Ontology approach for the interoperability of networked enterprises in supply chain environment

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Yan Lu[1], Hervé Panetto[1], Xinjian Gu[2],

[1] CRAN UMR 7039, Nancy-Université, CNRS, France
[2] Institute of Manufacturing Engineering, Zhejiang University, P.R. China
{Yan.lu, Herve.Panetto}@cran.uhp-nancy.fr, xjgu@zju.edu.cn

Abstract. The *System-of-Systems* (*SoS*) paradigm is widely recognized and has become quite studied since a decade, as it has potentially practical applicability in systems engineering. SoS-organized systems could make efficient use of resources from a variety of domains. In this paper, we are studying one of the typical forms of networked enterprises: the supply chain. We will apply the *SoS* paradigm to this kind of "so-called" system-of-networked enterprises and we will then explore and analyze the interoperation problem in heterogeneous networked enterprises systems. Focusing on information flows in supply chain, we are proposing an approach for developing a supply chain ontology for networked enterprises interoperability, based on an extension of the ONTO-PDM product ontology.

Keywords: product ontology, supply chain, interoperability, SCOR, ONTO-PDM.

1 Introduction

With the development of global manufacturing, systems should not be seen isolated; enterprises collaboration is no longer just between each other, and is evolving to enterprise networks, in the form of supply chain, extended enterprise and virtual enterprise and so on [1]. This new paradigm has increasing demands for information or knowledge exchange among enterprises. Meanwhile mass information or knowledge spread out in various formats among different enterprise systems, which leads to semantic interoperability issues between the existing enterprises applications systems. The heterogeneity of these systems and the knowledge disunity of expression methods are becoming barriers for the knowledge acquisition by stakeholders. While the collaboration is going on, there would be excessive knowledge accumulated, unorganized and decentralized, which could lead to a considerably low efficiency and inconsistency in their treatments. All these issues will definitely affect the comprehension of everyone's intelligence when enterprises collaborate in the context of networked enterprises.

In this paper, we give an insight into interoperability in networked enterprises, by analysing the *System-of-Systems (SoS)* paradigm and studying its characteristics in the context of networked enterprises. Considering that enterprises collaborating for a certain purpose may be considered as a kind of system-of-networked enterprises (SoNE), we then contribute to the "connectivity" (interoperability) property of supply chain networked enterprises by extending the ONTO-PDM Product Ontology developed by [2] with the SCOR model. The main perspective of this ongoing work is then the definition of a product-centric supply chain ontology for facilitating the interoperation between all enterprise applications involved in an extended supply chain.

2 Background and Problem Analysis

2.1 System-of-Systems (SoS) Paradigm

The term *System-of-Systems (SoS)* is widely recognized and has become quite studied since a decade. Its application area spans from original military to other domains, especially system engineering. Researchers tried to formalise this new paradigm in the field of information system, complex system in military and enterprise since many years [3][4][5][6]. Further, various efforts have been made to give a common definition to specify the characteristics or principles of the paradigm. Widely cited definitions are for example *Systems-of-Systems (SoS)* are large-scale concurrent and distributed systems, the components of which are complex systems themselves." [3], as well as [5]. Whichever definition is used, there are several principles that distinguish *SoS* from monolithic systems. The classical five principles are known as Maier's criteria [7]: operational independence of the constituent systems, managerial independence of the constituent systems, geographical distribution of the constituent systems, evolutionary development, and emergent behaviour. Based on the characteristics mentioned by Boardman [8] and DeLaurentis [9], Auzelle [10] summarized and extracted six characteristics of *SoS*, as shown in Fig. 1.

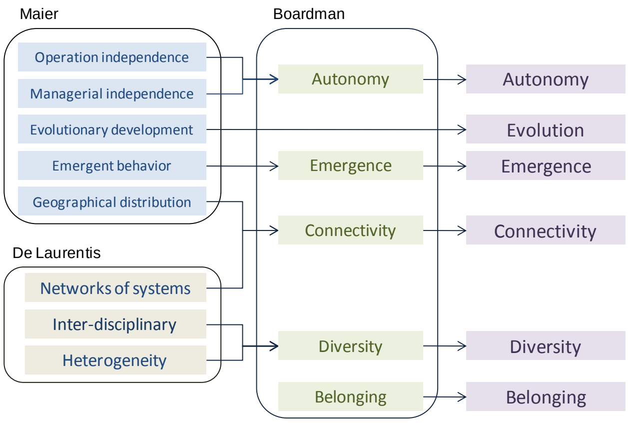

Fig. 1. Characteristics of *SoS*, based on the works of [7][8][9], adapted by [10].

Each characteristic means respectively:

• Autonomy: exercised by constituent systems in order to fulfil the purpose of the *SoS*

• Evolution: The *SoS* adapts to fulfil its (possibly evolving) mission as a whole as the underlying technologies evolve with time

• Emergence: Enhanced by deliberately not being foreseen, though its crucial importance. It creates an emergence capability climate that will support early detection and elimination of bad behaviours.

• Connectivity: Dynamically supplied by constituent systems with every possibility of myriad connections between constituent systems, possibly via a net-centric architecture, or by interoperability processes, to enhance *SoS* capability.

• Diversity: Increased diversity in *SoS* capability achieved by released autonomy, committed belonging, and open connectivity

• Belonging: Constituent systems choose to belong on a cost/benefits basis; also in order to cause greater fulfilment of their own purposes, and because of belief in the *SoS* supra purpose.

These characteristics represent the main distinguishes of fundamental components of a *SoS*. Thus, we could recognize a *SoS* by identifying whether the components are qualified with these characteristics or have capability to achieve these. A *SoS* is a concept at the core of research and development works to study the structure and dynamics of large scale collaboration between enterprise systems. The *SoS* approach does not advocate particular tools, methods, or practices; instead, it promotes a new way of thinking for solving grand challenges through the interactions of technology, business, even enterprises.

2.2 Interoperability of Networked Enterprises

Enterprises architecture could be classified in 5 types: sub-enterprise, single enterprise, multi-sites enterprise, extended enterprise and virtual enterprise. Table 1 shows an analysis of these different enterprise architecture crossed with the previously mentioned six *SoS* characteristics. At the sub-enterprise level and single-enterprise level, systems or applications are naturally belonging to a relatively homogeneous area, and normally systems do not have so much freedom to develop by themselves separately, they are usually bind together to execute a process for an enterprise. Meanwhile, multi-sites enterprises are generally an issue faced by large companies (e.g., Boeing, IBM, General Motors, and EADS), in integrating heterogeneous systems throughout their facilities [11]. A multi-sites enterprise has more autonomy, but its systems remain not fully independent. At a higher level, extended enterprises are loosely coupled and considered as a self-organizing network of firms that combine their economic output to provide products and services offerings to the market. Finally, virtual enterprises are a temporary alliance of enterprises that come together to share skills or core competencies and resources in order to better respond to business opportunities, and whose cooperation is supported by computer networks. So extended and virtual are not limited in one single enterprise, but span from enterprise to enterprise. They form a loosely or temporary network. Enterprises operate independently, share resources, skills, information, to achieve common goal or benefit. Related to these two kind of networked enterprises, autonomy, connectivity, and diversity *SoS* characteristics are obvious, while evolution and emergence characteristics appear as a result of each constituent. Based on the analysis of these *SoS* characteristics, we can conclude that extended and virtual enterprises fall into the paradigm of a SoS-like system, that we can call Systems-of-Networked Enterprises (SoNE).

Table 1. Differentiating *SoS* characteristics for each kind of enterprise architecture**.**

Level of integration	Autonomy	Evolution	Emergence	Connectivity	Diversity	Belonging
Sub-enterprise	none	By itself	Depends on itself	Processed by sub-systems or none	None	nature
Single-enterprise	none	By itself	Depends on itself	Processed by sub-systems	None	nature
Multi-site enterprise	limited	By itself	Depends on itself	Processed by sites	None or exists among sites	nature
Extended enterprise	complete	Result of constituent enterprises	Achieved by constituent enterprises	Processed by constituent enterprises	Exists among constituent enterprises	Can Choose
Virtual enterprise	complete	Result of constituent enterprises	Achieved by constituent enterprises	Processed by constituent enterprises	Exists among constituent enterprises	Can Choose

Our work contributes mainly to the “connectivity” characteristic, falling in the domain of networked enterprises interoperability. The IEEE defines interoperability as: the ability of two or more systems or components to exchange information and to use the information that has been exchanged [12].

Camarinha-Matos L.M et al, provides a high level classification of collaborative network, which use ICT for supporting the development of collaborative business.Supply chain was defined as a category of collaborative networks, and in the example of Supply Network Shannon, currently it have no common ICT infrastructure in place[13]. As it is frequent to find information often scattered within enterprises: say in the applications used to manage technical data (e.g.: Product Data Management systems (PDM)), in the applications that manage business information (e.g.: Enterprise Resource Planning (ERP)) and, finally, in the applications that manage manufacturing information (e.g.: Manufacturing Execution Systems (MES)). Related work [2][13][14][15][16] demonstrated that, while product is the centred value of enterprises processes, its information-based model may act as a common pivotal information system to make all enterprise systems interoperating. It is even more; the Product Ontology proposed by [2] is then a component element of *SoS*, embedded with the technical information related to product life cycle. However, in a networked supply chain, it must also contain information about business processes applied to such product [17].

3 SCOR and Product Ontology in Networked Enterprises

Supply-Chain Operations Reference-model (SCOR) is a process reference model developed and endorsed by the Supply-Chain Council[1] (SCC). The SCOR model provides a unique framework that links business processes, metrics, best practices and technology features into a unified structure to support communication among supply chain partners and to improve the effectiveness of supply chain management and related supply chain improvement activities. Several researches have already been done for decision making based on the SCOR model. Through building an ontology based on the core concept of the SCOR model, and inference rules, a coordination model was developed for supplier selection [19]. Another ontology was built for supply chain simulation modelling using SCOR as a core, which integrated several supply chain views and captured the required distributed knowledge [20].

In a complementary way, Tursi et al. [2] have worked on the product-centric information system interoperability in networked manufacturing enterprises, and proposed a Product Ontology, the ONTO-PDM, for Product Data Management and interoperability. This integrated and common model formalizes the knowledge related to product data management at the business and the manufacturing levels of enterprises (B2M, Business to Manufacturing), in order to achieve the interoperability between systems. Fig. 2 shows an extract of the ONTO-PDM ontology concepts [2]. It adopts two standards: the IEC 62264 [21] and the ISO 10303 STEP-PDM [22], and it concentrates technical data span during the whole product lifecycle, from its development to its manufacturing.

[1] http://www.supply-chain.org

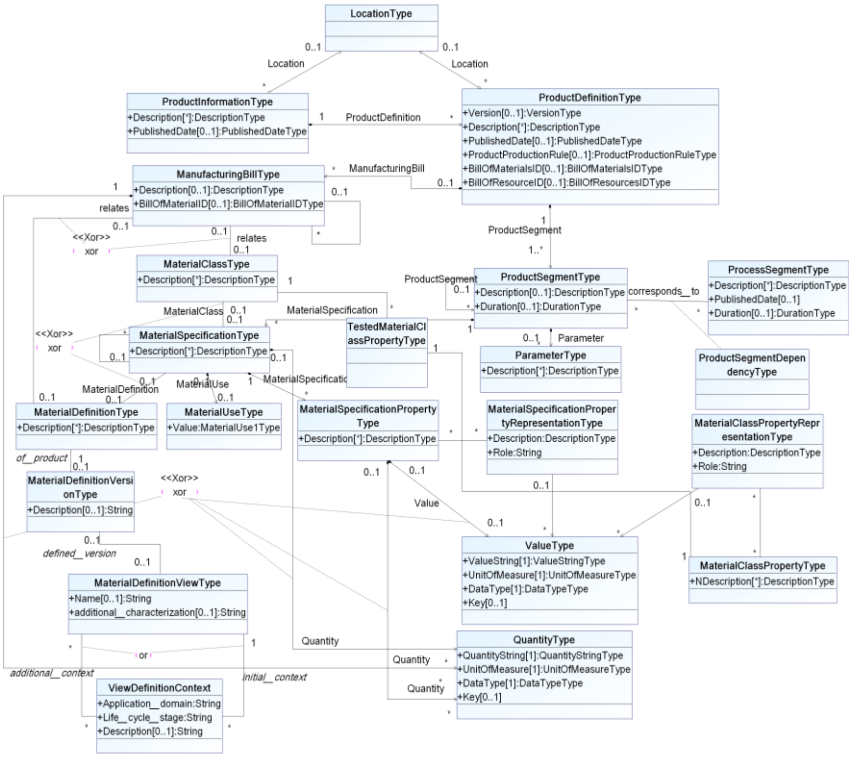

Fig. 2. An extract of the ONTO-PDM Product Ontology [2].

4 Towards a Product-Centric Supply Chain Ontology

4.1 Instanciation of SCOR Process from ONTO-PDM

In the context of networked enterprises, and mainly in supply chain environment, product data emphasize more about inter-enterprise relationships, which are not concerning only products but also processes related to customers, market and so on. Its focus is moving from integrated intra-enterprise application packages to internet-based and inter-enterprise application software. Improving Supply Chain Management (SCM) and Customer Relationships Management (CRM) are key processes to enable enterprise value chain [23]. Thus in order to reach maximum comprehension between enterprises, more knowledge is needed other than product data. As mentioned above, ONTP-PDM consists of the IEC 62246 and the ISO 10303 STEP-PDM. Meanwhile, IEC 62246 can be used to integrate business system such as ERP, supply chain management, with manufacturing system. The process segment schema of IEC 62246 is defined to present the process segment definitions that may be exchanged between business systems and manufacturing operations systems. Thus, ONTP-PDM has the promising capability to describe the information concerning supply chain processes. Then we try to formulise a detailed SCOR process by describing it as an instance of process segment model of ONTO-PDM. Fig.3 shows a detailed process element of SCOR level 2, M1 (Make-to-Stock). It describes the process of manufacturing in a make-to-stock environment which adds value to products through mixing, separating, forming, machining, and chemical processes. Make to stock products are intended to be shipped from finished goods or "off the shelf," are completed prior to receipt of a customer order, and are generally produced in accordance with a sales forecast. Each process of M1 is seemed as an instance of *ProcessSegmentType* of ONTO-PDM. And *ProcessSegmentDependencyType* is used to differentiate the sequence of the whole process, as showing in Fig.4. Besides, the inputs and outputs of each process are also presented by a most approximate instance of ONTO-PDM models, such as, *Equipment Plan* is presented by *EquipmentSegmentSpecificationType* as an input of M1.1, and *Product Schedule* is presented by *ProductionScheduleType* as an output of M1.1. However, there are still some inputs and outputs information could not be presented by models of ONTO-PDM appropriately. For example, the inputs of M1.2 *WIP Handling Rules*, *WIP Location Rule*, and also the outputs *Replenishment Signal*, *Sourced Product Location Information*. Therefore, although ONTO-PDM is a promising candidate for enabling interoperability of supply chain environment, a more specific ontology is needed to fully support information expression.

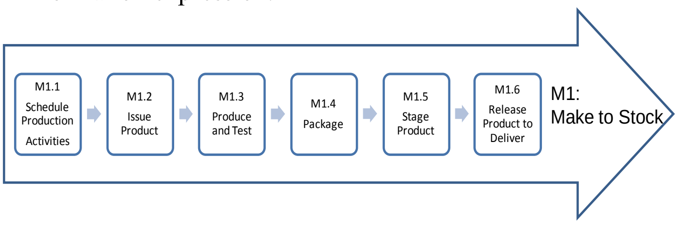

Fig. 3. A detailed process element of SCOR level 2 M1 (Make-to-Stock).

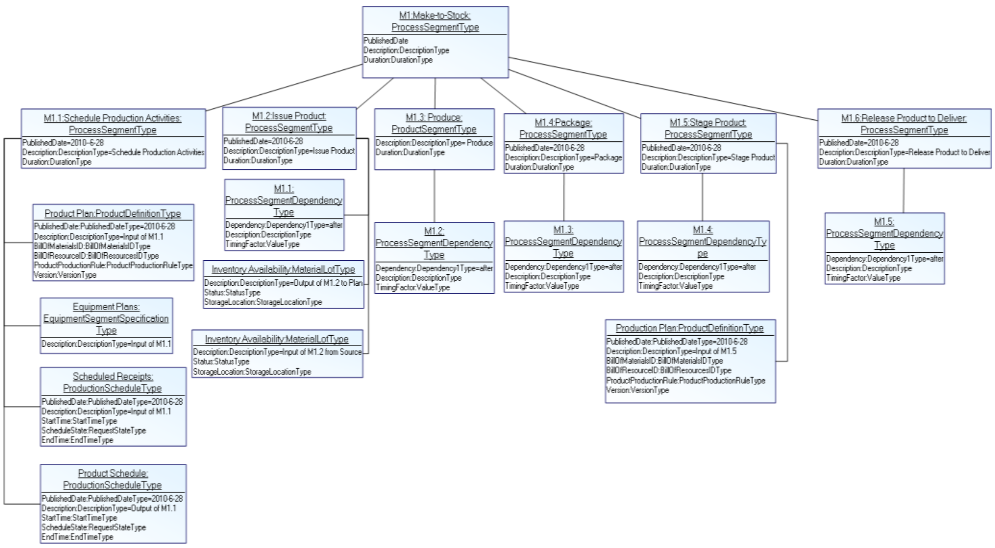

Fig. 4. An instance of SCOR process M1 (Make-to-Stock) based on ONTO-PDM.

4.2 Architecture of Supply Chain Ontology

Then, focusing on information flows in supply chain, we are proposing a supply chain ontology architecture for networked enterprises interoperability, in which the knowledge concerns not only the whole product life cycle, but also products sales, marketing, purchasing and dismissing, related to customers activities, marketing processes, human and organization structure, as summarized in Fig. 5.

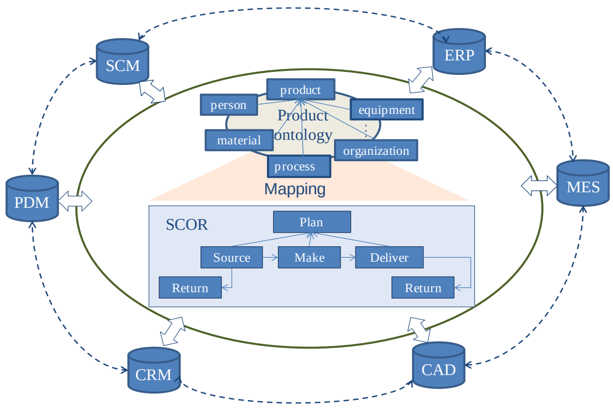

Fig. 5. Architecture of Supply Chain ontology for networked enterprises interoperability.

As it shows in Fig.5, the Supply Chain ontology extends the ONTO-PDM, considered as an upper ontology, and links it with SCOR ontology. The ONTO-PDM defines entities related to product engineering and manufacturing, for example product, equipment, material, person, process and so on. And it also has the definitions about process, which could be used for expressing information linked business systems with manufacturing systems. From a supply chain process perspective, products can also be considered as main objects with all the corresponding properties related to ordering, producing, delivering, and returning. So is the other objects related to product. Therefore, ONTO-PDM could act as an upper ontology to support specific supply chain expression in the architecture. As a complement, we are defining a SCOR ontology [24] [25] with more specific expression about supply chain processes. The SCOR ontology defines not only interacted activities between suppliers, customers and market, but also metrics used to better formalize supply chain process with close relation to SCM. It could be considered as a specific domain ontology in our architecture. The ONTO-PDM and SCOR ontology is linked through concept mapping. We compared the entities of ONTO-PDM with the inputs and outputs concept, and processes concepts of SCOR, then Table 2 illustrates the concept mapping segment between them with semantic relationships such as inclusion ($\subset$, $\supset$) or equivalence ($\equiv$).

Table 2. Fragment of mapping relations between ONTO-PDM and SCOR.

Entity of ONTO-PDM	Relationship	Concept of SCOR
EquipmenType	$\supset$	equipment
PersonType	$\supset$	customer
MaintenanceInformationType	$\subset$	maintenance
ProductInformationType	$\supset$	product
ProductionCapabilityType	$\equiv$	production-capability
ProductionPerformanceType	$\subset$	performance-plan
ProductionScheduleType	$\subset$	production-schedule

5 Conclusions

The main objective of this paper is to present a proposed research methodology to develop a Supply Chain Ontology for networked enterprises interoperability. We are only at the starting point of this work but our previous development of the ONTO-PDM ontology allows us to be effective in the next step to define a product-centric supply chain ontology by taking the ONTO-PDM one as upper ontology, and defining a more specific domain ontology--SCOR ontology, with core concepts coming from the SCOR model. Ontology is adopted to unify the metadata model to express knowledge resources which are diverse in types and disunite in forms. The current step of our research work concerns the formalization of ontological patterns for expressing semantics mapping between product concepts and enterprise processes inputs and outputs in order to facilitate the interoperation of enterprise software application in a supply chain context. A prototype, taking advantage of Web 2.0 techniques, will be developed to demonstrate the usability of such common ontology in a semi-industrial perspective.

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