MANAGEMENT AND COLLECTING DATA IN THE INFORMED MANUFACTURING

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Abstract. *Nowadays, production systems based on mass production paradigm have been characterized more by the control of the final items than the control of its process. The attempts to invert this situation (stimulated by the increasing of quality and personalization demand) is constantly hindered, or by information lack on the new product processing in its several transformation stages, or by the difficulty to identify which information would be relevant in a future analysis, or even the last too. The effective analysis of the productive process facilitates the identification of specific and prompt failures in the products even after its manufacture, making possible an oriented recall action, less traumatic and rough for the companies' finances and image. However, even more could be inspected and reported, as the cause-effect relationship among uncontrollable events and the resultant product, or the existence of repetitive and/or redundant steps, and so on. The increase of information follows the product complexity, principally in an automated shop floor, and to keep all the process description to those products is a challenge. This work consider a solution committed to deterministic and automated manufacturing processes, establishing a product standard behavior after manufacturing and a system that looks for atypical events, capturing the available contextual information either in the product, through an automatic data support as RFID; or in the manufacturing process, extracting sensors signals and machine states, expressed in Petri Nets. In this case, a perception system would register statistically the pertinent information related to the standard case and would capture details only about the standard misaligned occurrences, resulting in a considerable reduction in the amount of information and enabling a better environment for posterior analyses. In association with EPC (Electronic Product Code) network proposal, we named this tool Savant-2, since its behavior is different from that described for the original Savant.*

Keywords*: Informed Manufacturing; EPC network; SAVANT-2; Petri Net; RFID; Integration*

1. Introduction

Currently, the manufacturing companies are being forced to satisfy markets that demand an increasing variety of products, in shorter lead times and with size batches varying from unitary to mass production. The resulting sophistication of the processes (and the consequently related values) required by this situation leads to economic pressures for a maximum ROI. Efficiency and Assertiveness had become commodities and they can be reached only through a complete knowledge, domain and control of the production processes. Therefore, a wide information control that led to an optimized use of the manufacturing resources became a requirement for these companies survival.

Concepts as customer-centered manufacturing and mass customization of products are guiding the industrial minding, as they aim to unify reactivity, efficiency, and flexibility in the use of the manufacturing resources, and consequently to accomplish the geographic and time to market demands. The satisfaction of the customer became a credo that extrapolates the physical plant limits, as a result of the enterprise distribution and the execution of the engineering processes in a virtual way.

Nowadays, production systems based on mass production paradigm have been characterized more by the control of the final items than the control of its process. The attempts to invert this situation (stimulated by the increasing of quality and personalization demand) is constantly hindered, or by lack of information on the new product processing in its several transformation stages, or by the difficulty to identify which information would be relevant in a future analysis, or even both.

The possibility of an effective analysis of the productive process facilitates the detection of specific and prompt failures in the products after its manufacture, making possible an oriented recall action, less traumatic and rough for the companies' finances and image. However, still more could be inspected and reported. Frequently, atypical events occur inside the productive processes, which independent of being or not spotted and solved, is not followed by a generation of a proper database entry. Thus, production problems are perceived, and many times are worked-around, without being completely understood and/or solved.

The necessity of establishing a cause-effect correlation between uncontrollable events and repetitive and/or redundant production steps frequently is not achieved due to the lack of trustworthy and performing mechanisms of data capture and analysis on the plant floor. And the increase of information follows the product complexity, which turns almost impossible to keep all the process description.

I this work an integrative information system architecture based on EPC project is proposed (which we call Informed Manufacturing), which addresses specifically the events occurring during the manufacturing process. We consider a solution committed with automated manufacturing processes, where:

- A historical repository of important and atypical occurrences during the manufacturing process is maintained, making possible to correlate these occurrences and the events discovered after the product manufacturing. The improvement achieved is the fastness with which these linkages could be established and the precision obtained by dealing with reliable manufacturing information;
- The system looks for atypical events, capturing the available contextual information in the:
  - Product: through an automatic support of data capture such as those enabled by Radio Frequency Identification technology;
  - Process: extracting sensor signals and machine states, that should match the expected behavior represented in a Petri Net.

The perception system statistically register the pertinent information related to the standard case and capture details only from occurrences misaligned with the standard behavior mentioned previously, resulting in a considerable reduction in the amount of information which facilitates the posterior analyses.

2. The EPC network

The EPC-Global is leading the development of industrial standards related to the EPC (Electronic Product Code), based on the unequivocal identification of individual items (one requirement of the mass customization). For this task, radio frequency identification technology (RFID) is been used, which allows the localization and tracing of assets. The EPC network architecture inside the enterprise is presented in Figure 1.

The EPC network captures other information that belongs to available data item for previously authorized solicitants (EpcTagData, 2004). In this net, an intelligent structure was developed that integrates physical objects to information systems and related people automatically and synchronically (Clark et al., 2003).

As described in (Mcfarlane, 2003), the EPC network architecture presents as main components:

- An intelligent *tag* attached to the product, capable of storing a unique identification number (in an internal chip) and to communicate this number by means of a RFID communication system;
- A network of RFID readers and a data processing system collecting signals from multiple *tags* in a high speed, lately processing the data to eliminate duplications and reading errors;
- One (or a pool of) database (s) storing information related to the products (basic data, historical for traceability, processing recipes) which references are solely joined to the product number id.
- An EPC Information Service, associate to the ONS (Object Naming Server) – an object name server.

2.1. Tags with an unequivocal product identification

The smart *tags* or *label* refers to a device family that transfers data in a wireless form between the labeled object and special reader devices. When connected to a reader network, it is possible continuously to trace and track the identified physical objects.

The scheme of univocal numeration for physical object identification was named EPC number. This numeration is similar to the address used in the Internet Protocol (IP) (Sarma et al., 2000). A general identification or GID was defined as a 96 bits set composed by four fields: heading, owner of product numeration, product class and its serial number, as shows on Table 1 (EpcTagData, 2004).

The header is a binary value that defines the size and format of the fields referring to the Owner, Class, and Serial Number. The Owner identifies the company or enterprise that is the responsible entity for keeping the subsequent numbers. The Class identifies the object type, and the serial number is a univoque numeration for each object of a specific type. More information about this identification is available in (Epc Tag Date, 2004).

This numerical code is registered in a chip that must be attached to an individual product and physical object. The *tag* can be passive (a stimulation from the reader can be necessary to get the information) or active (the *tag* transmits the information itself). In case that a chip contains the *tag*, it is possible to add active data (register of new information). Thus, current, late or future states of the product can be stored and compared (Chokshi et al., 2003) (Palikad et al., 2003).

Readers are equipment that recover the data stored into the *tags* and transfer them from the physical world to the ISs (Information Systems). These readers, besides possessing simple filtering for reduction of the amount of collected data, also can carry through writing of data (Price et al., 2003).

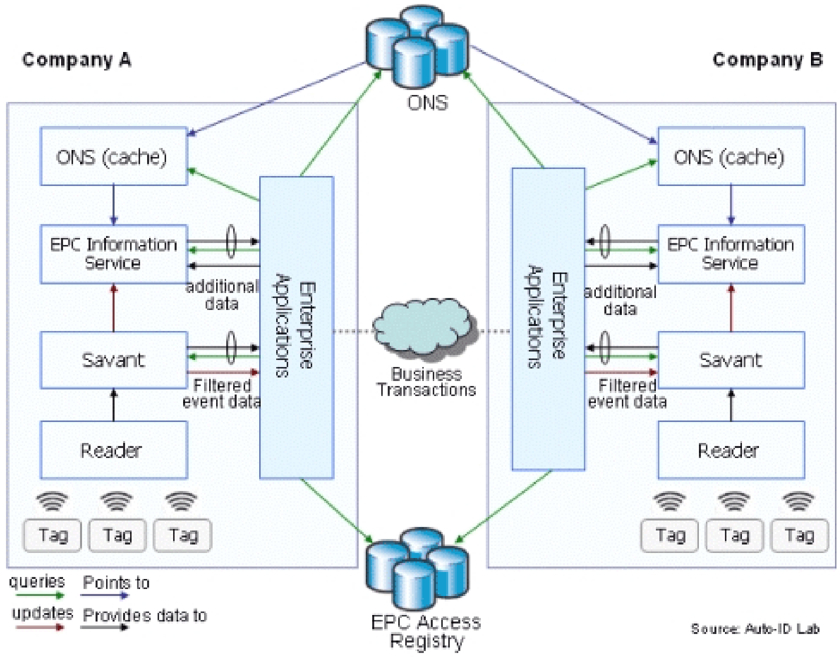


Figure 1. The EPC network architecture inside the enterprise (Auto-ID Lab).

Table 1. GID - 96 bits (EpcTagData 2004)

GID (96 bits)	Header	Owner	Class	Serial Number
# bits	8	28	24	36
# combinations	0011 0101 (binary value)	268.435.456	16.777.216	68.719.476.736

2.2. Savant or EPC Middleware

To manage the data being transmitted from the readers to the ISs, a software layer called Savant or EPC Middleware was developed. It acts as a rooter, performs monitoring operations, data transmission, tasks management and events generation. This component is responsible for the equipment management that perform the data capture by radio-frequency and for its integration with other vertical applications. The problems that the EPC Middleware intends to solve are related to the amount of captured data and in its release. (Clark et al. 2003) describe the EPC Middleware as software acting between the readers and the external applications. One of its tasks is the operation of data reduction by filtering and aggregating, for posterior release of it to external applications. Another feature is related to the integration with other components as ONS, EPC Information System or even messaging with other Savants. A general project of Savant or EPC Middleware is shown in Figure 3.

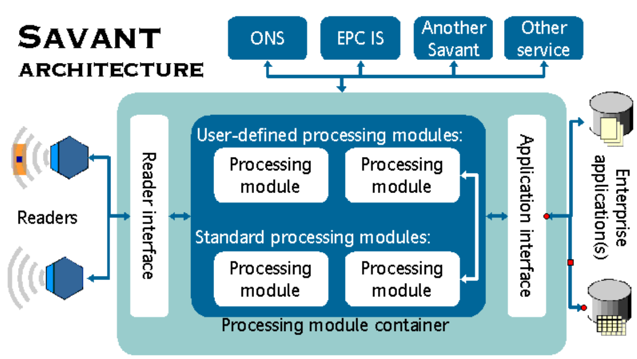


Figure 2. Savant or EPC Middleware Scheme

There are two basic interfaces for readers and the internal enterprise applications. The standard procedure modules are specified by the EPC-Global, the existing EPC Middleware must be available in all of them and can be classified in required modules (always must be used) or optional (used or not as identified by the user). The user-defined processing modules will be used and developed as the application needs. All processing modules can interact with each other, with other external services through specific interface, or with other EPC Middleware.

2.3. The EPC Information System

The EPC Information System [EPCIS] represents the data in PML [Physical Markup Language] format for the subscription and request of data service. The data available by the EPC Information Service can include the read data *tag* collected by the EPC Middleware, for example, to assist the traceability of serial numbers; instance levels data as manufacturing data and others; and class levels data as product catalogue information. In reply to the requests, the EPC Information Service integrates a variety of data sources internal to an enterprise and translates them into a PML format. When EPC data are distributed through the supply chain, an industry can create an access register that will act as a repository for the EPC Information Service (Clark et al., 2003).

The Figure 4 presents an example of the information in PML format. The Figure 5 presents the EPC Information Service inserted in the EPC network.

```
<pmlcore: Sensor>
  <pmluid:ID>urn:epc:1:4.16.36</pmluid:ID>
  <pmlcore:Observation>
      <pmlcore:DateTime>2002-11-06T13:04:34-06:00</pmlcore:DateTime>
      <pmlcore:Tag>
          <pmluid:ID>urn:epc:1:2.24.400</pmluid:ID>
      </pmlcore:Tag>
  </pmlcore:Observation>
</pmlcore:Sensor>
```

Figure 3. Example of information expressed in PML format

2.4. ONS - Object Name Server

The ONS provides a global search service to translate an EPC number in one or more URLs; or a localizer of uniform reference in the Internet, where more information about the object or product can be found. This URLs frequently identifies an EPC Information Service, even so the ONS can also be used to associate EPCs with sites and other Internet relevant resources for an object.

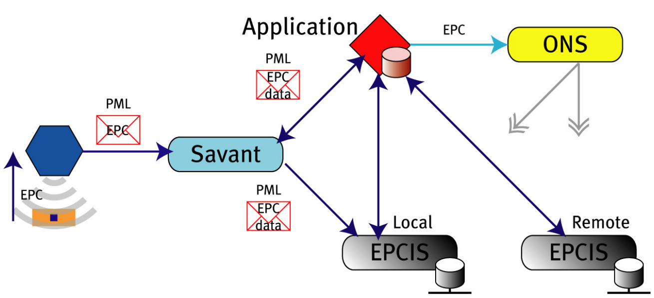


Figure 4. The EPC Information System scheme

ONS has static or dynamic services. Static services typically refer to URL's of information kept for the object or product manufacturer. Dynamic services record a sequence of information, as for which locals a product passed throughout its useful life. ONS was constructed with the same technology of the DNS [Domain Name Service] (Clark et al., 2003). It is foreseen the creation of the EPC Discovery Service which, essentially, is a register key performed in the EPCIS of each part throughout the chain (Verisign, 2005).

3. The Informed Manufacturing

The introduction of EPC network in the manufacturing systems can be considered as a context separation. The information and perception system will be carried on by EPC network, while the system of decision and performance will be performed by the process actuators. Figure 6 presents this model.

For the rollout of this disrupted system, it is necessary that not only one correlation exists between EPC network and the plant-floor, but also that it can be possible to determine in which development stage of the product a modification was introduced. As presented, the manufacturing process to which the product passes always becomes related with an engineering model, and frequently, believes faithful in the engineering project, not attributing the undesirable final result to a project error, but to a process error. In fact, this field is extremely complex, and this work does not intend to solve it.

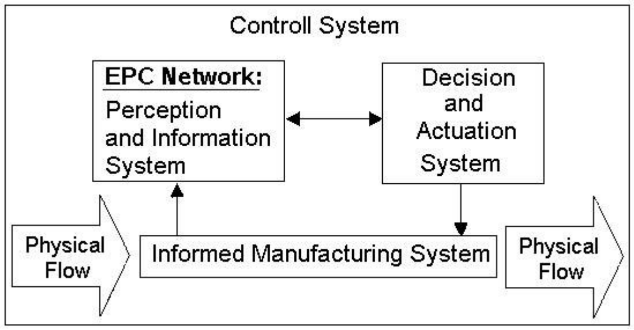


Figure 5: Control Inf. and Decision System Model for the Informed Manufacturing,
adapted from (Wortmann et al. 1997)

The approach to be used attributes to the EPC network the responsibility of re-feeding the corresponding systems. It was seen that the EPC network propitiates the integration of the internal systems through the EPC Middleware. This component will transmit and will be the interface to the internal control systems. In the case of the information being distributed throughout the involved parts, it is through the EPC Discovery Service integrated to the EPCIS and with the supply chain that will be possible to get information relative to the product description and history. This will propitiate that specific information about the product be available to the partners that do not hold them.

The data integration from the partners will allow the manufacturer company to get valuable information regarding use, maintenance, consumption and end-of-life of products, what will be primordial for all the customer requirements further analysis and satisfaction.

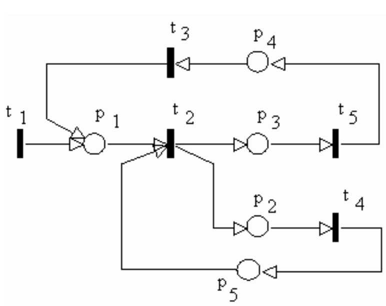
4. The SAVANT-2 proposal

In this work, we are considering a new category of EPC Middleware, which we call Savant-2. Its function differs from that described for original Savant middleware (associated to the collection, aggregation and filtering of information from a great number of RFID's attached on products) as SAVANT-2 deals with the process information and its context, stored in Petri Nets.

Once knowing the process information and the standard product behavior on the plant-floor, it is possible to perform in a more efficient way the diagnostic of atypical events that must be stored and/or transmitted to other systems throughout the informational hierarchy. A preliminary analysis of data is performed after capture just to verify if it belongs to an atypical sequence. If not the data can be discarded, otherwise it is stored in the historical bases for posterior use in analyses and tracing processes.

4.1. Mapping the manufacturing information trough Petri Net

Petri Nets (PNs) have a quite useful expressive power for modeling (graphically or mathematically) the manufacturing process, as well as a great capacity to formally verify the properties of the modeled system. These PNs characteristic facilitates the transformations of such process in computable routines that assist in the analysis task of the productive processes.



$$C_1 = \begin{bmatrix} 1 & -1 & 1 & 0 & 0 \\ 0 & 1 & 0 & -1 & -1 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 1 \\ 0 & -1 & 0 & 1 & 0 \end{bmatrix}$$

Figure 6. Graphic and algebraic representation of a productive process in Petri Net

A prescription commonly adopted for the modeling of a productive system using a PN representation can be:

- Identification of the resources, operations or activities in the system;
- Establishment of sequences of the activities in each step;
- Representation of the activities, generally for PLACES that are connected ace TRANSISTIONS, which indicates the beginning and ending of these activities;

- Definition of the resource through PLACES and connection of these to the beginning TRANSISTIONS and ending of each operation;
- Specification of the initial MARKING (been initial of the system)

There will be a difficulty to represent fairly the unexpected events since there is no different between those and the normal events. However in (del Foyo and Silva, 2001), there is a proposal for an object-oriented Petri Net where unexpected events are represented by pseudo boxes (places) that also fits the net formalism.

4.2. Application model and validation of the design process

One of the main contributions of EPC network is to make information available for interchange between all the players in the manufacturing value chain. Of course that is a good improvement in the manufacturing world (especially in the manufacturing automation), since all this information is reliable, implying that it comes from a synthesis of controlled shop floor information.

Thus, an important topic of the process is to control online manufacturing information, and that is the main objective of SAVANT-2. Such information could be dived in two blocks: I) the information about the manufacturing process which could be modeled with Petri Nets as explained in the subsection above (or about atypical occurrences in the manufacturing process); and II) the information that is contained in the tags attached to each product (the same that is available to EPC-Global). With both information we could associate atypical occurrences only to the items batch that were (supposed to be) affected by it. Which is the potential information that could be available, not to the whole supply chain, but to add value and reliability to the manufacturer, as well as to provide information to traceability.

In the present approach SAVANT-2 works with classical (untimed) Petri Nets, meaning that a time window is set (by the process designers) where the manufacturing (or enterprise) activities are tight enough to not be allowed to be dissociated. We call this time window a dynamic activity and consider that an untimed sub-net. Each step in this sub-net is monitored by reading signals marked in the original net by especial control events.

In a sequential process the event string generated in the plant should match the sub-string that could be read in the process model, otherwise an atypical event started. Even if the process is recovered, by a plant reset or by other measures, the resume of the process should mark the end of the atypical occurrence.

All the signs and values of variables from the beginning of the atypical occurrence until its end are stored as an atypical activity in a database that supports SAVANT-2 for further examination. Also the process that encloses the atypical event compose the data associated with the atypical activity, as well as all the IDs of the pieces actually in the range of this activity (by reading its RFID). The data bunch could be enriched with information about the state of the principal automated equipments as shown in Figure 7.

The implementation of this arrangement has been done in a UNIX system environment, composed of a multiprocessed SUN Ultra-2 as a data repository, running Oracle 9i, and a Ultra 10 running the system Sun Middleware over which our SAVANT-2 is being programmed. So far time windows are defined in the net furnished as a model of the process and possible atypical occurrences as faked in an occurrence net associated to the real process (even if these time windows match some industrial processes).

4.3. The overall integration

Even if it is not implemented in our current experiment, we imagine a further integration of our SAVANT-2 and our EPCIS-2, that analyses the information about the production system and its atypical occurrences with more high level Information System that can analyze the production of a factory during one year, for instance. In this larger time slice, the repetition of the programmed process (or even in a smaller time window) can be searched for error patterns that can eventually be associated with external factors such as the supplier of rough material, the supplier of parts, the specific season or temperature during the manufacturing, and so on. Also, different (or alternative) process plans could be compared, principally those supposed to be less harmful to nature (which otherwise could not be accepted as acceptable).

Independently of the type of comparison that is made, the important aspect is that we now can look at the general business process (the manufacturing) as a reliable association of data experimentally obtained from the shop floor to make some inference about the general production plan and strategy of automation. That represents a step forward compared with today availability of data and capacity of analyses.

It also enhances the possibility of vertical integration, putting together data a synthesis of the shop floor process and data from sails or management office.

Finally it offers a better strategy for using the data available by the use of RFID's to improve the integrated control of the manufacturing processes, that is, the control that leads to the business goals, considering the results of the process and not just the machine control.

5. Preliminary pilot results and planned validations steps

To validate the control accuracy of SAVANT-2, an implementation test case is being carried on DesignLab, dealing with some library automation tasks, integrated with the Sun Java System RFID Management. The workflow of self-loan-borrow-renew-return processes are being used to simulate discrete events and data capture task, atypical environmental disruption in the reading process and its consequences on the global inventory processes. The next step scheduled in the SAVANT-2 validation will be, as soon as possible for our partner, to implement a pilot test on its high volume cosmetic plant at São Paulo.

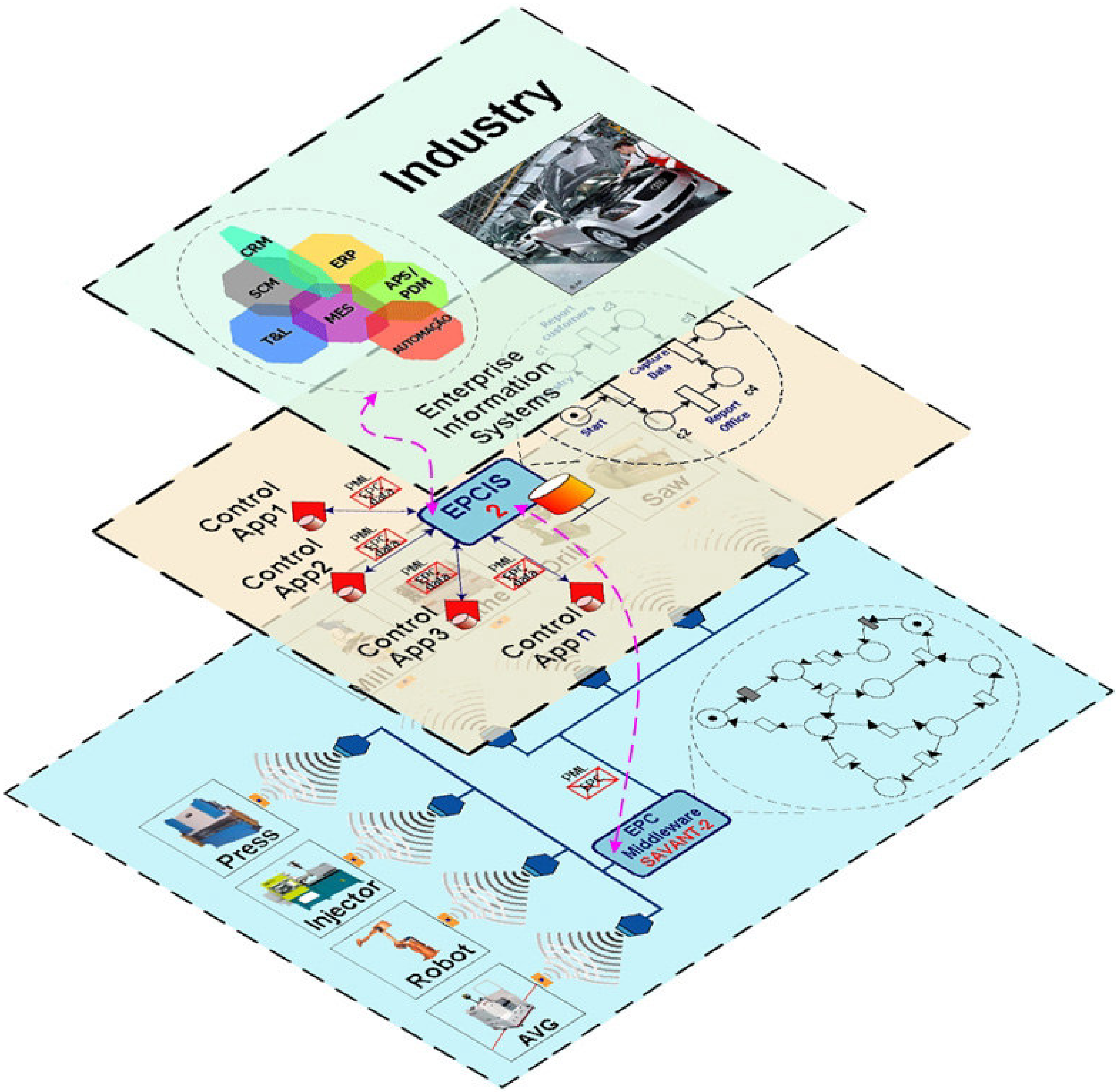


Figure 7. The SAVANT-2 and its participation through the vertical hierarchy of the systems.

6. Conclusion and further work

In conclusion, we remark that the new technology of making a huge network to make available data from all products in the global market will not be complete and established if that information could not be linked to the shop floor process in a reliable way. Naturally this information would not be spread all over the world but instead would be appropriated, the same way that the value of the respective products is. However the sharing of global information would make it possible that the pos-manufacturing life of the product could provide some clues on how to improve its quality and adaptability to the market.

Conversely, eventual problems in the use of such products due to manufacturing occurrences could be anticipated and lead to recalls.

Concerning our work we plan to continue with the experiments for more complex processes, including real RFID readers and sensor signals in our present computational environment. Also we plan to work with an Extended Petri Net, object-oriented, that has a specific representation to uncontrolled events, as mentioned before in this article. This net system is called GHENeSys (General Hierarchical Enhanced Net System) and has also the advantage to allow us to define the activity range easily and maintaining the net formalism.

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