An Approach to Formal and Semantic Representation of Logistics Services

Julia Hoxha [1] and **Andreas Scheuermann** [2] and **Stephan Bloehdorn** [3]

Abstract. Modern logistics systems are characterized by an increasing structural complexity and dynamicity, which arises from trends in the global economy, decomposition of supply chains and individual customer demands. These trends have amplified the need for greater flexibility in the (re-)configuration of supply chains and, additionally, the demand to move from centralized to decentralized IT solutions for planning and control.

This paper presents an approach to achieve flexibility and decentralization in supply chain configuration and management. The approach combines loosely-coupled logistics services with semantic technologies for a unified representation of diverse logistics data and service functionalities. The contribution is a formal knowledge model of the information in the logistics domain using ontologies. The paper further discusses the semantic representation of logistic services in a framework that enables automated and intelligent techniques for discovery, ranking, execution and efficient composition of services into more complex and flexible logistics processes.

1 INTRODUCTION

Globalization of markets, division of labor, decomposition of supply chains and individual customer demands lead to increased structural complexity and dynamicity of modern logistics systems. Formerly rigid supply chain structures with long-term contracts have diminished for the benefit of short-term contracts and event-driven supply chain configuration. The need to (i) flexibly assemble or adapt supply chains and corresponding control systems, and to (ii) integrate heterogeneous logistics data and exchange logistics information between globally dispersed actors have become key success factors.

Conventional IT solutions, mostly Enterprise Resource Planning (ERP) systems, are mainly based on centralized planning and control mechanisms, concentrating on services within a single organization. Consequently, these solutions insufficiently comply with the current demands and challenges, increasing the need for alternative flexible and decentralized approaches.

Meanwhile, from an IT viewpoint, current technologies, most notably Web Services, significantly facilitate the provision of services over computer networks, changing the way distributed computing systems are being architected. More and more software systems are designed as service-oriented computing architectures with loosely-coupled software components and data resources, which are easily accessible using standardized technologies [7, 10].

However, these service-oriented solutions are not fully adapted along supply chains. First, the external integration of logistics processes, i.e. the integration across organizational boundaries, still remains an ongoing and challenging issue. This is generally due to syntactical, structural, and semantic mismatches between enterprise systems, organizational disturbances, and constant reconfiguration of supply chains based on developments in the global economy [1, 14]. Therefore, we believe that the fundamental problems mainly lie in the lack of appropriate approaches, which support the efficient integration of the plethora of heterogeneous representations of logistics information, as well as the engineering of modular logistics services with flexible interaction. Second, we can assist in handling the complexity of making logistics decisions, which has constantly increased because of wider product variety, smaller lot sizes, more tiers, geographically dispersed actors and less vertical integration [13]. Significant advances in dealing with this complexity are needed, providing value-added services to the end-customers and increasing the flexibility of the involved supply chains. The added-value lies in finding those logistic services that optimally fulfill customer-specific requirements. This can only be realized if at least formal and correct descriptions of the services are available.

The objective of this work is to introduce an approach to formal and semantic representation of logistics services, adopting the concepts of service-orientation and Semantic Web technologies. We apply Semantic Technologies to formally model the information of the logistics domain. We further provide a semantic representation of modular real-world logistics services (e.g., transportation, storage, handling), so that they can be composed into more complex logistics processes and dynamic supply chains.

Our contribution is a principled approach that provides semantic representation of logistics information and services. We present (i) a motivating logistics application scenario, (ii) a formal knowledge model that captures the overall aspects of the logistics domain and (iii) an approach for the semantic description of logistics services in a service-oriented application framework.

The remainder is structured as follows: Section 2 illustrates an application scenario, which motivates the need for formal semantic representations. In Section 3, the formal knowledge model and the corresponding ontologies are presented, while Section 4 proposes a framework for semantic representation of logistics services. Section 5 discusses the benefits of using this framework in selected scenarios. In Section 6, we review related work, presenting afterwards in Section 7 conclusions and an outlook on future work.

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[1] Karlsruhe Institute of Technology (KIT), Germany, email: julia.hoxha@kit.edu

[2] University of Hohenheim, Germany, email: andreas.scheuermann@uni-hohenheim.de

[3] Karlsruhe Institute of Technology (KIT), Germany, email: stephan.bloehdorn@kit.edu

2 USE CASE

To illustrate the situation of the external integration of logistics services, we take a deeper look at the integration of transportation services from the perspective of a fourth-party logistics (4PL) provider. A 4PL provider is regarded as a non asset-based integrator of logistics services along supply chains. In the following, we contrast common decision situations of the 4PL provider, as they are typically handled now, with the desired target situation, thus motivating our solution approach.

2.1 Current Situation

Given the end-customer requirements, e.g., amongst others, delivery time, service levels, characteristics of goods, as well as source and destination, the 4PL's ultimate goal is to integrate transport services conforming to these needs.

Typically, large catalogs containing contact details of potential transport service providers are inspected manually - mostly based on keyword search. A lack of common terminology to expose the capabilities of a provider leads to ambiguous service classifications favoring suboptimal search results. When there are no appropriate transport services available, additional manual effort has to be invested in decomposing the transport process into two or more transport services, which in combination match the final customer requirements.

In a next step, inquiries about the service provisioning are carried out by phone, fax, email, or sometimes through proprietary IT interfaces, which in each case strongly depend on the providers IT infrastructure and applications. Subsequently, the selection of a transport service provider is performed in a two-staged process. First, the different offers received in heterogeneous data formats have to be transformed in a standardized representation format. Second, before final decision making, the customer requirements and the offered transportation services have to be matched because not all transport offers equally comply with the original request.

Integration of external logistics services is primarily characterized by manual effort and lots of human interaction. Therefore, errors occur increasing costs and leading to inefficient supply chains. The absence of formal semantics and service-oriented computing solutions not only prevents enhanced data processing, but also intelligent and automatic service integration.

2.2 Target Situation

Filling the afore-mentioned gap and overcoming the challenges necessitates an approach, which applies semantic techniques and adapts them to logistics systems. The deployment of a semantic service application framework for the logistics domain provides an explicit and formal representation of all information enclosed in logistics processes. The framework also enables a semantic and detailed description of logistics services, which are easily accessible, loosely-coupled, and open to combination or composition into more complex logistics processes, such as supply chain configuration. This semantic approach leads to automated and more intelligent external process integration.

The application scope of semantic service descriptions is significantly extended by the techniques that we may apply on top of these annotated services, such as automatic discovery, ranking and composition of all available transportation services. The formally and semantically described services, being published from a wide range of logistics providers, may be searched by a particular 4PL based on some desired criteria. Automated discovery and ranking of the services that optimally match these criteria is performed and final solutions are proposed to the 4PL.

The proposed solution enables the 4PL to configure the logistics system more efficiently. Errors caused by manual data integration efforts and unambiguous information are avoided. Decision-making is less concerned by handling structural complexity and dynamic behaviour of supply chains.

3 MODELING THE LOGISTICS ONTOLOGY

In this section, we propose an ontology that offers a unified representation of the logistics domain and facilitates the formal, semantic description of logistics services. Studer et al. [15] define an ontology as ”a formal, explicit specification of a shared conceptualization.” Based on this definition, a logistics ontology is an abstract and formal model of consensual knowledge about the logistics domain. Using an ontology, we are able to formally describe the semantics of terms representing an area of knowledge and give explicit meaning to the information. This enables automated reasoning, information integration and application of intelligent approaches such as semantic service description, decision support, semantic search, knowledge management and the like.

3.1 Ontology Domain and Scope

To model the logistics ontology, we have followed the ontology engineering method proposed by Noy et al. [9]. We have thus defined the scope of the ontology in terms of competency questions (CQ). We describe below a set of such questions, which our target ontology should be able to answer.

CQ 1. Which actors are involved in providing logistics services?
CQ 2. Which logistics services are required to realize the flow of goods?
CQ 3. What aspects are critical to selecting a logistics service?
CQ 4. Which logistics service providers are capable of providing a requested logistics service?
CQ 5. Which information is required to provide adequate logistics services?
CQ 6. What characteristics constitute a transportation service?
CQ 7. What kind of resources are used by logistics services?
CQ 8. What are relevant metrics to measure service performance?

In the following section, we present the logistics ontology describing in detail its most relevant entities.

3.2 Ontology of the Logistics Domain

The objective of the logistics ontology is to capture the essence of the logistics domain. Typically, an ontology contains the following constructs: concepts, relations, axioms, individuals and assertions. To encode the ontology we use OWL DL, a Web-based ontology language based on Description Logics (DL) that provides high expressiveness while maintaining favorable computational properties for reasoning [6].[4]

The ontology is modeled using Protégé,[5] a platform that offers support for ontology creation, visualization and manipulation. Specifically, we used the Protégé-OWL Plug-in to model the classes

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[4] http://www.w3.org/TR/owl-guide/

[5] http://protege.stanford.edu/

and their relations. In the following, we explain the entities that compose the modeled logistics ontology.

Classes. The top-level basic classes (concepts) are *Process*, *Service*, *Resource*, *Service Level Parameter*, *Actor*. The concepts *Process* and *Service* are further specialized as *LogisticsProcess* and *LogisticsService* respectively. A logistics process may be atomic, composed of only one logistics service, or it may be a composite process, containing a series of services that together form a workflow.

Properties. In OWL DL, relations between classes are defined by the *properties* constructs, distinguishing between two main categories: *Object properties* and *Datatype properties*. The *Object properties* link individuals to individuals, whereas the *Datatype properties* link individuals to data values. In our context, an object property *usesResources* links the individuals of the class *Service* to those of the class *Resource*.

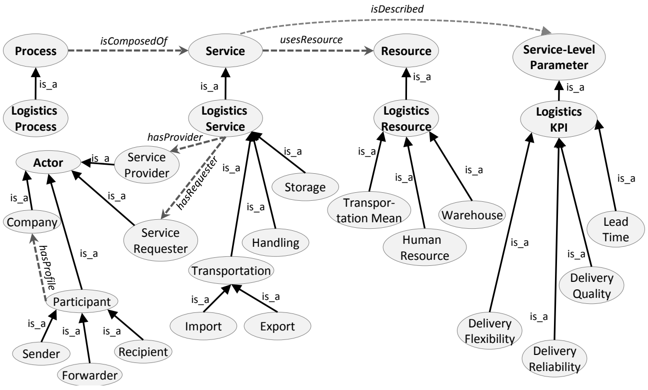


Figure 1. Top-level Concepts of the Logistics Ontology

A snapshot of the constructed ontology is illustrated in Figure 1. This part focuses on modeling the logistics services of a supply chain, which may often be linked together to form a process with resources, actors and performance metrics.

The concept *Logistics Process* is a specialization of the concept *Process*. We allow for composition and decomposition of logistics services regarding various levels of abstraction. Therefore, linked to the concept *Process* via the object property *isComposedOf* is the class *Service*, which is further specialized with the subclass *Logistics Service*. *Logistics Service* acts as an umbrella to model more specific services like transportation, handling and storage.

To provide complete service descriptions for each logistics service, a profile is specified comprising functional and non-functional characteristics. We adopted the upper level concepts of *Resource* and *Service Level Parameter* from the Web Service domain as basis for modeling logistics resource and logistics KPI (Key Performance Indicator) in our service-oriented approach. A logistics service uses *Logistics Resource*, a concept further specialized into more specific concepts: transportation mean, warehouse and human resource. To model non-functional properties, we derived the subclass *Logistics KPI*, specialized, among others, into subconcepts *Delivery Flexibility*, *Delivery Reliability*, etc.

To fully capture the information of the domain, we modeled many more concepts, varying from the different types of carriers, transportation, goods, logistics documents and logistics standards. Another important part is the specification of actors involved in the various logistics processes.

In our ontology, an *Actor* may be a service provider, a service requester or a participant in the logistics chain, who may play the role of recipient, sender or forwarder. Moreover, every actor has a particular company profile, ranging from logistics company to business enterprise, manufacturing company or a virtual organization. This entire information is captured and modeled in our domain ontology, another part of which is further shown in Figure 2.

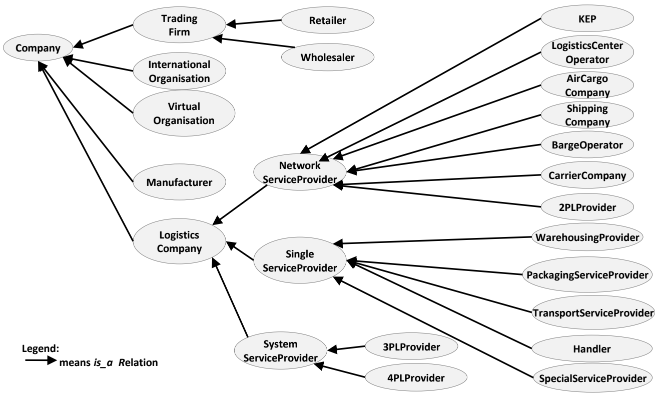


Figure 2. Modeling Logistics Actors

Axioms. OWL is provided with formal model-theoretic semantics corresponding to Description Logics. Beyond basic class subsumption relationships, the interpretation of the classes and relations of the logistics ontology can be constrained with additional DL axioms, examples of which we present below.

Axiom Set 1. One of the subclasses of the class *Actor* is the *LogisticsCompany*. A logistics company may be either a single-service, network-service or system-service provider, which are mutually disjoint concepts. A 2PL is a subclass of a network-service provider. A system-service provider is classified as a 3PL or 4PL company.

$$\mathit{LogisticCompany} \equiv \mathit{SingleServiceProvider} \sqcup \mathit{SystemServiceProvider} \sqcup \mathit{NetworkServiceProvider}$$

$$\mathit{SingleServiceProvider} \sqcap \mathit{SystemServiceProvider} \sqcap \mathit{NetworkServiceProvider} \equiv \bot$$

$$\mathit{2PLProvider} \sqsubseteq \mathit{NetworkServiceProvider}$$
$$\mathit{SystemServiceProvider} \equiv \mathit{3PLProvider} \sqcup \mathit{4PLProvider}$$

Axiom Set 2. A logistics process is composed of one or more services, representing respectively either an atomic or a composite process. A service has a provider and a requester, each of them with a particular company profile. Moreover, a service uses resources, which are classified as person, transportation mean or warehouse.

$$\mathit{LogisticsProcess} \sqsubseteq \mathit{Process} \sqcap (\mathit{AtomicProcess} \sqcup \mathit{CompositeProcess}) \sqcap \forall \mathit{isComposedOf}.\mathit{LogisticsService}$$

$$\mathit{AtomicProcess} \sqcap \mathit{CompositeProcess} \equiv \bot$$

$$\mathit{LogisticsService} \sqsubseteq \mathit{Service} \sqcap \forall \mathit{isFollowedBy}.\mathit{LogisticsService}$$

$$\sqcap \exists \mathit{hasProvider.ServiceProvider} \sqcap \exists \mathit{hasRequester.ServiceRequester} \sqcap \forall \mathit{isDescribed.LogisticsKPI} \sqcap \forall \mathit{usesResource.Resource}$$

Axiom Set 3. The performance of a service is measured by various metrics, such as service level, confirmation time, delivery time, order processing time, punctuality, reachability, etc.

$$\mathit{Performance} \sqsubseteq \forall \mathit{isMeasuredBy.(ServiceLevel} \sqcup \mathit{Punctuality} \sqcup \mathit{Reachability)}$$

Individuals and Assertion. The classes of an ontology are instantiated, specifying the concrete objects or individuals that belong to a particular class. For example, we instantiate the class *Service Provider* with the individual *Cargoliner GmbH*. Specific properties between individuals are instantiated in assertions.

Reasoning. We may automatically perform reasoning on the developed ontology, such as consistency checking, subsumption testing and instance classification. The ontology is presented in an OWL document, which is available online.[6]

The ontology is used as basis for the semantic representation of the logistics services. Some of its core concepts are adopted from the service modeling approach, which we use for the semantic service descriptions.

4 SEMANTIC REPRESENTATION OF LOGISTICS SERVICES

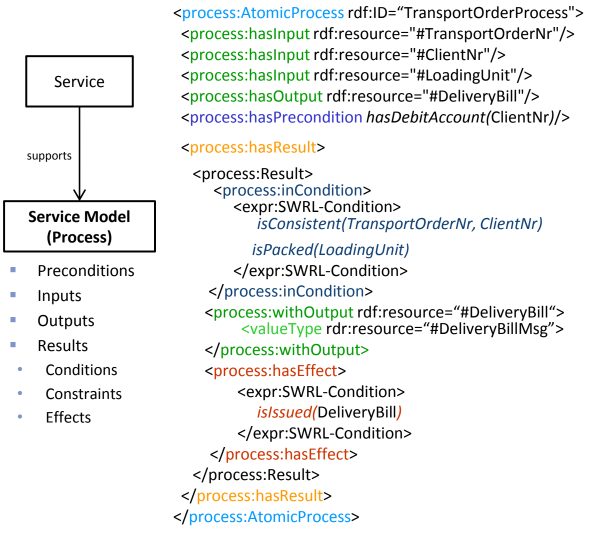
In this section, we introduce a framework for representing and implementing the different functionalities conducted in the logistics domain using Web Services standards and Semantic Web representations. Web Services, on one side, provide standard means for the interoperation among the different software applications of various platforms. They encapsulate software functionalities that are distributed, but programmatically accessible over internet protocols [11]. A service-oriented framework allows not only flexible interaction, but also greater reusability of the deployed functions.

On the other side, the Semantic Web markup languages used for the representation of these services provide the means for their computer-interpretable description and easier access to these services. Web Service standards yield a basic language for describing service functionalities, the Web Service Description Language (WSDL). It only provides syntactic elements with no formal semantics, i.e. no means for formalized reasoning about the description statements.

The approach we use for the semantic description of logistics services is OWL for Services (OWL-S), an ontology that enables the describtion of what the services provide and how they can be used. This representation supports the automated discovery, execution, monitoring, as well as composition and interoperability of the services.

4.1 Semantic Description of Logistic Services

We provide a semantic representation of logistics services using the three main clusters of constructs of OWL-S 1.1,[7] which are *Service Profile*, *Service Model* and *Service Grounding*. Respectively, they describe the capabilities that the service provides, the ways the service works internally, as well as details on how the service can be accessed and executed via linking to the appropriate WSDL file.



```
<process:AtomicProcess rdf:ID=“TransportOrderProcess">
 <process:hasInput rdf:resource="#TransportOrderNr"/>
 <process:hasInput rdf:resource="#ClientNr"/>
 <process:hasInput rdf:resource="#LoadingUnit"/>
 <process:hasOutput rdf:resource="#DeliveryBill"/>
 <process:hasPrecondition hasDebitAccount(ClientNr)/>

 <process:hasResult>
   <process:Result>
     <process:inCondition>
       <expr:SWRL-Condition>
         isConsistent(TransportOrderNr, ClientNr)
         isPacked(LoadingUnit)
       </expr:SWRL-Condition>
    </process:inCondition>
    <process:withOutput rdf:resource=“#DeliveryBill“>
        <valueType rdr:resource=“#DeliveryBillMsg”>
    </process:withOutput>
    <process:hasEffect>
        <expr:SWRL-Condition>
          isIssued(DeliveryBill)
        </expr:SWRL-Condition>
     </process:hasEffect>
   </process:Result>
 </process:hasResult>
</process:AtomicProcess>
```

Figure 3. OWL-S Service Model of a Transportation Service

Service Profile describes the functionality in terms of the basic sets of inputs, outputs, preconditions and effects (IOPEs) of the service for automated discovery. Service Model provides the details on its internal processes, describing how the service works. Hereby, the service is viewed as a process, which may be classified as atomic or composite. A composite process is a combination of atomic processes with a particular data flow and control flow defined using constructs like sequence, choice, iteration, etc. The conditions and effects are specified as logic statements, necessary for inference engines, utilizing Semantic Web Rule Language (SWRL).[8]

In Figure 3 we illustrate the semantic description of an atomic process representing a transport service. It is to be always considered that all the resources defined in the service descriptions are specified as concepts in the logistics ontology of Section 3. The process takes as input an identifying *transport order number*, *client number* and *loading unit* to be transported. The output is a *delivery bill*. If the process has a precondition, then it cannot be performed successfully unless the precondition is true. In our case, we have specified that the client should have an existing debit account.

The *inCondition* property specifies the condition under which the result occurs. We have specified that there should be a match between the input *ClientNr* and the *TransportOrderNr*. Effects determine changes in the state of the world upon service execution, e.g. a *DeliveryBill* is really issued after process invocation.

4.2 Semantic Services Application Framework

The formal and semantic description of logistics services supports the application of more intelligent and automated functionalities, which we present in a framework shown in Figure 4.

Initially, the services should be made available via the different *Service Providers*, who use the appropriate tools for semantic *Annotation* and *Publishing* of their services. An implementation of the service, represented in WSDL description, should exist in their platforms to enable future invocation. The semantically annotated services, precisely the generated service descriptions, are saved in a *Repository* together with the ontologies that these descriptions use.

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[6] http://www.interloggrid.org/dl34

[7] http://www.w3.org/Submission/OWL-S/

[8] http://www.w3.org/Submission/SWRL/

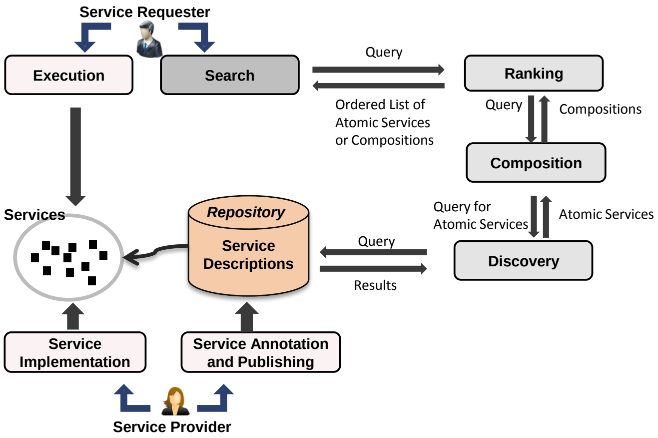

Figure 4. Semantic Services Application Framework

A *Service Requester* may search for services via a Web-based search interface, specifying the desired preconditions, inputs, outputs, and effects. The user´s query is processed, using complex reasoning techniques, to discover in the repository those descriptions, whose IOPEs optimally match those defined in the user´s query. The returned result may be a list of atomic services or even compositions (composite processes) of services. The list is ranked and displayed to the user, who is then able to execute, according to the implementation made available by the provider, the service that best matches his needs.

The power of semantics in logistics services lies in the automation of functionalities like discovery, composition, monitoring, or execution as shown in this framework. It allows the logistics clients to intelligently discover and invoke the processes that optimally match their needs from a wide range of services made available by the autonomous logistics providers.

5 APPLICATIONS OF THE LOGISTICS SEMANTIC APPROACH

In the following, we sketch approaches for the practical application of our framework. We first illustrate the benefits of using our ontology and semantic service description framework for the logistics domain conceptually in the following evaluations scenarios, then move on to potential ontology queries.

5.1 Evaluation of Logistics Models

Use Case 1 - Check for consistency and conflicts. We check whether concepts, relations and properties between the elements of two or more actors are specified in accordance to each-other. For example, seamless integration of a transport service, provided to an original equipment manufacturer, requires both lifting data models and mapping them to the proposed logistics ontology. Thus, we are able to identify conflicts and ensure consistency.

Use Case 2 - Check for consistency across process models. Information relevant to logistics services is captured across various actors and autonomous models, leading to inconsistencies. Our framework not only provides a vocabulary of consensual logistics knowledge, but also serves for detecting inconsistencies from incorrect model usage, e.g. the ontology assures that logistics services are linked correctly to the required resources, adequate metrics and actors roles.

Use Case 3 - Behavioral checks on process models. The provided representation of logistics processes, specifically using the control flow constructs of OWL-S, allows us to perform checks on their correct behavior, regarding the execution order of the activities. Behavioral monitoring of the process model checks e.g. activity *Issue Transportation Order* is performed before *Issue Delivery Bill*.

5.2 Querying the Logistics Ontology

We perform queries and gather results from distributed and autonomous systems, whose data may be highly heterogeneous. The logistics ontology provides a unique view of diverse data, allowing us to pose queries upon this model and retrieve integrated results.

In order to illustrate the benefits provided by such an integrated view, we list potential example queries that could be answered using our ontology framework. We formulated queries in SPARQL [9] and, due to space limitations, present the code for the third query only. Originally designed as a query language for graph patterns in Resource Description Format (RDF), SPARQL is practically also used to encode queries against OWL knowledge bases, interpreting the basic graph-matching capabilities using the semantics of the ontology language.

Query 1. Show the contact details and description of transportation services offered by providers satisfying delivery quality above 99%.

Query 2. List the logistics providers that offer storage and handling services.

Query 3. Show the name, description and website of the logistics companies that offer a transport service with delivery size *Full-Truck-Loaded*.

```
PREFIX pr: <http://www.example.com/Logistics.owl#>
SELECT  ?name ?description ?website
WHERE  {
&?subject pr:hasWebsite ?website .
&?subject pr:hasDescription ?description .
&?subject pr:hasName ?name .
&?subject pr:hasTransportService ?object .
&?subject pr:hasDeliverySize pr:Full-Truck-Loaded }
```

We have formulated and posed these, as well as similar queries, in the context of the initial case study analysis.

6 RELATED WORK

Related work of logistics ontologies can be grouped into three parts: (1) logistics ontologies freely available on the web, (2) logistics ontologies developed by companies, and (3) logistics ontologies presented in scientific publications.

On the Web, dedicated ontology search engines like Swoogle, [10] DAML Ontology Library [11] and SchemaWeb [12] reveal that the number of available logistics ontologies is very small. They can either be assigned to the domain of manufacturing or exclusively describe special logistics terms, such as e.g. capacity, aircraft types or hazardous cargo. All these ontologies only provide a taxonomy, lacking formal axioms or relations and can, therefore, be regarded as lightweight-ontologies. In companies, there is a widespread usage of information models. These models (e.g. SAP information models) are not regarded as ontologies because they are constructed by means of data modeling techniques and do not provide formal semantics.

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[9] http://www.w3.org/TR/rdf-sparql-query/

[10] http://swoogle.umbc.edu/

[11] http://www.daml.org/ontologies/

[12] http://www.schemaweb.info/

Considering scientific publications, Haugen and McCarthy [5] describe an extension of the REA Ontology concerning internal accounting to support logistics. The work of Wendt et al. [17] focuses on how to derive, by merging to domain specific ontologies, common logistics concepts for scheduling. Pawlaszczyk et al. [12] considered the Enterprise Ontology [16] as a foundation to describe the role of logistics ontologies in mass customization. The works in this group provide logistics ontologies, which only represent some basic concepts compared to real world complexity of logistics.

Another group aims at applying ontology languages ("ontologizing") to existing logistics models. For supply chain simulation, Fayez et al. [3] propose an OWL representation of the SCOR model without providing details on its implementation. Leukel and Kirn [8] develop a logistics ontology based on the SCOR model for describing activities in logistics, their properties and relations. Haller et al. [4] propose a methodology to ontologize the *RossettaNet* specification, in order to resolve heterogeneities in dynamic supply chain settings. While these works provide rich logistics ontologies, they either focus on enhanced communication or on modeling logistics elements and interrelations. Additionally, Ye et al. [18] propose an architecture for web-based integration of supply chains, adopting the Enterprise Ontology. However, none of these logistics ontologies has a grounding in top-level ontologies originating from service-oriented computing.

A greater deficiency can be observed in the area of semantic representation of logistics services. One relevant approach is presented by Cuadrado et al. [2], which applies semantic Web Services for integration in logistics. This work mostly keeps a case-study perspective focusing on freight logistics, defining aligned requirements for service description.

7 CONCLUSIONS

In this paper, we have presented an approach for the semantic representation of the logistics domain, which offers solutions to the integration challenges among heterogeneous data and interoperability of logistics services from different providers. We have developed an ontology model using OWL DL for the formal, unified representation of logistics data and a service-oriented approach for the semantic description of logistics processes using OWL-S.

Introducing semantics in the logistics domain and combining them with Web Service standards support automated discovery and composition of services from heterogeneous and external logistics providers. It helps both dynamic and optimal configuration of supply chains and facilitates logistics decision-making. We are currently extending the logistics ontology with additional relations and axioms, to enable more complex reasoning and inferencing, making it fully applicable to a broader range of logistics scenarios. We also investigate the mapping to existing modular sub-ontologies.

We will extend the repository of service descriptions with more real-world logistics services. Based on this, we will start to implement and integrate service discovery and composition techniques as part of an intelligent logistics services portal. Extending the repository of logistics service descriptions will allow us to test the alignment of services into more complex processes and evaluate their interoperability.

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