Designing a S^2-Enterprise (Smart x Sensing) Reference Model

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Abstract. The definition of the concept of S^2-Enterprise (Smart x Sensing) reference model is presented. The S^2 Reference Model (S^2-RM) is targeted to assist in the system specification and development of future computer based systems, which support the creation of this concept. It is a hybrid reference model that includes Enterprise Integration Engineering Concepts and Interoperability models. The Reference Model for Open Distributed Processing or RM-ODP is used as the basis to define S^2-RM because it allows the definition of the structure and characteristic of the Smart and Sensing systems in terms of five different views (enterprise, information, computational, engineering and technology). The importance of using reference models for the definition, design and implementation of S^2-Enterprise systems is outlined. A pilot system has been developed using a micro-factory concept and a collaborative networked organization.

Keywords: Sensing Enterprise, Smart Enterprise, reference model, RM-ODP.

1 Introduction

Research that is currently being undertaken by several research laboratories to address issues of Enterprise integration and interoperability has been reported in [1]. The aim of all these research is to move from highly data-driven environments to a more cooperative information and knowledge-driven environment in order to design and create the concept of an enterprise, which is smart and sensing [2].

Sensing Enterprise is described as "an enterprise making use of the sensing possibilities provided by interconnected 'environments', anticipating future decisions by using multi-dimensional information captured through physical and virtual objects, and providing added value information to enhance its global context awareness" [3].

A Smart Organisation is defined by [4]: "A smart organization is understood to be both, internetworked and knowledge-driven, therefore able to adapt to new organizational challenges rapidly, and sufficiently agile to create and exploit knowledge in response to opportunities of the digital age."

Smart and Sensing systems are highly complex and the activity of coordinating and structuring their design and development necessitates the use of formal methods for their representation. The development of complex integrated and networked

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environments, such as a Smart and Sensing Enterprise, requires that system developers and the users are able to hold meaningful discussions and share a common understanding of underlying goals and ideas. The use of reference models in such complex tasks has been proven successful [5].

A key issue in the research presented here is the development of a S^2-Enterprise (Smart x Sensing) reference model to provide a framework to support the development of new integrated enterprise concepts and hence the implementation and interoperability of networked enterprises by establishing a generic set of viewpoints. Methodologies and tools are recommended to assist in the specification, development and analysis of each view (e.g. UML, Petri-nets, Artificial Hydrocarbon Networks). This will ensure that certain key issues are considered during the design of a system, and that standardized methods are used for the design and documentation of the system. In the S^2- Reference Model (S^2-RM), a combination of reference models, methodologies and computer tools have been defined, to enable to address the complexity and interoperability of such systems.

In this paper, the next section offers a general overview of reference models and their major characteristics. Section 3 describe the issues involved in the definition of the S^2-RM. Section 4 describes a pilot system that has been develop using the S^2-RM to design and create a micro-factory and a Manufacturing Collaborative Networked Organisation. Finally conclusions are proffered about the authors' experiences on the use of reference models.

2 Reference Models, Frameworks and Architectures

Reference models provide general representations of different aspects (views) of a system, for example [6]: Function, Information, Resources and Organization (CIMOSA); Safety, Environment, Compatibility, Performance, Operability, Maintainability, Reliability, Qualifications and Description (ISO/TR 101314-1: 1990); Enterprise, Information, Computational, Engineering and Technology (RM-ODP). These representations can be referenced to assist in the development of a system during various stages of its life cycle (e.g. requirements, design, implementation, operation, decommission).

A reference model must be [7]:

1. Structured: based on readily available and acceptable terminology, methodologies or standards.
2. Flexible: able to be applied to wide range of systems within its domain of applicability and at different stages of the system life cycle.
3. Generic: independent of any existing implementation.
4. Modular: open-ended in its ability to be extended in order to incorporate new concepts and technologies.

In Manufacturing, reference frameworks and architectures used for developing information systems have been based on concepts delineated above. The terms framework and architecture have been used ambiguously within the manufacturing domain to denote reference models that assist in the development of an information system during different phases of, or throughout, the complete life cycle.

The Reference Model for S^2-Enterprise presented in this paper is based on the framework concept defined by [7] which describes a representation of characterized situation types that occur during an information system life cycle for enterprise integration. Enterprise in the context of this research is also a Collaborative Networked Organization (CNO) as described by [8]. Therefore the reference model could be used and applied in the creation of Smart and Sensing Collaborative Networked Organizations.

3 A Reference Model for S^2-Enterprise (Smart x Sensing)

The authors believe that a Reference Model for S^2-Enterprise (Smart x Sensing) should assist the users and developers in the following three tasks:

1. Identify the Enterprise requirements to support the concepts of Smart an Sensing Enterprise
2. Guide the design and implementation of the enterprise system itself.
3. Organize the process of implementation (people, methods and tools) to evolve the Smart and Sensing system towards the desired level of integration and automation.

The research into the development of a reference model for S^2-Enterprise has embraced issues related to distribution and sharing of information, integration of application by means of networking and multimedia environments, incorporation of new paradigms (Smart and Sensing), use of standards languages and modelling techniques, and the provision of services for co-ordination and collaboration. These systems are open in nature to allow the incorporation of a wide range of technologies, and distributed, to enable the interaction among remotely located people.

3.1 The Rationale of S^2-RM Based on RM-ODP

A well-documented standard related to these issues is the one concerned with open distributed systems, known as the Reference Model for Open Distributed Processing or RM-ODP [9]. This reference model was chosen to describe, design and implement the S^2-Enterprise concepts, due to the fact that the RM-ODP allows to represent an open and distributed information system from different viewpoints: Enterprise, Information, Computation, Engineering and Technology. Each viewpoint represents a specific aspect of the S^2-Enterprise and system at any required level of detail. Therefore the use of the RM-ODP views allows a complex system to be described from a number of perspectives (see Figure 1).

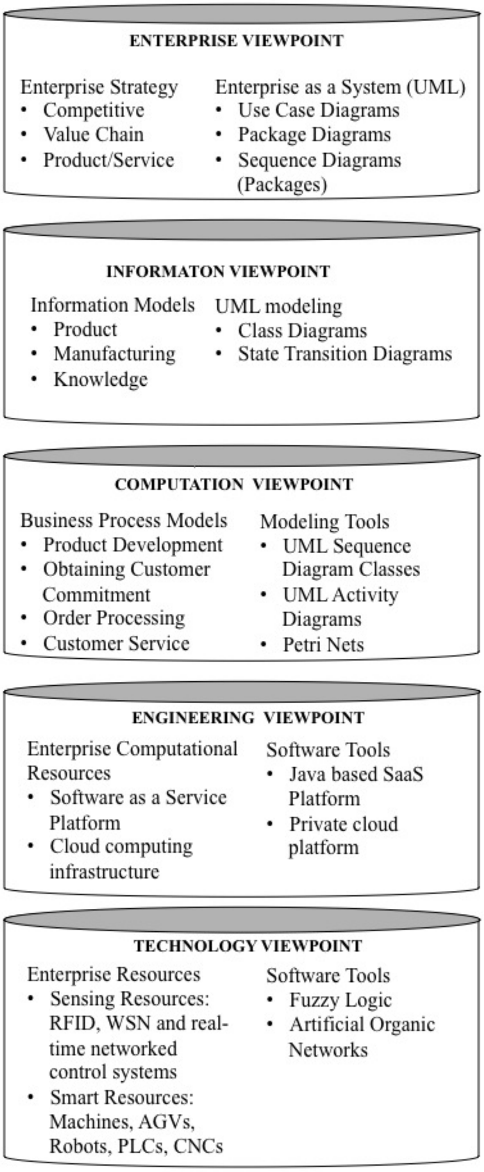

Fig. 1. S^2- Enterprise Reference Model (Smart x Sensing)

The S^2-Enterprise Reference Model (S^2- RM) enables the successful support the tasks defined above i.e. identification of requirements and guidelines for system development. However, the organization and management of the timely incorporation of people, methods and tools to evolve a Smart and Sensing environment towards the desired level of integration and automation requires further definitions at the different levels of integration, therefore models such as Petri Nets [10], Interoperability systems and control systems such as SaaS [11] are used.

The S^2-RM aims to support the development of existing and new systems by establishing a generic set of viewpoints that should be used to analyse any such system. Each viewpoint is represented by a view in the reference model. A view depicts the system from a known perspective. Methodologies and tools are recommended to assist in the specification, development and analysis of each view. This will ensure that certain key issues are considered during the design of a system and that standardised methods are used for the design and documentation of the system, hence enabling the comparison of different integrated and interoperable systems at different levels of abstraction.

The use of S^2-RM enables the generic structures and characteristics of systems to be compared. The reference model facilitates comparison by providing a standard representation format for system structure and characteristics. The measures against which the systems are compared are still in the domain of the comparator and have not been included in the reference model structure. This is because each user group will have a different specification for a Smart and Sensing system that best suits their needs and priorities e.g. a requirements definition model. Using this model as a driver the S^2-RM allows a system designer to select from a range of concepts the ones that most adequately fulfil their need and then for the system developer to be guided to the tools and methodologies that will most helpfully assist the integration of elements that realise the concepts.

The S^2-RM has been used to represent two distinct levels of system design i.e. concept and implementation. At the conceptual level the generic building blocks of systems are defined using UML [12]. It is possible that, depending on the requirements made of it; a given system may not require all the concepts that are modelled. This is perfectly reasonable as one of the key aims of the model is to provide a comprehensible representation that aids the description, understanding and discussion of system solutions with developers and users. It is also possible that a viewpoint may exist that is not adequately reflected in the current structure of the reference model. The modular nature of the reference model enables different viewpoints to be included as and when they become appropriate. At present the viewpoints are treated as distinct elements that can be considered independently. The reference model needs to be extended to map the relationships between the viewpoints more completely. This will improve the clarity of the reference model concept and its use.

At the implementation stage of a system the S^2-RM is useful because it defines the boundaries between software and hardware interfaces, the relationships between them, and it specifies the tools that should be used for the modelling of these elements. Wherever possible international standards have been followed in order to promote standardisation.

The reference model that is under development is designed to be applicable to smart and sensing systems. Many of the concepts can be applied to a reference model for any open, distributed computing system, however, the incorporation of the conceptual building blocks defines the specialisation e.g. product model, manufacturing model, integration environment, etc. By altering these building blocks the reference model could be adapted to suit a wide range of domains.

The definition of the S^2-RM is independent of vendor software and hardware systems. The reference model is a general description, which is acceptable to both users and developers. It is based on the principal that the whole function of Smart and Sensing systems can be represented in totality by a series of models, each representing one particular viewpoint. Instances of the S^2-RM would represent real systems.

Therefore the Reference Model can be used to define, design and create a Smart and Sensing Enterprise by defining the different levels for Enterprise requirements (UML), information/knowledge models (UML), computational interactions among all process and systems Petri Nets, infrastructure required to support distribution (Interoperation, Integration, communication protocols – SaaS platform) and Technology - RFID, WSN – Wireless Sensors Networks/Mobile Devices/Virtual Technologies.

3.2 The S^2-RM: Models, Methodologies and Tools

The S^2-RM is a five level model that is intended to represent open distributed systems (Figure 2). To achieve this, the following five levels have been defined based on the RM-ODP: Enterprise, Information, Computation, Engineering, and Technology.

The Enterprise Viewpoint is associated with the specification of requirements for ODP systems. Nevertheless, the scope of the information described, and the level of detail contained in the Enterprise View remains a point of debate. There are two main schools of thought regarding what the Enterprise viewpoint should represent. These are to:

1. Represent a model of the organisational environment, in terms of engineering functions and the relationships between them, in which Smart and Sensing systems could be used
2. Represent the functional capability of Smart and Sensing system concepts

In order to define a more flexible S^2-RM, the authors have agreed, to represent at the Enterprise Viewpoint the functionality that Smart and Sensing Enterprise is intended to achieve. In this research Enterprise also means a Virtual Networked Organization. Therefore, the Enterprise View is modelled using the EIE Framework and toolbox defined in [13] to describe strategies (competitive, value-chain, production/service), extended/virtual enterprises models and business performance measures. For the case of Collaborative Networked Organizations the concept of the Virtual Enterprise Broker is used at this level to design the type of CNO to be designed and created [14]. Also UML modelling is used to support a formal representation: User case diagrams, Package Diagrams, and Sequence Diagrams (Packages).

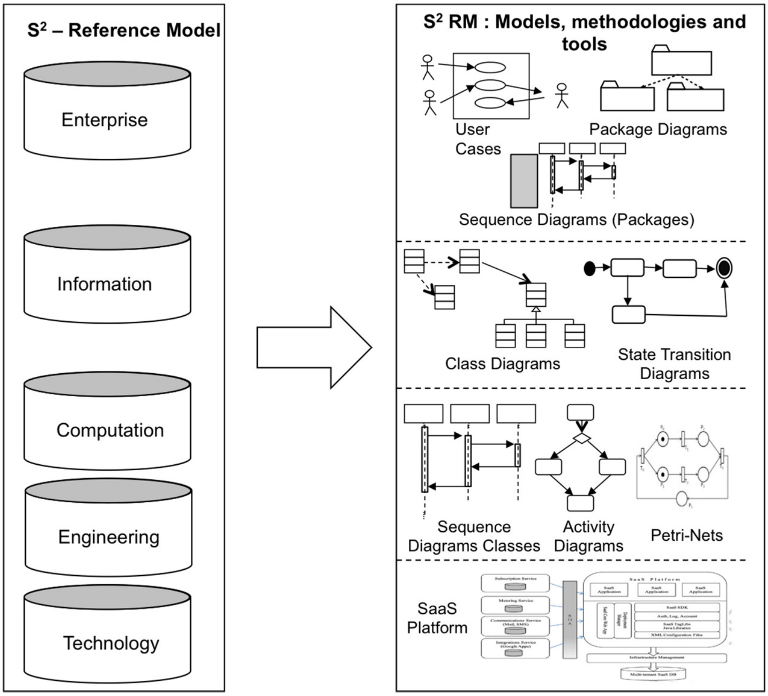

Fig. 2. S^2- reference model: Models, methodologies and tools

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 information and knowledge namely: Product, Manufacturing and Knowledge models [15]. In the S^2-RM this viewpoint is defined via a combination of UML descriptions of class diagrams and activity diagrams. This combination of models allows the description of the information flows together with the structure of the information elements, their relationships and quality attributes.

The Computational Viewpoint focuses on the representation of the functional decomposition of the system into objects, the activities that occur within those objects and the interactions between the objects. This level represents the Core Business Process (New Product Development, Obtaining Customer Commitment, Order Processing, Customer Service). Therefore UML (Sequence Diagram Classes, Activity Diagrams) and Petri Nets are used to model this this view.

The Engineering Viewpoint focuses on the infrastructure required to support distribution and interoperability. This view enables the specification of the processing, storage and communication functions required to implement the system PyME CREATIVA (Software as a Service Platform – Cloud Computing Infrastructure) and Software tools (Java based SaaS Platform and Private cloud platform), for more detail [16, 17].

Finally, the Technological Viewpoint focuses on the selection of the necessary technology to support the system. In this research the technologies for sensing resources used are RFID, WSN and Real-time networked systems [18]. For smart resources: Machines, AGVs, Robots, PLCs, CNCs with Intelligent Control systems based on Fuzzy logic and Artificial Organic Networks [19, 20].

The top levels of the reference model (enterprise, information and computation) are non-software specific and so they provide a base level description for system development. Although the S^2-RM allows the thorough description of a Smart and Sensing system from different views.

4 Pilot Demonstrations

Pilot demonstrations of a S^2 - Micro Factory / S^2 - Collaborative Networked Organization (CNO) have been developed using the S^2-RM to corroborate how the reference model can guide the design and implementation of a Smart and Sensing systems (Figure 3). The micro factory may be used to produce work parts based on machining parts. The CNO for manufacturing additional to machining process capacities, it has an entity (Virtual Enterprise Broker) which executes the process of Marketing, Product Development and Logistics.

4.1 Scenario 1: Micro – Factory (Make to Order)

A MTO Micro-Factory has been designed to produce machining components that are produced based on a product catalogue. The strategy for this facility is Operation Excellence where manufacturing should be executed in minimum time and cost. It also is organized as a Strategic Business Unit with all its operations embedded in one business entity and factory. Information models used to operate the Micro-Factory are Product, Manufacturing and Knowledge Model.

The product model is a catalogue of products that can be manufactured in this facility. Descriptions of all the products that can be manufactured in the catalogue are presented in e-marketing page.

The Manufacturing Model includes manufacturing resources and processes that can be performed with these resources. The detailed list of micro factory resources is: two mechanical kit (RmMT assembly); two storage spaces (store raw materials and finished products); two spindle (NAKANISHI AM-300 R); two air pressure regulator (NSK Air Line Kit AL-0201); two air control (NAKANISHI E2530); two linear actuator clamp (Firgelli PQ-12. 25 mm); six lineal actuator axes (PI M-111.2DG); two assembly toolkit (screwdrivers, wrenches, hoses, cables); one compressor (Truper 21/2 hp); one work station (UNC); three cutting toolkit (drills, cutters, polishers); one robotic arm with two metal gear motors, three servo motors, two kit encoder, one proto-board; and one acquisition card (PIO-D48U). Wireless sensors networks are used to sense vibration/noise/movement in the Micro-Factory, also RFID to track products has been implemented.

The Knowledge model includes strategies, procedures and rules to operate the facility. Also Fuzzy Logic and Artificial Organic Networks are used to implement intelligent control and automation algorithms. The core process to be executed at this factory is Order Processing that allows the customer to order any product in the catalogue.

PyME CREATIVA software enables the operation of the facility with the following e-services: e-marketing, e-brokerage, e-supply and e-productivity. PyME CREATIVA runs on the SaaS platform [21].

4.2 Scenario 2: Collaborative Networked Organization (Build to Order)

The manufacturing CNO has been implemented to satisfy the Build to Order paradigm with a mass customization strategy. Key performance measures for this model are time to respond and customer satisfaction. A pilot case of multiple sites of manufacturing facilities has been created to demonstrate the concept of a Virtual Enterprise Broker and Manufacturing Collaborative Network of manufacturing competencies. The CNO is configured of three manufacturing facilities (drilling, turning, milling), and a Virtual Enterprise Broker to execute product development, logistics, assembly and quality assurance processes [14]. The level of customization is implied in terms of time to deliver, volume, and configuration options. The Broker model works in a collaborative way with the customer; the customization will be measured as the capacity to respond to customer requests i.e. Customer Satisfaction.

The Virtual Enterprise Broker (Broker) is responsible for searching business opportunities and enabling the creation of Virtual Enterprises. In this scenario a Virtual Enterprise is the network of manufacturing facilities that will be required to produce a customized product. The Virtual Enterprise Broker performs the processes of partner search and partner selection, and configures suitable infrastructures for Virtual Enterprise formation/commitment i.e. physical, legal, social/cultural, and information. To achieve its goal the Virtual Enterprise Broker is supported by the services provided by the manufacturing facilities. The Broker model allows achieving Build To Order (BTO) strategies through the aggregation the manufacturing capacities and capabilities of each of the different facilities in the network. This aggregation of capabilities together with the core process of the Broker as an entity reaches the BTO flexibility required, and makes an adaptable model that can be applied to different kinds of companies and industries.

The activities of the broker include searching and selecting business opportunities and partners, developing products, logistics, and quality assurance to ensure that the final product is delivery to the customer. While on the other hand, the activities of the facilities are related to the manufacturing capabilities necessary for the manufacturing of the final product.

The core processes of the Broker are supported by the use of PyME CREATIVA in terms of e-services. Some of the e-services that support the operations are [16, 21]:

- e-Marketing intelligent web-portals for promotion of products and services of each member of the CNO and integrates a unique catalogue of products.
- e-Brokerage integrates software to enable the selection, evaluation and configuration of manufacturing facilities to produce an specific product.
- e-Supply integrates services related to e-factory, e-logistics for importing/exporting materials and products, ERPs, supply chain management and manufacturing execution systems.
- e-Productivity integrates technologies for the diagnosis, planning, evaluation and monitoring of manufacturing facilities.

All these e-services support the collaboration activities among all the facilities in the manufacturing network.

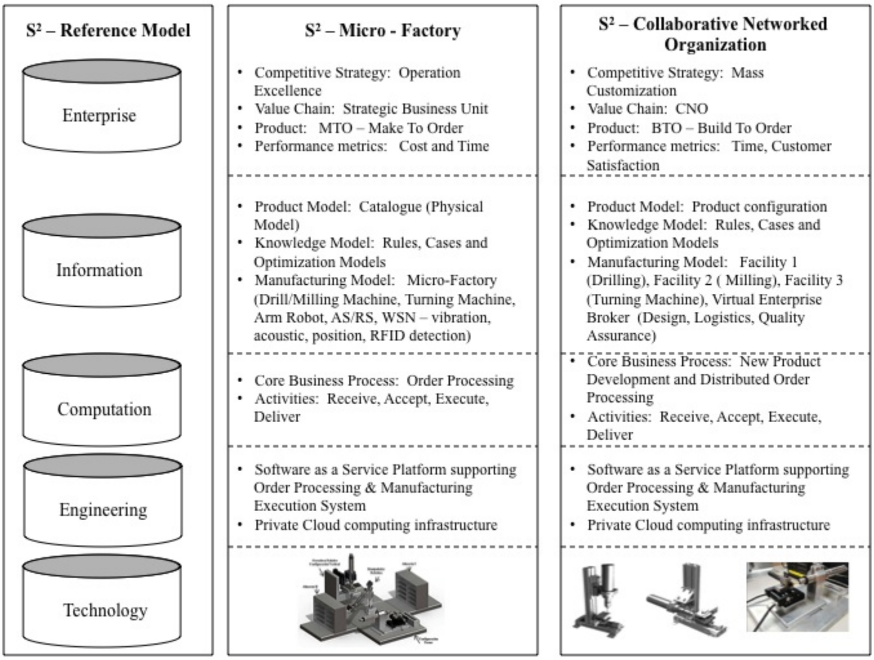

Fig. 3. S^2- Scenarios: Micro-Factory and Collaborative Networked Organization

5 Conclusions

In summary, this paper highlights the importance of using reference models for the definition, design and implementation of Smart and Sensing systems. The use of such reference models within modelling frameworks is being explored. A reference model for S^2-Enterprise has been defined to guide the design and creation of Smart and Sensing Enterprises. The reason for the choice of the RM-ODP has been explained.

Two pilot cases using a micro-factory and Collaborative Networked Organization have been created to demonstrate the use of the S^2- Reference Model

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