Reference Model for Smart x Sensing Manufacturing Collaborative Networks - Formalization Using Unified Modeling Language

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Abstract. This paper defines the Smart x Sensing reference model (S^2-RM) as a model that fulfills the requirements, characteristics and processes of a Manufacturing Collaborative Network to face the challenge of a digital economy. All the attributes have been formalized using Unified Modeling Language (UML). The S^2-RM allows a complete description using the five generic viewpoints stated in the Reference Model of Open Distributed Processing (RM-OPD): enterprise, information, computation, engineering and technology. A Collaborative Network Organization that produces micro-machines is used as pilot demonstration showing the specific purpose of each viewpoint and its relevance to achieve a smart and sensing environment.

Keywords: Collaborative networks · Smart organizations · Enterprise modelling · Sensing enterprise · Distributed systems · UML description · Manufacturing enterprise

1 Introduction

To compete in an ever-changing environment, enterprises face a number of challenges in the digital economy such as:

1. A connected economy and social networks as customers
2. Global clouds for share information services, data and applications
3. Worldwide real time design and on-site creation of product and services
4. International open innovation for new product and services
5. Universal global collaboration focuses on the right competencies
6. Collaborative networked organizations for manufacturing and services
7. Economical, ecological, and socially sustainable products and services

Collaborative systems play an important role in addressing these challenges. Smart environments require connecting all the smart and sensing objects of the physical and digital world [1]. There is a need for Enterprises or Collaborative Network Organizations to become aware of the global and physical context by means of sensing elements, which

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can be used to determine the actions needed to be agile and resilient. In PROVE 2014, we introduced the concept of the S^2-Enterprise (Smart x Sensing) reference model to address the above challenges [2]. According to Tolle et al. [3] a reference model is a model that captures characteristics and concepts common to several enterprises and organizations to capitalize on previous knowledge rather than developing the models from scratch. In brief, we designed a reference model using the RM-ODP as generic model to guide the design and development of Smart and Sensing Enterprises or Collaborative Networks Organizations in the manufacturing domain. An Enterprise in the context of this research is also a Collaborative Networked Organization (CNO) as described by [1]. Therefore the reference model could be used and applied in the creation of Smart and Sensing Collaborative Networked Organizations (Fig. 1). This paper develops further the reference model using UML as the formal language to model each of the five viewpoints of the RM-ODP standard: enterprise, information, computational, engineering and technology. Section 2 describes the general definitions of the S^2 Reference Model. Each of the viewpoints with their UML descriptions is presented in Sect. 3. A case study is presented in Sect. 4. Finally conclusions are drawn of the experiences of formalizing the reference model and experiences are shared on experiment with the pilot demonstration.

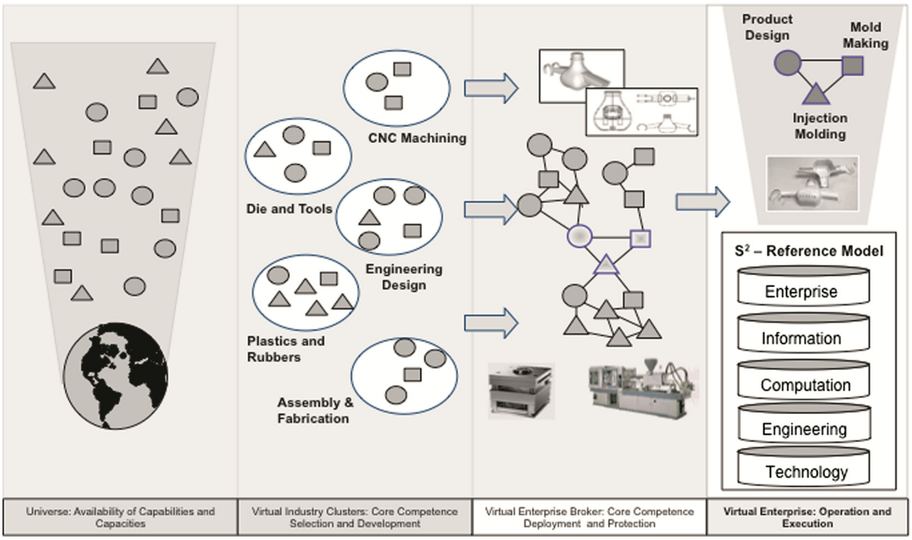

Fig. 1. The use of the S^2 Reference Model in the context of a Collaborative Networked Organization (Adapted from Molina et al. [13])

2 Smart x Sensing – Enterprise Reference Model (S^2-RM): Viewpoints Perspective

As stated by Putman [4], the use of 5 standard viewpoints proposed by the RM-OPD standard allows independence of business and architecture specification from technologies, therefore emerging technologies could be easily adopted by the enterprise without changing its elementary behaviour. The approach to the manufacturing system as an enterprise follows the description established by the RM-ODP standard; thus, the viewpoints inside the S^2-RM are used as described below (See Fig. 2).

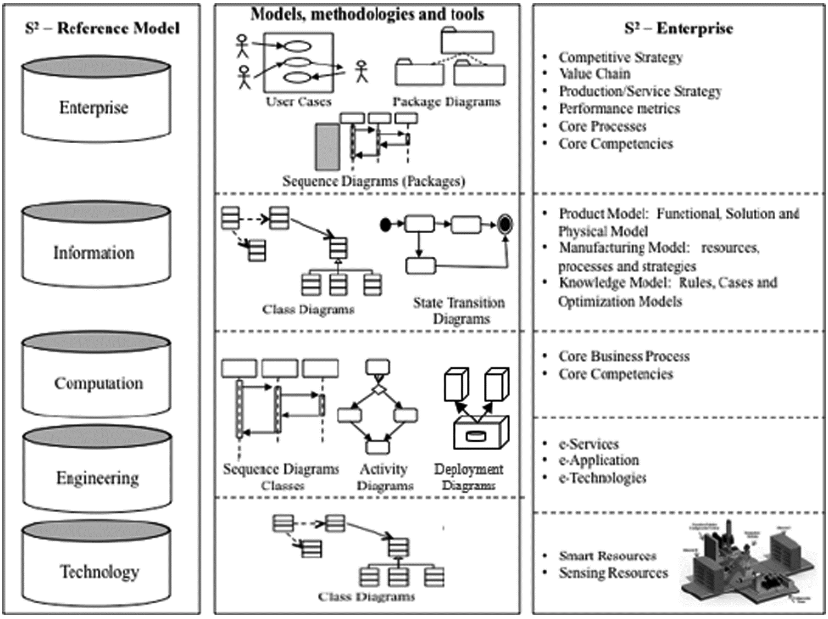

Fig. 2. The use of UML in the S^2 Reference Model and the definition of each viewpoint

The Enterprise viewpoint takes the perspective of a business model, so this viewpoint should be directly understandable to the stakeholders. As stated by Molina [2], this viewpoint represents the functionality that Smart and Sensing Enterprise is intended to achieve. Business concept creation, strategy formulation and action plan definition are the main issues identified for starting a description of the Enterprise, and thus, these components are proposed as the core of the enterprise viewpoint.

The information viewpoint focuses on describing the semantics of information and information processing functions in the system. Three information models are required in an enterprise to describe all data, information and knowledge required: Product, Manufacturing and Knowledge models [2].

The computational viewpoint represents a functional decomposition of the system; therefore this level represents the core business process and core competencies. Selecting the importance of business, customer and supplier related processes according to the Browne et al. [6] is important to know the level of detailed that must be represented. The internal processes of the business are: product development, obtaining customer commitment, order processing, and customer service. The interaction processes are co-engineering, co-design, and supplier and client relationships management.

The engineering viewpoint deals with the distributed nature of the system and the interoperability. This viewpoint offers the capability to support value added industrial networks or Collaborative Networked Organizations (CNOs). These networks rely on e-services in an open technological platform: e-HUB. PyME CREATIVA [7] is a project start-up enterprise that has the objective to develop and integrate the necessary technologies to create the e-HUB to enable interaction among organizations. As a result, engineering viewpoint focuses on the role description of PyME CREATIVA as a system for distribution and interoperability.

Finally, the technological viewpoint focuses on the selection of the necessary technologies to support the enterprise o collaborative network system. For sensing purposes candidate technologies include RFID, wireless networks and real-time networked systems. For smart resources candidate technologies include machines, AGVs, robots, PLCs, CNCs with Intelligent control systems based on Fuzzy logic and Artificial Organic Networks. All these resources are distributed in the network or are integrated in the enterprise manufacturing facility.

3 S^2 –RM Formal Representation Using UML

In order to represent the enterprise according to the different viewpoints of the S^2-RM some modeling languages such as the IDEF family and Petri nets has being analyzed. However, the Unified Modeling Language (UML) has been chosen as the language for that purpose because of its wide use as a standard for designing software. UML was created for the visualization, specification, construction and documentation of the artifacts that involves a great quantity of software [8]. It offers a set of elements, relationships and diagrams for achieving those objectives. There are UML diagrams that can describe the structural and behavioral perspectives of a system. UML has been efficiently used for software systems in banking, telecommunications, transport, commerce, medicine, space, etc. And because its flexibility, UML not only is useful for modeling software, but also for modeling juridical systems, security systems and hardware design [8]. And because UML has been used also in manufacturing systems [9], some diagrams will be proposed for the description of the S^2-RM.

For the representation enterprise viewpoint, Molina et al. [2] have proposed use-case diagrams and activity diagrams. In UML, use-case diagrams are used for representing actors and the actions they can accomplish. For the enterprise viewpoint case-diagrams specify actions such as defining and implementing the strategy (Fig. 3). Activity diagrams are used for the definition of the dynamics of a system. Then, it is used for the definition of the process suggested for defining the enterprise (Fig. 5).

The information viewpoint encompasses the product model, manufacturing model and knowledge model of the enterprise [10]. Because the object nature of the information in this viewpoint, UML class diagrams are convenient for modeling the information entities and their relationships.

In the computation viewpoint, key processes are nominated, so the business process strategy is defined. UML sequence diagrams and activity diagrams are used for this viewpoint (Fig. 2).

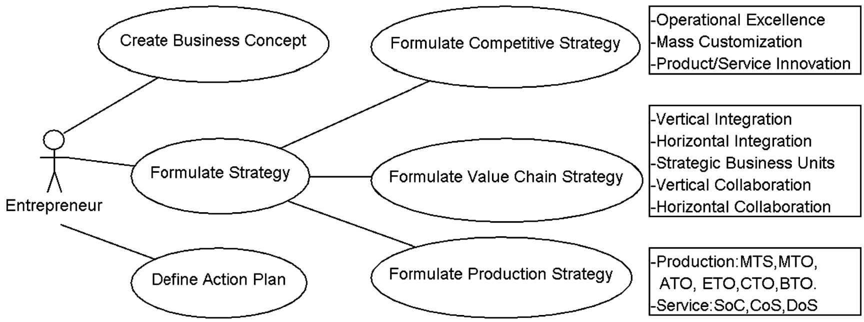

Fig. 3. Use case diagram for enterprise viewpoint activities

In the engineering viewpoint, information and communication technologies (ICTs) are seen as the key enabler for collaboration among SMEs, and consequently the creation of virtual enterprise [7]. PyME CREATIVA was born as an e-HUB to support e-partnership, and e-commerce. The use of that platform is described with a deployment diagram because it shows the nodes that participate in the execution and the components inside.

The technology viewpoint defines choices of technologies, products, standards and tools. For example, PyME CREATIVA platform was chosen as the e-HUB but other platforms that offer e-services can be used. For the representation of this viewpoint class diagrams together with objects-diagram can be constructed.

4 Case Study

In order to evaluate the effectiveness of the S^2-RM model, we are studying its application to create a S^2-micro-factory that produces reconfigurable CNC-micro-machines [14] in collaboration with Tecnologico de Monterrey. The pilot has being selected due to its simplicity and completeness; it is a single product where the main concepts regarding CNs and manufacturing can be found. The product is designed according to the user needs. For example, if the user is a low-income college the micro-factory may be for academic only purposes. In this case study, the objective of the enterprise is to design a low cost micro-machine where the precision is not an issue. The micro-factory has the capability to produce small sized products (e.g. gears, screws, joints, etc.). In addition, collaboration is necessary in order to manage resources, (e.g. motors, computers, DAQs, structural profiles, etc.) in an effective way. Expert engineers and researchers from Tecnologico de Monterrey manage the product development process. And finally, De Lorenzo is in charge of the distribution and sales. The micro-factory, suppliers, Tecnologico de Monterrey and De Lorenzo are the enterprises, which conform the temporary Virtual Enterprise (VE) for the creation of the micro-machine. The VE should accomplish the competences of a smart organization: internetworked, virtual in concept, dynamically adaptive, knowledge driven and hierarchically flattened (Fig. 4).

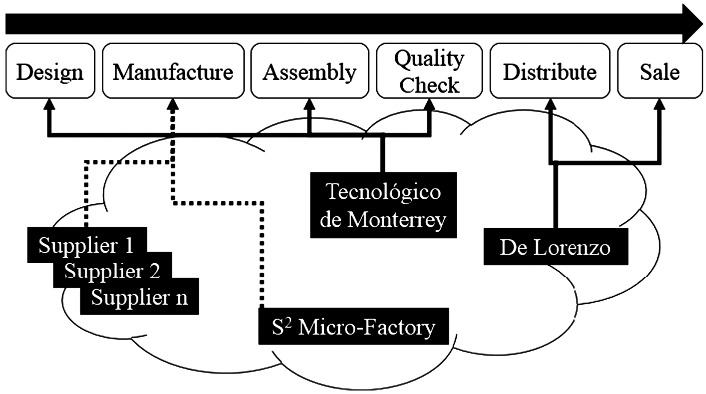

Fig. 4. Collaborative Networked Organization for the design, manufacture, assembly, distribution and sale of the reconfigurable CNC micro-machine.

4.1 Enterprise Viewpoint

For the definition of the enterprise a UML activity diagram is used (Fig. 5). It shows the steps to define the enterprise, the first one is the Business concept where the Canvas model, mission and vision, and values and policies are created. The second step is the strategy definition: competitive strategy, value chain strategy and product/service strategy. And finally the third step consist in the identification of core process and competences and the creation of the business plan.

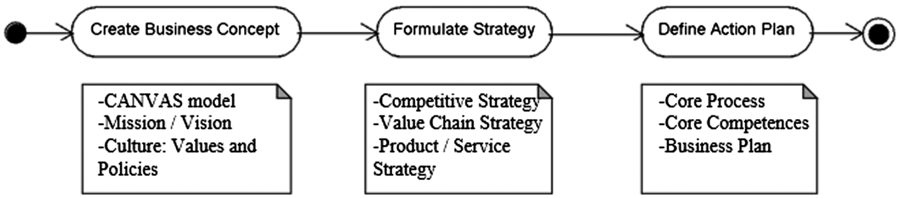

Fig. 5. Activity diagram defining the enterprise.

Regarding the pilot case, the strategies are exemplified. A competitive strategy is defined depending on whether the goal is for Product Innovation, Operational Excellence or Mass Customization [5]. Product innovation and client customization were selected as the competitive strategy for the Manufacturing Collaborative Network. This decision was made based on the assumption that the enterprise has a strong R&D area. Therefore, the objective is to implement the best technology available according to the needs of a specific client. This requires a network of suppliers to manufacture the micro-machine components.

The value chain strategy allows the design and creation of Collaborative Networks Organization with all the SMEs required to support the design and fabrication of the

Micro-Machines. The Value Chain Strategy could define two collaborative approaches: Vertical and Horizontal. Vertical is used when the enterprise collaborate by aggregating its competencies to build components and parts of the Micro-Machine. Horizontal Collaboration is when the enterprises share their competence to design and build together a new component. In this particular scenario Vertical Collaboration has been defined, as the type of collaboration require for this particular CNO because there will be many suppliers for each part of the micro-machine. The Build to Order (BTO) was selected as production strategy because there is a design according to each client needs and specifications [5]. For evaluating the strategy, the global KPIs are: time to market, time for customization, delivery time, customer satisfaction, total costs and ROI per product.

4.2 Information Viewpoint

Figure 6 diagram shows an overview of the information viewpoint and its basic interactions and contents. Product Model, Manufacturing Model and Knowledge Model should be represented in this viewpoint.

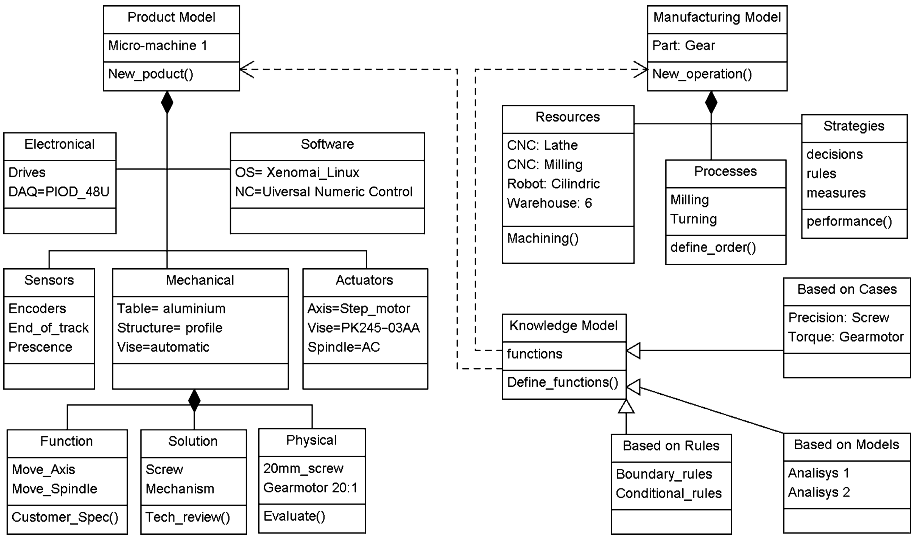

Fig. 6. Class diagram represents the information viewpoint of a micro-machine, manufacturing resources and knowledge to manufacture it.

The product model is divided into five different types of components due to the mechatronics nature of the reconfigurable micro-machine. Then within each type of component there are three different models. The functional model defines the set of functions the product has to accomplish. The solution model defines alternatives of solution to design the product. The physical model describes the final product with specific parts with restrictions and specifications. The technology used is a PLM system. Figure 6 illustrates how some functions for the mechanical components of the system are accomplished. A screw for a precision axis movement and a gear motor mechanism for high torque spindle movement. The specific design is stated in the physical model, where a 20 mm screw is selected for the Z axis for the specific micro-machine and a gear motor that increases the torque 20 times is selected.

The manufacturing model is presented as a class with three subclasses: manufacturing resources, manufacturing processes, and strategies of the company and operational rules. Figure 6 shows the case of a manufacturing model for the fabrication of a gear used for the gear motor. The resources listed are the components of the micro-factory, two reconfigurable CNC machines, a robotic arm, and a warehouse. Then the processes for the production of the machined product are stated: a milling and a turning operation for getting the gear. Finally the third part of the manufacturing model consist of a set of strategic decisions, operational rules, and performance measures on each of the levels i.e. factory, shop, cell, and station. This manufacturing model has being described within the capabilities of the micro-factory, nevertheless it offers resilience because the manufacturing model for collaborative networks has the ability to acquire manufacturing resources via e-services. The distribution nature of the collaborative networks that support this agile recovery in case of a failure of the micro-factory is explained in the engineering viewpoint.

The knowledge model is used to model different knowledge domains of the enterprise related to a product [11]. This model is especially important because it offers the manufacturing enterprise the knowledge driven attribute defined in [2] to have a Smart organization. The knowledge model is represented inside the information viewpoint by a class that is the generalization of 3 ways of creating the model. Knowledge based on cases is suitable for this case study because there are new micro-machines according to customer specifications. One example is "use of a screw when precision is important alternatively use a gear motor when torque is important." Knowledge based on rules represents direct relations between the product requirements and operation limits [12]. An example of rule based knowledge could be the decisions that allow the selection of the spindle motor depending on the materials the user want to mill. A knowledge based on model structures for this case study is being constructed for the motor selection but needs to be validated since there is no way to have control within its interior.

4.3 Computational Viewpoint

Figure 7 describes a sequential process diagram for the BTO micro-factory, the key external processes are co-design since it is a customized product, and supplier relationship due to the Vertical Collaboration strategy that will allow the CNO to have suppliers ready for operating the distributed manufacturing processes. The main internal process identified is customer satisfaction, related with the achievement of its loyalty defined as a KPI in the enterprise viewpoint. Once there is a selection of the process it is required to focus for designing the activity diagram. This diagram was selected because it captures de dynamic aspects of the system. It shows the flow control between activities. Figure 8 shows the creation of the micro-machine focusing on core processes.

The activity diagram describes the creation of the reconfigurable micro-machine tool for academic purposes and displays the importance of the core processes. As it can be seen co-design plays an important role, since there is a loop with the customer in the designing stage. This loop together with the *analyze clients* activity are sensing activities

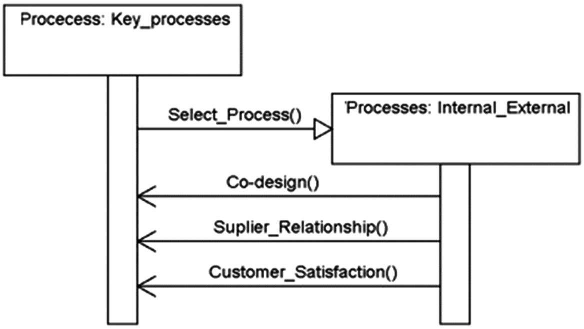

Fig. 7. Sequence process diagram showing the business process strategy selection for the S2-micro-factory that creates micro-machines.

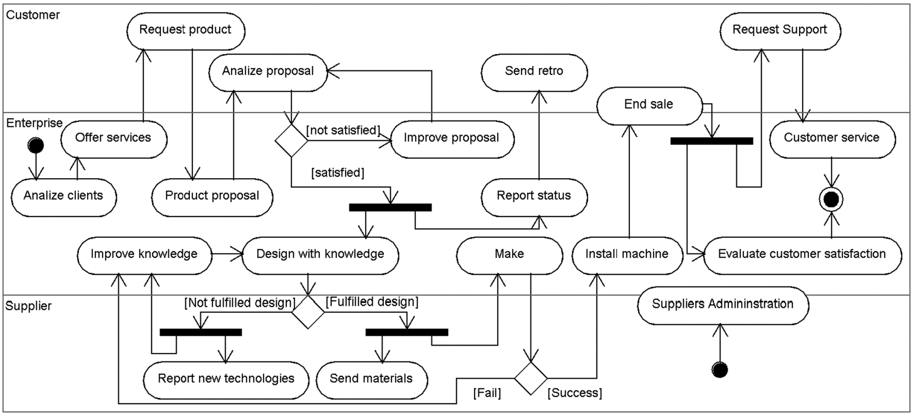

Fig. 8. Activity diagram specifies the enterprise activities according to business process strategy of the pilot demonstration.

since they makes the manufacturing collaborative network to be aware of its contexts in terms of client satisfaction and requirements. The supplier relationship is also important so there is an alternative start with no end that has supplier management activities. This activity is located between two swim lanes since it is an activity done by the Collaborative Network conformed by the enterprise and its suppliers. Finally, customer satisfaction stages have many related activities i.e. send retro, request support, customer service and evaluate customer satisfaction.

4.4 Engineering Viewpoint

The most important core processes are co-design, supplier – customer relationship management. The co-design process can be supported by expert engineers and researchers from Tecnologico de Monterrey. Then the supplier relationship will be supported by the e-Supply service provided by the e-HUB. Finally, e-Marketing services will be provided by De Lorenzo who is in charge of distribution and sales. This sharing of services is modeled in Fig. 9.

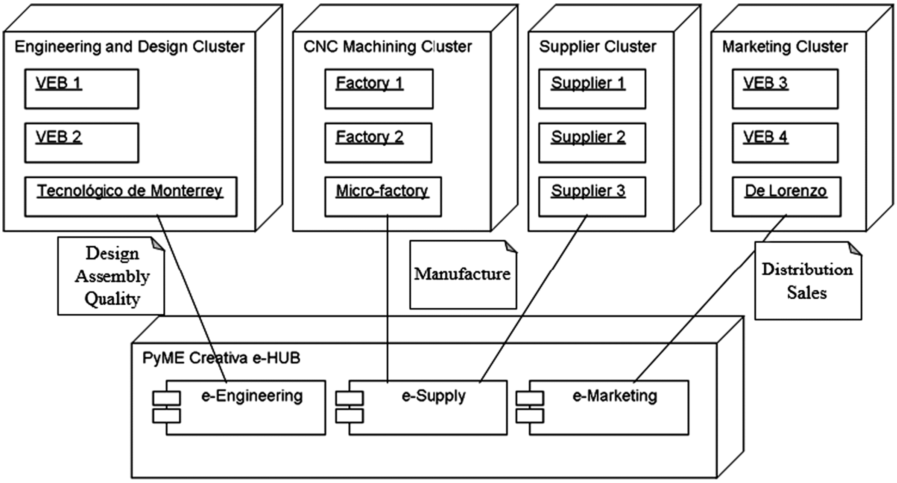

Fig. 9. Deployment diagram for representing the distribution of processes of the pilot case, using the e-HUB platform: PyME CREATIVA.

In the engineering viewpoint, the nature of a manufacturing collaborative network is well represented. The upper nodes represent VIC (Virtual Industry Cluster) with different capabilities and the down node represent the e-HUB. Within the VIC a VEB (Virtual Enterprise Broker) is displayed to have a set of options. The notes show the process developed by the VEB (e-HUB). The artifacts shown are e-services used by the pilot VE (Virtual Enterprise). The virtual enterprise or collaborative networks aim to capitalize individual capabilities by creating a temporary arrangement to share skills and core competences. And with platforms such as PyME CREATIVA the internetworking is easy to achieve, allowing the pilot enterprise to rapidly configure is competences to fulfill new customer requirements. Cooperation, ubiquity and ability to adapt are the main principles of this viewpoint that defines a smart organization.

4.5 Technology Viewpoint

A technology review is necessary before choosing any tool, since it guarantees smart and sensing capabilities of the organization. This paper presents the sensing and smart resources used by the collaborative network to produce the micro machine (Fig. 10). The sensing resources allows the acquiring of data and information. And the smart resources has to do with the efficient operation of the manufacturing. The independency of technology achieved with this viewpoint improves the resilience of an organization since a deficiency detected can be solved adopting new technology that deals with the shortage.

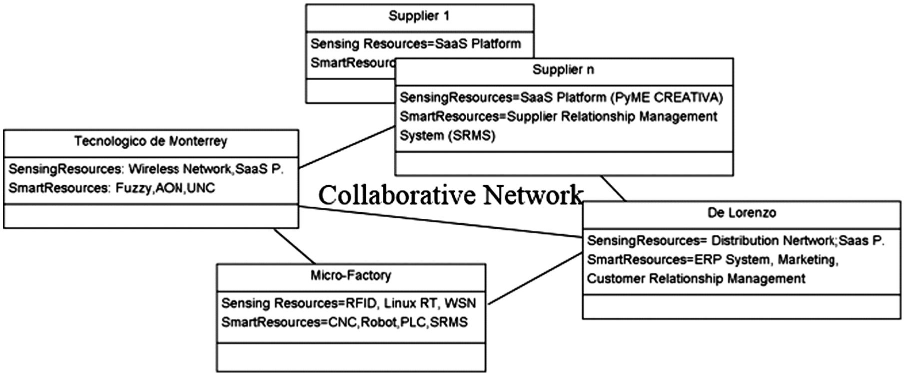

Fig. 10. Object diagram showing the actors with its smart and sensing resources for the fabrication of the micro-machine.

5 Conclusions

The S^2-RM defines a set of generic viewpoints to design and create Smart and Sensing Manufacturing Collaborative Networks using a structural approach by defining strategies, KPIs, core process and technologies. When applied to the pilot case it helps to have a better description of the system and hence identify the sources of advantage and key points for supporting collaborative networks. The functionality of each viewpoint can be formally represented using UML because its variety of diagrams. The enterprise and information viewpoints focus on the business perspective, strategies and core processes and core competencies. Therefore this viewpoint must define the smart and sensing concepts. The information computational and engineering defines the architecture of the system; especially the computational and engineering form a specific description of the core processes, and interactions inside the enterprise and the collaboration network. Here at these viewpoint the collaborative organization definition is established, and the advantages such as resilience and agility are identified. And finally, the technology viewpoint forms a constraint on the implementation of the system, but due to its independence it allows the integration of the latest technology to assure the best development of smart and sensing through all viewpoints.

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