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A Supply Chain Management Approach to Logistics Ontologies in Information Systems

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Abstract. Logistics models in information systems describe activities, organizations, transportation means, goods, and services being involved in logistics processes. The problem with most current such models, however, is a lack of formal semantics which prevents automated data integration across organizational boundaries. In this paper, we take the perspective of supply chain management and employ a well-grounded model which provides core concepts of interorganizational logistics. The contribution is that we (1) propose referring to supply chain management for ontologizing logistics models and (2) provide definitions of core elements of logistics ontologies.

Keywords: Interorganizational Information Systems, Logistics, Ontologies, Semantic Integration, Supply Chain Management

1 Introduction

Logistics concerns controlling and executing the flow of goods, services, and related information from sources to destinations. Logistics is a vertical function being important to almost any industry. It can be characterized by the involvement of multiple stakeholders in logistics processes and the need for coordination across organizational boundaries. Respective *logistics models in information systems* describe such processes and coordination mechanisms. For instance, ERP systems incorporate elaborated logistics data and process models, and allow for exchanging data via message exchange formats. The problem with such models is a *lack of formal semantics* which prevents automated data integration. This is in particular made complicated by the variety of respective models which is a good indication of the conceptual complexity and diversity of logistics.

In recent years, ontologies have attracted both industry and academia because of their potential contribution to solving integration problems in information systems. By providing to some extent consensual definitions of concepts and inter-relationships between these concepts in a domain of interest, ontologies represent a consolidated body of knowledge to which users can commit to. Current logistics ontologies, however, have not yet reached a high level of visibility and maturity. Surprisingly, few logistics ontologies are available on the Web, if any. Despite the relevance of the logistics domain, there is rather little interest by researchers.

The objective of this paper is to contribute to the advancement of logistics ontologies. Unlike other attempts to building logistics ontologies by following an engineering approach including a requirements analysis, we take the *perspective of supply chain management* and reuse the existing body of knowledge contained in the SCOR model [1]. This model defines a comprehensive terminology and a set of semi-formal models of interorganizational logistics; due to its wide acceptance it can be regarded as a reference model. Though this model is not directly aimed at information systems, but at the design of supply chains. The contribution of our research is that we (1) propose referring to supply chain management for ontologizing logistics models and (2) provide definitions of core elements of logistics ontologies.

The present work contributes to a research framework which concerns *logistics systems under customization*. Logistics systems provide services which transform goods with regard to location, time, and quantity. The goal of this research framework is to make logistics massively customizable by means of information systems. Customization is a major trend that can be observed in many industries and markets. It says that customers ever more demand customized goods and services which are tailored to their specific needs [2]. Firms have to revise their strategies and operations to meet this challenge; management science has developed respective differentiation strategies, e.g., [3]. This trend essentially concerns logistics systems which can be seen as the backbone of any industry of tangible goods. A *customized logistics service* is one that is tailored to the specific needs of an individual customer. The current work addresses the means how customers and suppliers specify and thus represent logistics systems in information systems. As such, we employ the SCOR model as a basis for describing activities in logistics, their properties, and inter-relations.

The remainder of this paper is as follows. Section 2 reviews related work. Section 3 introduces briefly the SCOR model. In section 4, we propose logistics ontologies being based on the SCOR model. In section 5, we outline use cases. Section 6 draws conclusions and points to future work.

2 Related Work

The related work can be grouped into two major areas: logistics ontologies and ontology engineering.

Logistics ontologies are a rather specialized subject which is being reflected in the number of work on such ontologies and available ontologies on the Web. For instance, both SchemaWeb¹ and the DAML Ontology Library² return only one entry each for 'logistics' and both are even no logistics, but manufacturing respectively product ontologies.

When widening the scope, one can identify the topic as part of other ontologies. Very often, these ontologies concern a particular domain or function within logistics. Next, we provide an overview: The work of Wendt et al. describes considerations on how to derive common logistics concepts for scheduling from merging two domain-specific ontologies [4]; however, the planned ontology has not been published.

¹ <http://www.schemaweb.info>

² <http://www.daml.org/ontologies>

Pawlaszczyk et al. describe the role of logistics ontologies in mass customization and consider the Enterprise Ontology [5] as a starting point without giving a specification [6]. Haugen and McCarthy propose to extend the REA Ontology which concerns internal accounting to supporting logistics and e-commerce [7]; Gailly and Poels provide a methodology for defining this ontology using UML and OWL [8]. All these works aim at providing some basic concepts of particular logistics systems and thus the resulting ontologies remain quite shallow compared to the true complexity of logistics systems. In particular, such ontologies do not provide a sufficient set of concepts and inter-relations for supporting customization which goes beyond generic logistics.

Hofreiter and Huemer show how to derive RDF ontologies from UML-based data exchange specifications [9]; though this work is not confined to exchanging logistics data. Fayez et al. propose to use an OWL representation of the SCOR model for supply chain simulation, though they do not provide details on their implementation [10].

Brock et al. argue against the use of logistics ontologies because of the ‘rigid and inflexible’ nature of ontologies which would contradict characteristics of logistics [11]. In particular, they claim that it would be unrealistic to believe in formulating an ‘all-inclusive canon that would stand the test of time’; Brock et al. relate this proposition to information systems in general, and propose to define rather light-weight abstractions such as multi-perspective taxonomies for the logistics domain.

Table 1 summarizes key properties of the related work on logistics ontologies.

Table 1. Related Work on Logistics Ontologies.

Author	Domain or Function	Language	Specification
[4]	Scheduling; Manufacturing, Healthcare	Ontolingua	Not available
[6]	Mass Customization	Ontolingua	Not available
[7]	E-Commerce and Supply Chains	None	Not available
[8]	E-Commerce and Supply Chains	UML, OWL	Not available
[9]	Data Exchange	RDF	Not available
[10]	Supply Chain Simulation	OWL	Not available
[11]	Business Logistics	n/a	n/a

To the best of our knowledge, there exist two approaches that link the SCOR model to ontologies: Fayez et al. consider SCOR as part of a wider multi-view ontology and do not provide details on their implementation [10]. Another ontology-based version under the label SCOR+ has been marketed by the firm Productivity Apex; though this is a proprietary approach and no further information is available to the public [12].

Ontology engineering aims at providing methods, languages, and tools for developing new ontologies and maintaining existing ones. An overview of this area can be found, for instance, in [13]. For the purpose of our work, we distinguish two approaches which start from different *prerequisites*.

(a) Building new ontologies: This approach requires a systematic engineering process which includes, among others, a detailed requirements analysis and definition by, for instance, involving end-users and/or referring to relevant theories and models.

Adopting this approach thus calls for respective analysis of logistics application scenarios, theories and models.

(b) Ontologizing existing models: This approach takes an existing model, specification, or standard and raises the degree of formal semantics by employing a respective ontology language (“ontologizing”). It necessarily changes the language used, but leaves most of the original model unchanged and thus reuses knowledge contained in the original. Literature yields a rich set of methods for model conversion in general (e.g., from XML to RDF; from UML to OWL) and also domain-specific adoptions of such methods (e.g., [14] on EDI, [15] on e-catalog data).

Considering the review of current research on logistics ontologies in the former part of this section, we have to state that approach (a) has so far attracted few researchers. In order to reuse existing knowledge relevant to logistics to a greater extend, we follow the direction of (b). Though, we do acknowledge that the former direction opens prospective and fruitful avenues of research.

3 Supply Chain Operations Reference Model

In this section, we briefly introduce the Supply Chain Operations Model (SCOR model) [1]. A supply chain is a system of entities being involved in producing, transforming and/or moving a good or service from suppliers to customers. SCOR provides a comprehensive set of means for modeling supply chains. Unlike generic process modeling languages, it defines a huge number of domain-specific elements for distinguishing different means of manufacturing and moving goods. SCOR has been developed by The Supply-Chain Council (SCC), an independent not-for-profit firm with more than 1,000 corporate members. It was first introduced in 1996 and is currently available in version 8.0.

The documentation of SCOR comprises of 540+ pages; it is available to the SCC of which we are member. The general structure and approach are also described in public documents which can be obtained from the SCC’s website. All SCOR elements are defined in natural language and semi-formally (tables and figures). Interrelations between elements are partly defined by referring to identifiers (i.e., metrics and process elements). Metrics are described verbally and, where possible, formally.

SCOR consists of a model stack of top level, configuration level, and process element level as follows:

Top level: This level distinguishes five core management processes called ‘process types’ that are relevant for all firms in a supply chain. These are: plan, source, make, deliver, and return.

Configuration level: It provides for each process type of the top level a set of ‘process categories’ which represent different operational strategies that a company pursues. For instance, the process categories for ‘source’ represent sourcing strategies. By connecting process categories, a company can describe its logistics processes in a so called ‘process map’. In addition, metrics and best practices are assigned to categories.

Process element level: It decomposes the process categories by adding (1) process element definitions and (2) process element information inputs / outputs. For instance,

a particular source category may be decomposed into process elements for receiving, verifying, and finally stocking the good. Metrics and best practices of the former level appear here also in greater detail. This level provides the most comprehensive set of modeling primitives. SCOR defines 295 information entities which can be input or output of process elements. They range from atomic entities such as ‘vendor lead time’ to complex and consolidated ones such as ‘payment terms’ and ‘service levels’.

4 Proposal of Logistics Ontologies

In this section, we propose a set of logistics ontologies being based on the SCOR model. We specify the ontologies in OWL and use a customized graphical notation which covers the following language constructs: Class, Object Property, Datatype Property, and subClassOf.

4.1 Logistics Top Level Ontology

The purpose of the Logistics Top Level Ontology is to define the scope of the ontology. On the respective level, SCOR distinguishes five process types which thus are sub classes of the generic process type class. Figure 1 depicts the OWL representation.

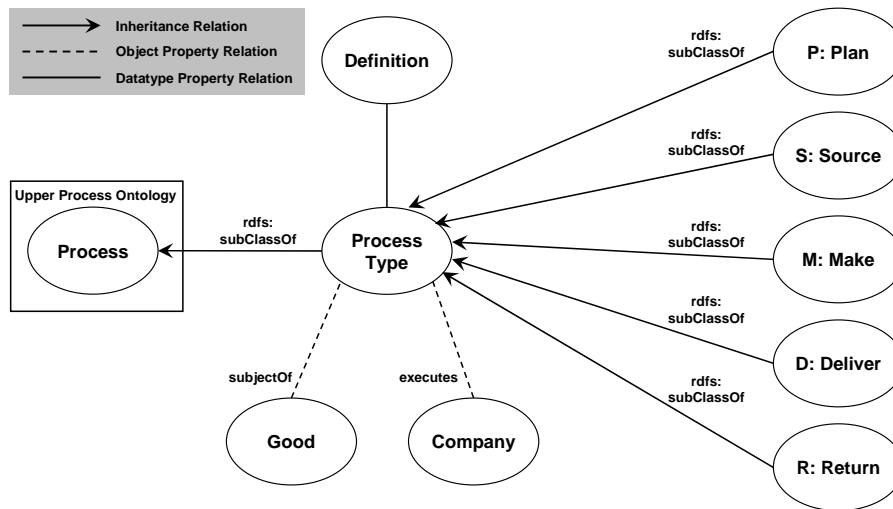


Fig. 1. Logistics Top Level Ontology.

When reconstructing the semantics of SCOR by studying the documentation, we identify two relationships to other concepts which are not described explicitly. First, goods are subject of logistics processes. Second, logistics processes are executed by companies. In both cases, SCOR does not limit the cardinality of these relationships which also holds for logistics in general.

The only other information that can be taken from SCOR is a natural language definition of each process type; this information is stored in a respective Datatype Property.

Since a set of logistics processes describes a supply chain, there are constraints on how to interconnect processes depending on the process type. For instance, 'source' → 'make' → 'deliver' reflects the flow of goods to customers while 'return' is in the opposite direction. Specifying such constraints in the ontology requires means for expressing *preconditions* of a process type.

Here, we employ an externally defined Upper Process Ontology which provides respective classes and interrelations; hence we avoid defining a custom ontology. We choose OWL-S which contains a process model for describing web services³.

The following OWL statement links to the respective 'Process' class of OWL-S:

```
<rdf:RDF [...] xmlns:process="http://www.daml.org/services/owl-s/1.1/Process.owl#">
[...]
<owl:imports>
  <owl:Ontology rdf:about="&process;" />
</owl:imports>
[...]
<owl:Class rdf:ID="ProcessType">
  <rdfs:subClassOf rdf:resource="#Process" />
</owl:Class>
```

4.2 Logistics Process Type Ontology

The Logistics Process Type Ontology provides definitions of operational strategies underlying a process type. Basically, there are three strategies that affect all process types and describe whether the good is (1) on stock, (2) made-to-order thus manufactured for a specific customer order, or (3) engineered-to-order thus it is designed and manufactured specific to a particular customer requirement. In SCOR, this distinction is justified by respective strategies of how manufacturers meet customer demand. These basic strategies also serve for describing interorganizational logistics, since they relate to sourcing and delivery in SCOR.

Building a respective ontology has to decide whether each process category should be represented by a class or instance of a class. The latter approach, however, would prevent defining process category constraints by the mechanism provided in the Upper Process Ontology; hence we choose the former.

³ <http://www.daml.org/services/owl-s>

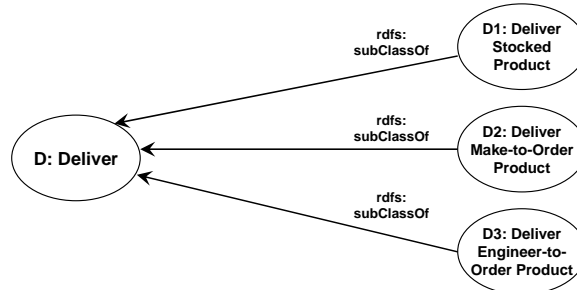


Fig. 2. Logistics Process Type Ontology for 'D: Deliver'.

Figure 2 shows the ontology for 'deliver'; those for 'source' and 'make' look very much the same while the 'return' ontology includes subclasses for returning defective, excessive, and other types of goods.

4.3 Logistics Process Category Ontology

The Logistics Process Category Ontology provides not only a more detailed level of logistics processes by means of process elements, but also enriches process categories with metrics and best practices. Process elements introduce the lowest level of abstraction by specializing process categories.

Metrics allow assessing the performance of a process category and best practices describe empirically proofed means for achieving good performance. In the ontology, both are modeled by Object Properties. Figure 3 does not show the list of metrics and best practices for the category 'Deliver Stocked Product' directly. The reason is that we subsume the entire set of metrics and best practices in separate parts. We then define the allowed metrics and best practices for each category by a constraint on the 'measures' and 'supports' relation.

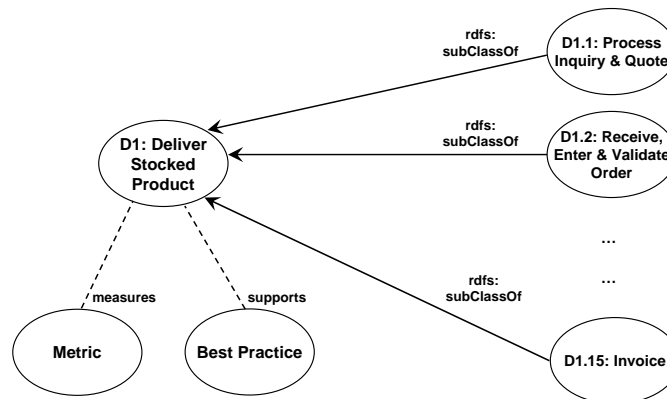


Fig. 3. Logistics Process Category Ontology for 'D1: Deliver Stocked Product'.

Figure 4 shows a cutout of the Metrics Ontology which showcases the hierarchy of metrics as well as Datatype Properties for definition and calculation. The respective ontology for best practices arranges all best practices as subclasses and includes one Datatype Property 'definition' only (not shown here due to space limitations).

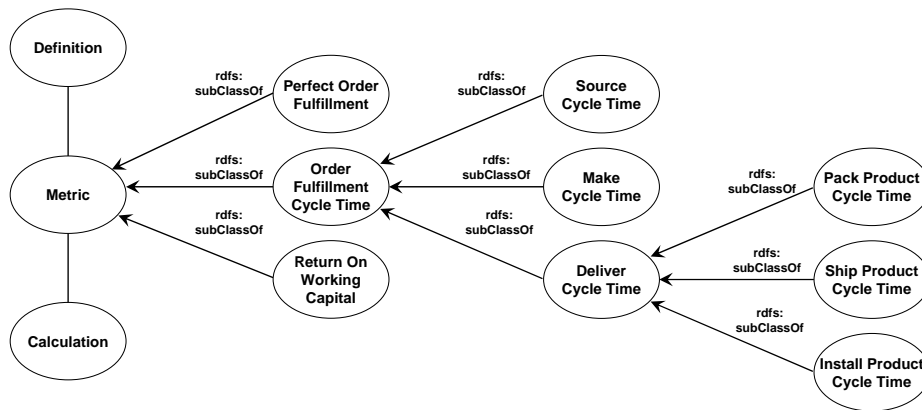


Fig. 4. Metrics Ontology (Cutout).

4.4 Logistics Process Element Ontology

The Logistics Process Element Ontology is rather small, since most interrelated classes and properties of its process elements classes are being inherited from its parent classes, i.e., definition, good, company, allowed sequences, metrics, and best practices.

This level adds input information required for executing a process element and output information as the result of it. The respective ontology for a particular process element is shown in Figure 5.



Fig. 5. Logistics Process Element Ontology for 'D1.2: Receive, Enter & Validate Order'.

Similarly to the case of metrics and best practices, Figure 5 does not list the inputs and outputs, since these are defined in another part of the ontology which provides the entire collection of information classes. Again, the allowed information is defined by a constraint on the two Object Property relations. The Information Ontology does not distinguish input and output but defines information only (see Figure 6).

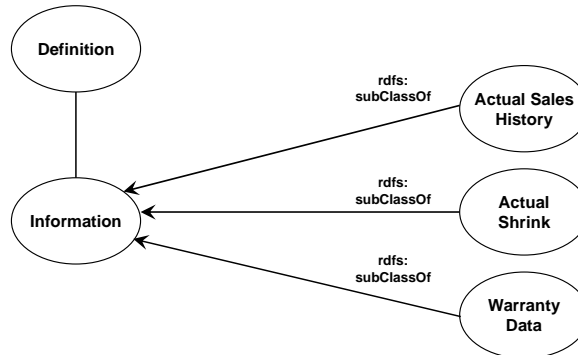


Fig. 6. Information Ontology (cutout).

5 Use Cases

In this section, we outline two use cases of the proposed logistics ontologies. Both cases are being based on the annotation of instance data. Thus we assume that the ontologies serve as consensual definitions to which users commit. For example, current means of data storage in ERP systems and interorganizational data exchange could make use of ontologies by annotating these instances accordingly, i.e., data records and messages. Tagging data, therefore, limits the required effort to changing existing data management means and processes.

(a) Searching for and aggregating logistics processes: In this use case, individual instances or the space of all instances are queried for particular processes according to the SCOR levels. While instances will include references to the lowest level of process elements, one can determine the respective super-processes by following the subclassOf relations, i.e., determine process categories and process types. This procedure allows aggregating diverse process instances on the lowest level to categories and types and thus presents a high-level picture of the current process space.

(b) Reconstructing the logistics network: In this use case, the process space is queried for a particular good and/or company in order to gain information about *all* associated process instances. The rationale is that single instance data does not provide information how the respective instance – and the associated good and company – are related with other instances and thus other goods and companies. By querying for a particular good, one can retrieve all process instances that relate to the good. Due to the transitive nature of the subclassOf relations in the process hierarchy as well as of the Object Property relations, one can reconstruct those parts of the logistics network which are relevant to the particular good; thus it allows viewing the process space from the perspective of a good.

6 Conclusions

This paper aimed at advancing the state of logistics ontologies in information systems. By taking the perspective of supply chain management, we were able to reuse existing knowledge contained in the SCOR model and applied an ontology language to ‘ontologize’ selected parts of this model. Therefore, we make the following contributions: we (1) propose referring to supply chain management for ontologizing logistics models and (2) we provide definitions of core elements of logistics ontologies.

The implications of our research are two-fold: First, few logistics ontologies are currently available and they lack comprehensiveness and domain coverage; thus, the proposed core elements help filling this gap. Second, a formal representation of the SCOR model could also contribute to its usage for information systems design, since it allows an easier adoption by accessing a machine-readable representation.

This research can be seen as initial steps required for enabling a semantic description of the logistics domain. In particular, such description means are required for logistics systems under customization. Customization materializes in logistics in the concept of customized logistics services. Such a service distinguishes from a standardized or off-the-shelf service in the degree of pre-specification, thus which characteristics of the service are specified in advance by the provider and which characteristics can be determined by the customer. By defining the core concepts of logistics systems and detailing such concepts by means of taxonomies for processes and metrics, we provide a basis for a rich description by providers and customers.

Our proposal has several limitations which also point to additional work required to arriving at truly comprehensive logistics ontologies. First, we base our ontologies on the SCOR model which does not provide formal semantics, thus we had to reconstruct the intended semantics by manually studying its documentation. The process of ontologizing is not deterministic and involves choosing alternative ways of modeling. Second, the current ontologies do not reflect the semantics of the entire SCOR model (due to the size of the original model); therefore we have focused the core concepts. Third, we did not specify the ontologies to the full extent (e.g., constraints). Fourth, the SCOR model does not aim at covering interorganizational logistics to the full extent, thus the ontologies lack some characteristic concepts of this domain. This observation is in particular true for transformations of goods which are not explicitly modeled; there are only processes such as ‘pack’ and ‘deliver’ that do not describe formally modifications of goods in terms of quantity, packing, place, and time.

Despite these shortcomings, we believe that the presented approach and the current ontologies provide a sound base for extending the ontologies in the directions outlined above.

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