# A NATURAL APPROACH TOWARDS MIXED-MODEL PHYSICAL PRIORITIZATION

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**ABSTRACT**: The $4^{th}$ Industrial Revolution brings in front smart products, Cyber Physical Systems and augmented operators. Centralized manufacturing became outdated as customer needs changed towards highly personalized products with high quality and short order lead times. Manufacturing nowadays heads from mass production to mass customization. An area where data was centralized and processed is order registration, production programming and sequencing of products on the production line. Manufacturing concepts and systems need to be defined to enable the visions of the new paradigm that comes with the $4^{th}$ industrial revolution. The main goals of the new paradigm are: autonomy, decentralization and communication. This paper will present a concept of prioritization realized in almost real time, directly on the production line, defining the principles and main phases.

**KEY WORDS**: prioritization, decentralization, autonomy, smart product, customization.

## 1 INTRODUCTION

"Industry 4.0" is a concept officially started in January 2012, together with the foundation of the Work Group that has as objective the development of new methods of manufacturing based on decentralized entities with unique identities that can interact autonomously with the system. A major objective of the "Industry 4.0" Work Group is to set the foundations of independent communication between the entities that take part in the production process, defining the concepts of self-organization between decentralized entities. Products are seen in the new vision as entities that follow their own interests in their evolution and communicate with the system and other entities in order to fulfill their objectives (Federal Ministry of Education and Research, Germany, 2012). The main entities that will take part in the fulfillment of the new vision are: smart products, smart machines and augmented operators (SmartFactoryKL website, 2014).

Smart products are defined as entities that are able to carry their own information and communicate autonomously with the system in order to fulfill their objectives.

Smart machines are defined as a complex of sensors, actuators and logic that is able to communicate and act autonomously towards fulfilling the tasks that rise at a certain moment in the system.

Smart machines are already associated in literature with *Cyber-Physical Systems* or *CPS*, a term that gained popularity in the last years and that doesn't describe necessarily a new type of entity that will take part in the production process, but that puts order and fulfills the gap in the theory of computer-controlled machines (Wolf, W., 2009).

Not everything will be 100% automatized in the new concept, operators will take part in the process further, but the way workers will operate in the system will be improved with virtual information overlaid over the real information to bring all necessary know how to the worker in order to avoid mistakes and to streamline the process. Augmentation of reality can mean assembly processes animated exactly over the product that the worker needs to next assembly, packaging information, preparation of processes, indication of real stocks capacity in almost real time, etc.

This new paradigm with all the general topics described above, is intended to put the bases of the $4^{th}$ industrial revolution, the revolution of decentralization, identity, autonomy and communication.

Industry 4.0 comes to change the paradigm of production which defines the industry today, industry that became obsolete by the customer demands that are continuously growing. Nowadays, the demands are heading towards high customizable, high quality products with short lifecycles, being created the need to change the paradigm from mass production to *mass customization* (Paulo Jorge Pinto Leitao, 2004).

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Among customer demands, one of the most important aspects is the order lead times which should be as short as possible. Together with the high complexity of producing highly customizable products, the problem of minimizing the order lead times increases even more the complexity of production.

To be able to produce high volume of customizable products, the system needs to have the workplaces designed correctly, so that preparation and finishing times form a type of feature to another should be negligible. Products should be designed as much as possible as variations of the same base model in several specific custom attributes/options. This type of manufacturing is found in the literature as mixed-model manufacturing (Boysen, N, and Other 2006).

Clear concepts of systems that permit mixed-model manufacturing need to be defined, but not only defined, the concepts will need to be performant so they won't affect or will even improve the parameters of the production of mass products or batch products that are produced today.

In 2012 and 2013, the first concept was presented by DFKI Kaiserslautern (SmartFactoryKL website, 2014) at MESSE (http://www.hannovermesse.de/home), concept that demonstrated the possibility of reconfiguration of a manufacturing system in almost real time.

In this paper we will present a concept inspired from a natural phenomenon, concept that will permit performant mixed-model manufacturing with respect to prioritization, using smart products.

# 2 PRIORITIZATION IN HIGH VOLUME MANUFACTURING SYSTEMS

In the literature, prioritization can be divided in two main categories: virtual prioritization and physical prioritization.

## 2.1 Virtual prioritization

Virtual prioritization is usually achieved by sorting the order list based on the purpose of prioritization, before the products enter the production line. This virtual prioritization needs to be made with respect to the available time. The most popular criteria of virtual prioritization are: FCFS, EDD, CR și SP.

### *2.1.1 First Come First Served (FCFS)*

This prioritization method of the orders, works, as also the name suggest, in a very simple manner, processing the orders in the sequence they enter the system, without any prioritization.

### *2.1.2 Earliest Due Date (EDD)*

According this criterion, the order with the highest priority will be the order that has the most recent delivering due date towards the customer. In case there are more orders with the same delivery due date, the FCFS method will be applied.

### *2.1.3 Critical Ratio (CR)*

This method of prioritization establishes if a product can exit the production line in good time. For this purpose, the critical ratio is calculated (*CR*) using two specific parameters: the time left until the due date (*TS*) and the necessary time required for the product to be finished (*TL*).

$$RC = TS/TL \qquad (1)$$

### *2.1.4 Shortest Processing time (SP)*

With this method, the task that has the shortest processing time will be prioritized and positioned first in the processing list.

## 2.2 Physical Prioritization

Physical prioritization is another method of prioritizing products in the manufacturing process, but this type of prioritization is not made before the product enters the production line, but is made directly on the production line after it enters the physical manufacturing process. To be able to achieve physical prioritization, physical devices need to be used instead of virtual methods. For this purpose, most used devices used are the, so called, buffers, which are categorized by Boysen and Scholl in four categories, as it can be seen in figure 1 (Nils Boysen , Armin Scholl, Nico Wopperer, 2012).

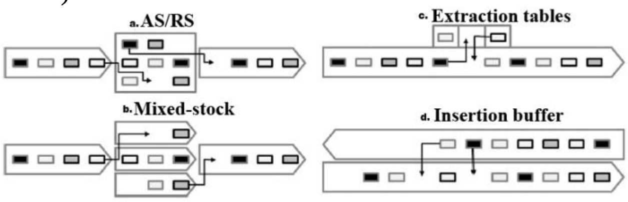


**Fig. 1 - Physical prioritization**

### *2.2.1 AS/RS Buffers*

Automated Stock and Retaining Buffers consist of multiple places for the products designed in a manner that every product can be accessible individually and independently at any time in the production process. (Fig. 1 a).

### *2.2.2 Mixed-Stock Buffers*

A Mixed-Stock Buffer consists of multiple parallel transportation lines, that do not permit assembly operations, having a small capacity (usually equal) for product storage. Every line is of series string type, and every product from the main line is introduced in the mixed-stock buffer line that has free space. At the other end of the buffer, the problem is which product should go again on the main production line to be processed first, this decision being made according to the optimum sequence that is followed and according to what is desired to be processed at the following work place in line. (Fig. 1 b).

#### *2.2.3 Extraction Tables*

The extraction tables are installed in parallel with the production line and have the capacity of extracting of specific products depending on specific defined criteria of selection. Extraction tables not only extract products from the production line, but they also have the capacity of inserting products into the main sequence, depending on what is the objective of the production in and the availability of the following machines.

#### *2.2.4 Insertion Buffers*

The insertion buffers consist of two parallel lines that are moving in opposite directions. The main line is feeding the secondary line. Product models that need to be eliminated from the secondary line and introduced later on the main line can be selected and introduced physically in the flow directly in the production process

## 3 AN ANALOGY OF PRIORITIZATION WITH NATURAL PROCESSES

We will present in the following section an analogy between a real phenomenon from the nature, called the gas bubble principle, and the industrial manufacturing of mixed-model products.

We consider a recipient with liquid where gas bubbles are systematically introduced through the bottom of the recipient. The bubbles will arrive at the surface of the liquid, will remain a specific time in contact with the atmosphere and will naturally disappear after the specific time. It is considered that the bubbles with bigger diameter will arrive at the surface of the liquid ahead of the bubbles with smaller diameters, when they are introduced simultaneously in the recipient, due to their higher buoyancy and thus, their superior travel speed. The container will not clutter to allow large bubbles reach the surface without being blocked because of excessive density.

Through analogy to the natural phenomenon exposed above, we consider the recipient as the manufacturing system, the liquid as being the transportation system, the bubbles as the products that need to be manufactured, the size of the bubbles as the priority degree of the product, the surface of the liquid (the atmosphere) as being the processing area of the system, the exposure time of the bubble to the atmosphere until the bubble disappears as the processing time of the product.
We will present further the prioritization processes currently used in the manufacturing systems, from the perspective of the natural process of buoyancy of the gas bubbles presented above.

### 3.1 Bubble model of prioritization process with based on programming and sequencing

In the figure 2 it is presented a sequential model of the production with programming and sequencing through the perspective of the gas bubble principle.

In the first phase the orders of the customers are stored in the system. The source of the orders it is considered to be permanently open and the priority degree of the orders it is considered to be stochastic as they enter the system. Also the moment when an order enters the system it is considered to be stochastic, the delay between order entrance in the system being considered to have different values.After the orders have been stored to some degree, in the second phase of the process the programming of production is being realized, meaning that the orders with the most important priorities are programmed to enter the production line. It is important to be observed that only the orders with high priorities are considered in this phase and not the sequence they need to follow during the manufacturing process. The programming phase will also take into consideration the capacity of the manufacturing system and will program a number of orders that can be managed in the production process (in the presented case from figure 3, it can be observed that the manufacturing system has a capacity of 10 orders to be processed at a time).

In the third phase the orders will be sequenced depending of their importance (translated from the priority degree) as follows: the orders with highest priority will be placed first in the sequence that will enter the in production process, while the orders with lower priorities will be placed last in the same sequence.After the orders have been processed in the third phase, the production sequence of orders is transported to the processing area, which is the fourth phase (process symbolized by the movement of the bubbles from the bottom of the

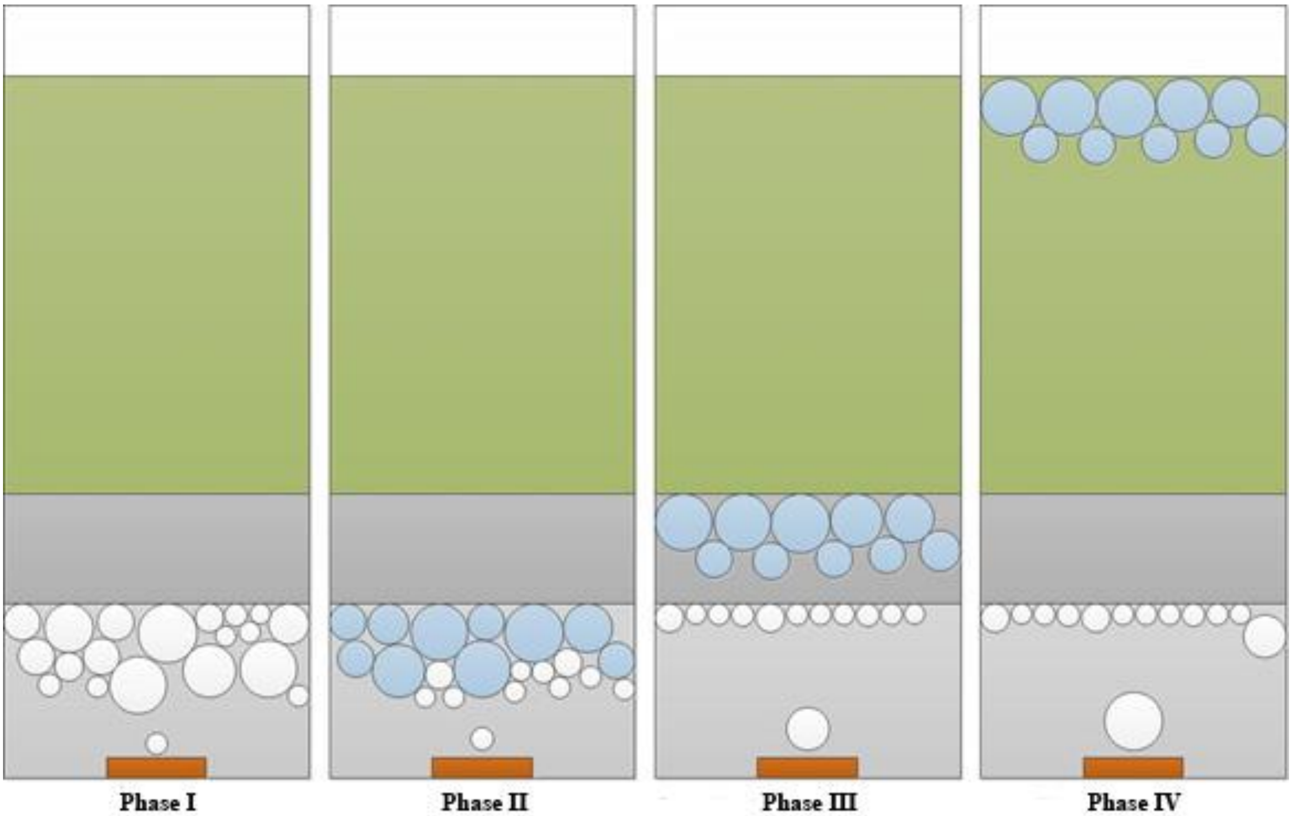


**Fig. 2 – The four phases of production with programming and sequencing**

liquid to the surface, due to their buoyancy). In the last phase, the orders will be processed and evacuated from the production system (process symbolized by the exposure of the bubbles to the atmosphere, together with the time necessary for every bubble in part, to disappear from the system.

Analyzing this process, it can be observed that in the programming phase of the orders and in the sequencing phase, the process is not following a natural behavior. Bubbles are artificially assigned to be processed in the programming phase, and as soon as they fill the buffer designed for orders that can be processed in the capacity of the system, they go through another artificial process where they are ordered in an artificial sequence that will be maintained throughout the whole manufacturing process until the bubble disappears from the recipient.

## 3.2 Bubble model of FIFO production

It can be observed that this type of manufacturing, besides the advantage that eliminates the programming and sequencing times, which are a big part of the order lead time – up to 50% according to T. Sturgeon (Timothy J. Sturgeon, Olga Memedovic, Johannes Van Biesebroeck, Gary Gereffi 2009), it has the big

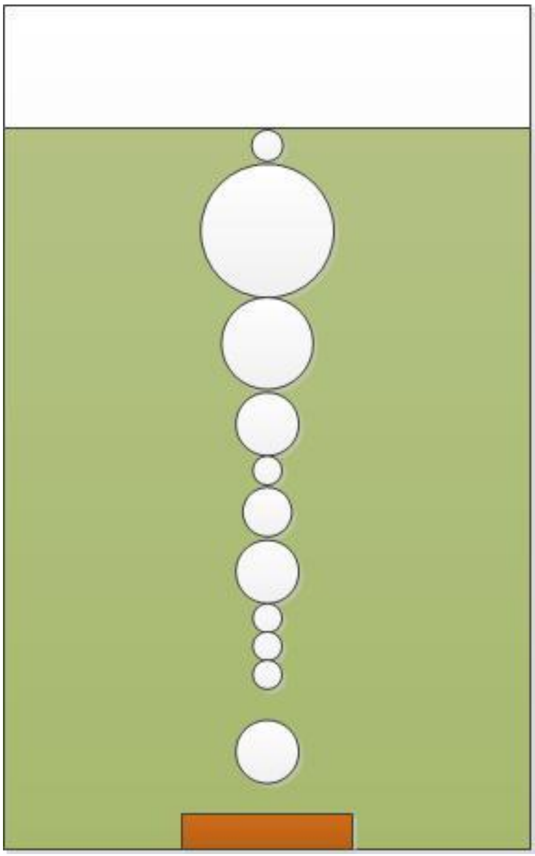

**Fig. 3 – Bubble model of FIFO production**

disadvantage that it doesn't process the orders according to their priority degree. The bubble gas representation of the process shows in a very clear depiction how unnatural the FIFO process is with respect to the priorities of the products that need to be processed.

### 3.3 Bubble model of the „natural" prioritization ideal

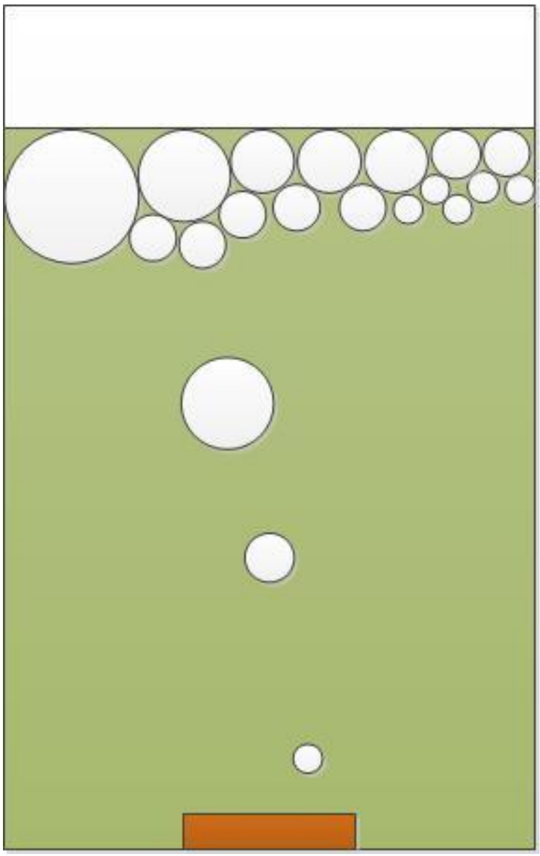

**Fig. 4 – Bubble model of ideal prioritization**

As shown in the description of the gas bubble principle, the new manufacturing concept introduces the processing of mixed models in a natural way, thus, the products with the highest priority will come first in the processing area, whereas the products lowest priority will be processed last, that unless there are higher priority products introduced in the meantime the system. It is considered that the products already in production area will be processed in order of their importance, and if a product of lesser importance are already in the processing area and shortly after it got there appears a product of higher importance, in this case the product of lesser value will remain in the area until its processing is finished and then will enter the product with greater priority. This rule is necessary to ensure continuity of production and avoid multiple preparing and finishing times for the same product thatg will be partially processed at least once.

If a larger diameter bubble, which came later in the system may outrun a bubble with smaller diameter, which came earlier in the system, until they reached the surface of the liquid, the bubble with larger diameter can do this only before the smaller diameter bubble has reached the surface and due to higher buoyancy.

The second case is when the bubbles that do not touch the surface wait the breaking of the bubbles currently touching the surface. It is considered that when a bubble has dispaeared from the surface of the liquid, its place will be taken by the bubble with the largest diameter from theat area.

So we propose a natural method of selection and order processing in the manufacture of mixed models, where, importantly, the selection is made without prior programming and sequencing, programming and sevențiere orders which, as noted in previous chapters, can consume over 50 % of the processing time of an order (Timothy J. Sturgeon, Olga Memedovic, Johannes Van Biesebroeck, Gary Gereffi, 2009).

#### *3.3.1 „Natural" prioritization*

The ideal case of prioritization reprezented above with the help of a gas bubble model shows a natural process of prioritizing the bubbles with bigger diameters. As the analogy described above says, bubbles are considered orders of the client.

To get closer to reality, from concept to real entities, a conceptual system needs to be defined with all its elements.

As entities, the most important ones are the, so called, objective entities, associated with the products that need to be manufactured.

As it can be seen in the bubble model of ideal production, entities follow their own interests in the system and are being processed according their priority. This means, real products need to posses a minimum intelligence that allows them to follow their own interests in the system. The behaviour of the products needs to be decentralized and autonomous. This type of entities is called in the new industrial revolution paradigm, smart products (SmartFactoryKL website, 2014).

To be able to endow the products with artificial intelligence and because they need to be able to find paths autonomously in the manufacturing system, the smart products need to communicate wirelessly in the system.

A technology that allow smart products to communicate wirelessly with the manufacturing system is the RFID technology (Radio Frequency

Identification). An RFID label, or transponder, allows information storage and instant communication at any moment, if the transponder it is interrogated by RFID readers. Also, a transponder allows dynamic modification of the data that it carries.

Alocating a transponder to every distinct product in the system would bring the following advantages:

- Ability of the product to carry its own objectives, like technology that needs to be applied for the product to fulfill customer demands, technological order of the workplaces, priority of the product in the system;
- Ability of the product to change dynamicaly its purposes, as soon as an objective has been fulfilled, meaning, for example, as soon as an operation from the technology of the product has been completed, the product will search the next workplace that can fulfill the next operations specified in the technology;
- Proframming of the orders will become dispensable;
- Sequencing of products on the manufacturing line will become dispensable.

The transponders can be attached directly on the main component of the product at the beggining of production, or, if this wouldn't be allowed because of the processes needed to be done on the product, the transponder can be attached on the container that carries the product through the system, and the same container will carry the product through the system until the end of processing.Transponders, as soon as a product exits the system, can be erased and ready for a new product that enter the system.

*3.3.2 General phases of smart products production*

The first phase should allow the customer characteristics of the product to be registered in a database. This process could be done using a GUI (Graphical User Interface) and specialized intelligent agents that register the order in a dedicated database.

After registering the product's characteristics, the processing of the technology of the product will take place.

The information that a database of smart products should contain are presented in tabel 1.

In the registration phase, the table that stands as database, will be filled with

- an automated generated ID based on relevant criteria;
- the priority of the product calculated acording relevant criteria and customer will;
- the status of the order which will be zero in registration phase, or not manufactured.

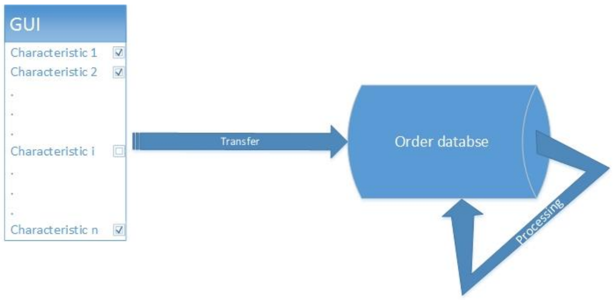


**Fig. 5 – Order registration and processing in a smart product manufacturing system**

In the second phase, the order will be processed by the technology engineer and the *Technology* field will be filled in the database.

**Table 1 – Order parameters**

| 1. ID | 3. Prio | 4. Tech. | 5. Status |
|---|---|---|---|
| 1 | 1 | P1.P3.P4.P5 | 1 |
| 2 | 3 | P2.P4.P10.P11 | 1 |
| ... | ... | ... | ... |
| i | 2 | P4.P5.P8.P9.P12 | 1 |
| ... | ... | ... | ... |
| n | 1 | P1.P3.P10.P11.P12 | 0 |

All this information, specific to each product, will be written before production on hte RFID tag that will be associated with the product during the production phase,until the product leaves the system.

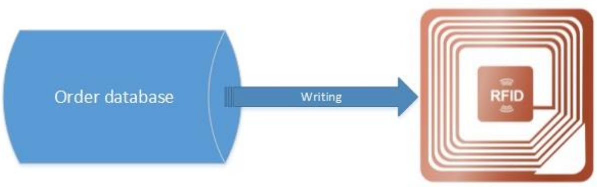


**Fig. 6 – Alocation of intelligence to the smart product**

## 4 A PRIORITIZATION CONCEPT ON FLOW-SHOP LINES

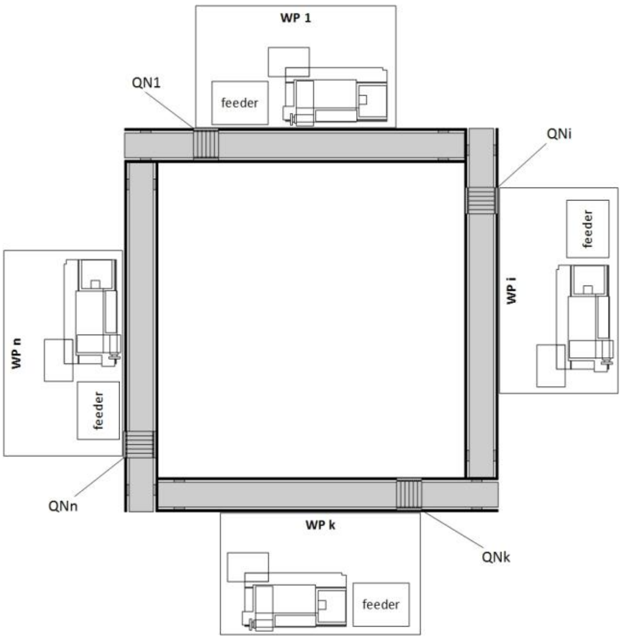


**Fig. 7 - Feeder concept**

In figure 7 it can be seen a manufacturing system concept consisting of:

- *n* workplace noted with *WP1* to *WPn*;
- *feeders*, represented near every workplace;
- a circular transportation system;
- query nodes, noted with *QN1* to *QNn*.

This concept describes the possibility of achieving the ideal situation of „natural” prioritization presented in figure 4.

Every workplace has a *feeder*, which represents an additional buffer area at the entrance of every workplace. The feeder has the responsibility to „feed” the workplace with the right parts that need to be produced at a certain moment.

The feeder keeps the parts that have the highest priority on the line and introduces them in the processing area. As soon as a part with a higher priority arrives, the feeder will switch the parts, replacing the part that already exists in the feeder with the new part that arrived on the conveyor and has a higher priority.

Wvery feeder is integrated in the workplace that it is allocated to.

The configuration of a production line that uses feeders should be circular, enabeling the possibility of multiple access of the same product to the same workplace. Enabeling multiple access to the workplaces will allow a „natural” selection of the products directly on the production line together with the help of the capacity of the *feeders* installed together with every workplace.

For the process to work properly, pecial devices are needed to be installed on the production line for the feeder to be able to always receive the highest priority part. We will call these devices *query nodes*.

In figure 7 there can be seen several query nodes positioned at the entrance of every workplace. The query nodes are not integrated in the workplace, as feeders are, but they are present on the transportation system. Even if they are not integrated in the workplace, communication between the query node and the feeder should be very closely made. A query node represents the intelligence of the selection and evacuation of the parts for the workplace and out of the workplace.

A query node communicates only with the feeder near it and not with other entities present in the manufacturing system. A query node will not be controlled by any central processing station and will take decisions deliberately. The only entities with which the query node will communicate are the products that evolve in the manufacturing system. This ability confers autonomy to the decision process, local, at every workplace.

The communication between the query nodes and the products is made based on the parameters presented in table 1.

From the product side, the communication is achieved passively, meaning that the product carries its own information throughout the system and is available at any moment to show the information if an entity from the production line asks for it.

From the query node side, the communication is achieved actively, meaning that at every time a product enters its area of influence, the query node will automatically interrogate the product with respect to the information that it carries. Based on the information that the query node finds on every product, it will take decisions by controlling actuators or by transmitting information or sending requests for information to other entities in the system.

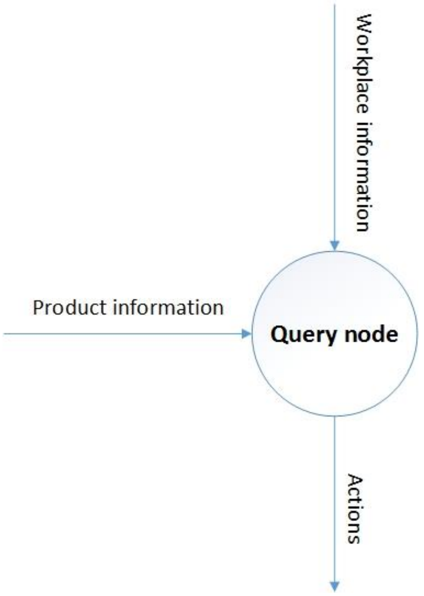


**Fig. 8 - Query node model**

Communication in a manufacturing system that uses feeders should not be made only between the query node and the workplace, but also communication should take place within the workplace.
There are two distinct elements depicted in figure 7 in the workplace:

- the processing area;
- the feeder.

Communication from the processing area side is active and cosists of „feed„ requests towards the feeder, namely, when a product was finished and evacuated, the processing area will send a prouduct request to the feeder.

From the feeder side, communication is made passively, meaning that the feeder is always in waiting mode reffering to the processing area. When the processing area sent a request for product, the workplace will have two options: fulfill the request, if a product is available, or send a notification for „empty feeder" if no product is available.

A *feeder* concept should enable smart products by adding intelligence to the entities that evolve in it, like: the ability to be aware of it's priority, the ability to be aware of the technology needed and the ability to follow it's objectives and change them dynamically as soon as an objective has been fulfilled.

A *feeder* concept could increase productivity, decreas lead-times and ad the ability of producing mixed-models on the same production line.

## 5 CONCLUDING REMARKS

We have presented a conept of „natural" prioritization and the information that can make possible the implementation of „natural" prioritization in a real manufacturing system, with the means available at the moment.
Future reasearch is needed to define the material infrastructure and the rules of manufacturing systems that can prioritize products directly on the manufacturing line. The concept promises high flexibility and agility, with the possibility of elimination of virtual prioritization that consumes a big part of the order lead time and that takes place before the product enters the production line.

## 6 AKNOWLEDGEMENTS

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