Ontologies for Intelligent Provision of Logistics Services

Andreas Scheuermann
Information Systems 2
University of Hohenheim
70599 Stuttgart, Germany
andreas.scheuermann@uni-hohenheim.de

Julia Hoxha
Karlsruhe Institute of Technology (KIT), Karlsruhe
Service Research Institute (KSRI), Institute of Applied
Informatics and Formal Description Methods (AIFB)
76128 Karlsruhe, Germany
julia.hoxha@kit.edu

***Abstract*—The complex and volatile global economic environment challenges Supply Chain Management and increases the need for advanced Information Technology. To enable flexible and intelligent management of supply chains, we present an overall approach based upon a combination of Semantic Web Technologies and Service-oriented Computing. This work developes dedicated logistics ontologies for enabling intelligent provision of logistics services.**

Keywords-Logistics Ontology; Ontology Engineering; Semantic Technology; Service-oriented Computing; Supply Chain Management.

I. INTRODUCTION

The 21st century global markets become increasingly turbulent and volatile: life-cycles shorten due to the global economic environment and ever growing individual customer demands, while competitive forces put additional pressure on companies supply chains. Lengthy and slow-moving supply chains bounded by rigid organizational structures endanger companies' competiveness. In such a complex and dynamic environment, logistics excellence has become a powerful source of competitive advantage [1].

However, the relentless effort of companies to strive for competitive advantage has ballooned complexity of logistics decision-making and intensified the need to flexibly provide logistics capabilities. This development highlights the vital role of Information Technology (IT) and especially the need for flexible IT architectures and intelligent approaches for exploiting logistics knowledge [2][3].

From an IT viewpoint, current technologies such as Semantic Web Technologies (SWT) and Service-oriented Computing (SOC) bear considerable potential to enhance Supply Chain Management (SCM). SOC, as a paradigm for distributed, potentially cross-organizational software systems, aims at rapidly and easily providing applications by combining single services to enable flexible business processes. In this paradigm, a service is a loosely coupled, autonomous, and platform-independent computational entity, which encapsulates discrete functionality and can be accessed by using established web standards [4][5]. SWT allows for describing consensual knowledge of a specific domain of interest by means of formal semantics. This enables automated reasoning, information integration, semantic interoperability, and, thus, the application of intelligent approaches [6], e.g., for decision support or discovery and composition of logistics services. While each of these technologies has revolutionized IT, so far, the capabilities and advantages of combining both approaches have been rudimentarily exploited.

The objective of this paper is to extend the previous approach [7], which combines the paradigm of SOC and SWT, by applying them both on the logistics domain and SCM to enable intelligent provision of semantic logistics services. We propose a refined three-layered semantic approach consisting of a logistics semantic layer containing dedicated logistics ontologies, a logistics service description layer, and a logistics process description layer. From the perspective of ontology engineering, the contributions of this work are dedicated logistics ontologies that provide formal logistics knowledge to unambiguously describe logistics services and artefacts. In contrast to state-of-the-art logistics ontologies, the proposed ontologies (1) sufficiently capture the logistics domain not only restricted to specific logistics areas, and (2) incorporate a higher degree of formal semantics.

The rest of the paper is organized as follows: Section 2 reviews related work. Section 3 introduces the underlying approach. Section 4 develops dedicated logistics ontologies, which are evaluated in Section 5. Section 6 draws a conclusion and points to future work.

II. STATE-OF-THE-ART

A query to dedicated ontology search engines (e.g., http://swoogle.umbc.edu) reveals that the actual number of logistics ontologies is very small. The available ontologies can be assigned either to the domain of manufacturing or exclusively to specific areas of logistics (e.g., aircraft types, IATA codes, hazardous cargo). These ontologies merely provide taxonomies lacking formal axioms.

In scientific publications, the work of Wendt et al. [8] presents aspects of merging two domain-specific ontologies (production logistics and hospital logistics) to derive common logistics concepts for scheduling and facilitate efficient communication processes. The ontology itself is not published. Chandra and Tumanyan [9] apply an ontology to

 ISBN: 978-1-61208-200-4

systematically record knowledge about organizational and problem-specific issues for SCM. They propose an information modelling framework to create a taxonomy of supply chain problems and operations to alleviate operational uncertainty. Madni et al. [10] introduce the IDEON ontology as a basis for designing, reinventing, managing, and controlling collaborative and distributed enterprises. IDEON integrates multiple perspectives, such as an enterprise context view or a process view. It is represented using the Unified Modelling Language. Lin et al. [11][12] develop a manufacturing system engineering (MSE) ontology to support an intelligent coordination tool within extended or virtual enterprises. The MSE ontology conforms to a taxonomy of different concepts: project, enterprise, process, extended enterprise, resource, and strategy. These ontologies are modelled by means of software engineering techniques, conform to simple taxonomies, and merely address specific logistics aspects.

Another group applies ontology languages upon existing logistics models ("ontologizing"). Fayez et al. [13] propose an OWL representation of the SCOR model for supply chain simulation. The ontologies should capture the distributed knowledge being required to integrate several supply chain views in order to support the construction of simulation models. Leukel and Kirn [14] develop a logistics ontology based on the SCOR model to capture core concepts of inter-organizational logistics. The proposed ontology facilitates the description of activities in logistics and provides relations and attributes. While these publications provide richer ontologies, they are still limited to few abstract concepts.

The last group aims at extending well-grounded ontologies. Haugen and McCarthy [15] propose an extension of the REA Ontology to support internet supply chain collaboration. Pawlaszczyk et al. [16] introduce an ontology based on the Enterprise Ontology to describe the domain of mass customization for optimizing inter-organizational and distributed cooperation. The ontology introduced by Soares et al. [17] focuses on production planning and control in a virtual enterprise environment to improve human communication and to support the specification of system requirements. The ontology is founded on the meta-ontology of the Enterprise Ontology, whereas the concepts are defined by natural language and object models. Ye et al. [18] propose a supply chain ontology to enable semantic integration between heterogeneous supply chain information systems. The supply chain setting is a web-based or virtual enterprise with no specific industry focus. The ontology is implemented in OWL and based on the Enterprise Ontology. This group of ontologies concentrates on supply chains rather than on a larger scope of the logistics domain. However, all listed ontologies lack rich formal semantics, remain rather abstract, merely focus on special logistics aspects, and neglect the service-oriented nature of logistics.

III. RESEARCH DESIGN

The overall approach underpinning our work is to combine SWT with SOC and apply them on the logistics domain. The ultimate goal is to enable the intelligent and flexible provision of logistics services in supply chains and customized logistics applications (Fig. 1).

SWT [6] comprises formal knowledge representation and reasoning capabilities. Thereby, ontologies provide appropriate means to formally structure and explicate knowledge about the logistics domain in order to enable semantic interoperability, information integration, and reasoning.

SOC [19], particularly Web Services, conform to modular, loosely-coupled software components that are accessible by established web standards and, thus, facilitate the provision of services in distributed and heterogeneous environments. Web Services allow for flexible business process management, which when combined with formal semantics provide capabilities for (semi-)automated service discovery, ranking, composition.

The combination of SWT and SOC lay the basis for semantic logistics services, which encapsulate discrete logistics functionality (e.g., transport), consume logistics resources, and whose quality is measurable by logistics performance indicators. Semantic logistics services consist of modular, reusable, and loosely-coupled logistics components for flexibly managing complex logistics processes.

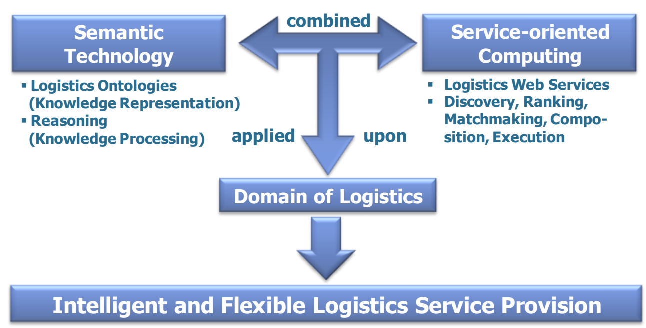

Figure 1. Combining SWT and SOC for SCM

Based on this approach, we introduce a three-layered model for engineering Semantic Logistics Services (Fig. 2).

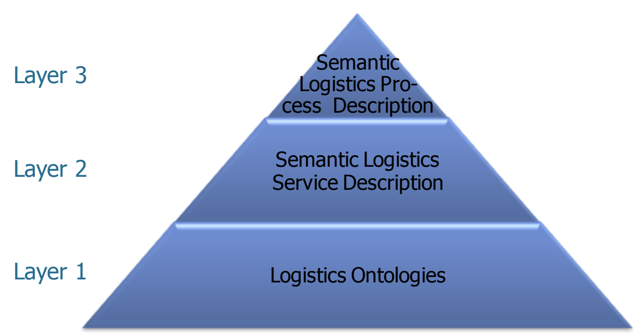

Figure 2. Three-Layered Model for Semantic Logistics Services

Layer 1: Logistics Ontologies build the foundation for defining formal semantics of consensual logistics knowledge. We provide a modular ontological setup, which allows for easy reuse, adaption, and refinement.

Layer 2: Semantic Logistics Service Descriptions are used for the representation of atomic logistics services. We exploit

 ISBN: 978-1-61208-200-4

OWL-S Service Profile [20] for the description of service features and utilize the logistics ontologies of Layer 1 for semantic annotation.

Layer 3: Atomic logistics services are composed into complex logistics processes, which are semantically described by SuprimePDL [21] process description language. Layer 3 consists of such Semantic Logistics Process Descriptions.

IV. Engineering Logistics Ontologies

We focus on Layer 1 to propose dedicated logistics ontologies for semantically describing logistics services.

A. *Scenario: The Case of Fourth- Party Logistics*

The increasing pressure on companies to rapidly and flexibly provide superior logistics capabilities has led to logistics outsourcing, which involves both operational logistics services (e.g., transport) and management capabilities (e.g., planning). As an optimal solution, the concept of fourth-party logistics (4PL) has emerged. A 4PL is challenged to provide logistics expertise and IT to integrate and manage – plan, implement, and control – logistics services in complex and dynamic supply chains without possessing own logistics assets [22]. In particular, a 4PL could significantly benefit from exploiting both SWT and SOC:

First, the use of the logistics ontologies and the OWL-S Service Profile allows 4PL and other logistics service providers (LSP) to unambiguously characterize their offered services. Accurately fulfilling customer service levels directly affects a retailer's or manufacturer's competitive ability. Exploiting formal semantics not only fosters semantic interoperability and (semi-) automatic data integration between heterogeneous logistics information systems along the supply chain but also speeds up communication and makes it more flexible and error-resistant. Further, logistics ontologies allow for automated reasoning to expose implicit knowledge. Customer requirements on logistics service provision dynamically change, thus, reasoning enables to check usability of services beyond explicitly stated characteristics.

Second, applying semantic logistics services allows for advanced functionality with regard to logistics service discovery, ranking, matchmaking, and composition. A 4PL faces both a huge amount of end-customers with individual requirements concerning logistics service provision and, moreover, a variety of LSPs for satisfying these requirements. Hereby, logistics service discovery and ranking accelerate matching demand with supply of logistics services. As supply chain complexity and dynamicity constantly increase, service composition enables a 4PL to rapidly and flexibly integrate logistics services, and, thus, to configure and manage highly complex supply chains.

B. *Logistics Domain Capture*

The ontology engineering approach is based on a dedicated methodology [24]. A main characteristic of this methodology is the formulation of informal competency questions (CQ) to determine the scope and purpose of the ontology. These questions incorporate the terminology and functional requirements of the ontology to be developed. In our case, the development of CQ is based on two main factors. First, the CQ relate to logistics theory in terms of logistics literature and standards (e.g., UN/CEFACT, SCOR). Second, domain experts – developers of logistics software, logistics experts and managers – participated in workshops to contribute to the development of the CQ. Table I depicts some general CQ, which are further extended and substantiated.

TABLE I. Competency Questions

CQ1:	What actors participate in the provision of logistics services?
CQ2:	What roles can logistics actors play?
CQ3:	What types of logistics services are offered by LSP?
CQ4:	Which functional and nonfunctional parameters characterize logistics services?
CQ5:	Which metrics characterize logistics service performance?
CQ6:	Which logistics units and goods flow through supply chains?
CQ7:	Which resources are needed for logistics services provision?

C. *Logistics Ontology Modeling*

The objective of the logistics ontologies is to capture and structure overall knowledge of the logistics domain to annotate logistics services. The logistics ontologies from [7] are further extended and modularized to facilitate reusability, extensibility, and maintainability. To encode the logistics ontologies we apply OWL 2 DL [25].

Figure 3 zooms into Layer 1 and provides an overview of the modularly organized logistics ontologies, their concepts, and relations.

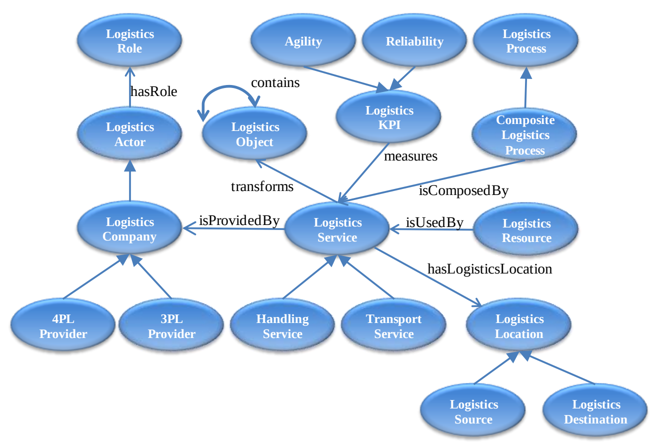

Figure 3. Logistics Ontologies

The main component of the logistics ontologies is the Logistics Service Ontology. Its fundamental concept is LogisticsService that encapsulates spatial, temporal, and quantitative transformations according to the logistics basic functions: transport, handling, warehouse, and complementing value-added services. Logistics companies provide logistics services that respectively represent a temporally and factually logic finite sequence of states to completely transform a logistics object.

$$\text{LogisticsService} \equiv \text{TransportService} \sqcup$$

HandlingService ⊔ WarehouseService
LogisticsService ⊑ ∀isProvidedBy.LogisticsCompany ⊓ ∃transforms.LogisticsObjects

The Logistics Process Ontology is especially important with respect to Layer 3 in order to handle dynamic aspects of real-world logistics complexity. Its key concept is Logistics-Process, which comprises atomic or composite logistics processes. Thereby, a composite logistics process conforms to a composition of at least two logistics services. For instance, a transport process contains various logistics services (e.g., transport, handling) being composed to realize the pre-, main, and on-carriage of a supply chain.

LogisticsProcess ≡ AtomicLogisticsProcess ⊔ CompositeLogisticsProcess

Subject to logistics transformations are Logistics Objects. According to the logistics unit-load concept, logistics objects are a combination of economic goods with charge carriers. For instance, microprocessors (goods) are packaged in boxes (charge carrier), which are in turn consolidated on pallets and/or containers. The unit-load concept aims at a smooth flow of logistics objects from source to destination.

LogisticsObject ⊑ ChargeCarrier ⊔ Good ⊔ ∃isTransformedBy.LogisticsService
ChargeCarrier ≡ Container ⊔ Box ⊔ Pallet

A supply chain consists of actors, which are defined in the Logistics Actor Ontology. Logistics actors are either individuals or corporative actors, i.e., legal entities created for business ventures. To model logistics actors, we consider the way they participate in supply chains. For instance, we distinguish between logistics companies dealing with the provision of logistics services and manufacturers aiming at the production of goods.

LogisticsActor ≡ LogisticsCompany ⊔ Authority ⊔ ManufacturingCompany ⊔ TradingCompany
LogisticsCompany ⊑ 2PLProvider ⊔ 3PLProvider ⊔ 4PLProvider

Further, we introduce the Logistics Role Ontology to depict the capabilities and responsibilities of logistics actors in a supply chain. The concept LogisticsRole is inevitable because a logistics actor could have different roles at a certain point in time or over a particular time period, e.g., a manufacturer may simultaneously act as a requester of logistics services or supplier of goods to another manufacturer.

LogisticsRole ⊑ ServiceProvider ⊔ ServiceRequester ⊔ Supplier ⊔ OEM

Whereas logistics services conform to the process organization (dynamic component) of a supply chain a Logistics Location Ontology represents the structural organization of supply chains. Therefore, we combine general location concepts such as country, zip code, city, and street with specific logistics concepts, e.g., source, and destination. For instance, the availability and performance of a transport service is strongly determined by the logistics object, its source, and its (final) destination (e.g., location of a manufacturer).

LogisticsLocation ⊑ LogisticsSource ⊔ LogisticsDestination

Providing logistics services requires Logistics Resources. Logistics resources are factors of production, which are used during logistics service provision. They can be conceptualized according to the different types of logistics services. For instance, providing a road transport service for heavy goods requires a truck being capable to transport goods with a weight greater than 50 tons.

LogisticsResource ⊑ TransportationResource ⊔ WarehouseResource ⊔ ∃isUsedBy.LogisticsService

Moreover, the availability and capability of logistics resources affects logistics service performance. Key performance indicators (KPI) measure logistics service performance. These KPI are modelled in the Logistics KPI Ontology and represent business key figures that assess the degree of logistics service performance. For this purpose, we reuse parts of SCOR [26] to provide a detailed classification of logistics performance indicators.

LogisticsKPI ⊑ Agility ⊔ Costs ⊔ Reliability

Beyond, we reuse and extend existing ontologies either specific to the domain of logistics or ontologies with a more general character. For instance, to model hazardous goods we reuse the hazardous goods ontology. Additionally, we reuse an ontology containing airport codes to unambiguously define airports as locations. To represent units of measurement we reuse and extend the units of measurement ontology (MUO).

V. EVALUATION

Ontologies are complex engineering artefacts. Their evaluation is crucial to fully put their potential into practice, to make them reusable, and maintainable. For instance, incorrect and low quality ontologies might not be readable due to vocabulary and/or syntax errors, and, in the case of incorrect semantics, they might not be usable by reasoning engines. The evaluation includes logistics vocabulary, semantic interoperability, and information integration.

A. *Vocabulary of the Ontologies*

Evaluation of the vocabulary of the logistics ontologies is based on the CQ and performed as a classroom experiment that simulates expert evaluation. The class room experiment comprised a review group of twenty persons. The group was composed of ten university students with a strong background in logistics and ten logistics practitioners. The review group was given the task of comparing and assessing the concepts/relations of the logistics ontologies with the keyword index of selected logistics textbooks and standards. To capture the results of the class room experiment, we used match strength. To achieve operationalization, we applied an ordinal scale with: 1st quartile below 25% (poor), 2nd quartile between 26% and 50% (satisfactory), 3rd quartile between 51% and 75% (adequate), and 4th quartile between 76% and 100% (good). For instance, the match strength 'adequate' displays that between 51% and 75% of the concepts and relations contained in the respective logistics ontology appear in the key word index of logistics textbooks. Homonym and synonym conflicts were dissolved.

TABLE II. OVERVIEW OF VOCABULARY EVALUATION

Logistics Ontologies	Logistics textbook [27]	Logistics textbook [28]	Logistics standard [29]	Logistics standard [30]
Logistics Process	adequate	adequate	adequate	poor
Logistics Service	good	good	good	adequate
Logistics Object	good	good	good	satis-factory
Logistics Actor	good	good	satis-factory	poor
Logistics Role	satis-factory	satis-factory	satis-factory	poor
Logistics Location	good	good	adequate	poor
Logistics Resource	satis-factory	good	adequate	satis-factory
Logistics KPI	satis-factory	adequate	adequate	poor

The experiment shows empirical evidence (Tab. II) indicating that across all developed logistics ontologies the match strength is good in 34% (11 out of 32), adequate in 25% (8 out of 32), satisfactory in 25% (8 out of 32), and poor in 16% (5 out of 32). Occurring deviations could be explained by (1) the transfer of concepts originating in SOC to the logistics domain, which in particular holds for the concepts of the Logistics Process Ontology, (2) terminological heterogeneities existing in logistics literature, and (3) the human factor when performing such experiments. In particular, the results in column 5 are influenced by the specificity of the corresponding logistics standard.

B. *Semantic Interoperability and Information Integration*

The logistics ontologies constitute a consensual terminological basis for semantic annotation of logistics services. Since logistics implies communications beyond organizational borders at a global range, there exists an urgent need of integrating heterogeneous and distributed data sources, in particular, to achieve semantic interoperability. The logistics ontologies should support the mediation between heterogeneous data sources and enable unambiguous service annotations. To illustrate the problem related to semantic interoperability, we review common terms and definitions used in conventional service descriptions of three real-world LSP and show respectively how they relate to concepts in the logistics ontologies.

TABLE III. SEMANTIC INTEROPERABILITY

Ontology Concept	LSP_1	LSP_2	LSP_3
Transport Service	Complete load	Full load	Truck load
Logistics Objects	General cargo	Parceled goods	Piece goods
2PLProvider	Shipper	Haulage contractor	Forwarder
Transportation Resource	Truck	Lorry	Commercial vehicle
Logistics KPI	Lead time	Period of supply	Time of delivery

Based on the content of Table III, we present an example originating from real-world data to demonstrate the evaluation of semantic interoperability in the proposed logistics ontologies. Thereto, we pose queries against the logistics ontologies formulated in SPARQL [31]. 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 by using the semantics of the ontology language.

Example: A manufacturing company requests a 4PL to provide logistics capabilities, which correspond to the capabilities of the logistics company type 'shipper'. To find all names of logistics companies that provide such capabilities, a query is formulated as follows:

```
PREFIX lo: http://www.interloggrid.org/
LogisticsOntology.owl#
SELECT ?logisticsCompany ?logisticsCompanyName
FROM <http://www.interloggrid.org/
LogisticsOntology.owl#>
WHERE {
  ?shipper rdfs:subClassOf ?2PLProvider.
  ?2PLProvider rdfs:subClassOf ?logistics
     Company.
  ?logisticsCompany lo:hasFirm lo:logistics
     CompanyName.}
```

The output of the query, comprises names of Logistics Company instances of LSP_1, LSP_2, and LSP_3. This is due to the fact that we established equivalence among the classes Shipper, Forwarder, and HaulageContractor, being all subclasses of 2PLProvider.

VI. CONCLUSION AND FUTURE WORK

The paper proposed dedicated logistics ontologies to semantically annotate logistics services. The overall approach combines SWT and SOC, applying them on the logistics domain for flexible and intelligent SCM. We propose a three-layered model for engineering semantic logistics services. This model includes elements to describe both declarative as well procedural aspects. The main focus is on the foundation of the three-layered model constituted by dedicated logistics ontologies. The logistics ontologies are modularly organized and capture the overall concepts of the logistics domain. The application of these ontologies fosters semantic annotation of logistics services and facilitates semantic interoperability, information integration, and reasoning capabilities allowing for intelligent applications. The evaluation comprises aspects of the logistics ontology vocabulary, semantic interoperability, and information integration. This work provides logistics ontologies for advanced and more flexible provision of logistics services to enhance dynamic configuration of complex supply chains. This would be of particular benefit to all participants in cooperative logistics scenarios assuming that the logistics ontologies are used to describe (annotate) logistics services.

Future work includes an extensive documentation and the full integration, as well as application of the logistics ontologies in a logistics platform prototype.

REFERENCES

[1] M. Christopher, “The Agile Supply Chain: Competing in Volatile Markets,” *Industrial Marketing Management*, vol. 29, Jan., 2000, pp. 37-44, doi:10.1016/S0019-8501(99)00110-8.

[2] P. Helo and B. Szekely, “Logistics information systems. An analysis of software solutions for supply chain co-ordination,” *Industrial Management & Data Systems*, vol. 105, Jan. 2005, pp. 5-18, doi:10.1108/02635570510575153.

[3] J. Leukel, A. Jacob, P. Karaenke, S. Kirn, and A. Klein, “Individualization of Goods and Services: Towards a Logistics Knowledge Infrastructure for Agile Supply Chains,” Proceedings AAAI Spring Symposium (AAAI), Mar. 2011, pp. 36-49.

[4] B. Iyer, J. Freedman, M. Gaynor, and G. Wyner, “Web services: enabling dynamic business networks,” *Communications of the Association of Information Systems*, vol. 11, 2003, pp. 525-554, http://aisel.aisnet.org/cais/vol11/iss1/30.

[5] M. Papazoglou and W.-J. van den Heuvel, “Service oriented architectures: approaches, technologies and research issue,” *The VLDB Journal*, vol. 16, Mar. 2007, pp. 389–415, doi:10.1007/s00778-007-0044-3.

[6] R. Studer, R.V. Benjamins, and D. Fensel, “Knowledge engineering: Principles and methods,” *Data and Knowledge Engineering*, vol. 25, March 1998, pp. 161–197, doi:10.1016/S0169-023X(97)00056-6.

[7] J. Hoxha, A. Scheuermann, and S. Bloehdorn, “An Approach to Formal and Semantic Representation of Logistics Services, “ Proceedings of the ECAI’10 Workshop on Artificial Intelligence and Logistics (AILOG10), Aug. 2010, pp. 73-78.

[8] O. Wendt, T. Stockheim, S. Grolik, and M. Schwind, “Distributed Ontology Management Prospects and Pitfalls on Our Way Towards a Web of Ontologies”, Dagstuhl Workshop, 2002.

[9] C. Chandra and A. Tumanyan, “Organization and problem ontology for supply chain information support system,” *Data & Knowledge Engineering*, vol. 61, May 2007, pp. 263–280, doi:10.1016/j.datak.2006.06.005.

[10] A.M. Madni, W. Lin, and C.C. Madni, “IDEON TM: an extensible ontology for designing, integrating and managing collaborative distributed enterprises,” *Systems Engineering*, vol. 4, Feb. 2001, pp. 35–48, doi: 10.1002/1520-6858(2001)4:1<35::AID-SYS4>3.0.CO;2-F.

[11] H.K. Lin, J.A. Harding, and M. Shahbaz, “A Manufacturing system engineering ontology for semantic interoperability across extended project teams,” *International Journal of Production Research*, vol. 42, 2004, pp. 5099–5118, doi: 10.1080/00207540412331281999.

[12] H.K Lin and J.A. Harding, “A manufacturing system engineering ontology model on the se-mantic web for inter-enterprise collaboration,” *Computers in Industry*, vol. 58, June 2007, pp. 428–437, doi: 10.1016/j.compind.2006.09.015.

[13] F. Fayez, L. Rabelo, and M. Mollaghasemi, “Ontologies for supply chain simulation modeling,” Proceedings of the 37th Conference on Winter simulation (WSC’05), Dec. 2005, pp. 2364–2370.

[14] J. Leukel and S. Kirn, “A Supply Chain Management Approach to Logistics Ontologies in Information Systems,” Proceedings of the 11th International Conference on Business Information Systems (BIS08), Springer LNBIP, May 2008, pp. 95-105.

[15] R. Haugen and W.E. McCarthy, “REA, a Semantic model for Internet Supply Chain Collaboration,” ACM Conference on Object-Oriented Programming, Systems, Languages, and Applications, Business Objects and Component Design and Implementation Workshop VI: Enterprise Application Integration, Oct. 2000, http://jeffsutherland.org/oopsla2000/mccarthy/mccarthy.htm, <retrieved: March, 2012>.

[16] D. Pawlaszczyk, A.J. Dietrich, I.J. Timm, S. Otto, and S. Kirn, “Ontologies Supporting Cooperation in Mass Customization - A Pragmatic Approach,“. International Conference on Mass Customization and Personalization – Theory and Practice in Cebtral Europe, Apr. 2004, pp. 1-19.

[17] A. L. Soares, A.L. Azevedo, and J.P. De Sousa, “Distributed planning and control systems for the virtual enterprise: organizational requirements and development life-cycle,” *Journal of Intelligent Manufacturing*, vol. 11, June 2000, pp. 253–270, doi: 10.1023/A:1008967209167.

[18] Y. Ye, D. Yang, Z. Jiang, and L. Tong, “An Ontology-based Architecture for Implementing Semantic Integration of Supply Chain Management,” *International Journal of Computer Integrated Manufacturing*, vol. 21, Jan. 2008, pp. 1–18, doi: 10.1080/09511920601182225.

[19] M.N. Huhns and M.P. Singh, “Service-oriented computing: key concepts and principles,” *IEEE Internet Computing*, vol. 9, Jan./Feb. 2005, pp. 75–81, doi. 10.1109/MIC.2005.21.

[20] OWL-S: Semantic Markup for Web Services, http://www.w3.org/Submission/OWL-S/, <retrieved: March, 2012>.

[21] J. Hoxha and S. Agarwal, “Semi-automatic Acquisition of Semantic Descriptions of Processes in the Web,” Proceedings of The International Conference on Web Intelligence and Intelligent Agent Technology (WI-IAT'10), IEEE, September, 2010, pp. 256-263, doi: 10.1109/WI-IAT.2010.271.

[22] M.A. Razzaque and C.C. Sheng, “Outsourcing of logistics functions: a literature survey,” *International Journal of Physical Distribution & Logistics*, vol. 28, Apr. 2008, pp. 89-107, doi . 10.1108/09600039810221667.

[23] A. Win, “The value a 4PL provider can contribute to an organi-sation,” *International Journal of Physical Distribution & Logistics*, vol. 38, 2008, pp. 674-684, doi: 10.1108/09600030810925962.

[24] M. Uschold and M. Grüninger, “Ontologies: Principles, Methods, and Applications,” *Knowledge Engineering Review*, vol. 11, Feb. 1996, pp. 93–155, doi. 10.1109/MIS.2002.999223.

[25] OWL 2 Web Ontology Language (OWL2), http://www.w3.org/TR/owl2-profiles/, <retrieved: March, 2012>.

[26] Supply-Chain Council. 2010. Supply Chain Operations Reference Model (SCOR®) Vers. 10.0, http://www.supply-chain.org, <retrieved: March, 2012>.

[27] H.C. Pfohl, Logistiksysteme. Betriebswirtschaftliche Grundlagen. Heidelberg et al., Springer, 2010.

[28] T. Gudehus, Logistik. Grundlagen, Strategien, Anwendungen. Berlin, Springer, 2005.

[29] Deutsches Institut für Normung (DIN): Transportdienstleistungen – Logistik- Glossar. DIN EN 14943:2006-03, 2006.

[30] Deutsches Institut für Normung (DIN): Transportkette-Grundbegriffe. DIN 30781 Teil 1, Teil 2, Beiblatt Teil 1, 1989.

[31] E. Prud'hommeaux and A. Seaborne, “SPARQL Query Language for RDF,” W3C Recommendation 15 January 2008, http://www.w3.org/TR/rdf-sparql-query/, <retrieved: March, 2012>.