An Ontology-based Platform to Collaboratively Manage Supply Chains

Tobias Engel (tobias.engel@in.tum.de)
Technische Universität München, Chair for Information Systems – 17, Garching, Germany

Manoj Bhat
Technische Universität München, Chair for Information Systems – 17, Garching, Germany

Vasudhara Venkatesh
Technische Universität München, Chair for Information Systems – 17, Garching, Germany

Suparna Goswami
Technische Universität München, Chair for Information Systems – 17, Garching, Germany

Helmut Krcmar
Technische Universität München, Chair for Information Systems – 17, Garching, Germany

Abstract

Setting up efficient supply chain networks is an important aspect of sourcing and supply chain management. We propose an ontology-based, knowledge-assisted platform to collaboratively create, adapt and steer supply chain networks. Such platforms allow reuse of domain knowledge captured in previous supply chain projects and supports simulation of various network configurations.

Keywords: Supply Chain Management, Collaborative Platform, Knowledge Management

Introduction

Supply Chain Management (SCM) allows firms to manage their upstream and downstream supply chains. This includes the physical flow of goods and information flows among supply chain partners from end users throughout suppliers of raw material (Cooper et al. 1997, Rai et al. 2006). Further, firms realize cost savings by analyzing supply chains and either improve the existing processes or implement new supply chains or supply chain strategies (Clark and McKenney 1994).

Intra- and inter-firm collaboration is crucial for achieving supply chain performance (Horvath 2001, Lee et. al 2000). Collaboration not only allows firms to achieve mutual goals and performance gains by sharing information such as ideas, forecasts, inventory data, knowledge, but also risks and rewards (Cohen and Roussel 2005, Nair et al. 2011). Within the field of SCM, inter-organizational information systems (IOIS) facilitate integration of unique processes across

the supply chain and enable collaborative information sharing (Humphreys et al. 2001, Premkumar 2000). Moreover, intra- and inter-firm collaboration results in greater end-customer satisfaction through improved supply chain visibility, reduced cycle times and increased flexibility to cope up with high demand uncertainties (Kumar and Banerjee 2014). However, the level of collaboration among partners is low, and providing solutions for integrated processes to plan and steer supply chains is a key research area (Cognizant 2014, Ooi et al. 2011).

The advancements in web 2.0 technologies have transformed the way firms collaborate, share, and organize information. Improvements in information and communication technology allow firms to collaborate in effective and efficient ways (Chui et al. 2009). However, managing the supply chain network with all upstream and downstream supply chain flows from the point-of-origin to the point-of-consumption is a challenging task as domain specific knowledge is required (Fawcett 2008), and firms need a platform to collaborate (Ooi et al. 2011). Therefore, supply chain practitioners are required to have domain knowledge to plan, design and manage supply chain structures and their configuration.

Despite that, shorter product-life cycles, increasing competitive pressure and market globalization force supply chain practitioners to shorten the implementation cycles of new supply chains, and to optimize the existing supply chains in more efficient ways. Firms need to ensure a quick, agile and flexible response time to changing customer needs (Lee 2002, Thomas and Griffin 1996). Further, supply chain practitioners need to collaborate across firms´ boundaries complicating implementation and improvement processes. Hence, the collaboration efforts and the dynamic environment create the need for assistance, and the creation of synergies to ensure supply chain performance.

Therefore, it is necessary that existing IOIS evolve and adapt these advancements to support collaborative planning and steering processes. These advancements allow an incorporation of new information and communication technologies to support firms with new collaborative solutions. Further, these solutions will allow firms to handle complex supply chains in a robust, reliable and flexible way using a validated knowledge base. In consequence, we propose a platform – iSupply – to support supply chain practitioners to collaboratively plan, design and manage supply chains within a short response time.

The requirements and advancements are realized within the platform by a feature to collaborate, drawing domain-specific knowledge by comparing existing data with planned data, and providing practitioners with supply chain specific constraints and KPIs. More specifically, to resolve the presented issues, the iSupply platform comprises of four main components, which can be used in a collaborative mode: (a) knowledge base, (b) simulation engine, (c) calculation model and (d) visual editor. The ontology forms the core of the knowledge base, the simulation engine allows "what-if" analysis, the calculation model provides business logic and the diagram editor supports the perception of changes and requirements for the supply chain experts and practitioners. Further, the knowledge base can be classified into (a) *supply chain*, (b) *context* and (c) *logistics* ontology; the simulation engine gives insights for setting supply chain network constraints; and the calculation model presents total supply chain costs using domain specific constraints.

Related work
Domain specific knowledge both tacit and explicit knowledge is often organized within knowledge management systems (Alavi and Leidner 2001). Knowledge management in itself is a systematic approach to capture, structure, disseminate, manage, and reason about the knowledge

throughout a firm (Douligeris and Tilipakis 2006). Previous research shows a growing interest in applying knowledge based approaches in the field of SCM (Marra et al. 2012, Samuel et al. 2011). These approaches integrate knowledge management at the granularity level of technical information, order information, material and financial flows (Pedroso and Nakano 2009). This level of granularity contributes towards achieving strategic goals such as agility, adaptability, and the alignment through efficient knowledge flows and knowledge sharing process (Whitten et al. 2012). In the context of SCM, knowledge flows and knowledge sharing processes represent domain-specific knowledge. However, domain-specific knowledge is not continuously explicit. Therefore, we propose a knowledge-based approach to capture, structure and reuse knowledge of supply chain projects. This includes, but is not limited to, requirements to design, plan, simulate and analyze variants of supply chains for identifying an optimal supply chain network.

Marra et al. (2012) study the role of knowledge management in SCM by reviewing 58 journal articles in which knowledge management approaches are proposed in supply chain context. Their findings highlight (a) Knowledge management and its fit for SCM, (b) a growing interest for applying knowledge management in supply chains projects and (c) the missing discussion on knowledge accumulation and sharing at the granularity of projects with different scenarios of supply chain networks. Further, Samuel et al. (2011) view knowledge management as an enabler for SCM and propose a conceptual framework for knowledge management in supply chains. However, the concepts in the framework are at an abstract level that focuses on capturing tacit and explicit knowledge among supply chain partners. To achieve supply chain competitiveness, Samuel et al. (2011) discuss the need to consider the concepts and the semantic relationships of the supply chain networks in the conceptual models and ontologies.

The benefits of using ontologies such as interoperability among disparate information systems, and reasoning about the knowledge through semantic inter-relationships of concepts are discussed in Douligeris and Tilipakis (2006). They provide only a minimalist view on their SCM ontology along with the use-cases. Despite that, even with such a minimalistic model, the advantages of semantic web technologies have been proven, and can be seen as first steps towards realizing information systems based on ontologies for SCM. Douligeris and Tilipakis (2006) however do not demonstrate in their proposed prototype how to handle knowledge interoperability among disparate information systems.

Knowledge interoperability is hindered by the use of inconsistent terms and semantics in supply chain domain (Ye et al. 2008). Ye et al. (2008) propose the use of ontologies for semantic integration. Further, their ontology is structured into different supply chain categories such as structure, activity, resource and management. This structure allows capturing domain knowledge of supply chains through concepts and their relationships. The challenge of interoperability and knowledge sharing in supply chain context is further addressed by Huang and Lin (2010). Huang and Lin demonstrate how semantic web technologies such as Resource Description Format (RDF) and RDF schema capture the meta-knowledge and address the problem of knowledge interoperability. Hung and Lin propose a platform which includes an annotation process that extracts concepts and relationships from heterogeneous knowledge sources.

Fayez et al. (2005) propose a supply chain ontology by extending concepts from the Supply Chain Operations Reference (SCOR) model. The concepts in supply chain ontology are categorized into different perspectives such as supply chain, enterprise, enterprises' elements, and interaction perspective. The supply chain ontology captures distributed knowledge to build simulation models for decision making in SCM. Fayez et al. (2005) identify three supply chain simulation modeling problems namely: Dynamics, Complexity, and Heterogeneity. To cover the

dynamic aspect, firms have to synchronize their knowledge sources and real-time data should be made available to run simulations and to perform analysis. Further, complexity results in long cycle time of supply chain projects and the solutions offered by the end of the projects might be outdated or the context of the problem could have changed. Finally, heterogeneity of information systems creates a need to harmonize structures, formats and availability of required data. Further, Fayez et al. (2005) discuss how the issue of interoperability can be handled with a supply chain simulation ontology, but miss to address supply chain dynamics and supply chain complexity.

Franzese et al. (2006) and Ruiter al. (2000) propose a template based approach for reusing knowledge and past experiences in supply chain projects. Their case studies show a significant reduction of time and effort in supply chain projects. However, the lack of an extensible conceptual model in these template based approaches makes the applicability very restricted to specific problem domains, and generalization of these approaches becomes difficult.

The importance of domain specific knowledge captured in ontologies for efficient SCM, and the role of web technologies in enabling interoperability and knowledge sharing has been validated in previous research. However, we found a missing integrated approach that addresses all the three aspects of supply chain dynamics, complexity and heterogeneity. In consequence, we propose a platform to enable the activities including knowledge sharing and decision making in an integrated collaborative environment to plan and steer supply chain processes.

Overview
In this section, we first briefly discuss the design science approach used to design and develop the iSupply platform, followed by an overview of the components in the iSupply platform. Design science is a technology oriented research framework (March and Smith 1995). Hevner (2007) propose three closely related activities in design science research, namely:
   (a) *Relevance Cycle*: is an iterative process which identifies opportunities in an application context and defines acceptance criteria for evaluation of the research artifacts. This cycle also involves testing of research artifacts and getting feedback from end-users.
   (b) *Rigor Cycle*: ensures originality in research projects by comparing the planned research contribution against the scientific knowledge base, and allows researchers to contribute their research insights and artifacts to the scientific knowledge base.
   (c) *Design Cycle*: is an iterative process for implementing and evaluating the design artifacts and processes based on the inputs from the relevance and rigor cycle.
   The design of iSupply platform architecture and the development of the prototype loosely follow Hevner's three cycle view of design science research. Introduction and related work section of this paper establishes the *relevance* of our research in SCM domain and captures the opportunities and requirements for the architectural design of the platform. Corresponding to the *rigor* cycle, we ground our design artifacts on the well-established, successfully implemented and tested technological concepts proposed by Bhat et al. (2013), Fayez et al. (2005), Ghaisas (2009), and Ye (2008); this allows us to contribute to the supply chain research community. Further, the internal *design* cycle involves the implementation of the iSupply platform.

iSupply Platform Overview
iSupply is a collaborative platform developed using web 2.0 technologies. The platform allows supply chain practitioners to collaboratively design supply chains in a user-friendly, HTML5-based diagram editor. Within the editor, practitioners have the possibility to visualize the supply chains. Further, the integrated wiki, discussion forum and polls allow practitioners to share

knowledge and communicate while working on supply chain projects. To enable knowledge reuse and collaboration in supply chain projects, iSupply platform incorporates different components such as knowledge base, simulation and collaboration engine and calculation models as depicted in Figure 1. We start by describing the knowledge base and the ontologies, followed by the iSupply platform architecture and its components.
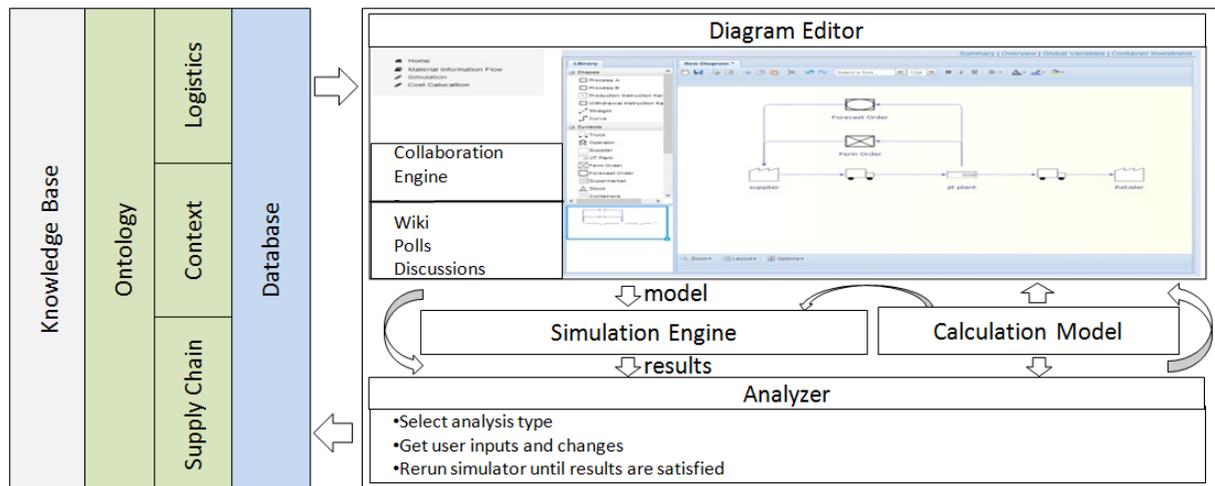

Figure 1 - iSupply Platform

iSupply Knowledge base

The knowledge base serves as an information repository and the integrated components can access this knowledge base through an integration bus. The **knowledge base** comprises of the iSupply ontology which allows capturing, structuring, and selectively reusing domain knowledge. iSupply Ontology is categorized into three ontologies namely supply chain, context and logistics ontology. The *supply chain* and *logistics* ontologies are derived from the existing SCM models proposed by Fayez et al. (2005), Lian et al. (2007) and Ye et al. (2008), and the *context* ontology is derived from (Ghaisas 2009) which defines the scope and boundaries of supply chain projects. An extract of the iSupply ontology is represented in Figure 2.

The **supply chain** ontology captures concepts such as *purpose*, *activity*, *resource*, *structure* and relationship between the concepts. For example, to satisfy specific *business goals* and *purpose,* and to meet *stakeholders'* requirements, supply chain *projects* involve performing *activities* such as *manufacturing*, *packaging*, *maintenance*, and *distribution* over a period of time. These *activities* are managed by *actors* with designated *roles* in an *organization*. *Actors* manage the allocation of *resources* such as *transportation*, *storage* and *human resources* to the *activities* and ensure optimal resource usage and timely completion of the *activities*. Further, the supplier-buyer relationships between *stakeholders* are captured in the supply chain *structure*. A detailed description of these concepts is documented in (Ye et al. 2008).

The **logistics** ontology further extends the concepts in the supply chain ontology through relationships with concepts such as *storage, transportation* and *human resource*. It also consists of concepts including *transportation, truck, truck capacity, frequency, source* and *destination location, round trip cost, manpower, shifts, labor cost, storage surface* and *surface cost* along with associations between concepts in logistics ontology as well as supply chain and context ontology. For instance, let us consider *distribution* of *containers* from a *Just-in-Time (JIT) plant* to different *warehouses* using *trucks* as *transportation units*. The trucks transport *containers*

from the *source* (JIT plant) to the *destination* location (warehouse). The *packaging size* of the container and the *capacity* of the truck determine the *number of containers* transported in one round-trip. Further, the number of containers transported and the *transport cost for one container* from the source to the destination location determines the total *round-trip cost*. The activity *distribution of containers* requires *manpower* for *loading* and *unloading* trucks, *moving*, *sorting* and *piling* arrived containers and so on. The *number of workers* involved in these activities, their *number of shifts* per day and the *unit manpower cost* for each corresponding activity determines the total *labor cost*. Apart from the transportation and human resources, the activity *distribution of containers* also requires *storage resources*. In this scenario, the storage resources are the *JIT plant* and the *warehouses*. A *JIT plant* has allocated *storage area* for performing further actions such as *storing containers* or a *quality check*. In consequence, all activities (costs) are summed up and determine the *total cost of the supply chain*.
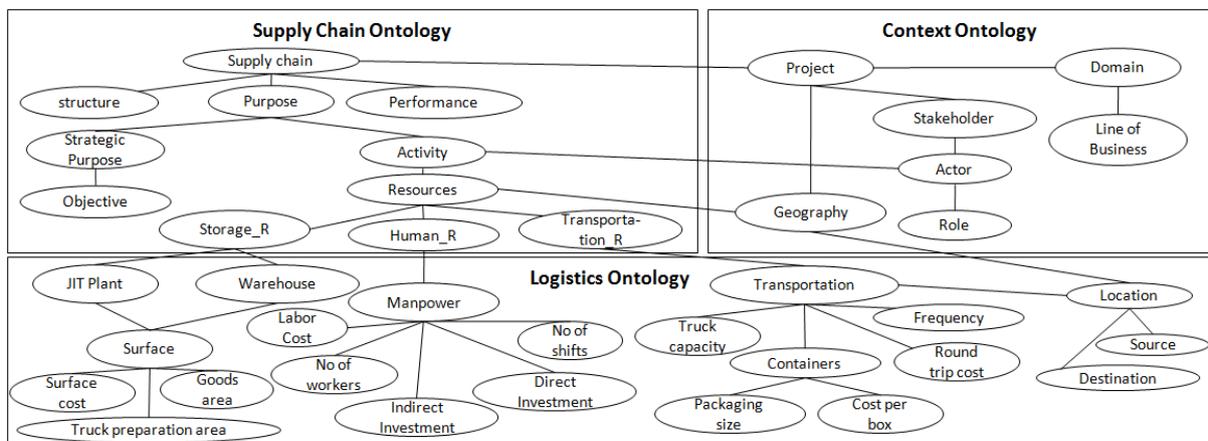

Figure 2-Extract of iSupply Ontology

The **context** ontology captures concepts specific to the project and its environment such as *project*, *domain*, *stakeholder* and *geography*. It also captures association between concepts such as "*project* belongs to a specific *domain*", "*project* is associated with multiple *stakeholders*" and "*project* has a corresponding *geography*". Supply chain practitioners can specify rules and constraints on the concepts in the ontology. For instance, consider a supply chain project in Germany (*geography*), the German law requires 24 working days (wd) as vacation (~11% if we use 220 wd) for direct labor. As an addition, it can be assumed that employees are ill for five wd (equals ~2% in case of 220 wd). Supply chain practitioners can capture such constraints as default values for *vacation* and *illness* attributes of the concept *direct labor* within the logistics ontology. While supply chain practitioners carry out projects with similar context and environment, these rules and constraints in the iSupply ontology allow deriving and presenting recommendations such as the minimum number of days to be considered for vacation and illness of the (direct) labor. This exemplary constraint (data) is further used by the calculation models of the iSupply platform to compute the total cost for (direct) labor in a supply chain.

Further, the data which has been captured throughout the process can be transformed into structured knowledge, and acts as a coherent source of information for the simulation engine and the calculation model within the iSupply Platform. This also allows using the diagram editor and collaboratively working on the supply chain.

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iSupply platform architecture

As in our iSupply platform all components – the diagram editor, the simulation engine, the calculation model and the collaboration engine – are inter-connected, it is necessary to gain a basic understanding of the iSupply architecture. The architecture is adapted from Bhat et al. (2013) enabling all components of the iSupply platform to interact with each other and access the same knowledge base through an integration bus. This inter-connectedness, and the modular setup of the iSupply platform allow users to add new components to the platform by using component adapters. These adapters allow integration of customized software components to the platform. All components are independent and can be (re-)configured or replaced by other components simply by being plugged into the iSupply platform. Further, component adapters provide extensibility allowing users to integrate custom simulation engines, calculation models and collaboration engines.

The **diagram editor** provides supply chain practitioners with the possibility to model the supply chain networks with symbols, derived and extended based on the definition from Erlach (2007). The editor allows to model material and information flows. The used symbols represent objects such as plants, trucks, operators, containers, or forecast order. The HTML 5 based diagram editor allows supply chain practitioners to add these symbols through an implemented drag and drop feature, and to capture specific attributes for each of the constructs.

Simulations form an integral part of the iSupply platform. Once the supply chain practitioners model the supply chain network and capture necessary details and data about the supply chain in the diagram editor, this model is used as input for the simulation engine. Simulations are run to identify bottlenecks in the supply chain network. For instance, simulations provide insights for supply chain network constraints such as the number and frequency of transportation units from the Just-in-Time (Sequencing) plant to the warehouse. Detailed reports of the simulation are presented to the supply chain practitioners, and based on the analysis they can update and re-run the simulation for the chosen supply chain model. For example, Figure 3 presents the report on transportation details from a supplier to a just-in-time plant. The iSupply platform suggests reducing the transport frequency and increasing its transportation units from one truck per day to about two trucks per day, so as to maintain an optimal storage capacity (85%) of the truck. In consequence, the simulation engine allows firms to gain an understanding to optimize specific processes on their own, and see the influence on the complete supply chain.

The iSupply platform consists of an integrated **calculation model** which is responsible for the calculation of all supply chain costs including costs such as transportation, labor, or indirect costs in plants. This allows supply chain practitioners to calculate for each supply chain specific costs, respecting and include the context of the project boundaries and specific rules. Based on these rules the platform calculates the total estimated costs of the supply chain network and presents a detailed report to the supply chain practitioners. The report captures a summary of the total costs per lifetime and total costs per piece.

The **collaboration engine** comprises of wiki, discussion forum and polls. The wiki serves as a documentation platform allowing users to capture and share information such as workflow of supply chain activities including outsourcing, manufacturing, warehousing and distribution. Moreover, users can also tag the content with keywords allowing other users to easily search and retrieve specific content. For example, a user can document the German labor law and tag the information with the keyword "law". At any point when the keyword "law" is searched, all the documents tagged with this keyword including the German labor law are retrieved. Users can

also create groups and discuss specific topics or post questions that could be answered by experts in the discussion forum. The discussion forum not only connects users from different supply chain partners but also provides a quick means to address problems by considering different perspectives from different partners. Further, polls provide an easy way to conduct surveys targeting specific groups or even polls across all the supply chain partners.

Figure 3 - Transportation details from a supplier to a just-in-time plant

In order to collaborate from different geographical locations, the iSupply platform has been developed as a web application, which allows users to simultaneously log-in to the system. In consequence, users can make changes to the supply chain models while mutually view changes and analyze the results in an integrated collaborative environment. As the web application is hosted on an application server, users can access the system using a web browser. No further client-side software installation is required.

Discussion and Implications

Recent benchmark studies on supply chains still reflect the need for improved collaborative and integrated supply chain planning and execution systems (Cognizant 2014 and Lori Simonson 2010). Since firms use a variety of planning components such as demand planning, supply planning, production scheduling, and supply chain network planning, integrating these components are key challenges; especially from an inter-firm perspective.

As discussed in the related work section, semantic web technologies are extensively being used to represent knowledge explicitly to enable interoperability among heterogeneous software components (Huang and Lin 2010, Ye et al. 2008). However, the supply chain ontologies proposed by Huang and Lin (2010) and Ye et al. (2008) do not consider concepts at the granularity level of supply chain projects along with its contextual information. Our research complements the above contributions and extends the existing supply chain ontologies with project specific concepts to enable reuse of knowledge in supply chain projects.

Apart from collaboration and interoperability issues, there also exists a need for shorter cycle times to cope-up with the demanding supply chain markets. Researchers have addressed this challenge through the use of reusable templates (Franzese et al. 2006 and Ruiteret al. 2000). However, these approaches do not discuss how the knowledge captured through the templates can be structured in the knowledge base and do not address the issues of supply chain dynamics

and heterogeneity. We also make use of templates, in the form of reusable projects comprising of supply chain configurations, its underlying models, simulations and results captured and structured in ontologies. The ontology and the knowledge base are incorporated into a collaborative platform for assisting supply chain practitioners to plan and steer processes in supply chain projects by reusing supply chain domain knowledge.

Limitations and future research

The design and development of the collaborative and integrated iSupply platform should be interpreted in the context of its limitations. In our approach, we do not focus on the annotation of heterogeneous information from repositories and mapping of heterogeneous ontologies. However, we build on the knowledge base to enable activities such as simulation and analysis in supply chain projects. It is critical that the knowledge base which acts as a coherent source of information to different components of the platform is consistent and reliable. Further, we did not test the scalability of our platform in real life industry projects; while the platform has been developed in cooperation with two supply chain experts. Thus, further evaluation needs to be done. Evaluation of the platform within the industry will help to identify shortcomings of our developed prototype, and provide new requirements and directions to improve the platform.

Conclusion

The main contributions of this paper are three-fold: We propose the architectural design of an ontology-based, knowledge-assisted SCM platform – iSupply – and discuss how practitioners can reuse supply chain knowledge to handle dynamic, heterogenic and complex supply chain environments. Secondly, the platform assists and guides practitioners in reusing domain knowledge to reduce the time and effort involved in supply chain projects. Thirdly, the platform architecture is extensible and configurable providing supply chain practitioners the flexibility to enhance the system by adding/replacing components.

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