Manufacturing Management - a New Approach

Gabriel Frumuşanu and Alexandru Epureanu

Abstract—**The manufacturing management plays an essential role in ensuring the required competitiveness on market. The main issue to be targeted by this activity is the manufacturing performance. This paper concerns a new vision about manufacturing performance management, adapted to the context of Industry 4.0 era, and a solution to implement this matter. The new vision is based on the conceptual rebuilding of the manufacturing process. It operates with basic notions as the manufacturing task, job, and cycle, defined in original manner, and looks towards the global performance as ultimate goal of manufacturing. The manufacturing process means, according to here introduced approach, the matching up of three actions: learning, which means jobs modeling, deciding, which means tasks releasing, and processing, which means transforming of material and generating information related to this. The manufacturing process is addressed as decisional process, instead of physical process, as in current approaches. Unlike conventionally considered as the changing of part state, from the current state up to the next one, the manufacturing task is approached as the change of state undergone by a certain unit of product, being under manufacture in a given manufacturing system, from the current state up to its final state. According to proposed approach, the manufacturing management consists in performant model-based decision making, which includes performance assessment, monitoring and driving. The operation management action means monitoring-based adjustment of the three manufacturing process components, namely learning, deciding, and processing, aiming performance improvement. It is addressed at task, job, and variable level.**

***Index Terms*—Manufacturing operation management, decisional process modeling, manufacturing performance, management driving loop, online management.**

I. Introduction

Production is defined as "the step-by-step conversion of one form of material into another form through chemical or mechanical process to create or enhance the utility of the product to the user" [1]. Manufacturing is a particular form of production and refers to the processing of raw materials or parts into finished goods through the use of tools, human labor, machinery, and chemical processing [2]. In other words, manufacturing means the transformation of materials into industrial products, through natural phenomena (physical, chemical, biological), artificially provoked [3]. Manufacturing is one of the most important components of the economy, hereby its efficiency and degree of compliance to the expected results is crucial.

At each processing step, there will be value addition. Manufacturing management refers to those aspects of the product manufacturing process that impact this. Managing a manufacturing plant means responsibility for the process, from assembly design to packaging and sending out the finished product [4]. Manufacturing managers plan, schedule, and direct an efficient layout of equipment and flow of materials. Being a manufacturing manager means ensuring that manufacturing performance, volume, and quality goals are met [5].

Unlike plant level management, operation management is the administration of business practices to create the highest level of efficiency possible for each manufactured product. It is concerned with converting materials and labor into goods and services as efficiently as possible to maximize the profit of an organization [6]. To get confirmations regarding the fulfilling of their objectives and goals organizations must keep checking over their performance.

To achieve this purpose, organizations must have to use the performance management systems. Simply the performance management is done by the organizations to confirm that either they are going in right direction or not. For measuring, managing, and comparing the performance the organizations are required to know about the performance indicators [7]. At operation management level, the performance indicators can be defined as the physical values which are used to measure, compare, and manage the overall organizational performance [8]. At higher levels, the Enterprise Resources Planning (ERP) platforms operate with so-called Key Performance Indicators (KPI-s), among which top 5 are: Production Volume, Production Costs, On-time Delivery, First Time Right, and Revenue per Employee [9].

Numerous papers have already addressed the manufacturing management topics, aiming to increase the performance in manufacturing. Among these, [10] proposes a new paradigm to go beyond the traditional approaches, namely the production quality. The authors of [11] present a systematic methodology to enable environmental sustainability and productivity performance assessment for integrated process and operation plans at the machine cell level of a manufacturing system. The issue of sustainable management as main manufacturing performance indicator, in the case of machining shop floors, whose manufacturing activities are usually characterized by high variety and low volume is addressed by [12].

Despite the operation management works on the base of successive decisions, current approaches regarding the increase of management performance focus on the physical processes. Thus, the management process shows a particular character, according to each physical process. Under these circumstances, the challenge to which this paper answers is to release a new approach concerning the manufacturing operation management, based on decisional process modeling. This will further enable to create a general and unitary conceptual basis for the management process, no

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matter of the physical process through which manufacturing takes place, and to management online performing.

Starting from here, the next section introduces the levels of approaching the manufacturing activity (process, task, job, procedure, and cycle). The third section deals with the new approach in manufacturing management, illustrated in the newly proposed manufacturing management diagram. The fourth section presents an illustrative example, while the last section is for conclusion.

II. MANUFACTURING ACTIVITY

According to proposed approach, the operation management refers here to the operational, online, day-to-day management. The distinctive features of the approach are introduced below and concern the manufacturing process, task, job, procedure, and cycle.

A. Manufacturing process

The manufacturing process means, according to here introduced approach, the matching up of the following three actions:

- **learning**, which means jobs modeling,
- **deciding**, which means tasks releasing, and
- **processing**, which means transforming of material and generating information related to this.

It should be noticed that the manufacturing process is here addressed as decisional process, instead of physical process, as current approaches do.

B. Manufacturing task

The manufacturing of a given part supposes that it successively passes through a certain number of states, until becoming deliverable. The manufacturing task is conventionally considered as the changing of part state, from the current state up to the next one. Unlike this definition, here the manufacturing task is approached as the change of state undergone by a certain unit of product, being under manufacture in a given manufacturing system, from the **curren**t state **up to** its **final** state.

The manufacturing task is **qualitatively described by *T*** vector, which can be defined at three levels:

- <u>Features level</u>, as

$$\boldsymbol{T}_{features} = \{\boldsymbol{S}, \boldsymbol{P}, \boldsymbol{Q}\}, \qquad (1)$$

where ***S***, ***P***, and ***Q*** are the task features – actually, three vectors describing, at their turn, the product state change, process performance, and operating conditions, respectively,

- <u>Attributes level</u>, as

$$\boldsymbol{T}_{attributes} = \left\{\{S_i\}, \{P_j\}, \{Q_k\}\right\}, \qquad (2)$$

each feature being described by a certain number of attributes, and

- <u>Variables level</u>, as

$$\boldsymbol{T}_{variables} = \left\{\{S_i{}'\}, \{P_j{}'\}, \{Q_k{}'\}, \{S_i{}''\}, \{P_j{}''\}, \{Q_k{}''\}, \{S_i{}'''\}, \{P_j{}'''\}, \{Q_k{}'''\}\right\}, \qquad (3)$$

each attribute having three remarkable levels (i.e., **imposed**, **set**, and **measured** level), described by as many variables and denoted by $'$, $''$, and $'''$, respectively.

The manufacturing task is **quantitatively described by the values** of the variables from (3), which can be retrieved in three sets having different extension and application, as it follows:

- The values of the imposed level of the attributes,

$$\widehat{\boldsymbol{T}} = \left\{\{s_i{}'\}, \{p_j{}'\}, \{q_k{}'\}\right\}, \qquad (4)$$

- The values of the imposed and set levels of the attributes,

$$\overline{\boldsymbol{T}} = \left\{\{s_i{}'\}, \{p_j{}'\}, \{q_k{}'\}, \{s_i{}''\}, \{p_j{}''\}, \{q_k{}''\}\right\}, \qquad (5)$$

and

- The values of the imposed, set, and measured levels of the attributes,

$$\widetilde{\boldsymbol{T}} = \left\{\{s_i{}'\}, \{p_j{}'\}, \{q_k{}'\}, \{s_i{}''\}, \{p_j{}''\}, \{q_k{}''\}, \{s_i{}'''\}, \{p_j{}'''\}, \{q_k{}'''\}\right\}. \qquad (6)$$

For an easier understanding the proposed description of the manufacturing task, structured on its three levels, this is illustrated in Fig. 1.

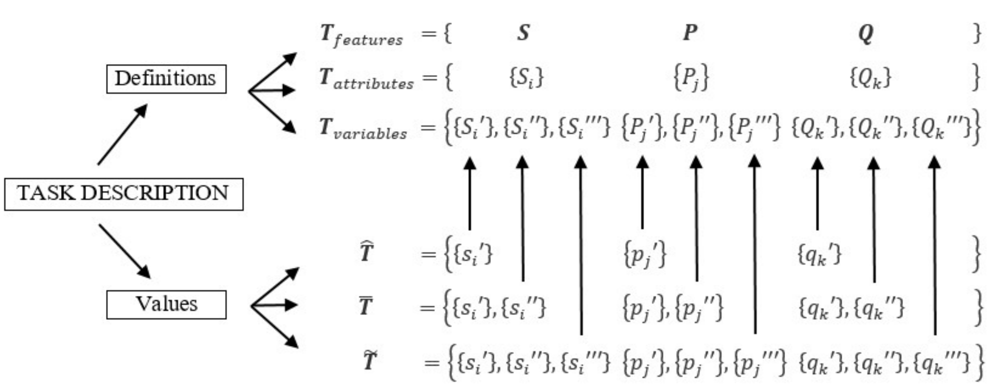

Fig. 1. Task description

The manufacturing task is completed after finding the variables values, corresponding to the given task, and it is addressed as a manufacturing sequence.

The following notations will be further referred:

- T_α – task following to be executed (α = a, b, c, etc.),
- T_n – released task (n = 1, 2, 3, etc.),
- T^* - task following to be driven, and
- M^* - model following to be driven.

C. Manufacturing job

The manufacturing job is addressed as a family of tasks that concomitantly satisfy two conditions:

- they have the **same definitions of the features, attributes, and variables,** while the variables values can be different, and
- they are modeled by the **same model,** describing the relationships between variable values.

D. Manufacturing procedure

The manufacturing procedure is addressed as an organized cluster (family) of **techniques** intended to carry out the manufacturing activity stages, namely the ordering, design, planning, programming, and processing (Fig. 2). The product takes a typical form after each stage.

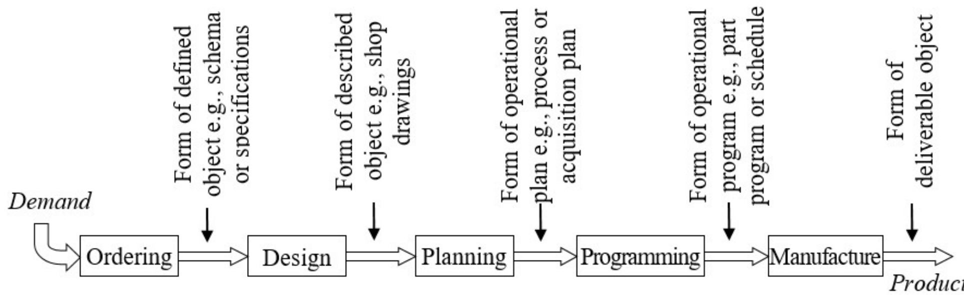

Fig. 2. Manufacturing activity stages & product typical forms [13]

E. Manufacturing cycle

The manufacturing cycle means a sequence, during which **a given task** is accomplished. It comprises a set of interdependent **learning, deciding,** and **processing** actions, these being associated with a set of **precedence** and **belonging** conditions. The manufacturing cycle is supported by the manufacturing unit that is considered as an organized cluster (family) of **assets** intended to implement a set of manufacturing **techniques** or to manufacture a set of industrial **products**. It is comprised as the boundary of the **operation management workspace**.

III. Manufacturing Management

According to proposed approach, the manufacturing management consists in **performance - model-based decision making** that includes performance **assessment**, **monitoring** and **driving**. The operation management action means monitoring-based **adjustment** of the three manufacturing process components, namely learning, deciding, and processing, aiming performance improvement. It is addressed at **task, job**, and **variable** level.

A. Task-level management

In manufacturing management diagram (see Fig. 3), the task-level management is addressed at "Task line" and consists in making of the best decision and driving of the released tasks.

- Making of the best decision regarding the reconfiguring of the initial task, i.e., by replacing it with one or several newly generated tasks, which may be execution or released tasks.

Here by released tasks, T_n, n = 1, 2, 3, ..., they are meant tasks for which only the imposed values of the attributes, indicators, and conditions $\widehat{\boldsymbol{T_n}} = \{\{s_i'\},\{p_j'\},\{q_k'\}\}$ are known, and for which the decisional process continues. At the same time, by execution tasks, T_α, α = a, b, c, ..., they are meant tasks for which the imposed and set values of the the attributes, indicators, and conditions are known, $\overline{\boldsymbol{T_\alpha}} = \{\{s_i'\},\{p_j'\},\{q_k'\},\{s_i''\},\{p_j''\},\{q_k''\}\}$ while their monitored values will be found during the execution of the task.

- Driving of the released tasks, which is based on the assessment of the monitored levels for the attributes - $\{s_i'''\}$, indicators - $\{p_j'''\}$, and conditions - $\{q_k'''\}$, for the current execution task.

The task-level management ends when the initial task is fully replaced by a set of executable tasks.

B. Job-level management

In manufacturing management diagram (see Fig. 3), the job-level management is addressed at "Job line" and refers to the structure, building, usage and driving of the model of the job corresponding to the given task.

- Model structure can take two forms, depending on the nature of the task that will be further addressed.

When an initial task T_0 is configured, thus resulting released tasks T_n and execution tasks T_α, the model variables are the imposed values of the attributes levels for the initial and released tasks, together with the imposed and set values of the attributes levels for the executed tasks, while model formalization means the function F_1,

$$F_1\left(\{\{s_i'\},\{p_j'\},\{q_k'\}\}_{T_0}\right) = \{\{s_i'\},\{p_j'\},\{q_k'\}\}_{T_n} \cup \\ \cup \{\{s_i'\},\{p_j'\},\{q_k'\},\{s_i''\},\{p_j''\},\{q_k''\}\}_{T_\alpha}. \quad (7)$$

When an initial task T_0 is configured, thus resulting only execution tasks T_α, the model variables are the imposed values of the attributes levels for the initial task, together with the set values of the attributes levels for the executed tasks while model formalization means the function F_2,

$$F_2\left(\left\{\{s_i'\},\{p_j'\},\{q_k'\}\right\}_{T_0}\right)=\left\{\{s_i''\},\{p_j''\},\{q_k''\}\right\}_{T_\alpha}. \quad (8)$$

- Model building algorithm is based on holistic monitoring [14], which generates an instances dataset of completed tasks, and on causal modeling [15], which generates clusters of causally related task variables.
- Model usage algorithm is based on comparative assessment [16].
- Model driving is based on the basic model $m(T_n)$, obtained by learning.

C. Variable-level management

In manufacturing management diagram (see Fig. 3), the variable-level management is addressed at "Variable line" and refers to adjusting the reference values of the variables for the execution task, $\overline{T_\alpha}^*$, based on assessment of the monitored levels of the attributes – $\{s_i'''\}$, indicators – $\{p_j'''\}$, and conditions – $\{q_k'''\}$, for the current execution task. Here, "Reference value" may refer to the reference of variable measuring frame, to the reference of variable control loop, or to both. On this manner, the final form of the vector $\overline{T_\alpha}$ results, and then, after processing, the vector $\widetilde{\boldsymbol{T}_\propto} = \left\{\{s_i'\},\{p_j'\},\{q_k'\},\{s_i''\},\{p_j''\},\{q_k''\},\{s_i'''\},\{p_j'''\},\{q_k'''\}\right\}$, that includes the values of the imposed, set, and measured levels of the attributes for the current execution task is generated.

D. Manufacturing management diagram

According to the here introduced approach, the manufacturing management is performed by following the algorithm illustrated by the diagram from Fig. 3. The algorithm supposes the running of three loops, as below described. Let us suppose that the task T_1, meaning the manufacturing of a certain part, must be accomplished for a given number of times.

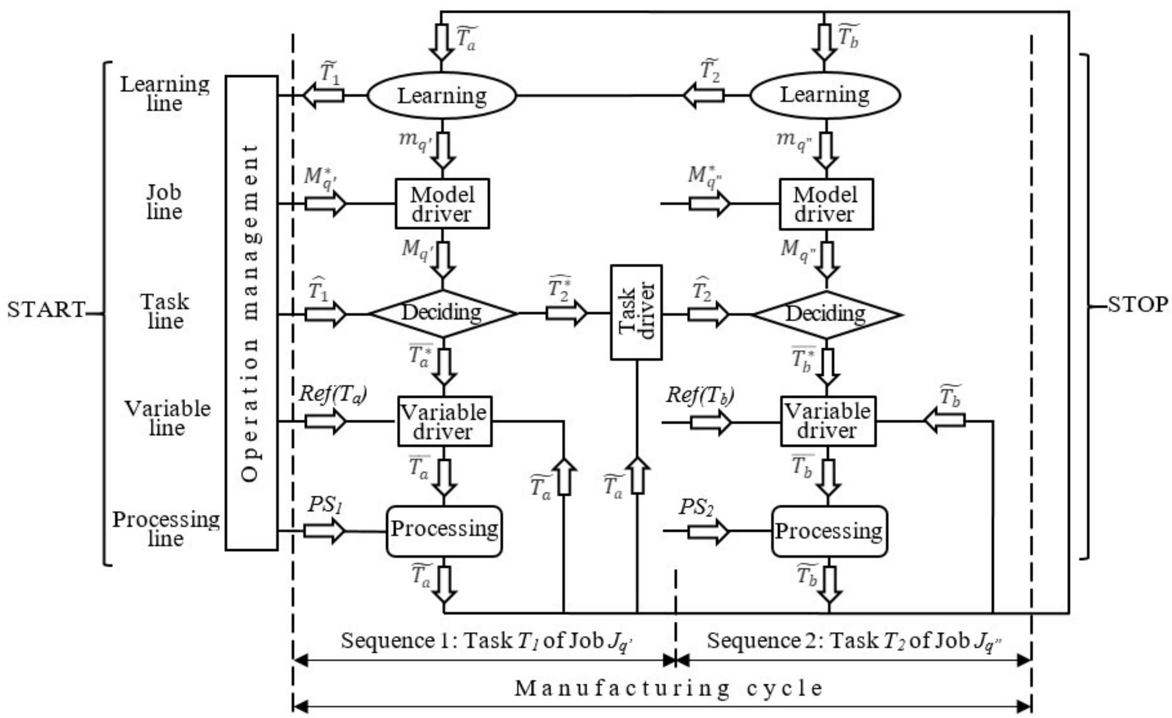

Fig. 3. Manufacturing management diagram

- Model driving loop is related to job-level management. At first, the *Operation management* identifies the job $J_{q'}$ to which T_1 belongs and then delivers to *Model driver* the existing model of this job, $M_{q'}^*$. Except the case of manufacturing the first part from a batch, the module also receives, from *Learning* station, the model of T_1 accomplishment in the case of previous part - $m_{q'}$. On this base, $M_{q'}^*$ is driven into $M_{q'}$ model, which is transmitted to *Deciding* station from *Task* line.
- Task driving loop regards task-level management and is included into the previous driving loop. After receiving the model $M_{q'}$ and the imposed values of the attributes, indicators, and conditions for T_1 task, namely the vector $\widehat{T}_1$, the deciding station makes the decision regarding which task T_a will be assumed for the current manufacturing sequence, and which task T_2 will be released for the next manufacturing sequence. Both T_a and T_2 could be actually composed by more tasks. The imposed values of the attributes, indicators, and conditions for T_a and T_2 tasks, namely $\widehat{T_a^*}$ and $\widehat{T_2^*}$ vectors are sent towards *Variable* driver and *Task* driver, respectively. The *Task driver* analyses the measured levels of the attributes for the current execution of T_a task, included in $\widetilde{T_a}$ vector, and drives $\widehat{T_2^*}$ vector into $\widehat{T}_2$, following to be considered as input information for performing the next sequence of the manufacturing cycle.
- Variable driving loop regards the variable-level management and is, at its turn, included into both previous driving loops. The *Variable driver* receives the $\widehat{T_a^*}$ vector, together with the reference values of the variables for T_a task, *Ref(T_a)* (from *Operation management* unit), and the measured levels of the attributes for the current execution task - the $\widetilde{T_a}$ vector (from *Processing* station). On this base, the driver adjusts the set values of the attributes, indicators, and conditions, included in $\overline{T_a}$ vector, which is sent to *Processing*

station. After the manufacturing task T_a is completed, which means the ending of the first sequence, the final form of $\widetilde{T_a}$ vector, including the imposed, set, and measured levels of the attributes concerning this task accomplishment is transmitted to *Learning* station.

The second sequence, which in the case of depicted manufacturing cycle is an execution task, takes place in similar manner to the first one, except the absence of released task component. More specific, the *Deciding* station only makes the decision regarding the execution of T_b task. The final form of $\widetilde{T_b}$ vector, including the imposed, set, and measured levels of the attributes concerning T_b task accomplishment is also transmitted to the *Learning* station afferent to second sequence. This station aggregates the results of all T_b tasks, composing the generic task T_2, and generates the $\widetilde{T_2}$ vector. Finally, the *Learning* station afferent to first sequence aggregates, at its turn, $\widetilde{T_a}$ and $\widetilde{T_2}$ and finds $\widetilde{T_1}$ that is communicated to *Operation management*.

IV. Illustrative Example

In ship structure, the pipe flanges (Fig. 4) are common parts (from piping system) that are used to connect one pipe section to another pipe section. Each flange is attached to its supporting pipe by welding.

Fig. 4. Pipe flanges

For a better understanding of the here introduced approach regarding the manufacturing management, we further present an illustrative example concerning the proposed approach application, in the specific case of a pipe flange manufacturing, meaning the task T_1. The afferent manufacturing cycle is represented in Fig. 5.

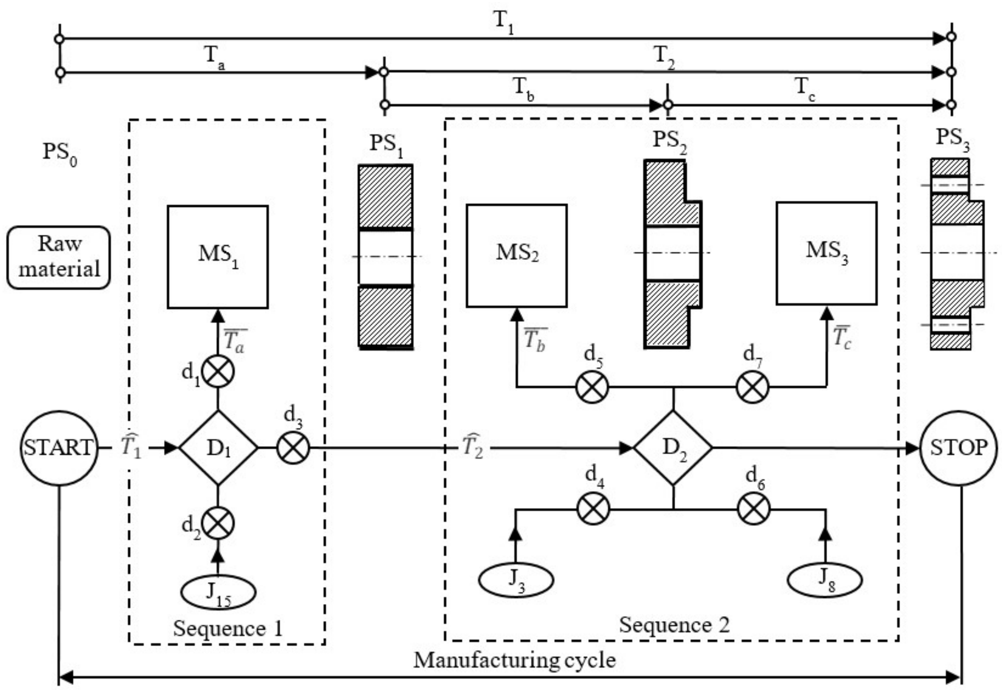

Fig. 5. Illustrative example

The manufacturing cycle fulfilment, in the addressed example, means the following decisional flow. At first, the task T_1 is communicated to D_1 decisional station as $\widehat{T_1}$ vector. Here, it is made the decision about both the next state of the product (PS_1), and the appropriate job to be performed to obtain the expected product. As consequence, two new tasks are generated, namely T_a and T_2. The first is an execution task (described as $\widehat{T_a}$ vector) of J_{15} type of job (cutting out) and is assumed to be executed during Sequence 1, on MS_1 manufacturing station. The second, which consists in bringing the product from PS_1 to PS_3 state is further released, as $\widehat{T_2}$ vector. The D_1 station also generates $\overline{T_a}$ vector, which is sent towards MS_1 station. Then, the D_2 decisional station configures T_2 in two execution tasks T_b and T_c, of J_3 and J_8 types of job (turning and drilling), described by $\widehat{T_b}$ and $\widehat{T_c}$ vectors. It also generates $\overline{T_b}$ and $\overline{T_c}$ vectors, which are sent towards MS_2 and MS_3 stations, respectively. The drivers d_2, d_4 and d_6 are model decision drivers, d_3 is task decision driver, while d_1, d_5 and d_7 are variable control drivers, and play the roles described in subsection III-D.

V. Conclusion

The proposed approach enables a better grounding for the operation management, hereby it is expected that its implementation will generate significant benefits concerning management performance. Some remarks sustaining this statement are presented below.

- According to the new approach, the operation management is based on the use of digital models, taking full advantage from digital technologies capabilities.
- Due to modelling of the decisional process, the resulted model is no longer dependent on the physical process nature, as in current, conventional situation. The only

element that differentiates two distinct cases is the dataset to which the model follows to be applied.

- The manufacturing system is seen as cyber-physical system, where the cyber-subsystem supports learning actions, the physical-subsystem enables processing actions, while operation management represents the decisional actions that lead to task accomplishment. Here, the cyber-subsystem can connect a large number of manufacturing stations, situated in different locations, and gathers, from each such station, a large volume of data from particular cases. Thus, a huge dataset can be obtained as the best support for managing new particular cases.
- It is also expected that the proposed approach will lead to the increase of management efficiency because, for the making of all decisions, the task representing the hypothesis is defined by the current and the final states of the product, instead as by its current and next states, as in conventional manner.
- According to here introduced approach, the management may be performed both offline or online. In second case, the management can be set more or less coarse, depending on the relation between the numbers of decision stations and manufacturing stations. On this way, a convenient trade-off between decisions accuracy (finer setting) and decisional process simplicity (coarser setting) can be made.

The main limitation for proposed approach implementation is the necessity of a significant investment necessary for the holistic monitoring of the manufacturing system and for building the manufacturing information system.

Conflict of Interests

The authors declare no conflict of interests.

Authors Contribution

Alexandru Epureanu developed the paper main concepts, while Gabriel Frumuşanu did the rest of the work.

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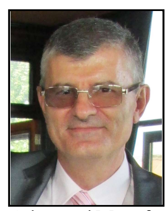

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