Supporting Value Chain Integration through Ontology-based Modeling

Corinna Engelhardt-Nowitzki
Logistikum, Upper Austrian University of Applied Sciences, Wehrgrabengasse 1-3, A-4400 Steyr, Austria
corinna.engelhardt@fh-steyr.at

Klaus Arthofer
Process Management in Health Care
Upper Austrian University of Applied Sciences
Wehrgrabengasse 1-3
A-4400 Steyr, Austria
klaus.arthofer@fh-steyr.at

Natalia Kryvinska, Christine Strauss
Department of eBusiness, School of Business, Economics and Statistics, University of Vienna
Bruenner Strasse 72, A-1210 Vienna, Austria
natalia.kryvinska@univie.ac.at, christine.strauss@univie.ac.at

Abstract—Operational communication and coordination between companies are most important in economic value networks. However, there are huge shortages concerning the integration of heterogeneous cross-company systems. Relevant supply chain management (SCM) issues, such as fast and flexible reaction of all companies concerned to the value creation process of a certain product, are not sufficiently facilitated. Thus, the ontological modeling could improve significantly the cross-company coordination proficiency through a semantic harmonization that enables faster and faultless information flows. However, ontologies are not yet applied broadly in SCM. Therefore, we first describe the state of the art regarding ontology-use in SCM and characterize actual business needs. Then, we propose a layer-based ontology framework for SCM, including basic modeling principles for each relevant layer. Further, possible obstacles that might inhibit a smooth integration of related information services are discussed. Finally, we draw conclusions regarding the consequences for information and business services and related architectural design.

Keywords: Cross-company integration, value network ontology, supply chain management (SCM), information services

I. INTRODUCTION

Increasingly fluctuating demand requirements, complex value network interdependencies and accelerated technology cycles have remarkably intensified the competitive challenges for most companies. This, in particular, concerns rising demand individualization and a distinct responsiveness towards short-dated change expectations from customers regarding delivery dates, volumes and product specifications. Thus, short lead and reaction times are critical success factors and have to be achieved despite the fact that current value creation processes usually will involve many, at most legally independent enterprises. Additionally, the majority of companies are concentrating on their core competencies, hence outsourcing non-core activities to other firms, e.g., suppliers, subcontractors or service providers. This leads to a highly fragmented division of labor throughout the value network. Depending on the in each value creation stage sold products, applied technologies, required services and purchased parts, the material flows may be convergent, linear or divergent. This, all in all, establishes a dynamic network topology. Respective SCM capabilities, especially a huge operational flexibility [1] and a proficient capability to adapt to structural changes [2], require a proficient cross-company information flow. Some authors even state the lack of a common taxonomy to be a main obstacle for the necessary integration of value network partners [3].

Ontological data modeling can be applied in an enterprise or SCM context for developing a standardized terminology to describe and subsequently computationally process relevant entities, relations, functions and rules. However, the use of harmonized cross-company knowledge domains is not yet common in practice [4], though a unified vocabulary offers substantial benefits also in a value network context. For instance, a uniform nomenclature of purchased parts (from the counter-perspective: sold items), could save enormous non-value-adding efforts (time and cost) regarding data harmonization and administration. Further, the failure rate and respective delivery delays could be remarkably reduced.

Thus, the objective of the present paper is, firstly, to inspect the mentioned gap between principle benefit potentials and the, even so, rather un-frequent application of ontology-based modeling techniques in a SCM context. Secondly, managerial implications are proposed and further research need is identified regarding the consequences for the design and application of information services.

Section 2 shortly defines relevant terms, discusses the principle advantageousness of value network ontologies, provides a literature review regarding the distribution of respective applications and mentions possible obstacles for a more widespread practical usage. Following, Section 3 uses a generic SCM layer model to substantiate interdependencies between technical and non-technical aspects of ontology-application and deduces managerial implications. Finally, the concluding section 5 mentions future prospects and shortly reflects on further research needs.
II. BENEFIT POTENTIALS OF ONTOLOGY-BASED MODELING TECHNIQUES IN THE CONTEXT OF ECONOMIC VALUE NETWORKS

The concept of ontology derives from philosophy, where it originally constituted fundamental assumptions about the existing reality [5]. Currently, the term ontology is used heterogeneously [6, 7]. In an epistemological context it indicates the essence of a certain knowledge domain, closely exploring its nature, fundamental concepts and theory-based laws. In contrast to this, ontological engineering assumes ontology to represent a semantic structure that “codifies features of things” [8, p. 5]. In this understanding a value network ontology incorporates economic entities (for instance, products, product variants, purchased parts, customers, suppliers etc.), relations between them and rules regarding their interaction. The definition, proposed in Benjamin et al. [9], states more concretely that ‘ontology’ describes physical and conceptual things that characterize a certain domain in terms of their attributes and relationships, using a formal language. Like any theory, also logistics theory provides an ontological framework [10], especially applying process modeling techniques to establish business rules, processes and organizational enterprise views [11] throughout a value network. However, there are lacking capabilities to apply multiple enterprise views and insufficiencies regarding a top-down process design in a cross-company SCM context [11].

Despite the obvious fact that there will be only few un-ramified network structures (linear ‘chains’), we nevertheless use the practically well established term SCM for the management approaches and methods, applied in the single companies that are participants of an economic value network. Anyway, our understanding of SCM implies a network-oriented perspective towards supply-side and sell-side processes, thus requiring logistics capabilities regarding demand management as well as supply-management. [10]. Herewith, we assume that managerial decisions are not taken by an abstract construct as ‘a value network’ or ‘a supply chain’, but in each single company that is in most cases part of several value creation processes (e.g., in different business units or markets). Hence, a value network is a heterarchical system [e.g., 12 ÷ 14] consisting of companies (network knots) with a mutually varying influence on other network participants. The interconnections between the knots represent cross-company cooperation. The literature often states, that supply chains compete with supply chains [see e.g., 15]. In our opinion this is a misleading interpretation unless several enterprises agree to jointly constitute and act as a strategic alliance (e.g., an informal working committee or a new legal entity), thus aligning decisions among each other and putting back at least some. Although this happens (e.g. a retailer cooperative) a predominant handing over of decision power, away from the acting companies towards the established alliance will be an exception.

The use of ontology-based modeling techniques is potentially beneficial for all relevant SCM domains:

- **Value network design**: this task provides the fundamental base for efficient and effective SCM [16], especially through configuring supply and distribution partners and flows. A shared ontology could alleviate the cross-company coordination remarkably
- **Value network boundary spanning**: since the number of tier1-customers and -suppliers, not to mention tier2 - tiern participants, usually forecloses exhaustive value network analysis, the critical, performance-influencing network segments have to be identified [17] through network boundary spanning. A common semantic understanding between relevant network participants could notably accelerate respective evaluation efforts, thus enabling a continuous application even in turbulent markets.
- **Value network planning**: this regards the coordination of materials and resources in a value network, taking into account customer service requirements and cost issues [18]. Again an ontology-based harmonization could reduce efforts and failure rates. Furthermore, continuous plan adjustments could be accelerated, thus allowing for the use of planning techniques also within shortening plan-validity time-spans.
- **Execution and optimization**: incorporates all activities, related to order processing, in particular production and transport activities [19] and its improvement. The use of ontologies could, in particular, support cross-company interfaces, especially through the support of operational flexibility (for instance, a rapid routing of change information through the network, across company boarders). Dynamic network phenomena as, for instance, the bullwhip effect, could be avoided to a remarkable extent through a suchlike synchronization.

The importance of a sound cross-company harmonization of vocabulary and interpretations for joint value-flow performance improvement is also supported in the literature. For instance, Brock et al. [20] claim flexible and dynamic description means for, firstly, enabling each single value network partner to build its own particular view and, secondly, enhancing the interoperability between companies. However, in most cases, different network actors will use different terms for equal or similar entities or coherences. Another, often occurring phenomenon is the appearance of target conflicts between actors. Finally, mutually differing perceptions of the same value network relationship may impact the business transactions between two contracting parties negatively, for example, if the reciprocal importance is evaluated differently. In the face of these conditions [cp. 4, 15 or 17], operating a business is a managerial challenge that has to be methodically well-supported.

Subsequently, several research initiatives have developed enterprise ontologies [e.g., 21]. Although the existing literature regarding enterprise- or value network ontologies is not yet voluminous, nor sufficiently exploited regarding SC-interoperability [4, 22], several conceptual contributions and also empirical applications provide insight into possible
ways to utilize ontology-based modeling techniques for the facilitation of SCM.

Basic supply chain ontologies are presented for instance in [23 - 26]. A specific emphasis should be given to the issue of heterogeneous information resources in a increasingly networked environment, herewith appropriately specifying metadata, ontology, and the mapping of relationships based on differing data formats [27]. Further, the semantic interoperability of product information is a vital enabler of value network cooperation [28, 29], since a proficient inter-organizational knowledge sharing relies much on the exchange of digital objects. Global interoperability standards (e.g., EAN, SCOR or at the IT-layer, EDI, XML) are highly important for the final performance of a value network towards the end-customer. However, ontology can accelerate network information only, if semantic precision is achieved. Besides, well-working semantic links have to be established between differing logistic models. In doing so, each entity has to be defined uniquely [20]. In the face of the dynamic and heterogeneous nature of value networks, in particular the consistent definition of relationships and rules is a challenging issue for the underlying information system architecture. Otherwise an ontology application might not yield potentially possible benefits [28]. Also, concrete ontological B2B e-commerce specifications have been developed, for example, in [30] up to a prototypic status.

Altogether, a smooth and reliable integration of network participants, in other words, a collaborative coordination of material-, information- and financial flows [31], is highly appreciable in principle, has proven its advantageousness in singular concrete examples but has not yet matured far enough in practical environments. Besides other issues, such as opportunism or mutually differing market power, one specific problem is, that there is no commonly agreed ‘value network ontology’ to alleviate company integration [4].

III. TECHNICAL AND NON-TECHNICAL VALUE NETWORK ONTOLOGY SPECIFICATION USING A GENERIC SCM LAYER MODEL

The use of layer models is common in informatics or automation [32 - 34], but less often found in a SCM context. In previous work [35, 36], we have proposed a generic model for this purpose (see Fig. 1).

Comparable to informatics, the basic principle is to conceptually encapsulate the layers to enable partial modeling steps at a in each case reduced complexity level. In order to achieve effective, reliable and efficient material flows between companies, each layer firstly, has to be designed and controlled adequately and secondly, has to achieve the aforementioned semantic precision and interoperability. If being extended on a cross-company context, the proposed layer model has to regard the following rules:

- ‘horizontal’ layer consistency: each layer is responsible for a sufficient performance inside its own borders; this means that, for example, process descriptions and interfaces (layer 4 in Fig. 1) have to be defined consistently not only within the company borders, but also with external parties (contracted suppliers, service providers, subcontractors, customers etc.)
- ‘vertical’ layer consistency: each layer is responsible for a proper communication towards surrounding layers; comparable to the first rule, also the vertical layer consistency has to be ensured inside and between the participating companies.

In contrast to technical layer models the SCM model doesn’t assume a layer sequence with a strict 1:1 link between the single layers, but rather adopts m:n relationships between layers – at least for the upper, non-technical layers 1-4. For example the business processes might be influenced by all three upward layers or the motivation of the employees might be determined from upward and downward layers in this model. As a project further advances toward technical architecture design and system implementation, the two lower technical layers might be detailed further through more specific models (e.g., database-, network- or operating system architectures).

In order to apply the generic SCM layer model to the present context of ontological value network modeling, we recommend using a top-down approach that first specifies the surrounding business determinants within a specific network segment (layer 1) and subsequently proceeds to define the specifications for all following layers – herewith conducting iterative corrections, if required due to the interdependency of the layers.

Layer one, the general external conditions, has to be analyzed carefully in the first step. While collecting the necessary data – e.g., regarding market data, competitive influences or the legal framework – the relevant definitions and terms from heterogeneous sources have to be compiled into a semantically harmonized model the represents the ontological framework for the acting company. Thus, using as many given standards as possible and uniquely defining non-standardized information, a first ontological
understanding is already created during the strategic value network scenario set-up.

Subsequently the fundamental business determinants (market conditions, competitors, products and customers, technology, supply conditions etc.) are defined in the course of business plan establishment, including the applied business strategy and objectives. This includes the aforementioned steps of value network design and network boundary spanning. The result is a rough map of the relevant surrounding economic value network topology (represented through the gray-shaded area in Fig. 2).

![Value network topology and network boundary spanning](image)

Since the basic value network conceptualization that has been defined through the focal company (layer 1), might not necessarily be shared from surrounding network participants, a respective communication between the relevant actors has to be established. Depending on the specific business scenario, this can be done on a bilateral communication or negotiation process, or within respective cross-company working committees – eventually even differentiated by region, industry branch or similar. The result for the focal company should be a strategic value network map that provides a valid model for the following layer-determining steps.

The following layers 2-5 are defined in a next, iterative step. In doing so, not the entire value network is enclosed, but only those areas that are indicated to be relevant according to the network boundary spanning results. Compared to the semantic harmonization on the first layer, the establishment of a value network ontology concerning the layers 2-5 will require a more detailed model and a respectively intensified communication with concerned tier 1 customers and suppliers. Typical harmonization requirements can be found on each layer and have to be addressed business-specifically, for example:

- Within any relevant dyadic company-relationship (e.g. customer-supplier), the most probably differing company cultures – in particular, decision behavior, communication means and trust-building issues – must be aligned at any point where they concern the interface between the parties and respective value or information flows (layer 2). For the focal company this means to establish a high proficiency, to select well-fitting value network partners, to design reliable and agile value flows despite the need to integrate heterogeneous firms and to setup a common understanding of important terms. For example a ‘delivery reliability target’ or a ‘service order confirmation’ must be based on compatible conceptualizations and mutual expectations to sustain and intensify a reciprocally achieved trust level.

- Each dyadic relationship has to setup contractual agreements to determine the inter-organizational material, information and financial flows. Since it is impossible, to establish complete contracts ex ante [38], also governance mechanisms have to be settled between the partners for ex post coordination (layer 3). Comparable with company-internal service level agreements, contracts and governance means have to be based on a common understanding of underlying matters. In order to reduce the necessary efforts and transaction cost [39] to a feasible level, it is recommendable, to define clusters (e.g. of suppliers, parts, products, geographic regions etc.) that can be handled using standardized means. These standardized organizational frameworks should be part of the value network ontology in layer 3.

- In principle there are standardized process models, e.g. SCOR [40], to harmonize the relevant processes – sourcing, production, distribution, planning etc. – across company-borders and in different business scenarios (make-to-stock, make-to-order, etc.). However, such business process standard models (layer 4) are not yet widespread in practical use. If, therefore, a company has to handle value chain constellations with an only partially standardized process landscape, the same segmentation approach should be used as recommended for layer 3. The higher the percentage of external partners that are using standardized process reference models, the less, the effort for semantic harmonization will be.

- Assuming the superior layers to be sufficiently defined among the relevant partners (fig. 2), the next steps are regarding the facilitating information services (layers 5 and 6). On these levels, ontologies can contain complex data structures with a large number of individuals.

A common ontology definition language for this purpose that can be seen as a meta-data model is the “Web Ontology Language” (OWL) [41]. OWL incorporates three essential concepts: individual, property and class [42, 43]:

- **Individuals** represent physical or virtual entities, e.g., a part, a product, a program, an employee, a machine and so forth. Individuals are instances of a class, i.e. their members.
• **Classes** are a hierarchically organized set of individuals, defined by membership rules, thus, altogether establishing a taxonomy. Properties are recursively inherited from a superclass to all its subclasses.

• **Properties** are binary associations that relate an entity either to a value (similar to the attribute concept in relational database architectures), e.g. a data value (numerical, string etc.), or to another entity (similar to a relation in relational databases).

OWL also provides several rules and functionalities to ensure the validity of contained entities, the so-called ‘reasoners’ [see 43]. Also numerous APIs are available. A broad variety of ontology editors serves ontology construction and the subsequent programming of ontology-based applications. Further, a specific query language, SPARQL, is available [44]. Thus, an application that is build upon this model instead of a direct instantiation on the underlying data model is highly adaptive. This is especially important, if turbulent market conditions (layer 1) are demanding modifications of the business setting (layers 2-5) – e.g. new suppliers, changed contract modes or modified delivery interfaces between companies. Thus, an OWL-based data definition enables a domain-independent software development. This offers remarkable advantages: the cross-company adaptation to demand fluctuations, changing production technologies or raw material market shifts is facilitated throughout the relevant value chain segments.

A previous industrial case study of the authors [4] has proven the feasibility of common development approaches [cp. 8, 45]:

• In the first phase, specification, the objective should be twofold: externally, the focal company has to achieve value network transparency. Internally, it is most important to establish a semantically well-integrated communication base and common understanding of intentions, objectives and strategic determinants between the responsible company departments and decision takers, that are often using ‘different languages’ according to their specific education and professional backgrounds (layer 1). If ontological modeling is a new method for the involved people, this can at the same time be used for qualification purposes.

• Phase two, conceptualization, requires the close cooperation of the parties responsible for the business process and the experts for ontological modeling, to an agreed view of the specific domain and the respective representation in easily modifiable attributes, relationships and rules. This step is already data-driven, but should respect specification claims from all superior layers. If there are lacks in cross-company semantic harmonization, substantial model invalidity can be the consequence. Thus, it may be necessary to iteratively prove and supplement specific matters on superior layers to achieve an appropriate model, during this step.

• The following phase, formalization, transfers the results from previous steps into a conceptual data model (see the example in fig. 3). The exemplary value network ontology [4] is build around the central class, called ‘Unit’, that enables a company to represent its complete product hierarchy (business unit – product group – product variant – assembly group – part), using the transitive relation ‘consistsOf’. Further relations, ‘is StoredIn’, ‘is FinalizedIn’ and ‘is ProcessedBy’ represent inventory locations (company-internal or external), assigned manufacturing resources and required working steps. According to the actual layer interdependencies (2-4), a working step may be linked to a certain location, factory or value network company. Of course attributes like technical, logistical or geographic information details may be attached as well.

![Figure 3. Value network ontology example [4].](image-url)

• The last two phases are implementation (using OWL) and maintenance (permanent ontology updating). According to the case findings in [4], the company-specific adaptation and extension of the generic ontology, shown in Fig. 3, is a particularly time-consuming step. Since the number of involved entities (e.g., purchased parts) can exceed several thousand, this in particular regards the class ‘Unit’, which allows for modeling all products, assembled parts or even services, offered by a company in cooperation with suppliers and service providers. Even, if a company has got well-structured operating data (e.g., bill of materials, operative production schedules and other ERP-data), and can partially automate such matters using batch scripts, the necessary harmonization efforts shouldn’t be carefully analyzed. This applies even more, if external partners have to be included that are most probably using varying numerical codes and different data structures.

The further progression depends now on the concrete optimization or integration purpose. If, for example, product variants shall be analyzed regarding their favorable or
inopportune influences on participating supply network parties, a next step would be the careful inspection of the bill of materials in the concerning companies. If, to provide another example, a supply network has to increase responsiveness and flexibility towards demand changes, the faster routing of forecast data, order data and order changes between producing companies and part suppliers with a long replenishment lead time could be a subsequent issue of analysis.

IV. CONCLUSIONS AND FUTURE WORK

Effective communication and coordination between companies are most important in economic value networks. Typically, existing process descriptions, data-models and IT-systems support respective company-internal planning and optimization efforts. However, there are huge deficits concerning the integration of heterogeneous cross-company systems. Relevant supply chain management (SCM) issues, such as the fast and flexible reaction of all companies, concerned with the value creation process of a certain product (distributors, manufacturers, suppliers) in the face of suddenly changing demands, are not sufficiently facilitated. This has multiple reasons of technical and non-technical nature. Ontological modeling could significantly improve the cross-company communication and coordination proficiency through a semantic harmonization that enables faster and faultless information flows. Besides, the distinct reusability, modifiability, extendibility and shareability of ontology-based value network models and software are offering attractive benefits. However, ontologies are not yet applied broadly in SCM. Thus, we explored and described in this paper the state of the art regarding ontology-use in SCM and characterize actual business needs. We also proposed a layer-based ontology framework for SCM, including basic modeling principles for each relevant layer. Furthermore, we discussed possible obstacles that might inhibit a smooth integration of related information services. Besides, we sketched also assumptions regarding the consequences for information and business services and related architectural design principles. In our further work, we plan to examine possible approaches of IT systems deployment for an efficient business services support.

ACKNOWLEDGMENT

We thank the Upper Austrian Government for supporting the research project AGTIL.

REFERENCES


[40] Supply Chain Council, see www.supply-chain.org/

