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SMART OBJECTS EMBEDDED PRODUCTION AND QUALITY MANAGEMENT FUNCTIONS

Abstract: *In this paper, smart objects embedded production and quality management functions are proposed, to promote accurately support decision-making processes, from the shop floor level up to higher decision-making levels. The proposed functions contribute for different kind of problems solving in production and quality management, such as production planning and control, scheduling, factory supervision, real-time data acquisition and processing, and real-time decision making. The web access at different middleware devices and tools, at different decision levels, along with the use of integrated algorithms and tools, embedded in smart objects, promotes conditions for better decision-making for optimized use of knowledge and resources in production systems. The relevance of the proposed smart objects embedded production and quality management functions has been validated positively in a manufacturing company.*

Keywords: *Smart Objects, Production Management, Quality Management, Manufacturing Systems, Sensors*

1. Introduction

The concept of "intelligent product" introduced by Wong *et al*. (2002), has a key role in the next generation manufacturing systems for exploring the integration of manufacturing physical resources with ICT technologies so these devices become "smart". This means that in a supply chain context, a product is not just a physical resource but a key element in the information infrastructure, interacting with other products, processes and stakeholders. The automatic monitoring and context awareness enable a better performance of information systems such as Supply Chain Management, Enterprise Resource Planning or Warehouse Management Systems (Bajic, 2009).

Thus, it's necessary to specify which type of information these smart objects need to capture and process. In other words, which production and quality functions should be embedded in smart objects in order to improve these advanced manufacturing systems.

It was considered relevant to explore the following subjects:

1) Real time management systems;
2) Manufacturing management support systems;
3) Key performance indicators (KPIs) of a production system;
4) Definition of "smart object".

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The first subject represents the capacity of these devices in capturing and processing information in real time. The proposed functions in this paper were based on functionalities of Manufacturing Management Support Systems such as Distributed Decision Making Systems, Manufacturing Execution Systems and Industrial Control Systems. The concept of KPI is relevant since some of the proposed functions evaluate the production and quality performance of machines and products. The last topic discusses the smart object concept. The characteristics of the smart objects and their embedded smart technologies are referred, as well as their applications and type of information captured.

In this paper, smart objects embedded production and quality management functions are proposed, to promote accurately support decision-making processes, from the shop floor level up to higher decision-making levels. The proposed functions contribute for different kind of problems solving in production and quality management, such as production planning and control, scheduling, factory supervision, real-time data acquisition and processing, and real-time decision making. The web access at different middleware devices and tools, at different decision levels, along with the use of integrated algorithms and tools, embedded in smart objects, promotes conditions for better decision-making for optimized use of knowledge and resources in production systems.

The paper is organized as follows. Section 2 presents a literature review about data capture and the use of sensors. Moreover, a brief review of production support systems, including manufacturing execution systems and industrial control systems. Production System performance measuring and visualization and Smart Objects concept are also explored. Section 3 defines the proposed smart objects embedded production and quality functions, which are briefly described, in the context of different modules of a production system hierarchy for supporting production and quality management. Section 4 presents validation of the proposed smart objects embedded production and quality management functions relevance, which has been validated positively in a manufacturing company. Finally, Section 5 presents conclusions and future work.

2. Literature review

2.1. Data capture using sensors

Sensors are transducers that measure real-world conditions, transforming physical phenomena in electric signs (López, 2011). There are several sensing methods and type of sensors, varying according to the desired price, size, precision and range.

Sensing devices are the most common elements in real time management systems as they automatically retrieve data about an infinity of parameters. According to Soloman (2009), the deployment of sensing devices, when synchronized with the enterprise strategic plan, allows to achieve the following results:

- improvement of productivity – cost per unit lower;
- improvement of quality – products more uniform and consistent;
- improvement of reliability – mitigation of failures and errors;
- lead time reduction – shorter delivery times;
- machine utilization – better machine utilization rate;

Nowadays, sensors already play a key role in production. However, Soloman predicts a significant increase in the influence exerted as sensors become more technologically advanced. The graph of Figure 1 illustrates Soloman’s prediction for 2020, in which will be possible to design fully automated and autonomous production systems, without machine programming.

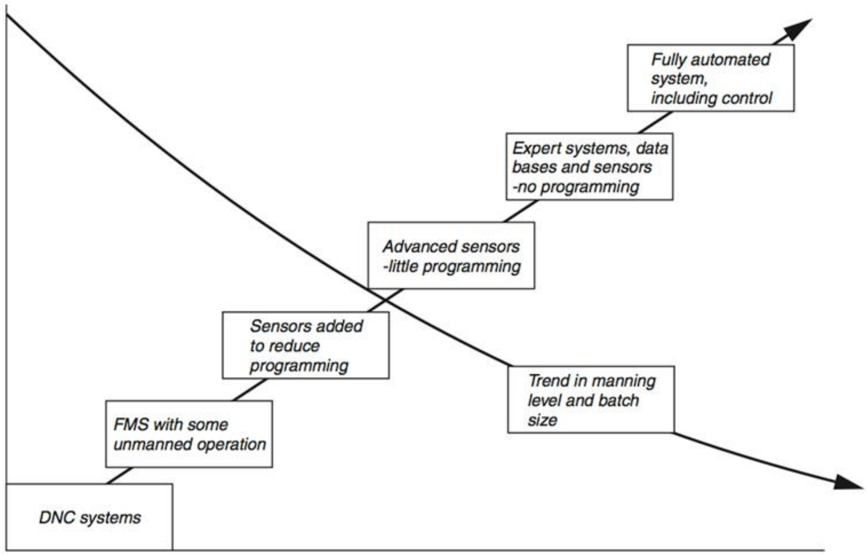

Figure 1. The role of sensors in moving manufacturing technology forward to the year 2020 (Soloman, 2009)

2.2. Production support systems

2.2.1. Manufacturing execution systems

The origin of Manufacturing Execution Systems (MES) dates from early 80's, when companies realized the importance of ending data redundancy. Figure 2 illustrates this concept of data integration between all the levels and information systems, existing in a company.

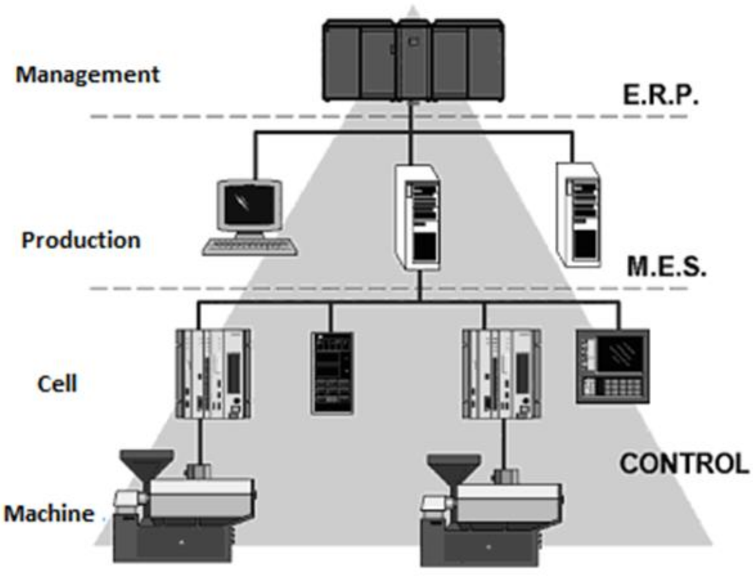

Figure 2. Concept of data integration (Penin, 2011)

Currently, MES functionalities may vary by manufacturer but, and according to Kletti (2007), most of the currently available solutions offer the following set of features:

- Production planning and scheduling;
- Control and monitoring of machines and tools;
- Information management for products, processes, production orders, work instructions, among others;
- Management of raw materials and intermediate products consumption;
- Performance analysis of production systems;
- Machine maintenance management;
- Data collection of manufacturing resources and processes.

2.2.1. Industrial control systems

Industrial Control System (ICS) represents a system with the ability to control and monitor a production process. ICS includes Supervisory Control and Data Acquisition (SCADA), Distributed Control System (DCS) and Programmable Controllers Logic (PLC). However, an organization should not just implement a single type of the referred above systems. The best solution is the adoption of a custom system based on different approaches and adapted to the individual needs of each company.

2.3. Production system performance measuring and visualization

2.3.1. Key performance indicators of a production System

KPIs represent the set of measures defined by an organization, according to its philosophy, and it is critical to its current and future success. In other words, a KPI is a quantified data that measures the effectiveness of a process or system in relation to a standard, a plan or a goal that should be given and accepted as part of the organization overall strategy (Courtois, 2007). Parmenter (2010) recognizes seven characteristics common to all KPIs:

- They are non-financial measures, i.e. they are not expressed in euro, dollars, among others. The reason relates to the fact that the financial measures do not specify particular "what to do" to improve its values;
- They are measured frequently. The indicators should be monitored daily, as they are the key to the success of an organization;
- They are established by the director and by the top management, since they reflect the strategy defined by the company;
- They are understood by all employees involved due to their level of importance;
- They carry individual or a team responsibilities. A performance indicator reflects the performance of an operation so it is easy to identify the group of people responsible for a measure in concrete;
- Causes a significant impact. A good performance indicator influences the success of an organization;
- It affects the other indicators. A good performance indicator also affects the other in a positive way.

2.3.2. Dashboards

The concept of dashboard derives from the need of having a tool that reflects the organization's strategy into objectives, metrics, custom initiatives and tasks for each employee. In an attempt to clarify the concept, Few (2004) proposed the following definition: "A dashboard is a visual representation of all critical information and necessary to achieve one or more objectives, consolidated and organized on a single screen so it can be monitored quickly". It provides a clear picture of the company's strategic objectives and what is needed to achieve the set targets, as you can see in Figure 3.

Figure 3. Example of a dashboard (Eckerson, 2010)

According to Eckerson (2010), this tool monitors the critical business processes through performance indicators that notify the user when they move away from its ideal value. It also allows to analyze the root of the problems from different perspectives and detail levels, based on real-time updated information. Finally, allows managers taking a more competent decision, leading the organization in the right direction, as illustrated in Figure 4.

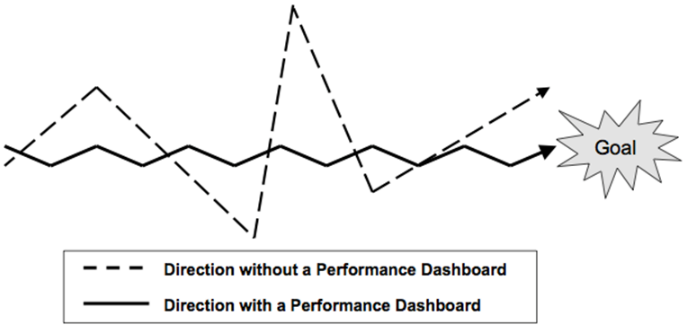

Figure 4. Dashboards' impact in the direction of an organization (Eckerson, 2010)

2.4. Smart objects

2.4.1. Properties

The smart object is the "final product" of the implementation of ICT in existing manufacturing physical resources, such as products or machines (Ruhanen *et al.*, 2008). According to Wong *et al.* (2002) and Bajic (2005), smart objects have the following features:

- Unique identity;
- Ability to communicate effectively with its environment;

- Ability to collect and store information about itself and its environment;
- Ability to participate in decision making;
- Ability to monitor and control its environment;
- Ability to generate interaction in the context of a product-service system.

In turn, López *et al.* (2011) proposed a classification system for smart objects, according to the attributes presented in Figure 5.

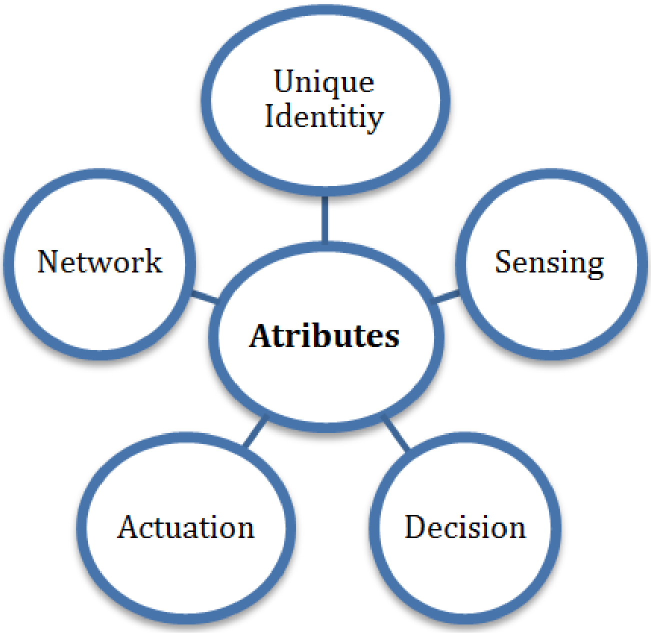

Figure 1. Smart objects' key features

According to Zhang *et al.*, (2011a), these technologically advanced objects can be divided into two classes according to their level of sophistication and respective role. Some devices play an active role so they are named as "active smart objects". In other words, belong to this class all the autonomous devices that do not need other devices to express their attributes. Smart objects with embedded RFID reader are an example of active smart objects. On the other hand, those who need to interact with other devices, they are called as "passive smart objects" such as, for example, any physical resource equipped with an RFID tag.

Nowadays, there are already available several platforms that allow the creation and development of smart objects. "Arduino" is an open platform where the user builds its own device through the hardware and software, distributed by the platform. Users have at their disposal a set of processors, sensors, actuators, among others, that allow to configure the smart object according to their needs. Figure 6 illustrates a board with integrated microcontroller using Java language that controls physical phenomena, lights, motors and actuators (Uckelmann, *et al.*, 2011).

Figure 2. Smart object board with "Arduino" (Uckelmann *et al.*, 2011)

2.4.2. Incorporated technologies

Automatic Identification and Data Capture (AIDC) and Information and Communication Technologies (ICT) are the "heart" of smart objects since they enable smart objects' properties. The graph of Figure 7 identifies the most common technologies embedded in these devices, as well as the level of intelligence and autonomy associated with each technology.

Autonomy refers to smart object's ability to work without human assistance or other devices. Moreover, the intelligence level indicates the capability of these devices to make decisions based on the information collected and processed by them. It also reflects the cost associated with its acquisition.

The barcode is the oldest and perhaps the best known technology, allowing to identify objects. However, it is considered a smart object, only if the product has a bar code with serial number, in order not to violate its unique identity. RFID technology is divided in two main groups: RFID systems with passive and active tags. Passive tags have no internal power supply, meaning they have a reduced data storage capacity. In contrast, active tags have battery, enabling them to: (1) perform more complex tasks, (2) increase the range of 3 meters to 100 meters and (3) support sensors or other external components. In turn, the smart card is mainly used in systems that need to make secure transactions in a simple manner. The WSN (Wireless Sensor Network) is the latest technology of the five. It is a branch of ubiquitous computing and consists of a high number of nodes that cooperate and exchange information with each other. Each node has a programmable microcontroller and may be equipped with sensors and actuators (Bajic, 2009).

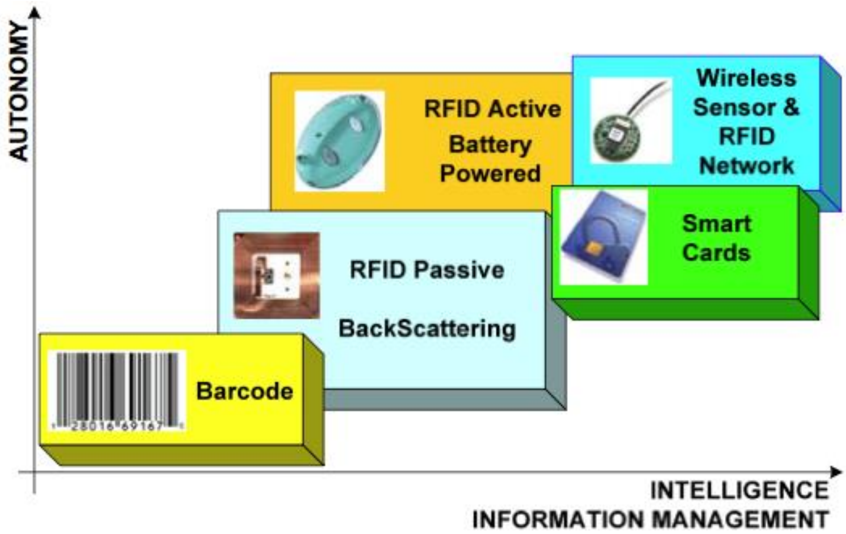

Figure 3. Smart objects technologies (Bajic, 2009)

In the end, the choice of technologies to incorporate into smart objects will depend primarily on two factors: the purpose of its use, or place of work, and restrictions on the hardware level. For example, passive tags do not support additional sensors (López *et al.*, 2011).

2.4.3. Applications in industrial environment

In recent years, the concept of smart object has been gaining strength. The reason is due, in part, the contribution of G. Q. Huang and Y. F. Zhang in the development of this area, i.e. RFID-based wireless manufacturing (Huang *et al.*, 2007), RFID-based smart kanbans (Zhang, 2008), RFID-based wireless manufacturing for real-time management (Huang *et al.*, 2008), agent-based workflow management (Zhang *et al.*, 2010), agent-based smart objects management system (Zhang *et al.*, 2011a), agent-based smart gateway (Zhang *et al.*, 2011b) and RFID-enabled real-time manufacturing information tracking infrastructure (Zhang *et al.*, 2012).

3. Smart objects embedded functions

In general, companies rely on information provided by their information systems such as ERP (Enterprise Resource Planning) to make decisions. However, most software packages are inserted with data collected manually by the employees. The problems associated with this are many: inaccurate, outdated and error-prone information. As a rule, the most important company decisions are taken from this information, which may have a negative impact on the economy of this.

Smart objects are envisioned to offer a viable solution to all companies with similar problems. In this paper, smart object embedded production and quality management functions are proposed. These functions are grouped in modules that represent a set of similar decision making tasks performed by smart objects. In addition to the function modules, the type of information sent from these devices that each employee has access is defined.

3.1. Function modules

In an engineering context, the term “function” means a "process, action or task that a system is able to perform" (Barker & Longman, 1990).

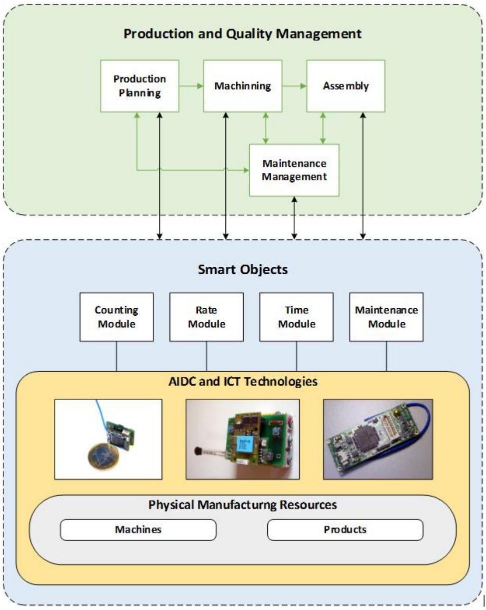

Figure 4. Proposed function modules

In other words, each function defines a specific task performed by the smart objects in order to support the company's production and quality management. Figure 8 shows the following function modules:

- Counting Module – Presents functions that count in real time the number of products produced by a machine;
- Rate Module – Presents functions that determine in real time the production rate by a machine, as well as its occupation rate.;

- Time Module – Presents functions that calculate in real time the productions times related to the STATUS of a machine;
- Maintenance Module – Includes functions that improve machine maintenance management (In this paper, embedding of maintenance management is not further considered.).

Virtually, all proposed functions could be used by both management domains i.e. by the production management and quality management domains. For example, the function "current order quantity produced with no defects in RT" could be used by production management for replanning and could be used by quality management to evaluate quality of production planning function or production process itself.

3.1.1. Module I – Counting

The first module allows the smart object to count the products produced by a machine. When a new order is released, the smart device receives information about the order (O_{ID}) and its planned quantity (O_{QTY}). By the time the machine starts its activity, the smart object record the number of items produced (O_{QTYRT}). As this registration is performed in real time, the system "knows" the exact quantity and the estimated time remaining to complete the order. The smart object also inspects the quality of the produced items, as described in Table 1. Thus, the device register the current number of produced items with defects (O_{QTYD}) and without defects (O_{QTYND}), produced by a machine.

Table 1. Function "Current Produced Quantity"

$\mathbf{O_{ID}}$	Order ID
$\mathbf{M_{ID}}$	Machine ID
$\mathbf{O_{QTY}}$	Planned order quantity
$\mathbf{O_{QTYRT}}$	Current order quantity produced in real time
$\mathbf{O_{QTYND}}$	Current order quantity produced with no defects in RT
$\mathbf{O_{QTYD}}$	Current order quantity produced with defects in RT
$\mathbf{O_{EFF}}$	Order Efficiency (derivate)
$\mathbf{SCRAP_L}$	Scrap Level (derivate)

Typically, the smart object requires only a photoelectric sensor. If the equipment processes items with different characteristics (color, size, etc.), the device may be able to identify and distinguish them using RFID tags.

The smart object to perform this task needs to have a certain degree of intelligence that varies with the accuracy required in the inspection. The greater the detail in the analysis the more advanced sensory technology must be embedded into the device. Based on the collected and stored information, these smart devices can be programmed to alert employees when, for example, the efficiency of the order is lower than a predefined value. It can also communicate the current level of scrap produced by the machine, i.e., the number of products with defects produced (O_{QTYD}) relative to the total number of products already produced.

In turn, the second function counts the remaining number of order operations that must done before the order is complete. In other words, it records and evaluates the progress of an order (Table 2).

Table 2. Function "Order Progress"

$\mathbf{O_{ID}}$	Order ID
$\mathbf{OP_{ID}}$	Operation ID
$\mathbf{M_{ID}}$	Machine ID
$\mathbf{OP_{\mathit{B}}}$	Beginning of the operation
$\mathbf{OP_{\mathit{E}}}$	End of the operation
$\boldsymbol{PO}$	Progress of the order

The complexity of the device is always dependent on the type (OP_{ID}) and number of operations to be monitored by it, as well as the details of the desired progress. In this sense, it may be necessary to use smart objects interaction as there is the need to register at least two moments: beginning of the first order operation and the end of the last order operation.

3.1.2. Module II – Rate

Module II consists of functions that calculate the production rate, i.e. the rate at which an equipment processes items. Thus, the smart object becomes a true smart stopwatch that checks if the machine is producing with a higher or lower rate according to is default value (nominal rate). In addition, the technological device can collect information about the utilization rate of a machine.

The first function of Module II measures the current rate of production, i.e. the number of articles produced per unit of time. In Table 3 the function's parameters are specified. The device is programmed with the machine's (M_{ID}) production nominal rate (RN_P) in order to compare it with the current production rate (RA_P) and average (RM_P) production rate.

Table 3. Function "Production Rate"

$\mathbf{O_{ID}}$	Order Id
$\mathbf{M_{ID}}$	Machine ID
$\mathbf{RN_P}$	Nominal Production Rate
$\mathbf{RM_P}$	Average Production Rate with no defects
$\mathbf{RA_P}$	Current Production Rate with no defects
$\mathbf{RM_P}$	Average Production Rate with defects
$\mathbf{RA_P}$	Current Production Rate with defects

The smart object can be programmed to send alerts if the current production rate is below or above the desired. In addition to sensory technology, the device needs to have a real time clock, responsible for recording the present time.

This smart object type also has the ability to record the current and average number of products with defects produced per unit time. The device stores in its internal memory the history of orders and respective level of quality. When there is a need, those responsible for quality can access this history to make decisions based on reliable and updated to the second information.

The second function analyzes the utilization of a machine according to its load factor. In other words, it compares the current number of items processed per unit of time with its theoretical maximum, defined by the machine manufacturer (Table 4).

Table 4. Function "Utilization Rate"

$\mathbf{O_{ID}}$	Order ID
$\mathbf{M_{ID}}$	Machine ID
$\mathbf{RN_O}$	Nominal utilization rate
$\mathbf{RM_O}$	Average utilization rate
$\mathbf{RA_O}$	Current utilization rate

The technology most appropriate to be embedded in these devices is dependent on the type of machine and type of process that needs to be monitored. Smart objects programmed with this function allow companies to identify in real time the equipment that is available to produce new items.

3.1.3. Module III - Time

Module III allows these smart devices to determine the productive and non-productive times associated to a machine: (1) processing time, (2) down time, (3) setup time and (4) waiting time. Each time represents a type of STATUS that a machine can present: (A) processing, (B) faulty, (3) change over and (4) idle (Table 5).

The smart object sensors are integrated in the machine, allowing to recognize when the machine is processing items. The device stores the values captured by its sensors, further elaborating the history of average processing times.

Table 5. Function "Machine STATUS time"

$\mathbf{O_{ID}}$	Order ID
$\mathbf{M_{ID}}$	Machine ID
$\mathbf{TA_P}$	Current STATUS* Time
$\mathbf{TM_P}$	Avarage STATUS* Time
$\mathbf{TI_P}$	Beginning of STATUS* time
$\mathbf{TF_P}$	End of STATUS* Time

3.2. Support functions by each hierarchy level

The previous modules have functions that are irrelevant to the decision making of certain employees. For example, the progress of an order is not relevant to the decision making of a machine operator. After all, every level in the company's hierarchy requires different responsibilities and decision making.

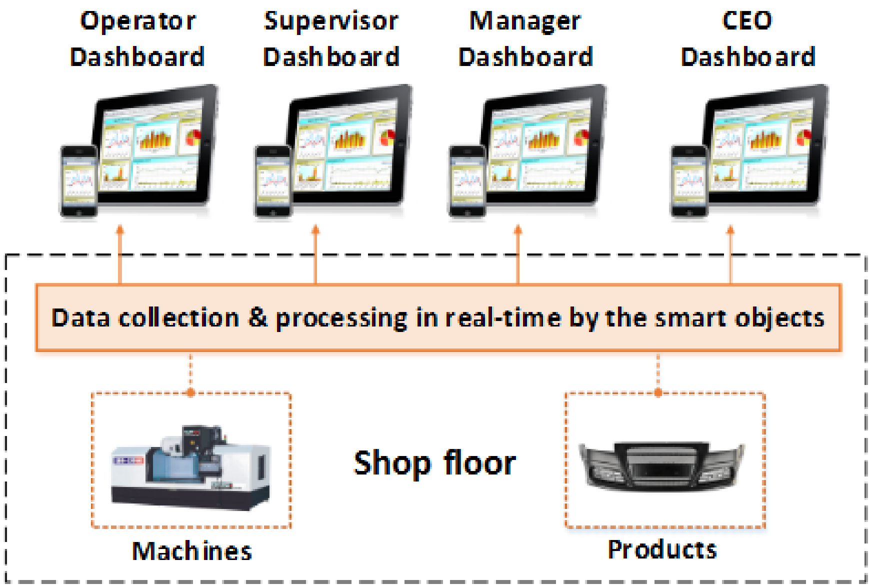

Figure 9. Decision Making Support Dashboards

In this sense, there is a need to specify what information is transmitted to employees depending on their job title. Therefore, it was considered four hierarchical positions: operator, supervisor, manager and CEO. New support functions which indicate the type of information displayed for each employee by dashboards were created, as shown in Figure 9.

3.2.1. Supervisor and manager support functions

The support function "Orders Delay" assists supervisors and managers to monitor progress of the orders. It is considered that an order consists of a set of operations, regardless of the order. Thus, the delay of an order is calculated by adding the delays related to all its operations. In this sense, whenever an operation is started is estimated an end time according to their average duration. Thus, when an operation is completed, the dashboard sends an alert if its duration exceeds the expected time. This dashboard is fed from smart objects information programmed with the "Time" module.

3.2.2. CEO support functions

The CEO has at its disposal a set of indicators that measure the productivity of the company. Thus, the support function allows to view, in a fast and in an intuitive way, the actual performance of the company by working shifts, lines or cell production. These indicators are based on the overall equipment effectiveness (OEE) concept. According to Muchiri and Pintelon (2008) OEE is calculated by multiplying the following three factors: equipment availability, equipment efficiency and equipment quality

The equipment availability indicator represents the time that a machine is able to process items over the time is stopped due to a fault or adjustment. This information comes from smart objects programmed with the functions from the Time module. In turn, the performance efficiency compares the actual rate of production with planned production rate. These values are indicated by Rate module. The equipment quality is provided by the counting module functions.

4. Validation of the proposed functions

4.1. Validation methodology

The validation process was based on a single case study. The reason for choosing this method is related to the fact it's the most appropriate strategy to investigate a contemporary phenomenon in its real and natural context, especially when the boundaries between phenomenon and context are not clear and specific. The case study method attempts to illuminate a decision or set of decisions made and responds to the "why", "how to" and "what". Thus, researchers can take a holistic view of certain events of real life as life cycles, organizational processes and maturation of industries. In turn, the instrument for the application of the methodology adopted was the questionnaire.

4.2. Case study: Metalworking company

The validation process was done through the collaboration of a metalworking company, on the feasibility study and interest in the proposed functions that are performed by smart objects. The collaboration consisted on the completion of a questionnaire developed for this purpose by the person responsible for the production in this company. The company has an annual turnover of around 50 million with about 400 employees, and has industrial units certified by ISO 9001. It also has a modern laboratory for the development of new products and quality control. The company uses ERP software application in production management but does not use RFID identification methods.

The questionnaire has six areas of questions:

1) Characteristics of the respondent;
2) Production typology;
3) Manufacturing Support systems;
4) Overall satisfaction of the company's KPI;
5) KPIs used by the company;
6) KPIs the company would like to implement.

4.3. Results and analysis

Regarding the proposed functions to be embedded in smart objects, the company expressed high interest in implementing them.

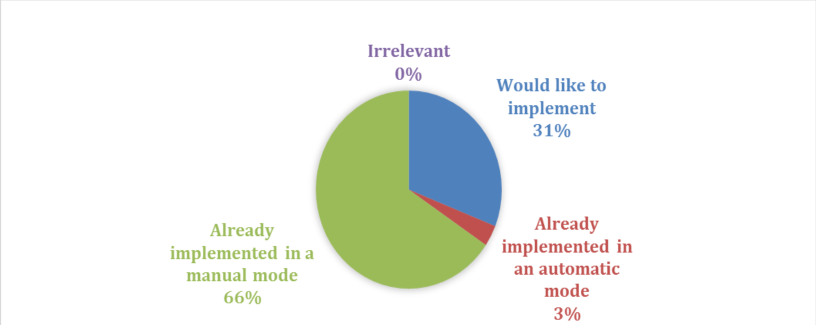

Figure 5. Expressed company's interest in the proposed functions

The graph in Figure 10 shows that more than half of the proposed functions have already been adopted in a manual mode by the company, only 3% were implemented in an automatic mode, and 31% the company were not implemented at all.

The graph in Figure 11 shows the distribution by modules, showing the only functions implemented in an automatic mode are the ones related to Couting module.

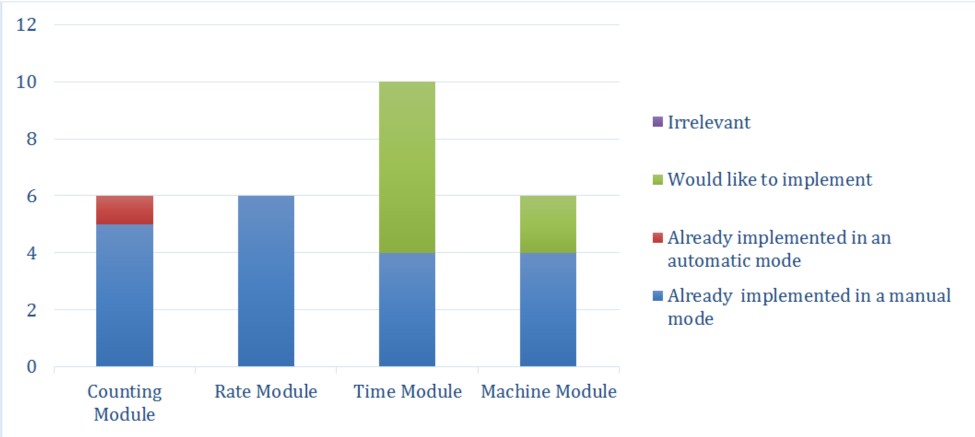

Figure 6. Expressed company's interest in the proposed functions by modules

Finally, the company would like to view in real time the collected values of all the proposed functions.

5. Conclusions

This paper defined the set of smart objects embedded production and quality management functions for supporting production and quality management decision-making.

An important aspect of these approach is that it represents a sub-system of broader concepts of advanced manufacturing systems, such as, ubiquitous and cloud manufacturing systems, cyber-physical systems, digital factory, factory of the future, industry 4.0 and similar, and including integration and embedding in more advanced ICT such as, ubiquitous and cloud computing technologies. Also related to the creation of huge volume of data, that implies the phenomena of Big Data and associated technologies and techniques.

Despite the topic of smart object is not quite new and, that is already reality in many aspects, the smart objects technology and implementations are still not in their mature phase. Therefore further research and developments are required. For example, the inclusion of other kind of data for dealing with higher levels of a decision-making hierarchy and corresponding management functions for inter-enterprises and networked collaboration, are topics relevant to ubiquitous and cloud manufacturing, as emerging advanced manufacturing systems.

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