPRISES*

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Abstract– Enormous loss of production time in machining, handling and assembly operations is caused mainly by resources' unavailability. For this reason companies, both large and small, should optimize the production processes with the detection and elimination in advance of the majority of possible mistakes and disturbances that could cause deadlocks in the production process. The optimization tools which are available on the market are usually too expensive for smaller companies, which search for their competitive position in small quantity production. Therefore, a low cost simulation tool for the optimization of the resource present management is presented in this paper, where resources are treated as one of the main parameters in the production process and which could also enable smaller companies to optimize their production processes from the resource presence viewpoint.

Keywords– Manufacturing process model, digital factory, simulation, manufacturing process, resources unavailability, production process optimization

1. INTRODUCTION

Small quantity production is one of the possible solutions for smaller companies and even smaller countries to survive in today's globally competitive market. Those companies able to adapt quickly to the new and very often quickly changeable market demands, and which can, at the same time, organize their production resources as well under unique and small quantity production (USQP) circumstances, can become and stay, successful, innovative, and globally competitive.

The data and practical experiences from many smaller companies prove that, for example, pure machining on a machining centre represents only 5 % of individual operation duration. The remaining 95 % of operation time is spent on placing physical resources at the preliminary operations or before the next operations during setup times and much of the time is unnecessary spent even on transportation and handling etc. of physical resources during the production process [1].

These numbers expose the enormous loss of production time in machining, handling and assembly operations, caused mostly by a lack of resources. The right resources in the right time is one of the most important factors and even a condition for the production process and for each individual production operation to be able to start it's execution.

For this reason, most companies, not only the smaller ones, should detect and eliminate in advance the majority of potential mistakes and disturbances that could negatively influence resource availability and herewith cause deadlock in production, especially the manufacturing process and consecutively, the

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unexpected costs or profit losses. Optimization of the production and manufacturing process in such a way is also one of the fundamental orientation lines of lean production.

Therefore, alternative, low cost simulation tools need to be applied and new approaches undertaken which could also enable smaller companies to optimize their production processes, under the small quantity production circumstances.

This paper deals with such an approach and suggests a new method, based on manufacturing in a digital environment, where resources are treated as one of the main parameters in the manufacturing process execution level.

2. DIGITAL MANUFACTURING

For smaller companies, especially those which are struggling to find an appropriate position on the market, optimizing their production processes is a necessity. This can be done by:

- either arranging the production operations in time scale [2-6], which is the most common approach in the practice, or
- improving the production process at the level of execution of the operation (s)[7, 8].

Many different simulation tools are used today for the optimization of production and manufacturing processes [4, 5, 9, 10]. Some computer systems, usually called Digital Factory [11, 12], are designed for use in large, mass production type enterprises [9, 10], and are not practically accessible by smaller companies, mainly due to the high price of digital factory systems [13].

The essential advantage of performing production and manufacturing processes in a digital environment like the digital factory, in comparison with real conditions in the practice and in a real factory, is that the digital factory operates only with data in a virtual environment and not with real resources and material flow.

For this reason, the production process in a virtual environment can be executed in any number of experiments and variations under different conditions before the actual production plan in the real production system is executed [14]. This is the main reason why digital or the so called virtual environment is so useful, and quite suitable, especially for the optimization of production processes in advance.

3. ADVANCED APPROACH

Based on fundamental presumptions from the literature [15, 16] and experiences from praxis, a new method and tool called MaDEIR (Manufacturing in Digital Environment Incorporating Resources) is suggested and presented in this paper, designed for the use of optimization of production processes in smaller companies.

The most important characteristic of the MaDEIR method, which distinguishes it from similar standard systems, is an advanced approach which takes into account all significant manufacturing physical and human resources that enable performing the manufacturing process. Standard systems for production planning in the abovementioned types of enterprises do not take into consideration the presence of manufacturing resources as required elements to perform a single manufacturing activity.

The concept of the MaDEIR method is based on the verification of a production plan and a schedule plan in smaller companies, dealing with the unique, small and variable quantity production. The basic idea of the concept is the presumption that a planned production plan, set up for the actual performance of a production process in a small company, can be performed in a digital factory before real manufacturing occurs.

It is very important to emphasize that the results of a verified schedule plan could be used for the prediction of the actual schedule plan execution in a real manufacturing system in the future activities of the small company, also in the case of small and unique quantity production. By considering different resources and their impact on the schedule plan course, it is possible to simulate and, herewith, to predict different unexpected deadlocks because of the unexpected unavailability of required physical and also human resources.

By using the suggested tool and methodology it is possible to indicate and obviate the unexpected deadlocks and consecutively to prepare corrections of a production plan and a schedule plan, and to optimize the production process in advance.

The MaDEIR system is composed of four modules like the module for manufacturing the system model, the data module, the module for setting up the environment for simulation and execution, and the module for the presentation of the results.

Manufacturing system model, in which the real manufacturing process is described with all the main characteristics which have a significant role in it, is based on the real manufacturing system layout and logical interdependence between the different elements of the manufacturing system. Data module is based on the data about the resources in the manufacturing system and the data about the schedule plan (manufacturing processes course).

The model of the manufacturing system, presented in Fig.1, is based on the characteristics of a typical small company's representative with unique quantity production and is composed of three sub models, which are mutually interconnected and intertwined:

- product sub model,
- process sub model
- resources sub model.

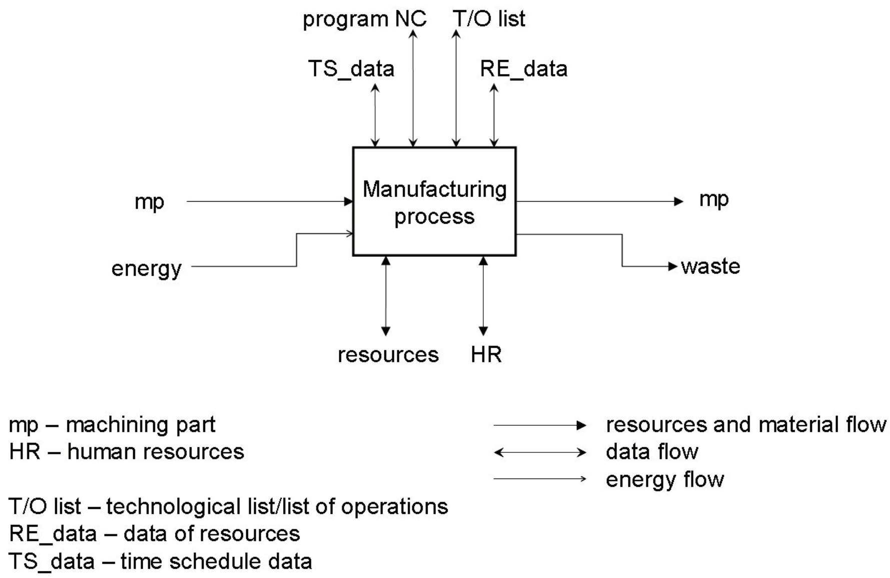

Fig. 1. Inputs and outputs of manufacturing process in small companies with unique and small quantity production

The product sub model represents all cases of products in an observed time period and includes all variants of processes that can be carried out in the observed time period and are defined in detail.

The resources sub model comprises all data about the resources in the production process and the data about the production process structure (factory structure) such as the manufacturing system layout and logical dependences between all the elements of the manufacturing system.

The manufacturing process model from Fig. 1 incorporates all basic suppositions for the single manufacturing process execution. The manufacturing process can be started under the condition that all manufacturing factors like program NC, time schedule data, technological/operational list, data about all resources, energy, physical resources, human resources and the machining part, described in Table 1, are presented at the location where the manufacturing process will be carried out.

Considering the previously mentioned sub models, the manufacturing process execution for the individual machining part is defined through a combination of the product sub model and the production process (factory) sub model. Manufacturing process execution actually consists of the sequence of operations [17] which are defined in the technological plan of the production process. The operations' execution sequence for an individual workpiece with its input and output elements, especially resources, is presented by a logical scheme of manufacturing process execution, shown in Fig. 2.

According to the MaDEIR method, the elementary unit of the manufacturing process is a production operation. On one side, the input to each individual production operation is represented by different physical elements like resources and workpiece as well as data elements like data and energy. On the other side, the output of each individual operation is also represented by different physical elements like resources and workpiece, data elements and additional elements like waste.

Table 1. Description of the manufacturing process factors

Manufacturing factor	Description
program NC	numerical control program for operations' execution on machining centres
time schedule data	time schedule data about machining operations executions in the time scale viewpoint
technological/ operational list	documents which contain technological and operational data
data of resources	data about all resources in the manufacturing system
resources	required physical resources
human resources	required human resources
machining part	machining part in the machining process
energy	all types of required energy

The condition for each operation to begin its execution is the required presence of all input elements to the operation (Table 1) on the location where the operation is carried out.

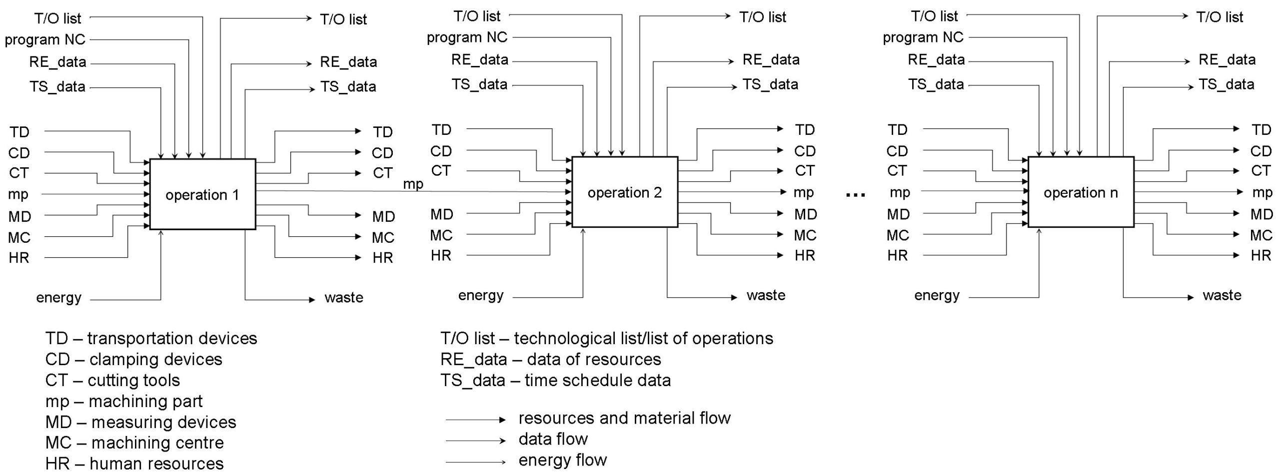

Fig. 2. Sequence of operations for individual machining part inside manufacturing process in small company

4. IMPORTANCE AND THE ROLE OF RESOURCES

The production process model is actually based on the layout of the real production process in the shop-floor with the flow of all resources and is composed of several sub models. They are very important, even indispensable for the execution of digital manufacturing in the virtual environment. The sub models of the production process are represented by the following resources:
- machining centres,
- cutting tools,
- clamping devices,
- transportation devices,
- measuring devices,
- special equipment and
- human resources

Every individual physical resource is very important for the MaDEIR model and influences its accuracy, as well as the reliability of the prediction ability of the model. Therefore, each individual physical resource has to be characterized by all of the most important parameters for the model.

In any case, it has to be characterized at least by the fundamental data set, from which the condition of the resource could be recognized in every moment of the production process, like:
- ID (identification) number, which uniquely defines a resource,
- location, with its code number, showing the momentary location of a resource,
- availability, which gives information about the resource if it is already in use or available to use in the observed moment, and the
- availability schedule, which gives the necessary information about the availability schedule of the resource.

a) Machining centre

The machining centre has a fixed location in the production process and on this location the operation is executed on the machining part. For the supervision and execution of all production operations performed on the machine, a qualified operator is required, who can manage the machine and who is also qualified to make important decisions during the production process, especially during the production operation execution.

From the production process point of view, the machining centre is basically characterized by a:
- production capacity,
- foreseen stoppage and,
- unforeseen stoppage.

The production capacity represents the number of agreed elementary units that can be produced in an elementary time unit. The foreseen stoppages are anticipated stoppages, when regular maintenance or moderating on the machining centre is carried out. The unforeseen stoppages are unexpected stoppages, caused by various reasons like mechanical breakdowns or fractures and, most often, by the unavailability of demanded resources which are needed for the execution of the production operation on the machine.

b) Cutting tools

The cutting tool sub model represents a set of cutting tools with which the machining operations are performed inside of an individual production operation. The cutting tools are located on different locations in the workshop: in tool storage, on presetting, where the preparation for machining is performed, on the machining centre, waiting for the machining operation or in the use and in the cleaning and maintenance process etc.

In the presented sub model the individual cutting tool is treated like a compounded tool, which is composed of elementary cutting tool elements like counted tool holders, adapters, cutting inserts, milling tools, turning tools, drills, milling heads, turning heads, different small elements, etc. Compounded cutting tool can be recognized over ID number on the holding part.

c) Clamping devices

The clamping device's sub model represents a set of clamping devices which are used to clamp the machining part on the machining centre table during the entire operation execution. An individual clamping device is intended for clamping on defined machining centres for defined geometry of a machining part. The clamping devices can be located on different locations in the workshop.

d) Transportation devices

The transportation devices sub model represents a set of all transportation devices which are required for the transportation of the machining part to the machining centre, for placing the machining part on the machining centre table and for the transportation of a workpiece to the warehouse. The transportation devices can be located in different locations in the workshop. Individual transportation device is intended for parts transportation having a defined geometry and weight.

e) Measuring devices

The measuring device's sub model represents a set of measuring devices which are required for the dimension checking of the machining part after the finished production operation or during/after the individual machining operation. The measuring devices can be located on different locations in a workshop.

f) Special equipment

Special equipment is a group of small pieces of equipment that is rarely and coincidentally used. Among this special equipment different standard parts, standard tools, appliances, etc. are classified. For every individual part it is important that it be available and functioning when it is required.

g) Human resources

Additionally, the most complex and demanding of all sub models is the Human Resources Sub Model (HRM). It is actually the operator model with all its possible physical and sociological conditions, activities, properties and features, which characterize the particular human operator. The most important features, which directly characterize the operator's work, are [18]:

- operator priorities,
- basic physical and sociological properties,
- operator decisions if more than one feasibility of prosecution is possible,
- operator's decision making if a prosecution is not defined but required,
- modelling the operator's tasks that are not precisely defined, but have to be considered as possible and inevitable.

One very important feature is the operator's decision making process, which depends on the instantaneous combination of individual and environmental parameters [19]. The human resources sub model of the MaDEIR method is based on different theoretical assumptions available in the literature [19-22] and on the human resources model developed for a specific digital tool-making company [18].

5. SIMULATION AND MODEL EXECUTION

The model of the manufacturing system and its execution are based on data acquired from an Integral Information System [23], a database of a small concrete company, in which all general data of elements and resources of a company are usually available.

For digital factory execution in a computer, it is first of all necessary to build up a simulation model, which is then carried out with the production process course data, usually called termin table data.

a) Simulation model

A simulation model is built up on the principles of the previously described MaDEIR method. For setting up the model, the expertise of discrete event simulation is used which enables the setting up and analysis of a dynamic model of a discrete event system. The model contains different elements of the manufacturing system and represents logical connections among them in a way that execution of the model in computer is possible. The core of a discrete event simulation is treating the events in the time moments, when the characteristics of the observed elements and processes are changed. This characteristic of a discrete event simulation makes it possible for the simulation of a longer time duration to be performed in a shorter period.

The base of the MaDEIR method is a specification of logical dependencies between elements in the simulation model that can be specified by mathematical principles and the mathematical background based on the Petri net theory [24, 25]. According to Fig. 2 and this theory, a single operation represents activity (transition) between two states in the manufacturing process. Every transition can be carried out when all input places are met; according to Fig. 2 places represent conditions. So the input places of activity can be understandable, like conditions and output places of activity like consequence. From this definition it is evident that the Petry net theory is a convenient base for simulation model construction. The list of activities and conditions are apparent from the termin table.

Execution of simulation is conducted so that transition t_i is executed in a defined moment that is enabled at that time. So the condition from M_k to M_{k+1} is changed, and can be noted down by a state equation like

$$M_k = M_{k-1} + C^T u_k \tag{1}$$

where C is the incidence matrix and u_k is the firing (or control) vector. These elements are all equal to zero except the element on *i-th* place, which is equal to 1, which means the execution of transition t_i at *k*-execution, often called firing.

Transition firing is repeated until the execution of the model is interrupted. The total simulation course can be also be written down like a firing sequence:

$$\{u_1, u_2, \ldots, u_d\} \tag{2}$$

that carry the observed system from the initial state M_0 to the final state M_d, where execution can be written down by the state equation as follows:

$$M_d = M_{d-1} + C^T \cdot \sum_{k=1}^{d} u_k \tag{3}$$

Termin table for the entire observed production process can be written as an element sequence

$$\{\{u_1, M_1\}, \{u_2, M_2\} \ldots, \{u_d, M_d\}\} \tag{4}$$

where u_k represents the transition or activity that has been executed in a defined moment and M_k indicates the condition after that execution. This type of record is quite extensive and may be unnecessary. Also, there are other important activities that cause condition modifications on places that are connected with the input conditions of operations (TD(i), CD(i), CT(i), mp(i), MD(i), MC(i), HR(i), T/O list(i), program NC(i), RE_data(i), TS_data(i) on Fig. 2). So the subset that is set to all transitions are formed like

$$T_j \subseteq \{t_1, t_2, \ldots, t_n\} \tag{5}$$

$$j \in \{TD, CD, CT, mp, MD, MC, HR, T/O\ list, program\ NC, RE\_data, TS\_data\} \tag{6}$$

Where, it is valid for each t that at least one input or output place from P_j, respectively, from the subset of the set of all places

$$P_j \subseteq \{p_1, p_2, \ldots, p_m\} \tag{7}$$

where it is valid for each p in which object conditions that represent resources or input conditions can be found.

Further, $\{v_1, v_2, \ldots, v_l\}_j$ can be defined like a sequence composed only of $\{u_1, u_2, \ldots, u_d\}$ sequence elements having transitions t from set T_j.

In the termin table, regarding resources or input conditions, it is not necessary for the entire system condition M_k, but only the output place $p \in P_j$ condition of transition t that has been executed in firing k, what is written down as r_k.

So the termin table regarding resources or input conditions can be noted down as a sequence of elements:

$$\{\{v_1, r_1\}, \{v_2, r_2\} \ldots, \{v_l, r_l\}\} \quad \forall j \tag{8}$$

All places $p \in P_j$ have capacity 1. That means that in a defined moment only one object's characteristic, which is often named token, can be in a separate place. Output place condition r_k is defined by token or token attributes that actually represent the condition of a separate resource or input condition.

b) Petri nets – basic definitions

A Petri net consists of *places*, *transitions*, *directed arcs* and *tokens*. Arcs run from a place to a transition or from a transition to a place, never between places or between transitions. The places from which an arc runs to a transition are called the *input places* of the transition and the places to which arcs run from a transition are called the *output places* of the transition.

Places may contain any non-negative number of tokens. A distribution of tokens over the places of a net is called a *marking*. A transition of a Petri net may *fire* whenever there is a token at the end of all input arcs. When it fires, it consumes these tokens, and places tokens at the end of all output arcs. A firing is atomic, i.e., a single uninterruptible step.

Execution of Petri nets is nondeterministic. When multiple transitions are enabled at the same time, any one of them may fire. If a transition is enabled, it may fire, but it doesn't have to [24, 25].

A classical Petri net is a four-tuple (P, T, I, O) and satisfying the following conditions [24]:

- P is a nonempty and finite set of places, and T is a nonempty and finite set of transitions
- I is a function which determines the input multiplicity for each input arc:

$$I: P \times T \rightarrow \{0, 1\} \tag{9}$$

- O is a function which determines the output multiplicity for each output arc:

$$O: T \times P \rightarrow \{0, 1\} \quad (10)$$

c) Simulation model setting up and execution

The setting up of a simulation model and its execution is carried out using a standard computer package Plant Simulation (Tecnomatix eM-Plant), designed for the execution of discrete event simulations. The standard basic tool is chosen from a reason to simplify the model corrections and adaptations. More complex logic of logical dependencies between model elements in the simulation model is built in through programming in the programming language SimTalk.

d) Simulation results

The results of the simulation, in the form of output data from the digital factory, comprise all principal data concerning the course of the manufacturing process in a digital factory, like:

- code of workpiece,
- identification number of operation,
- code of machining centre, where operation is executed,
- start time of an operation in digital factory,
- end time of an operation in digital factory,
- duration of an operation in digital factory, etc.

The most important data from the digital factory concerning individual operation are the beginning and the end time of an operation, as well as the operation duration. An example of the simulated production process and a comparison of the simulation results with the real schedule plan of the production process operations of one workpiece manufacturing in a small company, specializing in small quantity production of unique and small quantities of products, is shown in Fig. 3.

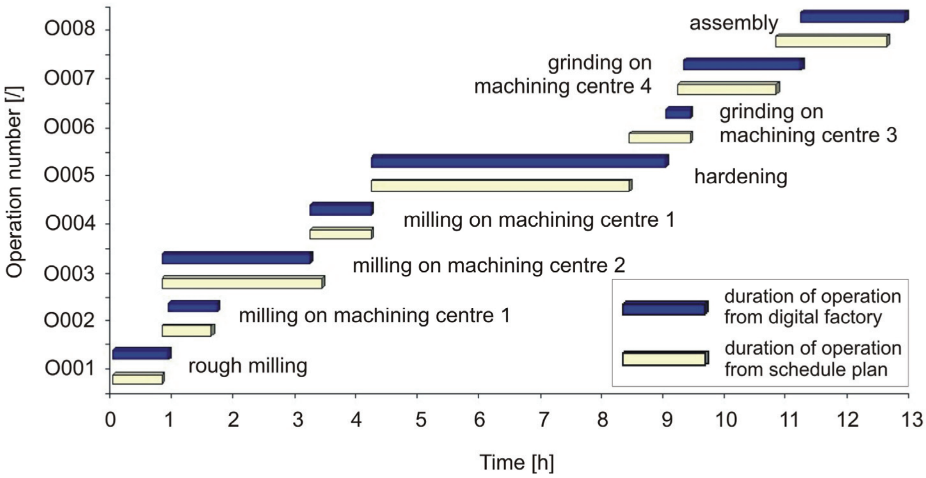

Fig. 3. Comparison between the simulation results and the real data from the schedule plan – first run

Simulation results and the output data from the digital factory are a basement for the accomplishment of operations course analysis and production process optimization. Comparison between the simulation data, concerning the anticipated course of individual operations of the production process and the real data from the planned time table of the workshop can show the following results:

- data from the digital factory are not showing essential deviations from the real time table data,
- data from the digital factory are showing essential deviations from the real time table data.

No essential deviations between the simulation and the real data show that planned resources for planned operations performance are available on the demanded terms. This means that the prepared manufacturing plan is planned well.

If there are deviations between both data, it means that the planned manufacturing process is not planned well. Reasons can be the unavailability of demanded resources or unexpected disturbances. It is then necessary to carry out additional analyses of data that are acquired from the digital factory to find out reasons for the appearance of the deviations and to eliminate deadlocks in the production process.

Additional analyses are made for critical operations in detail to find out why an operation cannot be carried out. A typical reason is resources unavailability and production plan corrections. This is possible in two ways: the critical resources should be replaced with similar resources or the critical operations should be moved on other termin to be performed.

A new simulation is then performed with the corrected and optimized data of the manufacturing process in the digital factory followed by the data comparison and optimization step. These steps can be repeated until the optimal production plan is achieved.

On Fig. 3 a comparison between the simulation results of the first run and the real data from the schedule plan, for example, from the real world are presented. It is evident that some greater deviations between planned production and the digital factory results and optimization of the production plan is necessary. So the correction in the production plan has been made, then the microplanning has been performed once again, and the second run in the digital factory has been done (Fig. 4).

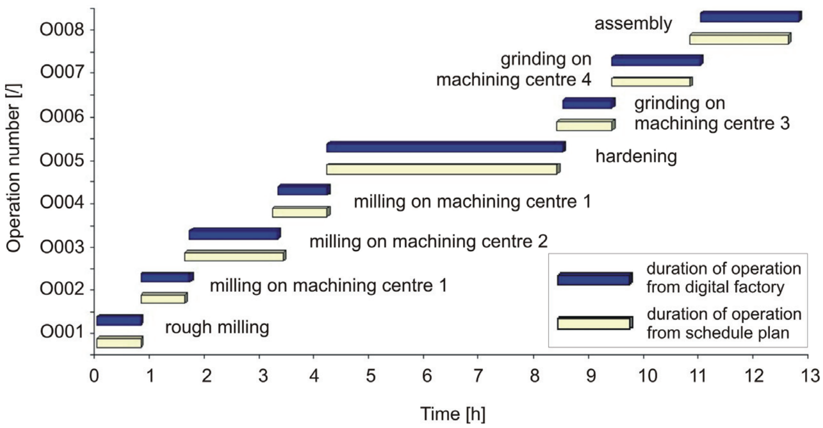

Fig. 4. Comparison between the simulation results and the real data from the schedule plan – second run

From the second run simulations analysis are evident and there is good accordance between the planned production data and the digital factory results. Additional corrections of the production plan are not necessary. The results from the presented example present the advantages of the planned production plan execution in the digital factory. Namely, the precise production plan ensures accurate production ability in enterprises.

6. CONCLUSION

The main aim of the presented research work is to propose a new, low cost optimization tool and method for the optimization of production processes from the resource presence point of view in small companies with small quantity production. A second important advantage of the proposed method is the use of the production plan data directly from the database of an integrated information system, which is used as input data for the simulation runs. The proposed method is based on manufacturing in a digital environment and incorporates all the resources present in the production process and are proven to be important for the prediction accuracy of the proposed method called MaDEIR. In this method all the resources are treated as one of the main parameters in the manufacturing process execution level.

On the actual development level of the MaDEIR method, an expert with considerable experience in setting up an appropriate simulation model and also in making the right decisions on the basis of the simulation results to perform the optimization of the production plan is required.

Previous studies have shown that further work has to be directed towards the development of parametric designing of a simulation model and in creating a database of decisions that are often made on the basis of simulation results. This ensures the usability of the developed tool for a wider range of users. And the desired goal of any future work is the integration of the MaDEIR method and production planning system, which would mean the simultaneous planning and optimization of the production plan.

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