Towards a Reference Ontology for Supply Chain Management

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Abstract

This paper summarizes the results from recent activities of the IOF Supply Chain Working Group (SC WG). The objectives of the IOF SC WG are to identify requirements, notions, and terms from the supply chain domain, develop a domain-specific reference ontology (DSRO), and validate the developed ontology by widening the scope to multiple use cases across the domain. The development of the current reference ontology was motivated by exploring two use cases related to supplier discovery and supply chain traceability. A draft of the OWL ontology is available for download through the provided GitHub link. This paper is not intended to provide a detailed discussion on linguistic and axiomatic analysis of the ontological entities. Rather, the intention is to provide an overview of the objectives, accomplishment, and challenges of this working group and highlight the key discussion points for the IOF workshop of I-ESA 2020

Keywords: Industrial ontologies, interoperability, supply chain

1. Introduction

As the need for supply chains, or networks, to become connected, agile, and dynamic continues, data and information integration among various supply chain participants becomes more pronounced [KIM 18]. To date, information integration is still costly, time-consuming and fragile due to the lack of *interoperability* (where we define interoperability as the ability of two or more heterogeneous, yet relevant, systems to communicate, correctly interpret, and act on information meaningfully and accurately with minimal effort [CHP 12]). The problem can be attributed to differences in the underlying semantic models and business rules implemented by different supply chain management software systems. Multiple ontologies have been proposed by researchers to resolve these differences and enable supply chain interoperability. However, the existing supply chain ontologies have failed to properly address the interoperability problem for several reasons such as weak methodological approaches, restricted and static views of supply chains, missing accounts of material traceability and service, and the dominance of taxonomies over formalized definitions [GRU 10]. To fill this gap, there is a need for a systematic ontology development methodology supported by a proper ontology architecture that includes a top-level ontology, and multiple Domain-Specific Reference Ontologies (DSRO). A DSRO can serve as shared ontology that can unify various application ontologies semantically. A proper, shared ontology architecture ensures that lower-level and application-specific ontologies are derived in a manner such that they can be used together. Such an architecture is still an open issue that will also be discussed at the IOF workshop. More details on how DSROs fill the interoperability gap can be found in [KUL 20].

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The objectives of the IOF SC WG are to identify the requirements of a reference ontology (RO) for supply chains, develop the corresponding DSRO and other lower-level ontologies as specified by the IOF architecture [KUL 20], and validate them through multiple use cases. This paper focuses on the Supply Chain Reference Ontology (SCRO).

2. Use Cases

The development of SCRO was motivated by two industrial use cases related to supplier discovery and supply chain traceability. The ontology is intended to support the identified use cases in different ways including standardization, semantic mediation, data integration, and automated inference and reasoning. Through analyzing these use cases, two of the most important requirements for an SCRO were 1) representations of flow of materials and information and 2) characterization of organizations involved in a supply network.

2.1. Use Case Descriptions

Supplier Discovery: Supplier discovery is often a manual, slow, and inefficient process of search and requirements matching. As the interaction between suppliers and customers becomes increasingly digital, and the lifespan of SCs becomes shorter, more efficient, and intelligent; approaches to supplier search and evaluation are needed. One of the root causes of inefficiency in the process is that manufacturing companies often publish and share their capabilities using informal and unstructured representation methods. Therefore, the process is difficult to automate.

Traceability Use Case: The traceability of food products to their sources is critical for quick responses to incidents where food contamination threatens public health. Food Safety Modernization Act, a US law, now requires stakeholders in the agri-food supply chain to track food materials they acquire and sell to support timely investigation of the sources of contamination and identification of affected product. However, this has proven difficult. The causes of difficulties include diversity of stakeholders and their lexicons, systems, standards, and methods; an unwillingness to expose information of internal operations; a lack of a common understanding of the steps in a supply chain and the information needed to be collected for them; and incompleteness of data. Ontologies can be created that formally define standard Critical Tracking Event (CTE) types and associated Key Data Elements (KDE). Ontologies can also support traceability data exploration and "what if" queries to discover important relationships and fill in missing information during a traceback and trace forward effort related to a food incident.

The top terms related to the discussed use cases are listed in Table 1. Formal and subject-matter-expert definitions for a selected subset of the top terms are provided in the next section.

Table 1. IOF Supply Chain WG top-20 terms

[1] Supply Chain	[8] Production Capacity	[15] Supplier Evaluation
[2] Supplier	[9] Supplier Capability	[16] Supplier History
[3] Customer	[10] Transportation Equipment	[17] Manufacturing Service
[4] Sourcing	[11] Traceable Resource Unit-TRU	[18] Container Location
[5] Facility	[12] Tracking Event	[19] OEM
[6] Inventory	[13] Logistic Unit	[20] First-tier Supplier
[7] /Lot/Load	[14] Container/ Package/ Cargo	[21] Delivery Lead Time

2.2. Competency Questions

Competency Questions (CQ) are used to validate the ontological content against the use case requirements which is a common practice in ontology development efforts [USC 96]. Examples of competency questions related to the two use cases are provided below:

Supplier Discovery Competency Questions:

1. Which factories can machine complex geometries?
2. What is the precision machining capability of this group of companies?
3. What is the minimum wall thickness that can be machined in this factory?
4. What are the capabilities of this organization with respect to fixture design?
5. How is the performance history of this vendor with respect to on-time delivery?

Traceability Competency Questions:

1. What types of CTEs take place in the Asheville malting facility and what data is required for each?
2. Does plant 50 have all the data required for all Transfer Events that took place between 0200-1300 local time on 6 June 2018?
3. In which bins at this site was grain stored for the outbound shipment with ID 18MZ1532?
4. What Containers in the history of TRU 5384 had grain containing gluten stored in them within two weeks prior to the material in 5384 or its inputs?

3. OWL Ontology

An OWL ontology (SCRO.OWL) has been created as a pilot ontology that is based on BFO, and which uses some of the IOF Core terms [SMT 19]. The SCRO also uses classes mireotted from mid-level ontologies such as Common Core Ontology (CCO) [CCO 20]. The OWL source file is available for download through the provided link[1]. SCRO is currently being developed and extended as a single OWL file but it is likely to be partitioned into multiple modules following the modular design approach recommended by IOF technical principles. The SC Reference Ontology is intended to provide the basic ontological constructs needed to represent both the structure (supply chain members and their roles, functions, and relations) and the operation (processes and flow of material and information) of industrial supply chains. There are two central notions in SCRO: 1) Group of Suppliers and 2) Supply Chain System. A *Group of Suppliers* is a group of agents (person or organization) who play causal roles in manufacturing products or providing services in the context of a specific supply chain. A Supply Chain System, on the other hand, is an *Engineered System* comprising all agents, equipment, facilities, software systems, and other systems and resources, governed by a set of rules, designed and deployed with the function of delivering a product or a service to some customer. Accordingly, Group of Suppliers is part of a Supply Chain System. In the domain of supply chain management, the term ‘supply chain’ is the generic term often used to refer to both the group of organizations (that participate in a supply chain) and the supply chain system. To avoid confusion, unambiguous labels are selected for these two closely related notions. Figure 1 shows the class diagram for some of the core classes and relationships in the SCRO.

[1] https://github.com/InfoneerTXST/SupplyChainOntology

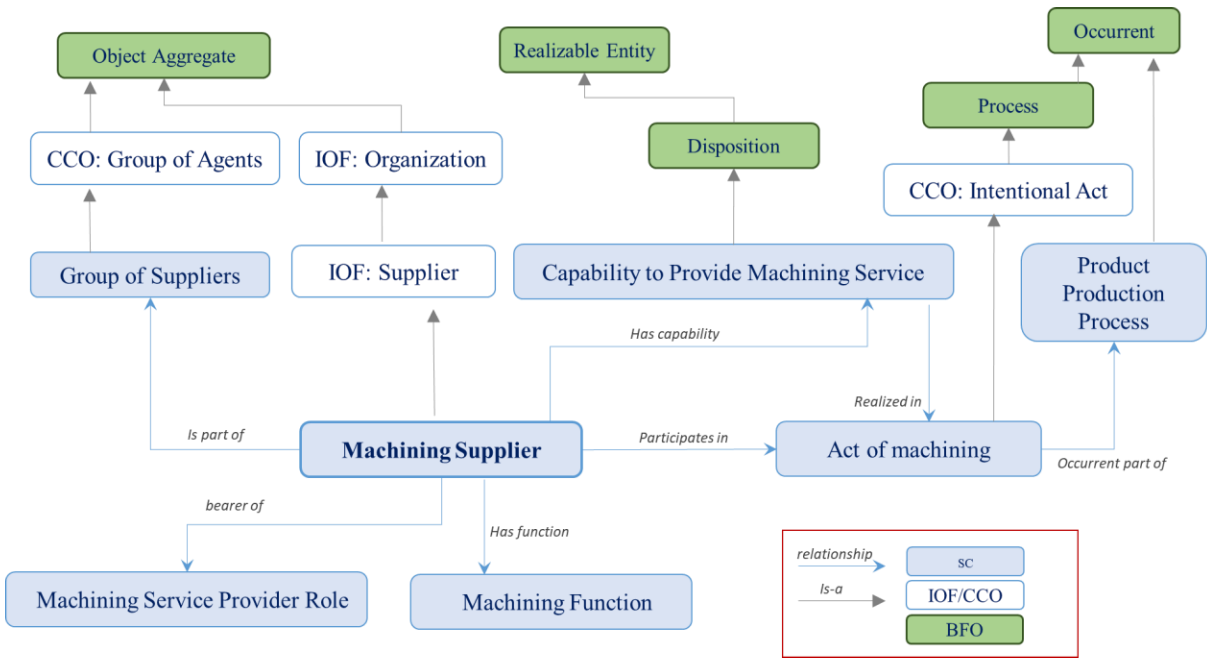

Figure 1. The class diagram for some of the core classes of the supply chain reference ontology

The classes and properties that are included in the SCRO's early draft are mainly geared towards describing the agents that participate in the supply chain and their roles, functions, and capabilities. There are two main types of Supply Chain Role included in SCRO, namely, Product Supplier Role and Service Provider Role. Manufacture Role, Wholesaler Role, and Distributor Role are example sub-classes of Product Supplier Role. Test Service Provider Role and Transportation Service Provider Role are examples of supply chain service provider role. Those roles can be inhered in various supply chain agents regardless of their nature of business.

SCRO is also intended to provide the ontological constructs for formal modeling and representation of organizational capabilities since they are crucial in supply chain design and planning phase. There are two possible approaches for capability representation in SCRO. The first approach (Approach A in Figure 2) is to use Modal Relations Ontology (MRO) to represent the processes and services a potential supplier can provide in future. The second approach (approach B) is to directly assert the capability instances for a given supplier. Those instances of capability can be realized in future processes that the supplier will participate in them once selected as a member of some supply chain.

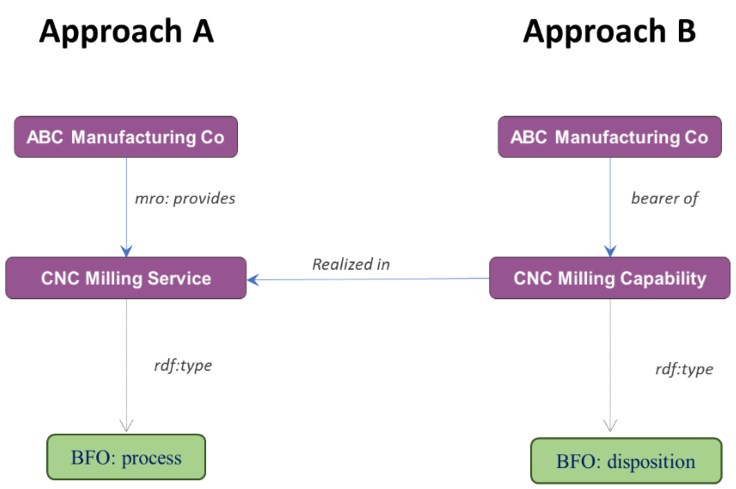

Figure 2. Two approaches for representing the capabilities of a manufacturing company

The current draft ontology is not fully axiomatized yet since the initial focus was on providing accurate natural language (NL) definitions. Table 2 provides the Natural Language (NL) and Semi-formal NL definitions for some core notions of the ontology. Semi-Formal NL is a human friendly version of the FOL axiom. The FOL axioms for some of the more stable classes are provided in Table 2 as well.

Table 2. Definitions and axioms for a selected subset of terms

Supplier	**NL Def.**	An organization or person who sells products or services.
	Semi-Formal	An Agent who bears a Supplier Role.
	FOL Axiom	*Instance-of(x, supplier,t) ≡ instance-of(x,agent,t)&∃y(supplier-role(y) & has-role(x,y,t)).*
Supplier Role	**NL Def.**	“role” classes are not user-facing. Therefore, no SME definition is provided for them.
	Semi-Formal	A Role inhering in an Agent that, if realized, is realized in some act of selling.
	FOL Axiom	*supplier-role(x) ≡ ∃y(agent(y) & has-role(y, x) &∀p(process(p) & realizes(y, p)) → act-of-selling(p))*
Group of Suppliers	**NL Def.**	Supply chain is a set of companies and other organizations involved in trading and other business relationships with one another
	Semi-Formal	A Group of Agents who are parts of some Supply Chain System and play causal role (are agent) in some Product Production Process that outputs some Product or in some Service Provisioning Process that outputs some Service.
	FOL Axiom	*instance-of (x, supply-chain, t) ≡ instance-of(x,group-of-agents,t)&∀y(member-of(y,x)& ∀process(p) &participate-in(y,p)) &occurrent-part-of(p,scp) & instance-of(scp, supply-chain-product-production-process)or instance-of(scp, supply-chain-service-provisioning-process)*
Mfg. Service	**NL Def.**	A valuable action performed to satisfy a need or to fulfill a demand related to manufacturing a product.
	Semi-Formal	A Planned Process in which a supplier performs a manufacturing process for a customer and in which service provisioning and consumption occur within the same temporal region.
	FOL Axiom	*Instance-of (x, manufacturing service, t)→ Instance-of (x, planned process, t)*
Mfg. Capability	**NL Def.**	The ability of a resource (such as a human agent, an organization, or an equipment) to achieve some desired manufacturing outcome usually through employing some additional resources
	Semi-Formal	A disposition whose realizations brings benefits to an agent or group of agents and can be graded on a scale from zero to positive.
Sourcing	**NL Def.**	The process of identifying a company that provides a needed good or service.
	Semi-Formal	A planned process with the specified output of an identified supplier who can provide a service or a product.

4. Conclusion and Next Steps

This paper reports the work in progress by the IOF towards creating a reference ontology for the supply chain domain. The focus of the Supply Chain WG in the first phase has primarily been on representing the *continuant* side of the supply chain domain. In the next phase, the supply chain processes will be formalized. The notion of Service, and its sub-types including Manufacturing Service, also needs further formalization and axiomatization. The taxonomy of supply chain roles also needs further expansion. Along the way, several ontological challenges were encountered, and still need to be addressed. For example, it is not yet verified if using the Process Aggregate class is the right approach for representing the collection of processes that occurs in a supply chain. In modeling the notions based on requirements from the traceability use case, the ontological quandaries include providing a better means for constructing the *history* of supply chain that can capture the flow of materials across various geospatial and temporal regions. Furthermore, representing supplier capabilities also poses a host of challenges since capability is a complex and multi-faceted notion. Ontology modularization also needs to be addressed in a more systematic fashion in IOF. Currently, SCRO selectively imports classes from CCO that are of direct interest and relevance for the supply chain uses cases in hand. As a group, the IOF should decide whether CCO, IAO, and other mid-level ontologies should be imported as a whole or class mireotting is an acceptable practice.

5. References

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