Supply Chain Management Ontology: Towards an Ontology-Based SCM Model

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SUPPLY CHAIN MANAGEMENT ONTOLOGY: TOWARDS AN ONTOLOGY-BASED SCM MODEL

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Abstract

Supply chains are complex and dynamic networks that involve quite a lot of constituents beginning from suppliers and ending with the customers. Supply chain management is a flourishing area that needs special attention and there is consensus among researchers and practitioners about the importance of shared knowledge among the constituents for effective supply chain management. Ontologies on the other hand is the study of the categories of things that exist or may exist in some domain, and they provide a common vocabulary for the purpose of knowledge sharing, communication and reuse about some topic. Viewed as a conceptualization of general knowledge into understandable and readable formats, ontologies are precious tools for supply chain decision-making situations. The paper aims to create an ontology for supply chain management by following a methodology driven from the literature. At the end of this study a conceptual schema is created that identifies the common concepts of supply chain management systems.

Keywords: Supply Chain Management, Ontology, SCM Model, SCOR, Supply-Chain Operations Reference-Model, Operations

1. Introduction

New businesses are constantly emerging around circles of horizontal and vertical supply chain structures in most industries. Supply chains are becoming more important and more difficult to manage because of the complex interactions and flow mechanisms within these structures. Businesses should understand the basic building blocks of their supply chains in order to conceptually develop and manage their supply chains for efficiency and sustainability. As this is quite important to gain competitive advantage, any tool that will help, should be appreciated and ontologies may be accepted as a tool that can be used to reveal the basics of supply chains.

Ontologies provide a simplified and explicit specification of a phenomenon that we desire to represent (Gruber, 1995). They are useful as they explicate the components which define a phenomenon and, thus, can help in systematically understanding or modeling that phenomenon.

The goal of this paper to show a general-purpose supply chain management (SCM) ontology that can be used by practitioners, researchers, and educators. The ontology is characterized in terms of formal definitions and axioms that have evolved from a collaborative ontology design process. The ontology presented here may be extended, refined, modified, or even replaced, but in its current form it provides a foundation for systematic SCM research, study, and practice.

A brief SCM-related literature survey will be given first, after which some fundamental ontology issues for building SCM ontology will briefly be discussed. Importance of SCM for modern economy and definition of SCM is a good beginning point. Following this, we will introduce ontological engineering together with the current practices in this area. The last section will be devoted to SCM ontology properties and frame of ontological architecture.

1.1. Supply Chain Management

Supply chain management represents a critical competency factor in today’s global business environment (Nissan, 2000) and accordingly supply chain management, analysis, and improvement efforts are becoming

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increasingly important. The literature includes approaches to supply chain management (see Lamming 1996; New, 1996; Waters-Fuller, 1995), in addition to supply chain models (Beamon, 1999).

Put simply, supply chain management is a collaborative, cross-enterprise operating strategy that aligns the flow of incoming materials, manufacturing, and downstream distribution in a manner responsive to changes in customer demand without creating surplus inventory (Cooper and Ellram, 1993; see also Quinn, 1998). As noted by Balsmeier and Voisin (1996), supply chain management is not the old wine of "supplier management" poured into a colorful bottle. Instead, supply chain management is a fresh, potent approach that integrates a network of operating entities into a delivery system that enhances customer value and satisfaction and that protects the competitiveness of the entire supply chain (Lummus and Vokurka, 1999), as is demonstrated by benchmarking studies conducted by the Pittiglio Rabin Todd & McGrath consulting company.

These economic enhancements do not flow inevitably from supply chain management (Jarrell, 1998). Effectiveness is required. Therefore, the traditional approach of managing the supply chain as a loose collection of independent segments, each concerned with achieving its own objectives regardless of the effect on other segments, squanders the promised benefits of supply chain management (Balsmeier and Voisin, 1996). A leading reason for the traditional approach's failure is its reliance on cost management systems that emphasize the minimization of controllable costs. Having recognized this, some companies have tried to mitigate the effects of biased cost management practices by expanding their ABM systems to partly cover supply chain activities (see Barr, 1996; Cooper et al., 1992; Player and Keys, 1995; Pohlen and La Londe, 1994; and Ortman and Buehlmann, 1998). Their efforts will likely end in disappointment because ABM focuses on the internal economics of activity costs; it fails to address the issue of how supply chains can improve customer value and satisfaction. (Smith and Lockamy III, 2000)

In today's markets, technological and competitive forces are changing at an ever increasing rate. To respond to these forces, radical changes in organizations have become necessary. The viability of a firm now depends largely on how well it is capable of responding to customer requirements while becoming lean. It is becoming increasingly more difficult and less economical for companies to produce their needs on their own. Instead, outsourcing is becoming one of their main strategies. Also, the ever-increasing trend in globalization and customer orientation requires a logistics-sensitive organization. Supply chain management (SCM) is an approach that has evolved out of the integration of these considerations. A definition of supply chain (Stevens, 1989) is:

> A system whose constituent parts include material suppliers, production facilities, distribution services and customers linked together via the feed forward flow of materials and the feedback flow of information.

From the beginning of this decade, SCM has been studied and practiced, and has been reported in the literature.

The field of supply chain management is reaching a new stage. After a period dominated by enthusiasm for the newness of the idea of managing the stream of products across the whole chain from supply through manufacturing to end-users, it is now realized that "one size does not fit all". An important contribution to the refocusing of the attention on this subject in SCM-literature is the contribution of Fisher (1997) that explains the need for matching the supply chain management technique to product characteristics. Aitken et al. (2003) state that there is a "need for tailored logistics channels" in delivering products, while Frohlich and Westbrook (2001) distinguish different levels of integration in supply chains, and Ho et al. (2002) emphasize the need for the relationship between context and integrative practices in supply chains. More generally, Mouritsen et al. (2002) state that there is a need for further research to explore how supply chains are managed under different circumstances, and at what point integration of activities and processes across the supply chain is beneficial for the participants. So far, the idea of focusing the supply chain has been developed across different lines. Fisher (1997) differentiates between functional and innovative products, while Aitken et al. (2003) relate the management of the supply chain to different stages of the product life cycle. One of their results is, for example, that MRP is more appropriate in the growth-stage, while KAN-BAN appears to be more suitable in the maturity stage of the product life cycle. Generally, this type of research concentrates on issues related to managing the supply chain. Less attention has been paid to supply chain design, and in the context of this paper, to the question of which resources can be shared to gain from economies of scale, and which resources have to be tailored to the needs of specific buyers in order to align processes across the supply chain (Fawcett et al, 2006).

In the mid-1990s, many industry pundits looked to the future, claiming that competitive success would depend on collaborative supply chain teams (Blackwell, 1997; Christopher and Ryals, 1999; Elliff, 1996; Harps and Hansen, 2000). For example, Harold Sirkin, Vice President at the Boston Consulting Group, noted that, "As the economy changes, as competition becomes more global, it's no longer company vs. company but supply chain vs. supply chain" (Henkoff, 1994).

The increased complexity of products and hence the higher level of outsourcing have moved the level of competition from single companies to groups or chains of firms (Gomes-Casseres, 1994; Rice and Hoppe, 2001). For this reason, literature widely acknowledges the strategic relevance of supply chain management as a source of competitive advantage (Christopher, 1992; Fine, 1998). This can be achieved by considering the network as a whole, and hence pursuing global instead of local optimization (Ellram, 1991; Cooper and Ellram, 1993; Simchi-Levi et al., 2000), and by integrating all key business processes from end-users to original suppliers (Cooper et al., 1997; Burgess, 1998, Cagliano et al, 2006).

Closed-loop supply chains, embodying remanufacturing and reverse logistics, might be expected to be important means to enable businesses to meet the growing demands of corporate social responsibility, and to meet wider social goals to reduce the resource-intensity of contemporary economic life (Hart, 1997; Steinhilper, 1998; Environmental Protection Agency, 1997; Commission of the European Communities, 2000). There is a clear resonance with the concepts of eco-efficiency (Schmidheiny, 1992) and eco-modernism (Ayres et al., 1997): that closed loops offer opportunities to achieve the so-called "triple bottom line" of social, business and environmental benefits (Hawken et al., 1999). Waste streams – including mechanical products that can be made serviceable again – can provide useful value added business opportunities (Wells and Seitz, 2005).

Organizations seek competitive capabilities that enable them to exceed customers' expectations and enhance market and financial performance (Hayes and Pisano, 1994; Lado et al., 1992, Tracey et al, 2005)

1.2. Ontology Theory

An ontology is nothing else than a rigorously defined framework that provides a shared and common understanding of a domain that can be communicated between people and heterogeneous and widely spread application systems (Fensel 2001).

Gruber described an ontology as "an explicit specification of a conceptualization." This definition is short and sweet but patently incomplete because it has been taken out of context. Gruber was careful to constrain his use of *conceptualization* by defining it as "an abstract, simplified view of the world that we wish to represent for some purpose" – a partial view of the world consisting only of those "objects, concepts and other entities that are assumed to exist in some area of interest and the relationships that hold among them."

Ontology today is in a state similar to that of analysis in the late 18th century. The practical power of the calculus had been convincingly demonstrated in the work of Newton and his great successors. Moreover, the field of real analysis itself had seen an explosion of creativity, exemplified most notably in the work of Euler. However, Euler's own work also revealed worrisome foundational problems. For techniques used with great success in one instance to prove deep and dramatic theorems in another instance could lead to absurdities, e.g., that the value of certain monotonically increasing infinite series was -1. Such results led to a conceptual crisis—how can any results be trusted when the methods that generate them can lead to error? This crisis was addressed, and successfully eliminated, by the development of rigorous foundation for analysis — widely known as the arithmetization of analysis — by Cauchy, Weierstrass, Bolzano, and others in the early 19th century. Building on the sound foundation of number theory, mathematicians replaced the intuitive but undefined notions of analysis — limit, continuity, series, integration, real number etc. — with clearly defined counterparts (e.g., the now-familiar ϵ; δ definition of limit) and banished unruly notions like that of an infinitesimal altogether.2 With these solid underpinnings in place, mathematicians were able to identify clear conditions of applicability for their analytic methods that prevented the derivation of absurdities without limiting their ability to prove desirable results. (Menzel, 2002)

A similar foundation is needed in the study of ontologies. As with analysis prior to arithmetization, the potential of ontologies is evident, but the fundamental notions remain largely intuitive; notably, there is no precise characterization of the notion of an ontology. What we need, then, is our own "arithmetization"—in a nutshell, we need *ontology theory*: a mathematical framework, akin to number theory or modern analysis, which enables us to characterize the notion of an ontology formally and develop accounts of their properties and the various ways in which one ontology can be related to another. It is in this respect analogous to computability theory. No one actually programs turing machines (except as a heuristic exercise). Rather, the notion provides a model of computation that serves as a foundation for both theoretical and, therefore, indirectly, applied computer science.

2. Ontological Engineering

Merriam-Webster definition: *a branch of metaphysics concerned with the nature and relations of being or a particular theory about the nature of being or the kinds of existents.*

This is the abstract philosophical notion of "ontology", a more applicable term for this field is "formal ontology" (McGuinness, 2002). (Gruber 1993) provides the definition "a specification of a conceptualization". An ontology thus provides a set of concepts from a certain domain that are well specified.

"Ontology" is the term used on the internet when discussing the semantic web. The Web Ontology working group at W3C emphasizes that ontologies (in their definition) are a machine-readable set of definitions that create taxonomy of classes and subclasses and relationships between them.

McGuinness (2002) states that the minimum requirements of an ontology are a finite set of unambiguously identifiable classes and relationships, including strict hierarchical subclass relationships. Typical, but not mandatory is property specification on class basis.

The term ontology has been in use for many years. Merriam Webster, for example, dates ontology circa 1721 and provides two definitions (1) a branch of metaphysics concerned with the nature and relations of being and (2) a particular theory about the nature of being or the kinds of existents. These definitions provide an abstract philosophical notion of ontology. Mathematical or formal ontologies have also been written about for many years. Smith (1998) points out that at least as early as 1900, the notion of a formal ontology has been distinguished from formal logic by the philosopher Husserl. While ontologies (even formal ontologies) have had a long history, they remained largely the topic of academic interest among philosophers, linguists, librarians, and knowledge representation researchers until somewhat recently.

Ontologies have been gaining interest and acceptance in computational audiences (in addition to philosophical audiences). Guarino (1998) provides a nice collection of fields that embrace ontologies including knowledge engineering, knowledge representation, qualitative modeling, language engineering, database design, information retrieval and extraction, and knowledge management and organization.

3. Supply Chain Management Ontology and Ontology-Based SCM Model

As there is no standard supply chain configuration, the specific requirements must be analyzed in the process of establishing a SC. A close co-operation of all parts in a SC is required in order to attain the common goal. The criterion to accept compromising solution should be the maximum pay-off for the system as a whole, not to accept maximum pay-off for individual subsystems. (Frankovic et al. 2002)

Many current applications, such as commerce, production, delivery, sales etc., which appear also in supply chains, with different types of resources or agents to interoperate with each other may be solved on the basis of the ontological methodology. In some cases, interoperation becomes more complex, because agents might have been developed independently; therefore it is not possible to assume that agents use the same communication language and the same terminology in a consistent way. When dealing with independently developed agents, their interoperability depends on the agent's ability to understand them, which leads us directly to ontology. Ontology is an explicit formal specification of a shared conceptualization, where *conceptualization* refers to the abstraction of some phenomenon by having identified the relevant concepts of that phenomenon, *explicit* means that the type of concepts used, and the constraints on their use are explicitly defined, formally refers to the fact that the ontology should be machine readable. The ontology provides a formally defined specification of the meaning of those terms that are used by agents during the interoperation.

Ontology usually consists of a set of class (or concepts), definitions, property definitions and axioms about them. The classes, properties and axioms are related to each other and together form a model of a system or in general of the world. We suppose that a change constitutes a new version of the due ontology.

Methodology of ontology development may be considered in the following steps: (Frankovic et al. 2002)

Specification - which may be the determination of classes

Conceptualization - which is the modeling at the knowledge level using for example tables and graphs. The proposed tables and graphs allow modeling, concepts, attributes, first order logic formulas etc. and they are thought to be manipulated by experts in the domain to be modeled. The methodology does not propose how to add a new type of table, how to add a new field to a type of table, how to delete one of the types of the proposed graphs, or how to elaborate a completely new modeling way with completely new graphs and tables. Therefore several groups in different locations (or different situation) have to build an ontology collaboratively, there are problems to agree and change the characteristics of the tables and graphs to be used.

Formalization - using for example a formal language or some frames.

Implementation - using for example a special language of ontology.

It is needed to notice that the potential of ontology is evident, but the fundamental notions remain largely intuitive.

Building the supply chain ontology requires the concepts in the domain or classes and subclasses to be identified, together with the properties of each concept describing various features and attributes of the concept (slots), and allowed values for these slots (facets) The ontology together with a set of individual instances of classes will constitute a knowledge base for SCM systems.

In our SC ontology we preferred to use product, agent (member), flow and operations as the classes. We thought that it is a good approach to cover the main elements of a supply chain.

Our supply chain management ontology framework is given below:

Table 1: Supply Chain Management Ontology Framework

PRODUCT	**AGENT (MEMBER)**
Goods • Parts, components, supplies • Nondurable (consumer) goods • Durable goods • Industrial goods Goods Properties: Process Type: (facets: extracted from the nature; made-to-order; made-to-stock; assemble-to-order; imported) Weight: (facets: bulky, heavy, light) Size (facets: small, large) Resistance (facets: fragile, non fragile) Durability (facets: perishable, non-perishable) Characteristics (facets: functional, innovative)	Supplier • 1st tier • 2nd tier Producer Transporter Distributor Customer • Consumer • Industrial user Properties: Kind of production activity (facets: manufacturing, transportation, trade) Utility created (facets: form, place, time, ownership)

Type (facets: food products, electronics, textile, etc.) Service • Governmental services • Municipal services • Trade services (wholesale retail) • Finance, insurance, real estate • Medical (healthcare) • Personal services • Business services • Education <u>Service Properties:</u> Service content (facets: high, low) Service location (facets: in- house, at site) Degree of customer contact (facets: high, low)	Produces (food products, electronics, textile, transportation service, trade service, etc.) Size (facets: small, medium, large) Geographic location (facets: domestic, global) Service content (facets: low, high) Make-buy decisions (facets: produce in house, outsource) Operations performed (facets: plan, source, make, deliver, return)
FLOW	**OPERATIONS**
Material Money Information <u>Properties:</u> Direction of flow (facets: forward, backwards, both sides) Flow between (facets: supplier-producer, producer-customer, producer-wholesaler etc.)	Plan • Plan supply chain • Plan source • Plan make • Plan deliver • Plan return Source • Source Stocked Product • Source Make-To-Order Product • Source Engineer-to-Order Product Make • Make-to-Stock • Make-to-Order • Engineer-to-Order Deliver • Deliver Stocked Product • Deliver Make-to-Order Product • Deliver Engineer-to-Order Product • Deliver Retail Product Return • Return Defective Product • Source Return MRO Product • Deliver Return MRO Product • Return Excess Product <u>Properties:</u> Performed by (facets: supplier, producer, transporter, distributor, customer)

A supply chain is considered as a loop from customers' demand to customer's satisfaction by final product or service. It is a complex and dynamic system which has a character of hybrid-distributed system. It consists of a chain of producers, suppliers, distributors, and transporters. In MAS language, a supply chain can be modeled as a system of intelligent agents, which agree to cooperate to reach the final goal. A new, modern, and cost-effective implementation of supply chain management (SCM) is enabled by rapidly developing information and communication technologies. (Frankovic et al, 2002) SCM covers a process of creating and configuring a supply chain, identifying measuring metrics in the chain, determining weak points in the chain and works to achieve the best results to meet customer demands. It aims to develop strategies for managing all resources (raw materials, services) and balance cumulative demands and supplies. Each basic SC is a chain of Plan, Source, Make, Deliver and Return process. The details of these steps are given below (Supply-Chain Council, 2006):

Plan – a strategic part of SCM. The aim is to develop strategies for managing resources and balancing demands and supplies. A set of metrics to monitor the SC efficiency has to be proposed.

Source - the aim is to choose a set of suppliers for producing goods and services.

Make- goods and materials are transformed to final products. This step is the manufacturing portion of the supply chain. Production scheduling, testing, packaging, etc. are the activities that take place at this step.

Deliver - coordination of orders from customers, developing a network of warehouses, distribution and transportation of products to customer, invoicing system to receive payments from customers. This part is known as "logistics"

Return - deals with the problematic of defective products, how they can be returned to producer and how customers are dealt with to satisfy their requirements on problematic products. A “help desk” application is used in this part.

The basic scheme of SC is shown in Figure 1a, Figure 1b and Figure 1c. Production gets customers’ demands and purchases material from suppliers on the basis of these demands. Products are delivered to distributors where they are for sale for customers. This scheme is also shown in Figure 2 with a ontology language (Protégé).

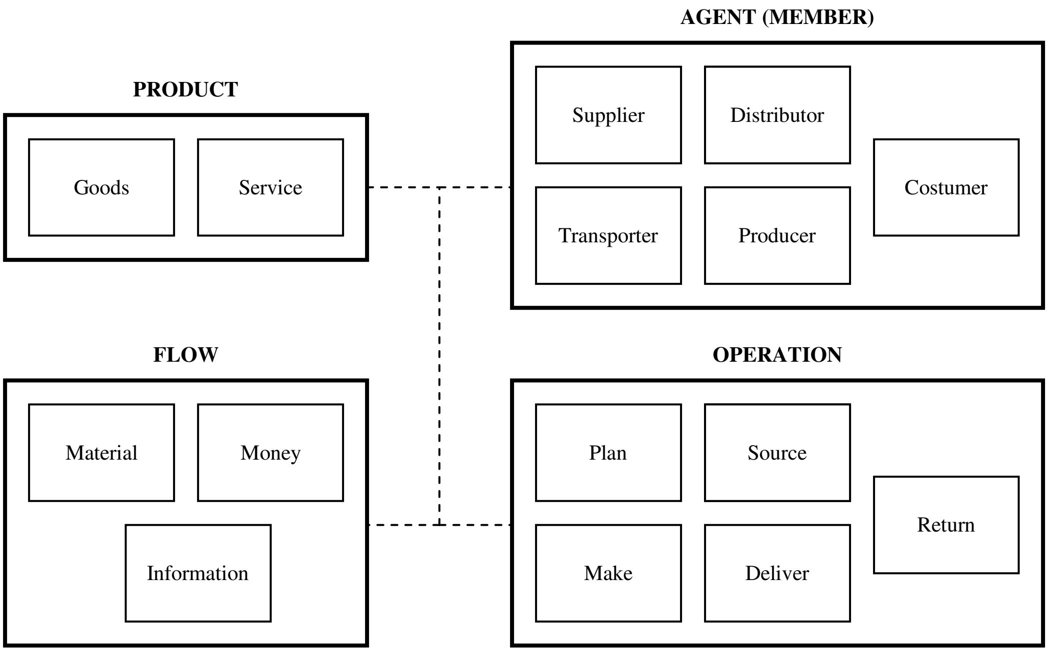

Figure 1a. Ontology-Based SCM Model

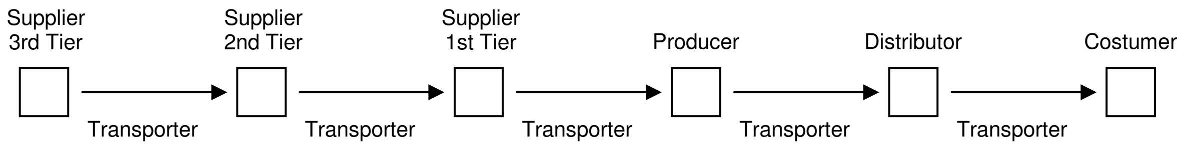

Figure 1b. Products and Agents Layer of Ontology

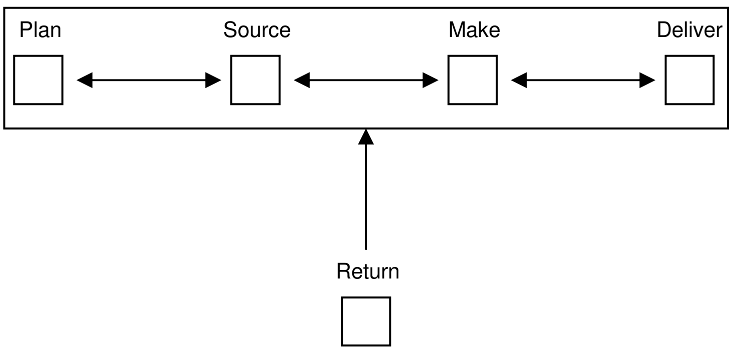

Figure 1c. Flow and Operation Layer of Ontology

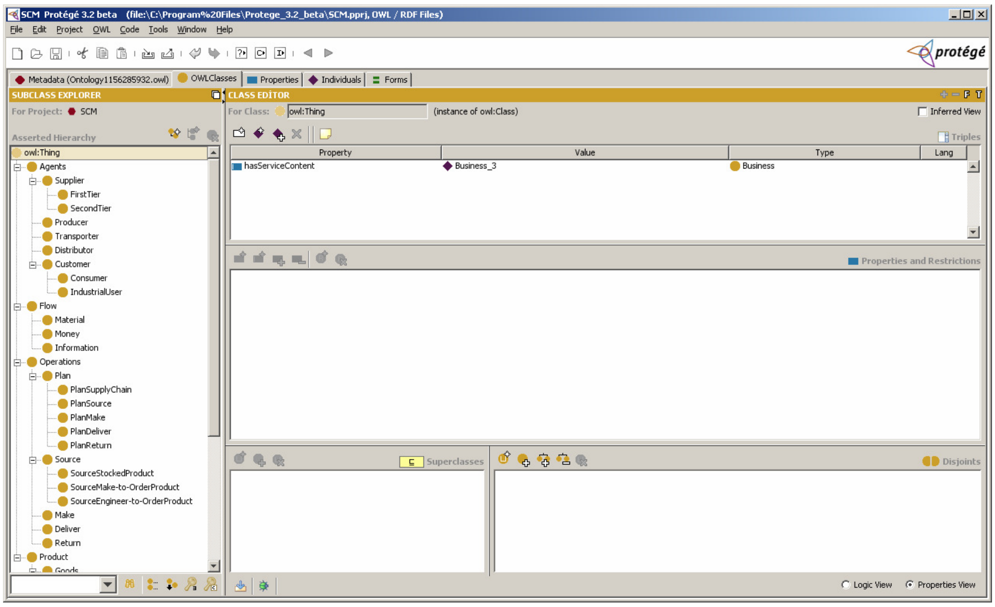

Figure 2. SCM Ontology in Protégé

5. Conclusion

A brief literature survey indicates that quite a lot of efforts have been devoted to ontology studies in different areas such as medicine, telecommunication, biology, botany etc. This stems from the need to standardize and formalize languages to ensure a common understandability among agents, humans and computers. In designing and managing supply chains which are complex and dynamic networks, it is important to share a common language among the constituents. The supply chain management ontology has the goal of providing a framework to better formulate, understand, analyze and share a company's supply chain management model. Therefore ontologies can be regarded as precious tools that can be used to increase the efficiency of supply-chains. But literature survey indicates that there is not much work devoted to this area. This was the reason for deciding to make an ontology study on SCM systems. The aim of this paper is to create a better understanding of supply chains by identifying the basic notions used through the chains. The methodology used for constructing a general-purpose ontology for supply chain management is presented along with the resulting ontology and an ontology based SCM model.

This study can be used as a framework for further studies. The ontology may be enhanced by including supply chain performance drivers and by including other concepts such as forecasting, warehouse location, aggregate planning, etc. More effort can be devoted to synchronizing the ontology with the SCOR (Supply Chain Operations) model in which the operations of supply chain is classified as plan, source, make, deliver and return, as is used in our ontology. Further research can also include computerizing the SCM ontology or extending the general-purpose SCM ontology into various application areas.

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