Ontologies for Supply Chain Management

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Abstract

There are many stakeholders involved in supply chain management, and the supply chain itself is a complex, dynamic network that involves suppliers, manufactures, warehouses, retailers, and customers. Ontologies on the other hand are semantic primitives that specify a shared domain of knowledge. Having ontologies for supply chain management will facilitate knowledge sharing and communication among the various supply chain partners. In this paper, we present a methodology for constructing a general-purpose ontology for supply chain management along with the resulting ontology. This general-purpose supply chain management ontology can then be extended into various application areas including supply chain specification, supply chain knowledge management systems, various supply chain models and applications.

Keywords
Supply Chain Management, Ontologies, Knowledge Bases, Knowledge Management, Supply Chain Models.

1. Introduction
Supply chain management entails the management of all the stages involved in fulfilling a customer request. The term supply chain management is relatively new; nevertheless it has its roots throughout the study of integrated logistics, and integrated production and distribution systems. The supply chain includes manufacturers, suppliers, warehouses, and selling centers. Supply chain management is concerned with managing the flow of products, funds, and information among the various supply chain stages [2].

The complexity of supply chain management stems from at least two reasons, the first is the need for considering multiple objectives simultaneously, which may result in tradeoffs. The other reason is that any slight modification on a supply chain stage may adversely affect the entire supply chain profitability. The importance and complexity of supply chain management resulted in massive amounts of research on both the theoretical and practical sides. Supply chain management research ranges from case studies that demonstrate the application of theoretical results in real life applications, to building new supply chain models that aim to improve the performance of supply chains, through cutting costs and enhancing the supply chain profitability.

Ontology, on the other hand, is "a formal, explicit specification of a shared conceptualization" [8]. In this regard, ontologies can be thought of as semantic primitives that specify a particular domain of knowledge. The main advantage for having such formal specification is to facilitate the knowledge sharing and re-use among the various parties interested in that particular domain of knowledge. Having a set of standardized ontologies for supply chain management will enhance the interoperability between the various supply chain management systems. It will also serve as a basis for building more specialized ontologies, for example, an ontology for building discrete-event supply chain simulation models. Using the ontology for developing supply chain knowledge management systems will result in a reusable, easy to integrate knowledge bases.

In this paper, the literature related to ontology development is reviewed, and a particular focus is placed on the efforts that relate ontology development in supply chain management related applications. After that, a brief introduction on ontology development is given. The paper proceeds by discussing the approach used for constructing the supply chain ontology, and the resulting structure for the supply chain management ontology.

2. Literature Review

2.1 Ontology Development
Ontologies are considered a corner stone in the development of DARPA's (Defense Advanced Research Project

Agency) most ambitious project, the "Semantic Web", or in other words, web of information. Ontology standards were developed by DARPA, and referred to as DAML- DARPA Agent Markup Language, and its successor DAML-O. At about the same time, similar development was undertaken by a group of European researchers, and resulted in the development of OIL – Ontology Interchange Language or Ontology Inference Layer. The current ontology development standard is a result of merging the DARPA initiative with OIL, and resulted in the adoption of DAML+OIL as the ontology development standard for the semantic web [7].

Maedch and Staab present a framework that extends ontology-engineering environments by incorporating semiautomatic ontology-construction tools [12]. Typical questions associated with ontology development relate to development time, difficulty, and confidence. The authors survey the existing ontology learning approaches and classify them based on ontology domains. For example, in free-text domain, ontology learning is done through clustering, inductive logic programming, association rules, frequency-based pattern matching, or classification. For the dictionary domain, the learning is done through information extraction or page rank. And for knowledge-base domain, learning can be either by concept induction or A-box mining. Ontologies have been used in a variety of applications that include: enhancing web searching [5], as conceptual models for XML documents [3], and for automatic target recognition [11].

2.2 Ontology use in Enterprise Engineering

There has not been a lot of use of ontologies in supply chain management research or in enterprise engineering research in a broader sense. Slade and Bokma describe the use of ontologies to facilitate the collaboration within extended enterprises [15]. In extended enterprises, there is a need for managing the body of shared documents, and for developing a shared understanding about these documents. The ontology development is part of the Burma-X project – funded by the European Commission. It is expected to enable better managing the ever-growing sources of information, and will ultimately lead to the prevention of duplication of effort. Ontologies are used as a domain modeling technique to capture the concepts of the domain and the various relationships that exist among these concepts. Within the Burma-X project, ontologies will be used as a cataloguing system for information by referring to these information sources using appropriate links.

Jones, Ivezic and Gruninger describe the challenge of making use of the web (more specifically, the emerging semantic web) for implementing self-integration among Supply Chain Management software applications [10]. The authors start by describing the environment required to achieve this self-integration. This environment should allow for semantic querying, semantic mapping, and semantic inferencing. They then describe three ongoing projects that aim to build test beds for these self-integrating software applications, namely: Ontologies for Co-operative Product Engineering, Semantic Resolution, and Service Coordination. These test beds shall provide the required infrastructure for the interaction among manufacturing companies, software vendors, and standards organizations.

Smirnov and Chandra describe the elements of a general methodology for utilizing ontologies in knowledge management for the co-operative supply chains configuration. Supply chain configuration entails managing the supply chain knowledge, modeling the constraint network, and managing knowledge among network agents [16]. Modeling coordinated supply chains requires specifying the following concepts: activity, process, supply chain processes, communication. The authors focus on designing supply chain configurations for manufacturing systems based on GERAM, the Generalized Enterprise Reference Architecture, and Methodology (ISO TC 184/SC 5/WG 1 1997). Based on GERAM enterprise models can be defined using natural language explanation, some form of Meta models, or ontological theories.

Pathak, Nordstrom and Kurokawa describe the construction of an MIC (Model Integrated Computing) multi-agent supply chain-modeling system [14]. The development will allow supply chain domain experts to create models for software agents to simulate and control the on-line negotiation process. The system is being built using the ZEUS Agent Building Toolkit for constructing the agents, and the Generic Modeling Environment (GME) for constructing the GUI. In ZEUS, the designer needs to define ontologies in the process of application realization. These ontologies serve as a Lingo by which the agents can communicate.

Chatfield and Harrison present SISCO, Simulator for Integrated Supply Chains Operations, which is a Java-based tool that aims at simplifying supply chain simulation model development [1]. SISCO is composed from three stand-alone modules, which play an important role in the final system and are flexible enough to be collaborated with other software. It maps the various supply chain descriptions, which are stored in XML based supply chain modeling language (SCML). SISCO is a very sound approach for performing simulation modeling of supply chains, and it has 3 distinctive components: graphical supply chain editor, model parser, and experiment designer. The graphical editor is user for constructing supply chain models by simple drag and drop interface, and the resulting supply chain model is saved in SCML format. The SCML can be considered as an attempt to construct a special modeling language for constructing discrete-event supply chain simulation models.

3. Ontology

3.1 What is ontology?

The word ontology first appeared in Aristotle's philosophical essays, where it used to describe the nature and organization of being. Artificial Intelligence (AI) practitioners are currently using the word ontology to formally represent domains of knowledge. There are four main types of ontologies, these are: domain ontologies that provide a vocabulary for describing a particular domain, task ontologies that provide a vocabulary for the terms involved in a problem solving process, meta-ontologies that provide the basic terms to codify domain and task ontologies, and knowledge representation ontologies that capture the representation primitives in knowledge representation languages [6]. Gruber states that formal ontologies need to be designed and provides a preliminary set of design criteria for the ontologies developed for knowledge sharing. These criteria are clarity, coherence, extendibility, minimal encoding bias, and minimal ontological commitment [9].

Ontologies are simply hierarchal description of the important concepts in a domain, coupled with a description of each of these concepts. Ontologies consist of various concepts that include: class, subclass, class hierarchy, instance, slot, value, defaults value, facet, type, cardinality, inheritance, variable and relation [13]. A class represents an object category, and is usually made of a set of subclasses (subclasses by themselves are classes), thus forming a class hierarchy. The most upper class in ontology is referred to as "Thing". All the other subclasses and instances inherit from this "Thing" class. In a sense, the "Thing" class will enable having one integrated set of ontologies, developed for various applications by different ontology developers. An instance of the class is an object (or example) that belongs to that class, lets take for example, students in a particular university can be either graduate students, or undergraduates. A graduate student, on the other hand, can be either a degree seeking, or a non-degree seeking. Individual students in a particular university represent instances of these classes, for example one of these students might be Ali. Figure 1 illustrates this class hierarchy.

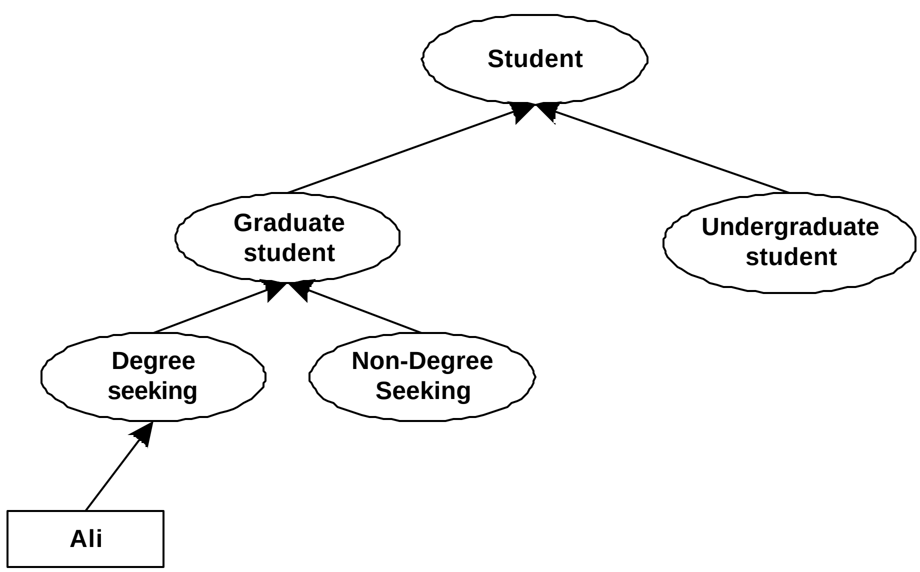

Figure 1. Class hierarchy example

3.2 Ontology Tools

Ontology tools can be classified into Ontology editors, Ontology-based annotation tools, and Ontology-based reasoning tools [14]. Ontology editors facilitate the ontology developer's task in constructing ontologies, in terms of defining the domain concepts, and the relationships among these concepts in the form of a class hierarchy. Some ontology editors include: OntoEdit, OilEd, and Protégé 2000.

OntoEdit is an Ontology Engineering Environment that supports the development and maintenance of ontologies using graphical means. It was developed by AIFB, University of Karlsruhe. OntoEdit is built using a powerful internal ontology model, which can be serialized using XML, thus supporting internal file handling. The modeling paradigm in OntoEdit supports representation-language neutral modeling for concepts, relations and axioms. Multiple graphical views can be used to support the ontology modeling during the different phases of ontology engineering cycle. OilEd is a free OIL editor implemented by the University of Manchester. It aims to provide a simple interface for developing OIL based ontologies. It is not intended to be a full ontology development environment, nor it supports the development of large-scale ontologies. OilEd includes the necessary functionality required by an Ontology development kit, in terms of creating class hierarchy, various class operations, describing classes and class properties, and others. Protégé-2000 is an integrated software tool developed by Sanford University. It is used to develop knowledge-based systems and various domain problem solving and decision-making applications. It has a uniform GUI (graphical user interface), which consists of several tabs. This tabbed structure facilitates the creation of a knowledge-acquisition tool for collecting knowledge, the entering of specific instances of data and creation of a knowledge base, and the execution of applications. Protégé ontology defines a set of concepts and their relationships. In Protégé, the knowledge-acquisition tool is domain-specific, thus allowing domain experts to easily input domain instances utilizing their knowledge of the area. The resulting knowledge base can be used with a problem-solving method.

Contrasting the pros and cons of each of the development tools, protégé 2000 was selected as the ontology development tool of choice for the following reasons: Easy to use, supports the development of fairly large ontologies, an integrated package, and it supports building end-user applications.

4. Supply Chain Management Ontology

4.1 Approach

The developed ontology future use is anticipated to provide a standard means of communication among the various supply chain management stakeholders, to enabling supply chain management software vendors to build software using agreed upon supply chain management concepts, to be used as a basic ontology upon which more specialized ontologies may be constructed.

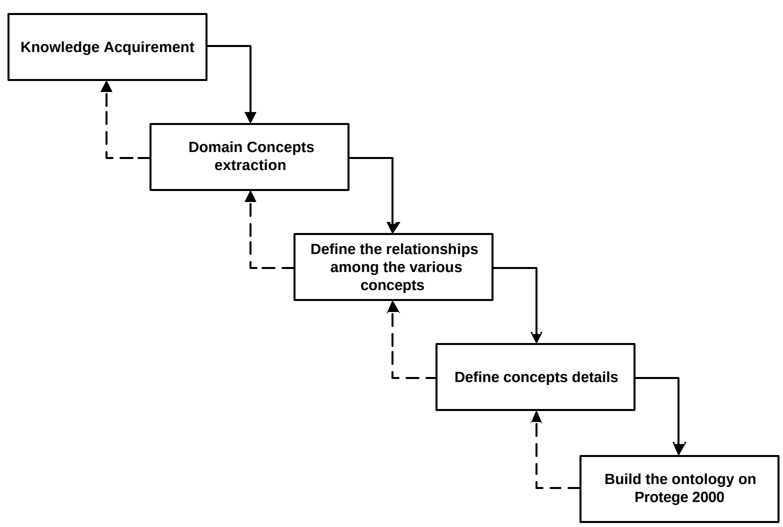

Figure 2. Approach for constructing the supply chain management ontology

As depicted in Figure 2, the ontology development starts by acquiring the required information pertaining to supply chain management, through surveying the supply chain management literature, and building a concise definition of supply chain management domain. After that, the various supply chain management domain concepts are extracted from the acquired knowledge. In this regard, only the most prominent and agreed upon concepts are extracted. Then the domain concepts are divided into various groups and the relationships among the various concepts and groups are drawn. Upon having a clear definition of the various supply chain management concepts and their relationships, the various concepts details are extracted. And finally the ontology is constructed on protégé 2000. The feedback loops depicted in the figure denote the iterative nature of the design process.

4.2 Results

Supply chain management ontology captures the various supply chain management concepts and their relationships among each other. Supply chain management concepts are constructed to cover the various supply chain stages, functions, decisions, and flows [2].

The supply chain stages are manufacturers, suppliers (for either components or raw materials), transporters, warehouses, retailers, and customers. Each of these is modeled as a concept where it contains the concept details pertaining to that particular stage. For example, the supplier details include: supplier address, supplier contact information, material (or component) supplied, which is linked to the material (or component) information, stages next in chain, price information, and discount tables.

The supply chain functions are centered on new product development, marketing, operations, distribution, finance, and customer service. These functions are contained within the various supply chain stages, with some functions crossing the boundaries among two or more supply chain stages. These functions aim to facilitate the flow of information, funds and products among the various stages. Within each stage, an order cycle takes place. The order cycle can be customer order, replenishment, manufacturing, or procurement. Each of these cycles has own characteristics and triggering events. For example, the customer order cycle starts when the customer order is received, and ends when the customer need is fulfilled, and the customer has paid for the service.

Successful supply chain management requires the achievement of strategic fit. Which entails understanding both the customer and the supply chain. The customer characteristics that need to be captured are quantity, response time, product variation, service level, price, and desired rate of innovation. On the other hand supply chain understanding requires capturing the responsiveness and cost efficiency of the supply chain.

The supply chain performance is governed by the various supply chain drivers, which include inventory, transportation, facilities, and information. The choice and level of these drivers can have substantial effect on the supply chain responsiveness and efficiency. The inventory can be decomposed into cycle, safety and seasonal inventories. Transportation decisions include mode, route and vehicle selection, and whether to have it in house or to outsource.

Supply chain management concepts are also extended to include forecasting, aggregate planning, supply chain decision making, among others. The relationships and properties among these concepts serve as the basis for the supply chain management ontology.

4.3 Future work

The ontology is currently being validated using two case studies. Where the ontology is used to describe the operations described in the case studies. The next step is to make the ontology synchronized with the SCOR (Supply Chain Operation Reference) model. SCOR model is developed by the supply chain council and aims to describe the operations of various supply chain constructs, it classifies the operations of supply chain as Plan, Source, Make, Deliver and Return.

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