A SELF-ORGANIZING APPROACH FOR MIXED-MODEL MANUFACTURING BASED ON AUTONOMOUS ENTITIES

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ABSTRACT: Decentralized autonomous entities are desired to be implemented in the production systems to fully function in the future, not only to close the gap between the high computer power, high communication capabilities and the way goods are produced nowadays, but also because of the advantages they bring. In the last years, mass production and build to stock (BTO) turned out to be defectuous because of the customer needs that changed dramatically towards customized products and short order lead times. Practically mass production is heading towards mass customization nowadays, raising problems of managing high complexity of options. The complexity increases even more if it is taken into consideration that some customers are more demanding than others, wanting their products to be prioritized in the production process. This paper will present a manufacturing system concept that takes advantage of smart products and cyber-physical systems to achieve high flexibility and agility towards prioritization.

KEY WORDS: self-organizing system, mixed-model, prioritization, customization, intelligent manufacturing systems.

1 INTRODUCTION

Customer needs have changed in the last years and can be defined briefly as follows:

- Highly customizable products;
- Short lead times;
- High quality products.

To respond at the current customer needs, since January 2012, when the "Industry 4.0" Work Group was formed (BMBF, BMWi, 2012), the new paradigm of the 4th Industrial Revolution started to gain substance closing the gap between the high processing power and communication capabilities reached nowadays, and the outdated, centralized manufacturing methods widely used to produce goods at the moment (Sturgeon et al, 2009) steering the way of producing goods towards decentralized entities with unique identities and autonomous behavior (McFarlane, 2012).

The main actors in the new paradigm are the smart products, smart machines and the augmented operators (SmartFactory^{KL}, 2015).

Smart machines can be assimilated to the, so called, Cyber-Physical Systems (CPS), which are entities capable of computing, communicating and acting autonomously, according to the events that occur in the system (Wolf, 2009).

Intelligent monitoring and autonomous decision-making processes are important in this context and need to be optimized in order to be able to control, in almost real time, the value adding networks (BMBF, BMWi, 2012).

In this paper we will present a self-organizing system concept that is able to process the products with respect to their priorities through a method that can be integrated in a physical prioritization concept. The sequence of products it is considered to have stochastic characteristics (priorities of the products, time of entrance of every product in the system, specific characteristics/features that every product possess) and the system it is considered to be able to process the products regardless the position of the different workplaces in the system, being able to take advantage of modularization.

The system is designed to process models that are variations of the same base product and differ only at several specific custom attributes/options. In literature these type of production is found under the name of "mixed-model manufacturing" (Boysen et al, 2006).

2 PREREQUISITES

We consider a manufacturing system consisting of the following representative entities: **workplaces**, **transportation and manipulation system** and **query nodes**. Products that need to be processed enter the manufacturing system through a specific point (main source) and exit the system through other specific point (main exit), that can, if the case, coincide with the entering point. The secondary sources and exits, as shown in fig. 1,

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represent the entries and exits of the needed materials for the manufacturing process.

Products need to be processed on one or more existing workplaces. The representative characteristic of every product is its priority.

The purpose of the system is to process a specific sequence of products with respect to their priorities, so that the final sequence of the same products will be ordered, in some extent, as follows: the products with higher priorities will be processed first, being found at the beginning of the final sequence, and the products with lower priorities will be processed last, being found last in the final sequence. In other words, the system will balance the production lead times (leadtimes.org) in favour of the products with high priorities, minimizing them. (Marin, Brîndașu, 2014)

The initial sequence of products is characterized by: **stochastic priorities**, **stochastic time of entrance in the system** and **stochastic characteristics**.

Stochastic priorities refer to the sequence of priorities extracted in the same order as products enter the system, without considering the time of entrance or characteristics of the product.

Table 1. Priority Sequence Example

Product	a	b	c	...	n
Priority	3	5	1	...	2

Stochastic time of entrance refer to the delay between the entrance of the products in the system, without considering the priority or characteristics of the product.

Table 2. Stochastic Time Example

Product	a	b	c	...	n
Delay of entrance (sec)	0	6	25	...	2

Table 3. Stochastic Characteristics Example

		Product				
		a	b	c	...	n
Characteristic	C1	1	0	1	...	0
	C2	0	1	0		1
	C3	0	1	1		0
	...					
	Cn	0	1	1		0

Stochastic characteristics refer to the number of processes that need to be performed on every product, translated in the number and type of workplaces a product needs to visit to be completely processed. In the example below, a product will have the characteristics marked with “1” and not have the characteristics marked with “0”. In this paper we consider that a workplace is able to process a single characteristic from the whole range of characteristics available. For example, “wp1” can process only “C1”.

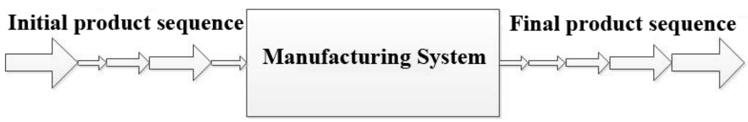

Figure 1. General principle represented from the priority, product characteristics and time of entrance point of view

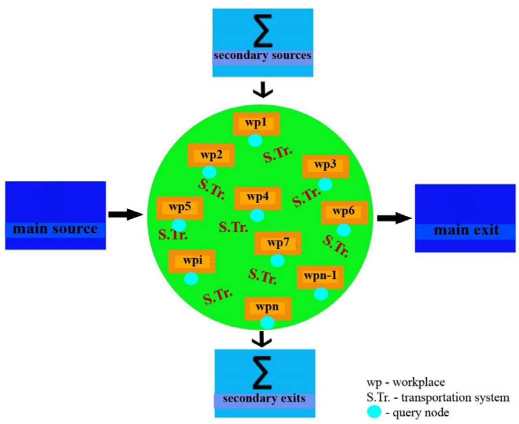

Figure 2. Generalized model of the system concept

3 ENTITIES

3.1 Workplaces

The structure of a workplace treated in this paper consists of:

- Buffer area with size of one product;
- Processing area;
- Temporary stock area for raw materials needed in manufacturing process;
- Temporary stock area for waste products resulted from the manufacturing process;
- 4 interfaces:
  - Entrance of products in the workplace;
  - Exit of products from the workplace;
  - Entrance of raw materials in the workplace
  - Exit of waste materials from the workplace.

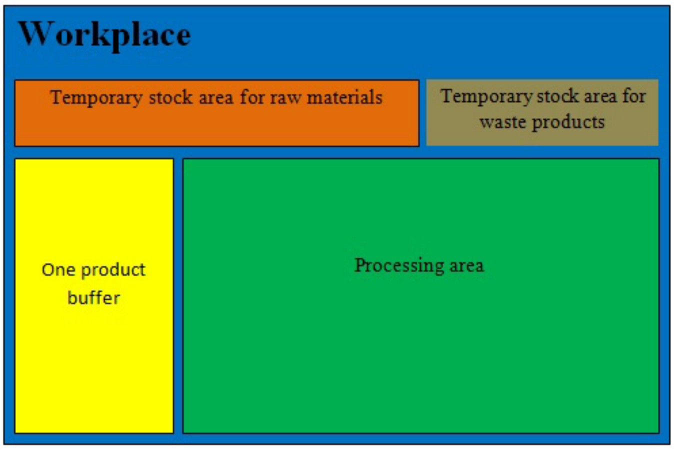

Figure 3. Workplace model

The representative characteristic of the workplace is defined as follows:

$WPt = Pt + At$ (1)

Where:

WPt – workplace time, represents the total time spent by the product in the workplace without buffer time;

Pt – processing time, represents the time required for processing the required characteristic/option on the product;

At – auxiliary time, represents the time required for preparation and finishing o f the processing together with the time required for the manipulation of the product inside the workplace (manipulation of the product from the transportation and manipulation system to the buffer, manipulation of the product from the buffer to the processing area, manipulation of the product from the processing area back to the transportation and manipulation system, etc.);

Bt, which represents the buffer time (the time spent by the product in the one-place-buffer waiting for processing) is not considered in (1) because of the increased difficulty of its determination, as it will be seen later on in the paper.

Temporary stock areas for raw materials (*TSA*) have the purpose to support the process with the needed materials for the materialization of the characteristic the product needs to have. Supply of the *TSA* can be done using a capacity threshold determined according the time needed to refill the *TSA* with needed raw materials.

3.2 Transportation and manipulation system

The transportation and manipulation system needs to assure:

- access of every product to all workplaces in the system.;
- plural access of the products in the system, to every one specific, existing workplace;

- optimum flow of materials and avoidance of bottlenecks.

3.3 Query nodes

A query node is allocated to every workplace and represents the gate for the products that need to access it.

The query nodes interrogate products about the following information in the order presented below:

1. characteristic that needs to be processed on the product at that point in its production process;
2. priority of the product.

The query nodes interrogate the workplace about the following information in the order presented below:

1. capacity availability of the one-place-buffer;
2. priority of the product already existing in the one-place-buffer, if the buffer is occupied.

The decisions that a query node make are presented below in the order they are taken:

1. if the product needs to be processed on that specific workplace the query node will have the following behaviour:
    a. if the one-place-buffer existing in the workplace is empty, then the query node will command the transportation and manipulation system to load the one-place-buffer with the product that initiated the query;
    b. if the one-place-buffer is full, then the query node will:
        i. request from the workplace the priority of the product that already exists in the buffer and
        ii. compare the priority of the product that requested the query with the priority of the product in the buffer;
    c. if the priority of the product that requested the query is higher than the priority of the product that already exists in the one-place-buffer, then following actions will be taken by the query node:
        i. the product that occupies the buffer will be ejected from the buffer by the transportation and manipulation system;
        ii. the product that requested the query will be loaded in the one-place-buffer by the transportation and manipulation system;
    d. if the priority of the product that requested the query is lower than the priority of the product that already exists in the one-place-buffer of the workplace, then the query node will command the transportation and manipulation system to release the product to continue to evolve in the system;
2. if the product doesn't need to be processed on the specific interrogated workplace, then the query node will command the transportation and manipulation system to release the product to continue to evolve in the system.

3.4 Smart products

Every product will have a unique identity and will be able to carry all needed information for its processing during the whole production process.

The representative information that a product needs to carry is:

- identity – read-only;
- all characteristics that the product will have, translated in the workplaces that the product needs to visit and their exact sequence – dynamically modified as soon as a characteristic was implemented.

The information will be carried directly on the product or on the container that transport the product in the system.

4 COMMUNICATION MODEL

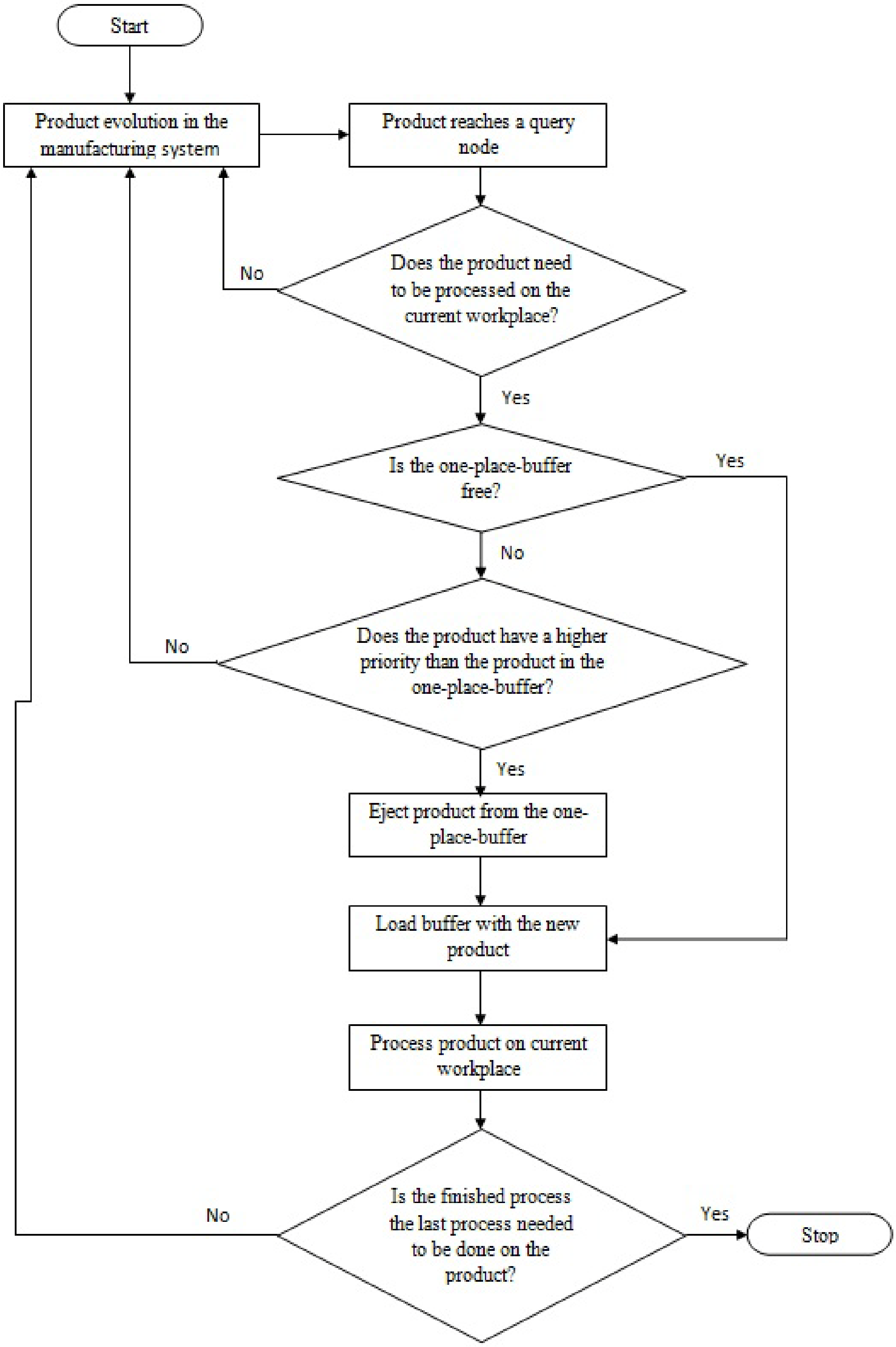

Figure 4. Self-Organizing communication model towards prioritization

The self-organization towards prioritization in the proposed model is achieved mainly through the communication between the smart products that evolve in the system and the system itself.

A *CPS* can be defined as the assembly of sensors, actuators and logic incorporated in a query node as well as the assembly of sensors, actuators and logic incorporated in a workplace.

By simple interrogations and actions taken based on the interrogations, the system is organizing the smart products sorting them locally with the scope of achieving a final sequence of finished products in the highest possible degree of prioritization. This is achieved by locally exchanging the product form the one-place-buffer of a workplace with a product with higher priority, as soon as this product arrives at the workplace, and express the will to access the services of the workplace.

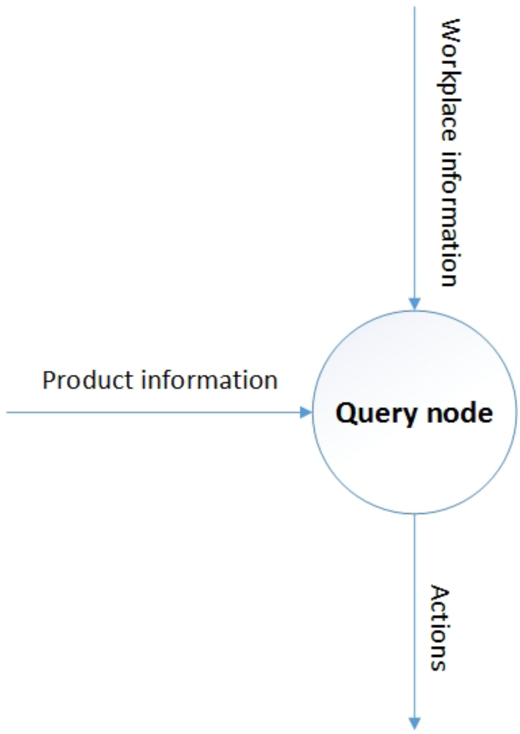

Figure 5. Query node model (Marin, Brîndașu, 2015)

An important rule in this model is to let the products that already started to be processed in the workplace to be finished, even if a product with higher priority arrived in the meantime at the query node and accessed the one-place-buffer, assuring the continuity of the process. Together with this rule, the one-place-buffer assures also the continuity of the process and also the maximization of the active times of the workplaces.

The workplace, defined as a stand-alone CPS and the query node defined as another stand-alone CPS will communicate between them and act according to the information provided by the product that evolves in the system. We will gather these entities in one single module and use them further under the name of *option module* (*OM*).

The entities within an *OM* will communicate between them, but the *OMs* in the system won't communicate between them. This decentralized approach brings the advantage of a high flexibility in the configuration of the *OMs* on the production line and a high agility in case of relocation of workplaces.

For the success of this concept, a very important role has the transportation system, which needs to assure a continuous flow of products for the workplaces.

5 CONCLUSIONS

The self-organizing system presented in this paper takes advantage of the smart products and cyber-physical systems in order to assure physical prioritization directly in the production process, making the need of scheduling and sequencing the products on the production line before the start of production dispensable, allowing high flexibility and agility for reconfiguration and new products.

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