Towards an approach for formalizing the supply chain operations

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ABSTRACT
Reference models play an important role in the knowledge management of the various complex collaboration domains (such as Supply Chain Networks). However, they often show a lack of semantic precision and, they are sometimes incomplete. In this paper, we present an approach to overcome semantic inconsistencies and incompleteness of the Supply Chain Operations Reference (SCOR) model and hence, improve its usefulness and expand the application domain. First, we describe a literal OWL specification of SCOR concepts (and related tools), built with intention to preserve the original approach in the classification of process reference model entities and hence, to enable effectiveness of usage in original contexts. Next, we demonstrate the system for its exploitation, in specific - tools for SCOR framework browsing and rapid supply chain process configuration. Then, we describe the SCOR-FULL ontology and its intended use. Finally, we elaborate the potential impact of the presented approach, to interoperability of systems in Supply Chain Networks.

Categories and Subject Descriptors
I.2.4 [**Artificial Intelligence**]: Knowledge Representation Formalisms and Methods - *Representations*

General Terms
Management

Keywords
Supply Chain Networks, Ontology, Supply Chain Operations Reference (SCOR), Semantic Interoperability.

1. INTRODUCTION
In order to gain real benefits from Supply Chain Management, relevant systems must span full horizontal organization of enterprises and beyond – its customers and suppliers. For dealing with the complexity of such environment, reference models played an important role. Supply Chain Operations Reference (SCOR) [1] is a standard approach for analysis, design and implementation of five core processes in supply chains: plan, source, make, deliver and return. SCOR defines a framework, which aims at integrating business processes, metrics, best practices and technologies with the objective to improve collaboration between partners. In this paper, we present an approach to overcome semantic inconsistencies and incompleteness of the SCOR model, by using ontologies and thus, enabling effective knowledge management in Supply Chain Network, facilitating semantic interoperability of its participants and contributing to a further improvement of the reference model.

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Semantics analysis can be useful at different levels of Supply Chain Networks. First, the semantic representation of queries and information may improve the relevance of the results and thus, improve the quality of partners' selection process. It can be used in place or in addition to usual request representation. Second, semantics can be used to represent participants, or groups of them, leading participants to better know each other. Such information can be useful for routing the requests to other participants in order to obtain the relevant answers within a short time and with a low traffic load. Third, this information can also be used to organize the network so as to improve efficiency. This is very important for the open settings of the supply chain networks, where the traditional approaches to business process management, which attempt to capture processes as monolithic flows, have proven as inadequate, resulting with moving research focus from process to interaction modelling [2]. All these research directions have received partial answers but more work is needed on the interaction between all these elements and their impact on the efficiency of the global system. The use of domain ontology is already proven as beneficial for supply chain management (SCM), in the development of self-integrating SCM systems [3], or facilitating collaboration of inter-enterprise design teams [4], simulation of Supply Chain Network [5], or online negotiations [6], etc. There are, also influential efforts to provide the exhaustive ontology-based semantic models for SCM [7], organized in a modular way to support the reusability and maintainability of the involved micro-theories. However, it is still very hard to integrate all these efforts in a single formal theory which would enable a multiplication of achieved impacts. Ontologies are formal models of collective knowledge. The consensus on their structure is extremely hard to reach [8], particularly for a very expressive (or richly axiomatized) ontology with large number of concepts.

The development of reference models in different domains is a community response to interoperability problems. They aim at the standardization of domain collaboration by providing categorization schemes or taxonomies – knowledge structures, interpreted in organized way – to be used as guidelines in the collaboration of humans and systems. Like most of the other reference models, SCOR is a form of knowledge organization system. The key feature of these systems is subjectivity, or context-dependent determination [9]. Hence, SCOR lacks semantic precision. SCOR's Input/Output entity entails all resources exchanged between process elements and actors - physical or non-physical, states, events, documents, etc. System entity includes information systems, modules, capabilities, approaches or volume of use, integration levels, etc. Sometimes, reference models do not provide enough expressivity for a complete formal model. In case of SCOR, this is evident from the lack of relationship between metrics and systems, which could point out to the source of information needed for performance measurement. A high level of expressivity provides the most beneficial environment for automated support, but it should not be the ultimate objective. Namely, domain knowledge evolves at highest rate at lower levels of abstraction, in community interaction, where consensus is more likely to be reached. Thus, we consider the balance between creation, evolution and use of specific, highly contextualized knowledge and development of formal expressive models as a very important factor for the usefulness of domain ontology.

Main research problem we are addressing in this paper is SCOR's lack of semantic precision. We also argue that securing the integrity of existing standard by using multiple levels of models' expressivity is crucial. Hence, we propose the use of semantically aligned models of SCOR reference (SCOR-KOS OWL), application ontology (in this paper, we use SCOR-CFG OWL for process configuration) and proposed micro theory for supply chain operations (SCOR-FULL), which semantically enriches the SCOR reference model. Finally, we elaborate the benefits of this approach for semantic interoperability of the relevant systems in supply chain networks.

2. SCOR KNOWLEDGE ORGANIZATION SYSTEM (KOS) OWL MODEL

For building the fully expressive SCM semantics, we start from the obvious point of community consensus – reference models, in specific - SCOR. Because of the SCOR's weak semantics, in the first step, we model it as a knowledge organization system, but we use semantic tools in doing so – OWL language. Figure 1 shows entities of SCOR-KOS OWL model and relationships between them.

Competency of a SCOR-KOS OWL model is validated by using following questions: which process elements constitute one SCOR process and in which order? What are the input and output resources for the selected process element? What are the metrics and best practices for the selected process element? Which systems can facilitate the improvement of the selected process element and/or process category?

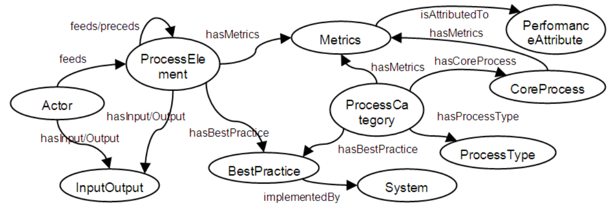

Figure 1. Entities of SCOR-KOS OWL model

The actual order of process elements is determined by executing SPARQL queries against asserted "precedes" (meaning direct precedence) triples. The definition of concurrency in a SCOR-KOS OWL model is used only for the determination of flows branching and hence, it is not semantically correct. Concurrency is inferred on basis of "isConcurrentWith" relation and modeled by property chain axioms, on basis of asserted "precedes" and inferred (inverse) "succeeds" property:

precedes o succeeds => isConcurrentWith, or by using RDQL query: ∃precedes.(≥2 succeeds)

Flows of input and output resources are determined by SPARQL queries, which return instances of "SCOR_InputOutput" concept from domain of asserted triples of "hasInput" and "hasOutput" properties. The source of these properties is determined from the domain of "fedBy" property, which is used to assert connections between process elements from different process categories. Inference of systems which can facilitate improvement of selected process elements (categories) is achieved by implementing properties:

implements(SCOR_System,SCOR_BestPractice), and:

facilitates (SCOR_BestPractice,SCOR_ProcessElement),

as inverse to "implementedBy" and "hasBestPractice", used for the assertion of relationships between process elements, best practices and systems. The properties above are defined as sub-properties of transitive property "enable", hence, enabling reasoning of relationships between "SCOR_System" and "SCOR_ProcessElement". By defining inverse property "enabledBy", the inference on relationships between systems and process elements (categories) becomes possible in the opposite direction. Thus, it is possible to identify systems which can improve the performance of a selected process element and/or category.

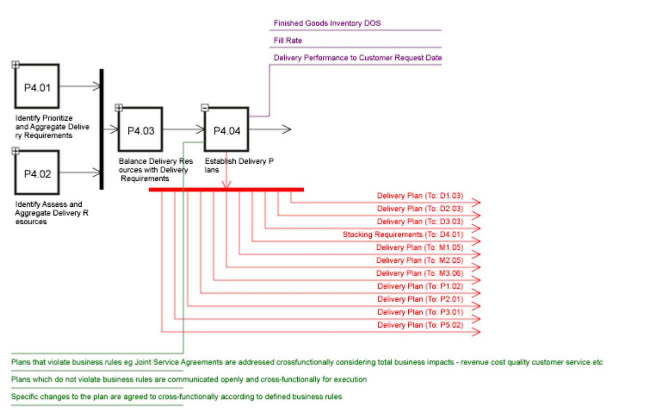

Figure 2. „P4. Plan Deliver" process category

SCOR-KOS OWL is used for the development of the web application for browsing and visualization of the SCOR framework. Main features of the web application are: display of the selected process category map, display of the input/output resources (including sources/destinations), best practices and metrics for selected process element and customization of the display. Figure 2 shows the web application’s work area, with displayed output resources, best practices and metrics for „P4.04. Establish delivery plans“ process element of „P4. Plan Deliver“ process category.

One possible practical use of the SCOR-KOS OWL model is demonstrated in the development of web application for supply chain process configuration, namely, the inference and presentation of a SCOR thread diagram - configuration of source, make and deliver processes, on basis of asserted product topology, participants and production strategies for each component. Product configuration is asserted to an application ontology: SCOR-CFG OWL model, consisting of following concepts: SC_project, SC_product, SC_production_type, SC_process (with child concepts, corresponding to different process types) and SC_participant. The generation of a SCOR thread diagram is done by selecting (and rendering) participants of supply chain project, its products (components) and, finally, processes, in exact order.

The approach in supply chain process configuration is demonstrated on a simplified case of snow making facility product engineering, which involves purchase of fan guns (from stock), hydraulic equipment (by order) and sourcing engineering and production of a pump house. Figure 3 shows the basic interface for the definition of snow making facility product topology and generated SCOR thread diagram.

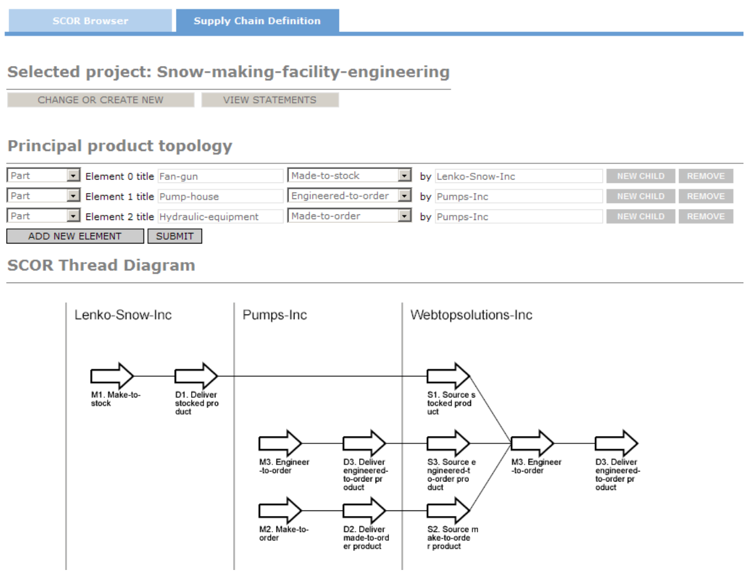

Figure 3. Web interface for definition of a product topology and generated SCOR thread diagram

Main features of the web application are: development of complex thread diagrams, generation of process models and workflows and generation of implementation roadmap.

First, the above example shows only interactions and collaborations between customer and its first-tier suppliers. The number of visualized levels depends on the submitted product topology: if the detailed product topology is entered, the full supply chain would be represented, with the number of tiers corresponding to the depth of a product topology. Also, the horizontal organization of individual supply chain actors can be represented in more detail, by inferring additional participants for different manufacturing strategies: warehouses (D, S), plants (M) and headquarters (P).

Second, a SCOR thread diagram is not a process map. In fact, it is just a representation of a supply chain configuration. The full process model can be generated by adding new rules for configuration of the SCOR PLAN activities and by exploiting alignment relations between the SCOR-KOS and SCOR-CFG OWL models.

Third, alignment relations between the SCOR-KOS and SCOR-CFG OWL models also provide opportunities for the generation of a detailed implementation roadmap, consisting of proposed best practices, relevant systems (or their modules, capabilities, intended use, etc.) for their execution, resource tracking (SCOR Inputs and Outputs) and environment for measuring the performance of a supply chain, by using the SCOR metrics.

3. SCOR-FULL ONTOLOGY

SCOR-FULL is a domain ontology – a micro theory for representation and management of knowledge of the supply chain operations. It is developed by resolving semantic inconsistencies of a SCOR reference model, namely, by formalizing SCOR Input/Output element.

Main concepts of the SCOR-FULL ontology are: agent, course, inf-object, function, quality and setting. Agent is the concept which describes an executive role and entails all entities which interact within the supply network: equipment, customer, organization, facility and information-system. Course classifies prescriptions of ordered sets of tasks: activity, process, method, procedure, policy, strategy or plan. Function concept entails elements of the horizontal business organization, such as stocking, shipping, control, sales, replenishment, return, etc. Quality is the general entity which can be perceived or measured, eg. capability, capacity, availability, or time/location data. Setting concept provides the description of environment of a course, by defining rules, metrics, requirements, constraints, objectives, goals or assumptions of a prescribed set of actions. Finally, inf-object is a general term which encloses communicable (comm-item, e.g. notification, response, request) and configured (conf-item, with defined state) information items (inf-item), such as order, forecast, report, budget, etc., and physical items (phy-item). Figure 4 shows the main concepts of SCOR-FULL ontology and relationships between them.

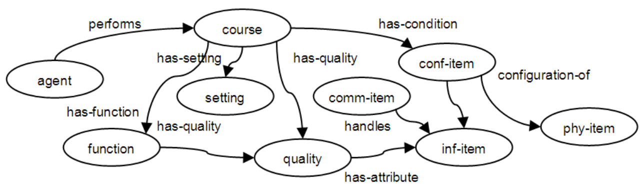

Figure 4. Main concepts of SCOR-FULL ontology and relationships between them

Currently, SCOR-FULL ontology has 207 concepts and 18 properties and is semantically mapped to the SCOR Input/Output elements. In order to increase the flexibility of semantics framework, SWRL (Semantic Web Rule Language) rules are used for mapping the SCOR-FULL concepts to SCOR-KOS OWL instances. For example, all instances of the business-rule class from SCOR-FULL ontology are the same as SCOR Input/Output concept "Business_Rules_For_Return_Processes", if there exist a return process in SCOR-FULL ontology which has a business rule from above, as a setting:

business-rule(?x) $\wedge$ return-process(?y) $\wedge$ has-setting(?y, ?x) $\Rightarrow$ SameAs(?x, Business_Rules_For_Return_Processes)

Semantic mappings between SCOR-FULL and SCOR-KOS OWL enable characterization of supply chain operations managed by using SCOR-FULL ontology, in context of SCOR reference model. For example, based on the above SWRL implication, it can be inferred that a business rule, which is asserted in SCOR-FULL ontology as a setting for an instance of the return process, is an output of the SCOR process element ER.01 Manage Business Rules for Return Processes. In the opposite direction, relevant inferences of SCOR-KOS OWL model can result with a formal semantics of the selected SCOR element. This is useful when SCOR-KOS is integrated with the tools, such as ARIS EasySCOR by IDS or e-SCOR by Gensym, used for the benefit of implementation process.

SCOR-FULL ontology is expected to support knowledge management in supply chain operations. It classifies concepts and relevant data objects, to be used in collaborative systems, such as Semantic information pool for manufacturing supply networks (SIP4SUP) [10], currently in development. It enables lookup of data objects, required for consistent and complete definition of supply chain operations concepts. It provides a roadmap for implementation of SCOR reference model. Last, and most important, SCOR-FULL ontology is expected to facilitate the semantic interoperability of systems, relevant for Supply Chain Networks management.

4. ONTOLOGIES AND SEMANTICS ISSUES IN SUPPLY CHAIN NETWORKS INTEROPERABILITY

Supply Chain Networks may be considered, to a certain extent, as systems-of-networked systems. The System-of-Systems (SoS) paradigm is widely recognized and has become quite studied since a decade [11], as it has potentially practical applicability in systems engineering. SoS-organized systems, such as Supply Chain Networks, could make efficient use of resources from a variety of domains. One of the main characteristics of SoS is what authors are calling the "connectivity" property [12]. "Connectivity" refers to interoperability of the many suppliers taking part in Supply Chain Network.

Interoperability is typically defined as the ability of two or more systems or components to exchange and use information [13]. Integration is generally considered to go beyond mere interoperability to involve some degree of functional dependence [14]. Integration is desirable within the horizontal organization of the single enterprise or, in some cases, between focal partner and first-tier (strategic) suppliers (for example, with third-party logistics partners). However, in lower levels of supply chain, the tight couplings can produce unacceptable outcomes, mostly related to decrease of flexibility. The main prerequisite for achievement of interoperability of the loosely coupled systems is to maximize the amount of semantics which can be utilized and make it increasingly explicit [15], and consequently, to make the systems semantically interoperable.

While database interoperability has been widely studied by the research community, it takes into account technological concerns. Interoperability in supply chain is mainly related to semantics issues. Many researches are trying to demonstrate that semantic interoperability can be enabled through setting up an Ontology. The use of ontology is required as it acts as a conceptual model representing enterprise consensus semantics [16]. It aims at reducing the semantics loss among heterogeneous information systems that are sharing mostly common concepts from the same area of knowledge. Furthermore, ontology provides a common understanding and a formal model of the basic entities, properties and relationships for a given domain that are essential to overcome semantic heterogeneity. Semantic interoperability ensures that the meaning of the information that is exchanged is automatically interpreted by the receiver of a message. In centralized systems, this property improves the relevance of query answers. In distributed heterogeneous systems, it is compulsory to enable autonomous heterogeneous sources understand each other to obtain relevant results [17].

Many works rely on the assumption that a single ontology is shared by all the participants of the system. However, in systems-of-systems with autonomous sub-systems, this assumption is not realistic anymore. On the contrary, one has to consider that the participants create their ontologies independently of each other. Thus, most often the ontologies differ. Still, the distinctness of ontologies does not prejudice logical inconsistency of their terms, especially if they focus on different contexts of the same concepts. Namely, ontology is not a tool for checking correctness of reality, but for its subjective or objective representation. To tackle this problem, research on ontology matching proposes several techniques to define correspondences between entities of two ontologies. So, in some way, ontology matching highlights the shared parts of two ontologies. Thus it provides the basis for interoperability between heterogeneous systems and by "transitivity" in the whole system [18]. Typically, correspondences between two interacting ontologies are expressed by logical equivalences, subsumption or sameness relations, assertions of constraints, based on the object properties or identification of rules, with the form of logical implication between the antecedent and consequent statements.

Also, meanings from ontologies, developed in isolation, can be reconstructed or re-created by using contextualization or logical theories, such as ontology of descriptions and situations (DnS) [19], which enable the first-order manipulation of micro-theories and models, independently from an upper ontology.

5. CONCLUSIONS

The proposed approach relies on and builds upon widely accepted industry practice, represented in its native format (SCOR-KOS OWL). The native representation is expected to attract attention and gain understanding of SCM experts' community and, hence, to facilitate the transition towards using more sophisticated, knowledge-based tools in the domain. Its mapping and alignment with higher-level ontologies (such as SCOR-FULL, DOLCE, and others) will enable a structured support in other SCM processes, such as partners' selection, performance tracking, exceptions handling, etc. Also, it is expected to contribute to further development and/or refinement of the SCOR reference model.

Although ontology matching, contextualization and other semantic web techniques provide a basis for interoperability, the challenge is still to define a whole semantic infrastructure in which participants' search for information is both relevant and efficient. In response to this challenge, this approach proposes the use of sets of semantically aligned models, on different levels of expressivity, consisting of knowledge organization system (SCOR-KOS), helper contextual models (SCOR-CFG) and domain ontology (SCOR-FULL) and, thus, potentially improving the relevance of ontology matching and facilitating contextualization.

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