An ontology for a lean supply chain

AN ONTOLOGY FOR A LEAN SUPPLY CHAIN

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The following faculty members have examined the final copy of this thesis for form and content, and recommended that that it be accepted in partial fulfillment of the requirement for the degree of Master of Industrial Engineering.

Lawrence Whitman, Committee Chair

Don Malzahn, Committee Member

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DEDICATION

To my family, thanks for your support

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ABSTRACT

In today's completive manufacturing environment supply chains are spread across the oceans. For a large number of companies lean effort means closely examining the factory floor processes to pull the work. In reality the work on floor is triggered by demand from customer and lean goes well beyond four walls of the company. Today there is more reliance on the suppliers and contract manufactures for shorter lead times and quick responses to any changes in customer demand. Lean supply chain ontology proposes a model to achieve these goals of shorter lead times and faster response. The process adopted in this research to come up with the ontology starts with listing the terms related to a lean supply chain followed by classification of these terms in to various classes based on their importance to the core subject. One these two steps are completed the terms are defined and a model is proposed to come up with a lean supply chain. This model also can help to maintain a low level of inventory across the supply chain since inventory build up is avoided and parts are not built to forecast.

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INTRODUCTION

1.1 Introduction to Lean Supply Chain Ontology

A supply chain is a complex network of all stages, involved in the fulfillment of a customer request. It included suppliers, manufacturers, warehouses, and the customer. "A supply chain is a web of autonomous enterprises collectively responsible for satisfying the customer needs by creating an extended enterprise that conducts all phases of design, procurement, manufacturing, and distribution of products" (Whitman et al. 1999). A supply chain involves a large number of stakeholders, who interact with each other in order to make sure a smooth flow of products, funds and information (Ahmad, 2004).

Lean manufacturing can be defined as the relentless elimination of waste. The concept of lean production essentially calls for the investigation of the whole supply chain, since in almost every industry a large part of the manufactured product is supplied by the outside supplier (Lamming, 1996). A customer requirement for a manufacturing company may trigger production from its suppliers and supplier’s supplier for various components needed for the final product. Therefore in order to better understand the lean concepts and to be lean in real terms, the entire supply system should be investigated.

Ontology can be defined as “a specification of a conceptualization” (Gruber, 1993). In other words ontology defines a common vocabulary for various stakeholders involved in a particular domain of knowledge, who need to share information. The main advantage of an ontology is that it enables knowledge sharing and re-use among various partners involved in the domain. The lean supply chain ontology will serve as a knowledge base that will provide a common understanding of the concepts involved in a lean supply thereby enabling better communication between different stakeholders. It can also be used as reference ontology to develop more specific ontologies.

1.2 Environment Analysis

To look at the benefits of carrying research in the field of lean supply and generate an ontology, a SWOT (strengths, weaknesses, opportunities, threats) analysis is carried out.

1.2.1 SWOT Analysis

A SWOT analysis for creating an ontology is carried out to determine the strengths and opportunities and to identify the weaknesses and threats in creating such an ontology for a lean supply chain.

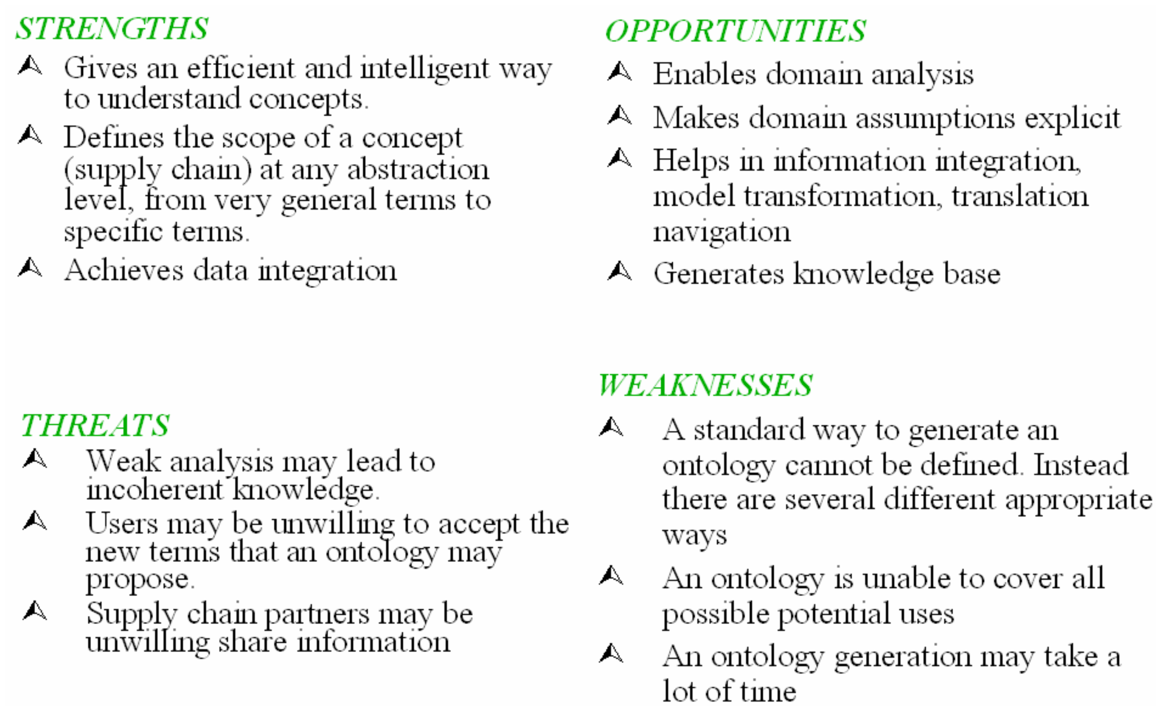

Figure 1.1 SWOT Analysis for Ontology

Strengths: An ontology defines a common vocabulary for researchers, to share knowledge about a particular area of interest. Generally its not the vocabulary that is the intent of the ontology, instead the conceptualization that the terms in the vocabulary intend to capture (Chandrasekaran, 1999). Suppose we have an ontology for electronic devices that defines various conceptual items like transistors, operational amplifiers and voltages; ontology will also define the relations that exists between various components like operational amplifiers are a type of electronic device, transistors are a component of operational amplifiers. Hence, an ontology not only defines various terms in a knowledge base but also the relations that exist between those terms. Different electronic-component manufacturers and suppliers can build an ontology that can be integrated and shared as a common ontology, and then the manufacturers can have common terms in their catalogues that will help efficient designing of components. An ontology helps in data integration which indeed helps in better sharing of knowledge. Ontologies also vary in abstraction, they can be very general in description or very specific, and hence, depending on scope, an ontology can be defined.

Weaknesses: Apart from various strengths stated above, ‘developing an ontology’ also has some weaknesses. One weakness is that there is no defined method of developing an ontology, rather there are several different ways and the best way to develop an ontology will depend on the application. What use will the ontology serve, and how detailed an ontology will be? Initially, a rough model should be developed that will closely model the knowledge base and then it can be revised and refined to represent the reality as accurately as possible (Noy, 1999). Ontology is a model of reality, but it cannot include the whole world in its scope, the desired level of detail has to be decided before the modeling can be done and it will guide many modeling decision later in model development. Ontology development is an iterative process, as stated before initially a rough model is presented that is revised and refined. Hence once an initial model is developed it has to be evaluated and debugged by using it for applications, or by discussing it with experts. As a result some changes are always made in an ontology after its first proposal, which might be time consuming.

Opportunities: An ontology forms the heart of any knowledge domain. Without an ontology that defines various concepts and their relationships, it is impossible to represent a domain of knowledge. The first step towards developing an ontology is to perform an ontological analysis of the field and make various assumptions explicit

(Chandrasekaran, 1999). Ontologies help in data integration and knowledge sharing, once an ontological analysis is performed and a satisfactory set of conceptualizations are reached with their representative terms, the resulting ontology can be shared between people who have common research interests in the same field of knowledge. With the use of ontologies, domain knowledge can be separated from operational knowledge.

Threats: An ontology provides a structure to a knowledge base. Without an ontology there cannot be a vocabulary representing a knowledge base (Chandrasekeran 1999). Hence, the first step in defining any knowledge base and/or its vocabulary is to conduct an ontological analysis of the knowledge domain. A weak analysis might lead to an incoherent knowledge base. Which means some of the concepts are either not analyzed at all or they are not analyzed properly. Therefore some of the terms related to the knowledge base might be missing because of an incomplete analysis. Another threat is that companies might not be ready to share information that is critical to them (for example key processes and terms relating these processes). The assumption that different supply chain partners use the same terminology and communication language might not hold true as many terms in a lean supply chain like production and sales might have been developed independently by different partners and may have different meanings. Hence, there might be some resistance in companies accepting these terms with a different meaning as specified by the ontology (Frankovic, 2006).

1.3 Thesis Roadmap

The thesis roadmap is explained in this section and the current condition is presented along with the desired condition. A strategy to achieve this desired condition is discussed along with the objectives and obstacles that are needed to be overcome in order to reach the desired condition. The roadmap is explained in figure 2.

1.3.1 Present Condition

A supply chain is a complex network which involves the manufacturer, customers, suppliers and the supplier's supplier all working in a closed loop to provide final product or services and a lean supply can be defined as elimination of waste throughout the supply chain (Stratton 2003). Different supply chain partners may have independently developed and implemented lean concepts and therefore may not share the same terminology, concepts, or relations needed to share information. Hence, there is no common understanding of lean supply concepts across the supply chain.

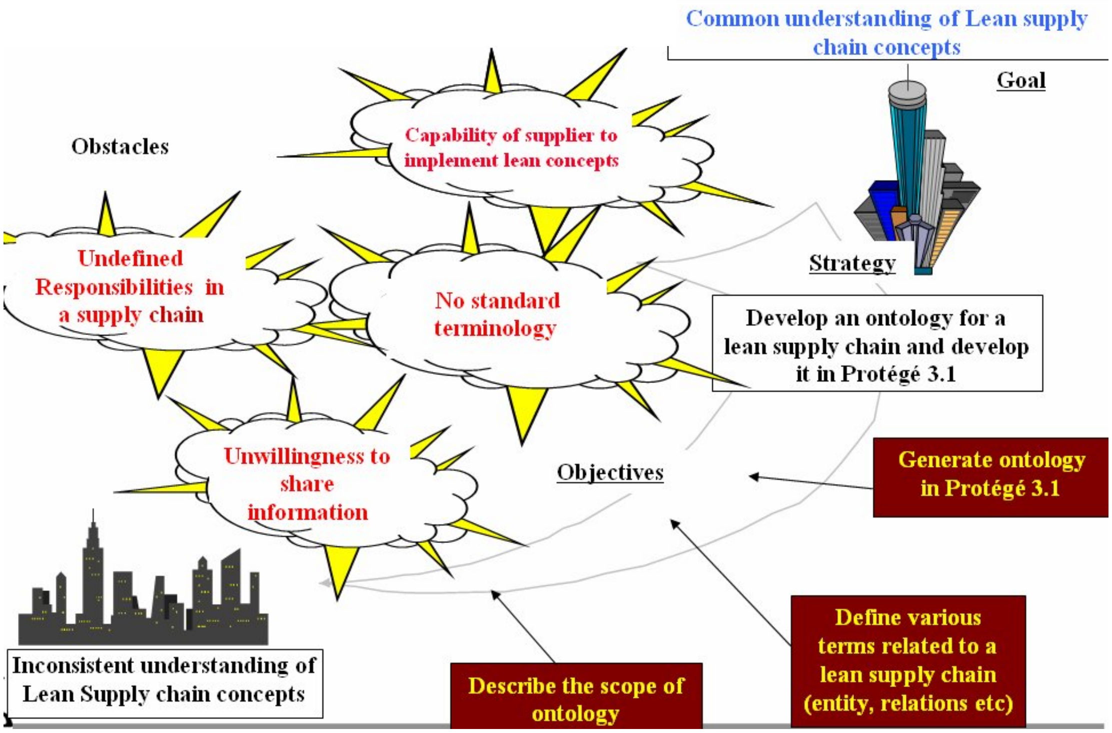

Figure 1.2 Thesis road map

1.3.2 Desired Condition

Systems and organizations which work closely and communicate with each other should share an ontology (Huber 2006). Ontology as defined by Gruber (1993) is an "explicit specification of a conceptualization" of terms involved in a knowledge base. Here conceptualization refers to the important terms that are used to define the concepts that have been identified. Explicit means that the relations and constraints about how these terms will be used is clearly defined.

The desired condition is to have a common understanding of lean supply concepts across supply chain partners. An ontology can help achieve this goal. One of the main goals of ontology development is sharing a common understating of terms associated in the knowledge base and structure (Noy 1999). A lean supply chain ontology will help to define a common vocabulary for companies who need to share information.

1.3.3 Obstacles

Some of the obstacles that need to be addressed in order to reach the desired condition include:

1.3.3.1 Unwillingness to Share Information: An ontology needs various key concepts and their relations to be discussed between supply chain partners. Some companies or supply chain partners may not be comfortable sharing their company's critical information with other members of the supply chain.

1.3.3.2 No Standard Terminology: One of the key factors in integrating different components of a supply chain is to share information across all partners of a supply chain. To effectively achieve this objective it is important to organize information and continuously update and inform the involved parties. The main obstacles in achieving this is a lack of standard terminology across supply chain partners. There might be several reasons for this. For instance, information might have been built across different hardware platforms using different operating systems and database management systems.

Providing a shared common terminology across the supply chain will make sure that each member of the supply chain shares the same view, where some data is available across more than one source but essentially provides the same meaning. Ontology is a common understanding of a knowledge domain that can be shared and communicated across systems, companies, and people (Chandra, 2004).

1.3.3.3 Undefined Responsibility in Supply Chain: A typical feature of operating systems in a supply chain is the use of blame (when something goes wrong) in absence of any defined responsibilities in the supply chain. This is the result of false importance given to ones own company in a supply chain, like blaming suppliers for lost orders. In a lean supply chain, the entire process from the raw materials to the finished goods is considered as a single entity. Hence, the cost of blaming and making excuses is identified and assessed (Lamming, 1996). An ontology will define different components of a lean supply chain, it will help in understanding the complete structure of the supply chain.

1.3.3.4 Capability of Supplier to Implement Lean: It is strongly recommended that first-tier suppliers already have some lean implementing experience. Without experience in lean initiatives the supplier will not be able to contribute enough to the improvement process. Further, the credibility of the whole process might be weakened by the inability of the first tier supplier to implement lean. Any supplier lower in the supply chain working towards attaining leanness should be approached to join the initiative (Altarum 2003).

1.3.4 Strategy

To achieve the desired condition of common understanding of lean supply chain concepts, the objectives defined below should be met. The strategy adopted is to develop an ontology using Protégé.

1.3.5 Objectives

1.3.5.1 Define the scope of the ontology: An ontology can never define the whole world. Hence, there is a need to determine the scope of the ontology. It is important to answer several questions upfront in order to define the domain and scope of the ontology.

The course of the ontology can be changed in the middle of the design process. It is important to be clear about the purpose of the ontology initially. The main purpose of this supply chain ontology is to come up with a model for a lean supply enterprise. Therefore the focus of this ontology will be on integrating lean and supply chain concepts. The scope of the ontology is defined and documented as a part of chapter 4. The following questions defined by Noy (2006) will be used to determine the scope of the ontology:

- What is the domain that ontology will cover?
- Who will use the ontology?
- What purpose will the ontology serve?
- What information should be included in the ontology?

A brainstorming session will be conducted to determine the scope of the ontology. The brainstorming session will be conducted in second week of

April 2007 and the team will consist of Drs. Don Malzahn and Lawrence Whitman. The agreed to scope will be documented in chapter 4 and the original brainstorming document and ideas presented in the session will be included as an appendix in the thesis.

1.3.5.2 Define Terms Related to Ontology: This step essentially means to identify and define key concepts and the relationships that these concepts share with each other. There should be an unambiguous definition of these concepts and their relationships.

Two brainstorming sessions will be conducted to determine the terms related to a lean supply chain ontology and relations between them. The first session will be held in the second week of April of 2007 with the same team as above and the second brainstorming session will be also be conducted in the second week of April of 2007 and the team will consist of Jerry Kukuruda, supply chain planning manager at LSI Logic Corporation, Wichita, Kansas and Kevin Parker supply chain analyst also at LSI Logic Corporation. Initially, all the terms that seem important to the lean supply chain ontology will be documented. This will create a detailed list of all the terms and relations that the ontology might cover. Initially all terms shall be listed without worrying about the overlapping of terms. Ambiguous terms can be deleted later. This is an important step in defining any ontology. Chapter 4 will consist of a complete list of the terms related a lean supply chain and relations between them. The complete results of the brainstorming sessions will be included as an appendix to the thesis.

1.3.5.3 Generate the Ontology Using Protégé: Generating an ontology involves generating the class hierarchy and defining the properties of the classes. It is not simple to define the hierarchy in a first attempt. Once an initial structure is developed (i.e. the important concepts are arranged in classes and sub-classes); their properties and relations are defined. The various constraints governing these values are identified. The process of creating an ontology is described in detail later in the thesis in chapter 3. Once the final version of ontology is created after several iterations, the final design of the ontology will be described in chapter 4 and a reviewed (by the committee and industry) software model of the ontology will be provided separately.

1.4 Brainstorming

Brainstorming is a tool to provide possible solutions to any unresolved problem. It is an effective way to generate ideas and set a framework that can lead to a possible solution to the problem. The main idea behind the concept of brainstorming is to generate as many ideas as possible in a short duration of time. Brainstorming leverages its success on the thinking power of a group.

Brainstorming was developed by Alex F. Osborn, it has been successfully used as a problem solving tool over several years now. A brainstorming session lets member to help shape decisions and actions of the final outcome similar to a group discussion. However the main difference in a group discussion and a brainstorming session as defined by Taylor(1982) is premature evaluation of the ideas, in a brainstorming session ideas are produced and recorded without any criticism till the leader says to evaluate ideas. A brainstorming may provide “an equilibrium solution in some form of resolution, but the result may not be desired or satisfying for those who have to contend with it” (Loffler & Philips, 1993). Brainstorming helps come up with a common acceptable solution of a problem.

1.4.1 Basic Rules of Brainstorming

Six basic rules of brainstorming as defined by Kerwin (1983) and Loffler & Philips (1993) include:

i. There should be absolutely no criticism and judgments about any ideas during the session.
ii. Quantity of ideas is important. A large number of ideas will increase likelihood of better ideas afterwards in the session.
iii. Number of participants should be between six and eight.
iv. Participation should be complimented. If leader compliments specific ideas it might create an atmosphere of reward seeking.
v. Each idea should be recorded as it is produced, but the name of author should not be recorded with the idea created.
vi. A brainstorming session should last for 30 minutes.

1.4.2 Preparation for a Brainstorming Session

There are a few simple guidelines as suggested by Taylor (1982) that can play an important role in making a brainstorming session successful. The first important point to consider is facility a meeting room with large enough seating place would be the ideal option. Some pens or markers along with a pad of writing papers will be needed to record ideas being generated in the brainstorming session. Once a sheet of paper is filled with ideas the sheet of paper should be taped off to the wall in order to display the list of ideas already generated in the brainstorming session. A list of possible ideas should be prepared by the leader and presented at the start of the brainstorming session, these ideas can be used for further expanding the discussion. In some cases leader can send a selected key participants a background of the problem that needs to be brainstormed. Tischler (2001) suggests that a brainstorming session might follow a curve; it might start slow then pick up and again fall slow and Tischler suggest that fluency and flexibility should be the two important things in brainstorming session. After a fluent flow of ideas, a moment of silence is important. At this point the leader or facilitator should help the group to approach the same idea from a different viewpoint (flexibility).

1.5 Thesis Organization

The second chapter will include a literature review related to the thesis. It will explain the concept of lean and agile supply and how it can be applied to a supply chain. It is not possible to convert the whole supply network into lean in a single attempt. Initially a simple supply chain is identified and leanness is applied throughout this supply chain, which can be later expanded. Chapter 2 will also include an introduction to a brief process of developing a lean supply chain. Chapter 3 will include an introduction to the basics about ontology and how an ontology can help share information. The chapter also explains the method used to develop an ontology. Finally, chapter 3 gives an introduction to Protégé and its capabilities. Chapter 4 will contain the actual informal ontology and its Protégé model. Protégé software is an ontology editing tool developed by the Stanford

School of Medicine and is used to implement the ontology. Chapter five will summarize the thesis and discuss future work.

Chapter 2

LEAN SUPPLY CHAINS

2.1 Introduction

In today's customer oriented market scenario, success of a product and/or company is highly dependent on the end customer. Providing the right product at the right time and at the right cost is the key to success. In order to provide quality products at a lower price many companies are expanding their supply base to the extent that their supply chains exist across continents. This puts companies and their supply chains under high pressure to provide shorter lead times and faster deliveries at low cost, while at the same time keeping the inventory to a bare minimum. Companies have largely implemented cost cutting improvements only in their own facilities or the factory floor (Tinham, 2005). Hence there is a need to develop a new solution.

A lean supply chain is one concept that can really overcome various problems in the form of shorter lead times, lower inventories and better information sharing among partners.

2.2 Supply Chains

A supply chain can be defined as "a web of autonomous enterprise collectively responsible for satisfying the customer by creating an extended enterprise that conducts all phases of design, procurement, manufacturing, and distribution of products" (Whitman et al., 1999). A supply chain can be assumed as a set of connected suppliers and customers with the free flow of product and information across boundaries. A supply chain can be as simple as having a supplier, manufacturer and end customer, or it can something as complex as shown in figure 2.1. Different suppliers and customers are arranged in tiers. Each figure represents a different component of the supply chain which can be adding value to the product directly or providing service.

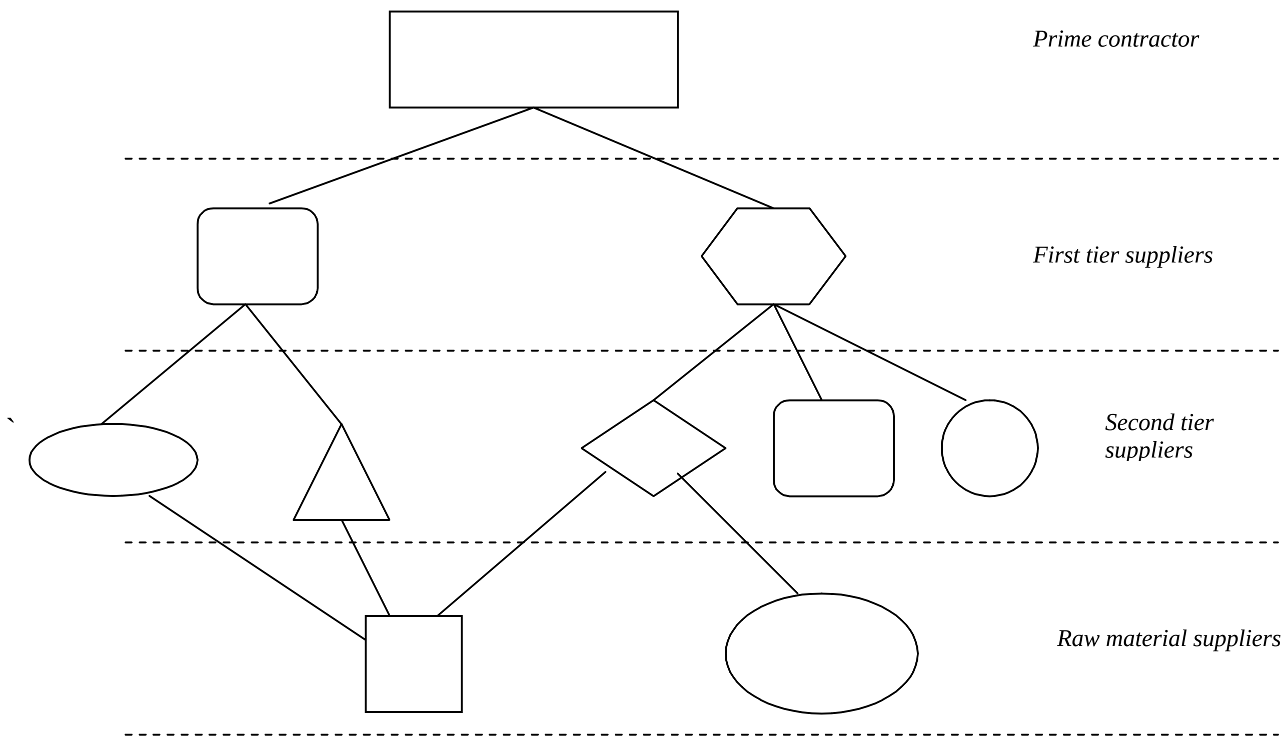

Figure 2.1: A Conceptual Supply Chain (Altarum, 2003)

People commonly think of a supply chain network as a triangular shape with the main contractor located at the top and various suppliers located at the bottom. In reality, many supply chain networks are more like a diamond shape with the prime contactor assumed at top, a number of suppliers in the middle and as the supply chain reaches the raw material suppliers it again becomes narrow at the bottom (Altarum, 2003). A small number of suppliers at the bottom may add another dimension to the supply chain.

Because of the limited number of raw material of suppliers, their size can be bigger the than rest of the supply chain members and other members of supply chain will hardly have any influence on these suppliers(Altarum, 2003).

As shown in figure 2.1, the supply chain can have suppliers assumed to be separated in several tiers. The concept of addressing a supply chain as a single system is appropriate because all the partners in the supply chain are either suppliers or customers to another partner. Hence each component of the supply chain can be the source of waste or value creation in the supply chain. From the end customer's perspective, lead time and cost starts as soon as raw material is bought by the main contractor. Hence, in order to add value from the customer's point of view the whole supply chain should be considered as a single system.

2.3 Supply Chain Management

Supply chain management defines the "flow of goods from supplier through manufacturing and distribution chains to the end customer" (Laming, 1996). Hence there is a need for close relationships between suppliers and customers in order to ensure a smoother flow of product and information throughout the supply chain. Many researchers have focused on the need of working closely with suppliers. A supply chain tries to match demand with supply and to achieve this it should successfully overcome various uncertainties that exist across companies. Uncertainties are sometimes impossible to remove, hence companies must develop strategies to overcome these uncertainties and still be able to match demand with supply. Many uncertainties present in the supply chain can be attributed to "bullwhip effect" instead of being present in the market (Mason-

Jones et al. 2000). The supply chain demand wave was first defined by Forrester in 1961 as demand amplification, these days it's commonly known as the "bullwhip effect". It can be termed as constantly increasing and magnifying behavior of demand as observed upstream from the point of distribution (Mason-Jones et al. 1997).

2.3.1 Bullwhip Effect:

Consider a simple supply chain consisting of four partners; a manufacturer, a distributor, a wholesaler, and a retailer. A retailer places an order to the wholesaler which in turn further places an order to the distributor in order to fulfill this demand. Hence, the distributor will finally place an order to the manufacturer to fulfill this order from the distributor. Variability, in the order placed by a retailer, will be more than the actual variability in the customer demand pattern, hence a wholesaler will have to carry a higher safety stock to cope with this variability. Now consider the wholesaler who receives orders from a retailer and will place an order with a distributor to fulfill the order. The distributor will have to forecast the retailer's demand to meet these orders in time and in the absence of direct access to this demand information, the distributor must carry even higher inventory as compared to the wholesaler. In a similar way the manufacturer will have to carry even higher inventories. Hence, we can say that this increase in variability which causes each member upstream to carry higher safety stock which leads to higher variability up in the supply chain is called bullwhip effect (Simchi-Levi, 2003). Some factors that influence the bullwhip effect as mentioned by Simchi-Levi are:

- Demand forecasting
- Lead time

- Batch ordering
- Price fluctuation
- Inflated orders

2.3.2 Supplier Development

Supply chain management states that in order for a product or a service offered by a company to be successful, value should be added to it faster than cost (Lamming 1996). Value added should be the value perceived by the customer. Hence in order to achieve this, the company needs to work in close cooperation with their suppliers. One such strategy is supplier development, where a company tries to improve its supplier's capabilities by engaging in a short term or a long term improvement initiative. Beyond the boundaries of the firm most companies till now have only focused on improving its purchasing strategy or better logistics. Some of the techniques adopted by companies include the below items.

2.3.2.1 Vendor Managed Inventory (VMI)

A vendor is allowed to obtain data regarding the companies' inventory and based on that it can take replenishment actions. But the final goal of many companies is to eliminate the retailer's intervention completely and a specific supplier is allowed to maintain inventories at the retailer (Simchi-Levi, 2003).

2.3.2.2 Cross Docking

A cross docking center is different from a normal distribution center. Inventory is never stored in a cross docking center, it only helps in sorting and shipping of inventory to its destination. A cross docking center is information intensive in a way that all information is used in effective and efficient inventory sorting and shipping. There is a trade off between inventory and service that can be offered (Swaminathan 1998). It can take longer to respond to change in demand in a cross docking environment since it doesn't store any inventory. Hence, effective information management is needed in a cross docking environment.

2.3.2.3 EDI (Electronic data interchange)

Effective communication is one of the most important parts of a successful supplier partnership (Krause, 1996). EDI is one technique for effective and efficient information exchange from both the customer as well as retailer. EDI, which can be used to send POS (point of sale) information to the supplier is an essential component to reduce the cost and time taken for data transfer. Bar codes, RFID and scanning can eliminate human data entry mistakes and increase data accuracy.

2.4 Lean concept

The logic of lean production defines lean as elimination of waste from the process in order to increase the efficiency of the process (Womack & Jones, 1997). Waste elimination is broadly associated with reduction in inventory. As the inventory is reduced, sources of waste can be identified in the form of late or missed delivery dates, poor quality, large set-up times etc. Lean describes a total view of the process from raw material to finished products; it is also not restricted by the idea of necessary and unnecessary processes. Any type of waste must be eliminated (Lamming, 1996).

2.4.1 Types of Waste:

Taiichi Ohno, an executive with Toyota, was the first to identify seven types of waste in a production environment. These seven types of waste or muda (the Japanese term for waste) can be listed as follows:

1. over production
2. inventory waiting for further processing
3. unnecessary movement of employees from one place to another
4. movement of goods from one point to another
5. material waiting for another process to be completed
6. producing defective parts
7. producing goods that do not meet customer's requirements (Womack & Jones, 1997).

2.4.2 Just in Time (JIT)

The origin of just in time is related to the Toyota production system. The goal of just in time environment is that each workstation can acquire goods from upstream workstation as and when it is needed without delay. Just in time requires a very smooth flow of material through out the process. This has been stated in absolute words as a production process with zero inventories or stockless production (Hopp, 2000). Zero inventory can be thought of as an ideal situation or an ideal production process which does not carry any inventory, this can never be achieved but the standard is always set higher in order to accomplish continuous improvement in search of this ideal scenario.

The seven zeros as mention by Hopp in 2000 which are needed to accomplish zero inventory are described below.

1. *Zero defects*: a defect will always lead to a delay in production, as in a JIT environment there is no excess inventory to make up for a defective part
2. *Zero lot size*: since a downstream workstation can take any number of parts from the workstation above. It won't be possible to replenish the stocks immediately if it has to produce large batches of parts, instead it can be achieved if parts are taken and replaces one at a time.
3. *Zero setups*: a common reason for large batch sizes is long set up times. If there is no set ups or zero set up times continuous production can be achieved.
4. *Zero breakdowns*: since there is no inventory (WIP) to buffer against any down time at any workstation any breakdown of machine will cause delay in production.
5. *Zero handlings*: if parts are made in correct quantities and correct times then the handling needed will be minimum.
6. *Zero lead time*: if perfect JIT is implemented, parts are available to the downstream workstation immediately as it is needed. Hence there is margin for lead time.
7. *Zero surging*: since there is no inventory in the system to respond to any surges in the demand or quantity, the system might be forced to stop or delayed because of this.

2.5 Lean Supply in Theory

The traditional concept of lean manufacturing involved implementing lean concepts on a company's own manufacturing floor. Companies were aligned vertically and they used to think of only their best interests (Lamming, 1996). The present scenario has changed a lot; there is a huge dependency on the suppliers and contractors. Hence, it is not only required for a plant to respond quickly to change in demand, instead the whole supply chain should be able to respond quickly. The key lies in the fact that variations in demand should be visible to the entire supply chain.

A lean supply can be described as a flow of goods and services from the raw materials stage to the finished goods stage without adding any waste. This includes the flow of information in either direction from suppliers to the end customers.
A lean supply chain will look at the process from raw material to finished goods as one integrated process. A lean enterprise will consider a flow of product as it goes from a supplier to a buyer; it extends lean principles beyond manufacturing in the company covering suppliers and all other partners (McIvor, 2001). Boundaries between companies and partners are considered artificial and not as naturally created in the value adding process. Instead they are thought of as hindrances created due to economic and geographic distributions. A fundamental principle of lean supply can be stated as any deviation from the perfect execution of the process which causes waste creation and leads to added costs. The effects of this added cost (due to non-value added steps) are not limited to the physical location of the non value added step (Lamming 1996), for example a company appoints an order expediter whose job is to expedite orders and make sure

delivery dates are met. If the process is already suffering from late deliveries by the supplier, then there is not much that an order expediter can do. So due to an inefficient step at the supplier, the whole supply chain will not be able to meet its delivery dates.

Similarly the attempts of implementing lean concepts can fail if the problem is simply transferred from a customer to a supplier without addressing the root cause of the problem. Hence, lean supply thinking should analyze the cost effect of any non value added step throughout the supply chain. Value should be added keeping in mind the customer. In theory it is possible to achieve ‘leanness’ but practically it is acceptable to be leaner than the company’s competitor. Lamming (1996) explains three features of a lean supply chain as follows:

i. *Cost transparency*: As mentioned before, a lean supply chain considers boundaries between companies as artificial. Hence, supplier and customer should share information regarding sales, inventories and capacity. Cost information should also be exchanged to explore all possible areas of cost reduction and adding more value than cost in each production step. Ideas must also be accepted from both suppliers and customers

ii. *Relationship assessment*: The concept of vendor assessment became popular during the 1980s. Vendor assessment is a customer assessing a supplier’s facility recommending improvements, employing new technologies and implementing processes with increased level of sophistication. In the late 80s some supply chain partners found this concept flawed. A customer might criticize a supplier’s production methods but would remain inefficient itself. This method is not so useful without criticism from suppliers as well. Best practices in supply chain may include a two way assessment of both supplier and customer in order for both to be efficient and for the complete supply chain to be leaner and more responsive.

iii. *Excuses and blame:* A commonly observed feature of certain production processes is the use of excuses and blame to avoid penalty. Excuses and blaming the other partner for a problem can never lead to a solution of the problem. The luxury of excuses and blame should not be permitted in a lean supply environment. Instead a cost should be associated with blames and excuses for a problem. This cost then can be attacked as a non value added cost.

2.5.1 Agile Supply Chains

Outsourcing of manufacturing to suppliers offshore, does offer some costs benefits but it has some trade-offs. Since suppliers are mostly in different countries and often across different continents, the response time is large and higher levels of inventory might be needed to support this extra lead time (Stratton, 2003). This higher level of inventory poses a risk of obsolescence and higher inventory carrying costs. Sometimes it is impossible to eliminate uncertainty from the system and it is not possible to eliminate the entire inventory from the system. Hence, certain supply chains are faced with a situation where they have to accept certain level of inventory and come up with a strategy, that makes it more responsive or agile (Mason-Jones, 2000). There is a need to distinguish between the kinds of products a supply chain is focused on. In case of innovative products and products with constantly varying styles, in addition to leanness a fast response from a supply chain is needed to satisfy the ever changing demands.

An agile supply can be defined as a more responsive supply chain as compared to a lean supply. The main focus of a lean supply is low cost, stable product range and long product lives. On the contrary agile supply focuses on ability to quickly deliver a wide range of products with uncertainty in demand and shorter life cycles of products (Stratton, 2003). A lean supply may also focus on eliminating waste to achieve low cost production, whereas agile is more focused on fast response to demand variation. As mentioned by Stratton (2003) there are two main distinctions in case of an agile supply.

1. Non standard nature of product will always inherit some fluctuations in the supply chain.
2. Highly variable demand will make it impossible to use finished goods inventory to decouple supply.

Mason-Jones et al (2000) suggest that once leanness has been achieved in a supply system, partners should focus on making the supply as agile.

2.5.2 Benefits of a Lean Supply Chain

Some of the benefits of a lean supply chains as stated by Tinham (2005) include

- Shorter lead times
- Reduced costs; both direct and indirect
- Lower inventories throughout the supply chain
- Better customer service
- Responsive supply chain

2.6 The Lean Supply Process

Altarum (2003) gives an introduction to form a lean supply system. the process is outlined below:

i. Select a target supply chain
   a. Identify the product and goals that will create a level for optimization
   b. Short-list and identify first-tier suppliers
   c. Define performance goals and create a context for optimization for a selected supply chain
   d. Try to do the same for rest of the supply chain
   e. Select sub-tier suppliers

ii. Assess the current supply chain
   a. Assess first-tier suppliers and contractors, review baseline
   b. Bring the supply chain partners together and explain goals to them and try to buy-in sub-tier suppliers
   c. Come up with a macro view of supply chain

iii. Determine future strategy
   a. Draft a future state
   b. List opportunities in current supply system
   c. Evaluate opportunities and compare them with goals
   d. Discuss analysis results with partners

iv. Implement results
   a. Plan improvements

b. Implement improvements

c. Measure and document changes and improvements

d. Celebrate success with all supply chain partners, define results and discuss future road map to continuously improve

v. Share results with current suppliers and select further supply chains to advance towards a lean enterprise.

2.7 Ontology

Researchers in the field of artificial intelligence were the first to work with ontologies. The main purpose is automated information sharing. More recently ontologies have become more popular among researchers in the field of intelligent information sharing, digital libraries, e-commerce and knowledge management (Antoniou 2005). According to the classical artificial intelligence definition, an ontology may be defined as "a specification of a conceptualization" (Gruber, 1993). An ontology language should specify, at an abstract or conceptual level, what will be true about this domain of knowledge. More specifically, an ontology should be able to define constraints that will help identify what will always hold true in any particular domain. According to Staab and Maedche (2000) the main role of an ontology is to capture knowledge and provide some commonly agreed upon terms. The terms in a particular ontology are generally organized in a taxonomy and contain relations, concepts and axioms. It includes machine interpretable definitions of these concepts and relations.

An ontology has potential to make software models and web pages more efficient and adaptive at the same time. Ontologies are used in the area of bio/medical informatics for a long time. Protégé, an ontology editing tool, has been developed by the school of medicine at Stanford University. Ontologies also find use in information sharing and reuse of knowledge.

Ontologies are common on the World Wide Web. From categorizing taxonomies on Yahoo to arranging products in different categories on shopping websites like Amazon.com. The “WWW consortium is developing a Resource Description Framework (RDF)” (Noy, 2006). RDF is a language used to encode web pages which enables electronic agents to search information online from web pages. The Defense Advanced Research Projects Agency (DARPA) along with the WWW consortium is developing another DARPA Agent Markup Language (DAML). DAML will have more expressive constructs that can efficiently interact with other web agents available online (Noy, 2006). Many standard ontologies are available on the internet which can be used to share information. A lot of ontologies in the field of medicine are available over the web such as SNOMED (Price & Spackman 2000) and the Unified Medical Language System (Humphreys & Lindberg 1993).

2.7.1 Uses of Ontology

Ontology in AI (Artificial Intelligence) is defined as the study of ‘kinds-of’ things that exist in the world. It is considered that an ontology breaks the world at its joints (Chandrasekaran, 1999). An ontology can be assumed to consist of a vocabulary for a particular domain and it also consists of knowledge about this domain in the form of relations that exist in these terms. Hence ontologies are basically used to structure knowledge about a particular domain. This can be achieved in the following ways:

i. Enabling better communication between people and computers

ii. Making explicit assumptions in a domain
iii. Reusing information already available
iv. Enabling Interoperability
v. Analyzing domain knowledge

2.7.1.1 Enabling Better Communication Between People and Computers

Enabling a common understanding of terms and their structure in a knowledge base is among the main goals of most ontologies (Musen, 1992). Ontologies can eliminate conceptual confusion by providing a shared framework, to which different users in the organization agree. Different people in the organization view terms from a different perspective to define terms. An ontology can eliminate this confusion by establishing a shared understanding of the knowledge base. An ontology helps to create an unambiguous definition of terms. These terms can then be arranged in a structure based on some relations. Ontologies also help to keep track of these relations. Any software that interacts with other software must have clearly defined terms and structure (Uschold, 1996). Ontologies help to identify logical relations between terms and hence make assumptions explicit.

2.7.1.2 Making Explicit Assumptions in a Domain

An ontology helps to make assumptions in a domain explicit. It is easier to change an assumption if it is clear what is implied. On the other hand, it is difficult to change an assumption hard-coded assumption in programming, especially for a person who is not familiar with the programming language. An ontology helps to clearly state all assumptions explicitly (Noy, 2006). So assumptions can be modified whenever the researcher's knowledge about the domain has changed.

2.7.1.3 Reusing Information Already Available

Another important purpose of generating an ontology is to share it with other researchers interested in the particular field. For example, if one group develops an ontology for time, then the other group can reuse the same ontology in its research to define *time*. Hence, a lot of effort and time can be saved by reusing the ontologies (Noy, 2006). Suppose an ontology covering a complex domain of knowledge and consisting of a large number of terms and relations needs to be built. Then, various small ontologies (which might have been already built by some researchers) in the same domain of interest can be combined to build a large ontology.

2.7.1.4 Enabling Interoperability

An ontology also addresses the issue of interoperability. An ontology can serve as an integrating software tool in such cases (Uschold, 1996). Information can be required by different people using different computer applications, but information might be stored in a format which is incompatible with other applications. Ontology can provide a common understanding by mapping of the terms. This is achieved by the use of an ontology in an interchange format and using a translator.

2.7.1.5 Analyzing Domain Knowledge

Analysis of terms and relations between them become extremely important when reusing a previously generated ontology or extending an ontology (Noy 2006). Most times, creating an ontology itself is not the only goal of the researchers (Khoury, 2005). In fact, an ontology is built to be further used by some other applications or to assist a software tool. For example a supply chain ontology built by some researchers can be used to build and model a supply chain based on this ontology. The same supply chain ontology can be used by someone else and extended further to build an ontology used for tracking orders in a supply chain.

2.8 Types of Ontology

Ontologies often play different roles in defining a domain of knowledge. An ontology can be very generic in its description, for example an ontology for 'time' will consist of highly generic terms. Also, ontologies can be very descriptive and conceptual about a particular domain or its application. There are various ways to describe types of ontologies based on its application and the purposes it will serve. Some important types of ontologies are described in this section:

2.8.1 Upper Ontology

An upper ontology can be assumed as an ontology that describes what exists in the world (Mizoguchi, 2003). An upper ontology can be considered as an ontology which does not need other terms to define its concepts. It is generally used to define the basic terms and concepts in a very large and complex ontology. "Compliance of a large scale ontology with a principled upper ontology provides a good justification and it provides useful guidelines on how to organize domain knowledge" (Mizoguchi, 2003).

2.8.2 Domain and Task Ontology

According to Guarino (1998), a domain ontology will essentially consist of vocabulary and terms related to a general domain like medicine or automobiles. A task ontology on the other hand will consist of terms which are more specific about an activity (diagnosis or selling an automobile) in a particular domain. A task ontology may refer to the actual problem solving or diagnosing process. In the past ontologies were not considered as very useful, in fact they were thought of as very 'task-specific' (Mizoguchi, 2003). In practice if a domain ontology is defined after defining the task ontology, the resulting ontology will be very generic and free from task-specific terms.

2.8.3 Light-weight Ontology and Heavy-weight Ontology

Another criterion to look at ontology as defined by Mizoguchi (2003) is a light-weight ontology and a heavy-weight ontology. A light weight ontology is one which does not contain detailed definition or relations in the terms and concepts it uses. It stresses more on the hierarchy of the terms and how they are arranged. For example, the main purpose of such ontologies is to power an online web-site or a search engine like Yahoo.com. Contrary to this a heavy weight ontology is one which has more details in terms of definition of the terms and relations between them. Rigorous thinking and discussion goes into the defining of relations between the concepts defined in the ontology.

Summary

A lean supply chain extends the principles of lean beyond a company's four walls. It looks at the flow of products and services from a supplier to its customer without any boundaries. Lean supply emphasizes on eliminating the waste or non value added step from the supply chain instead of transferring from a company to a supplier. The main notion is that supplier and buyers are a part of one enterprise. Lean supply should have a free flow of information, goods and technology across supplier's and buyer's boundaries. The impacts in all parts of the supply chain should be measured, of a decision taken at another part in a supply chain.

The need for minimum inventory in the supply chain needs a kanban system of supply. Hence, supplier buy-in is really important to ensure defect free and on-time supply. Vendor assessment and willingness of a supplier may be used to develop an initial lean supply chain that can be used as a model for rest of the supply chain to follow. Similar to lean production system a lean supply system is competition driven and companies won't have the luxury to ignore it.

Chapter 3

Method to Generate a Lean Supply Chain Ontology

3.1 Introduction

This chapter discusses the method used to generate an ontology. Although there is no exact method to generate an ontology, the best method may depend on the type of ontology being created and the purpose it will serve. The method suggested in this chapter is an iterative approach. The concepts selected will be as close to the 'lean supply chain' domain as possible and the terms (relations) sometimes will have a meaning not the same as the dictionary meaning. The chapter also includes a brief overview of what is an ontology. Some uses of an ontology are also described and finally the chapter ends with an introduction to Protégé, the ontology creating tool used in this thesis. Some of its advantages are also discussed.

3.2 Ontology Generation

Ontology generation defines the structure of any knowledge domain. The ontological analysis is crucial in representing the structure of the knowledge domain. A weak ontological analysis may lead to an incoherent ontology, which might have overlapping terms and relations (Chandrasekaran, 1999). There is no exact method to build an ontology (Noy, 2006). There might always be a better alternative method available. Choosing the best method is dependent on the kind of ontology being created, such as whether it is an upper level ontology which will consist of only basic terms and what exists in this world or a light weight ontology which empowers a search engine on the internet. The amount of detail that needs to go into an ontology will highly depend on the purpose it serves. Ontology creation is an iterative process (Noy, 2006). It might start with a rough draft first and then every time it is reviewed, more details are added to the ontology. The process is like revising and refining the ontology during iterations until it consists of sufficient details about the domain and is useful for the purpose it is intended to serve. After an initial version of ontology is defined, it can be later modified to contain more details. An iterative approach of ontology generation is presented in this section. The process can be broken into various steps as described later in the chapter.

Deciding the level of detail and the purpose of the ontology plays an important role in the ontology generation process. It should be kept in mind that the ontology model will represent a reality of the world hence the terms and concepts used to define the ontology should be as close to the real world as possible (Noy, 2006). A design criterion as defined by Gruber (1993) can be summarized as:

a. Clarity

An ontology should clearly define the terms in the knowledge base. A definition should be provided for each term and natural language should be used as far as possible. In order to make the definition more clear in meaning, examples might be provided to help the users of the ontology to understand the meaning of the terms and relationships. This means that ambiguity should be removed as far as possible in order to make the ontology useful for other users and researchers.

b. Coherence

An ontology should be consistent in its meaning of terms and axioms defined by the relations and the terms in it. Also the relationships defined should be logical and consistent.

c. Extensibility

A major aim of creating an ontology is sharing knowledge and making it available for reuse by other researchers interested in the same knowledge domain. An ontology should offer strong conceptual fundamentals in such a way that it can be extended into a more specialized field. For this to happen, it is important to model terms in such a way that other researchers may the take terms from the old ontology and use them in a more specific and specialized form without changing any previous terms or relations between them.

d. Minimal ontological commitment

An ontology is used to represent concepts in a knowledge base. It should need a minimum number of commitments in order to achieve knowledge sharing. Gruber (1993) defined an ontology commitment as a specific way in which the vocabulary (concepts, relations and queries) will be defined, so that it is consistent with the theory represented by the ontology. An ontology can serve different purposes in the knowledge base as it can be used as a vocabulary or for solving a specific problem in a knowledge base. Therefore making too many commitments and claims about the knowledge base being modeled may lead to constraining the use of the ontology. It may even cause a flawed view of the model (Uschold, 1996). Allowing the freedom to specialize the concepts will help researchers to instantiate the ontology easily. At the same time, making too few commitments may lead to an unintentional or an incorrect model (Guarino et al., 1994).

3.3 Steps in Creating an Ontology

A step by step approach to create an ontology is presented here. It is not claimed to be the best approach for ontology creation, rather it is one of the various ways that can be successfully used to generate an ontology. A brainstorming session as defined in chapter 1 will be used to define scope and terms in the ontology. Once the ontology is created a software model of the final ontology design in Protégé will be provided separately.

3.3.1 Step 1 Define Scope of Ontology

Defining the scope of the ontology will be the first step to start ontology construction. This helps in identifying boundaries of the ontology (Uschold, 1997). One method to limit the scope of the ontology is to ask some basic questions regarding the purpose of the ontology. These questions as suggested by Noy (2006) might include:

1. What is the domain that the ontology will cover?
2. Who will use the ontology?
3. What purpose will the ontology serve?
4. What information should be included in the ontology?

It is not possible to define all concepts related to supply chains in an ontology. This ontology will try to come up with a model for lean supply chains that other users and researchers can refer to if they need information regarding the construction of a lean supply chain. The scope and domain of the lean supply chain ontology is presented in chapter 4.

3.3.2 Step 2 List Terms in Ontology

One approach for this step is to list all the terms that are relevant to the knowledge domain, which is a lean supply chain in this case. Initially, importance should be given to get a comprehensive list of all the terms related to a lean supply chain without being concerned about overlap between the terms, concepts, or the properties or relations they might have (Noy, 2006). This will produce an unstructured list of various terms related to lean supply chains.

Terms can then be divided into different categories based on their importance in lean supply chains. Terms that are more closely related to each other will be grouped together as compared to terms not closely related to the main 'idea' of the ontology. The groups will be formed in such a way that the terms in one group will have more similarity in meaning and there will be minimal need to refer to terms from other groups in order to explain them. For example, all the terms related to lean concepts can be grouped together and terms related to supply can be grouped together. Similarly, terms related to demand can be placed in a separate group. Priority can then be assigned to these terms or groups of terms. Once terms are organized into groups based on importance to the ontology; duplicate terms or synonyms can be deleted from the list. More terms or concepts can always be added during various iterations.

Brainstorming sessions will be used in order to list all the terms and concepts that are relevant to a lean supply chain. This will also help to list all the ambiguous terms, ambiguity about relations of the terms with each other and the differences in perspective and opinions. The list of all the terms included in the ontology will be presented and discussed in chapter 4. The actual ideas presented in the brainstorming sessions will be included as appendix.

3.3.3 Step 3: Define Terms

The purpose of defining terms in an ontology is to describe how these limited terms will be used to define concepts and relationships between concepts and constraints on these concepts (Uschold, 1997). The meaning of terms in an ontology can be totally different than their dictionary meanings. Before defining a term in an ontology it is important to understand the relation of the term with all the other terms in the ontology.

Terms will be defined one group at a time. Basic terms will be defined first and then other terms will be defined using these basic terms as far as possible. Definitions of the terms will be defined with simple words as much as possible. Some basic terms like matter, quantity, entity, relationships and so on will be defined in a separate 'Meta-Ontology' which is discussed latter in this chapter. Terms defined in a meta-ontology serve as building blocks for other terms in the ontology (Huber, 2003). In order to define other concepts in a lean supply chain environment, the APICS dictionary and Supply Chain Council will be referred to as much as possible.

A middle approach will be adopted to define the terms related to the ontology. Three approaches commonly used to define terms as defined by Uschold and Gruninger (1996) are as follows

a. *Top- down approach*: in a top-down approach, the most general terms are defined first. Then subsequently specialized terms are defined in a domain of knowledge. A top-down approach helps to better control the level of detail. A top-down approach results in researchers picking up limited high-level terms which are later developed into specified concepts. Sometimes a top-down approach may lead to an arbitrarily strict level of detail since the terms are not naturally listed into an ontology but are listed under some high-level category.

b. *Bottom-up approach*: in a bottom-up approach, most specific terms are defined first. Based on the definitions they are grouped into different categories and then high-level terms are defined. A bottom-up approach can result in a high level of detail in an ontology. Since all specific terms are listed first, researchers might tend to group them into more categories than needed. This often leads to an increased effort in ontology generation and it even increases the risk of overlapping and inconsistent concepts.

c. *Middle approach*: in a middle approach, terms that are most common will be defined first. These common terms will then be used to define high-level terms and the more specific terms. A middle approach strikes a balance between the top-down approach and bottom-up approach by defining important concepts first and then defining higher level categories. Hence, higher level terms are defined, if the need arises, so unnecessary restriction is avoided. Also it does not start with the most specific term therefore it results in a less detailed ontology as compared to a bottom-up approach, which results in less overall effort wasted in ontology generation.

3.3.4 Step 4 Define Classes and Class Hierarchy

From the list of the terms listed in step 2, classes will be defined first. Classes are "terms which define objects that have independent existence rather than terms that describe these objects" (Noy 2006). Classes are then organized into hierarchies by determining which class will act as a super class. If all the objects listed under Class A can also be listed under Class B then class A is a sub-class of class B. Hierarchy depends on the use of ontology and the amount of details that need to go into an ontology structure. Some guidelines that will be used to define class hierarchy as defined by Noy (2006) and Uschold (1996) are:

a. Plural names of classes will be avoided throughout the ontology, using plural names of a class may lead to confusion that the singular form of the class is a sub-class of its plural form. For example class *supplier* may be mistaken as a sub-class of another class *suppliers*. To avoid this confusion only singular forms of words will be used to represent classes.
b. Names of classes will represent the concept in the domain of knowledge and not necessarily the meaning of the word.
c. Synonyms of the same class name will not be used as a name for a different class.
d. Class cycles will be always avoided always. For example, if there is a class A which has a subclass B and at the same time it is defined in class hierarchy that class B is also super class of class A. This kind of hierarchy is called cyclic hierarchy which leads to the conclusion that all instances of class A can also be listed as instances of class B. In other words class A and B are equivalent. This adds redundancy to the ontology, therefore cyclic hierarchy should be avoided.
e. Classes, or sub-classes, at the same level in the class hierarchy should have the same level of generalization.

3.3.5 Step 5 Define Properties of These Classes

Classes alone are not able to define the complete structure of an ontology (Noy 2006). Once the class hierarchy is defined, there is a need to define different properties of these classes. Properties help to define a class better. Suppose a class *supplier* is defined in step 3 and 4 of the ontology generation method. Then some possible properties for this class may include supplier name, address, material supplied, preferred supplier and so on. Properties can also be used to define relationships between different classes.

Since most terms that were listed in step 2 would have been selected as classes or sub-classes, most of the remaining terms will be properties. Each property will be linked to at least one class.

3.3.6 Step 6 Define Constraints on the Properties

Properties defined in step 5 can take different values based on the needs and use in the ontology. But some constraints need to be defined regarding the type of values or the total number of values that a particular property can have. A property can have multiple values or a single value, for example the *name* property can have only one value. Whereas the *maker* property can have more than one value. Property cardinality will be used to define how many values a property can have. Cardinality will be mentioned in Protégé (ontology editing tool used for this study) model. Protégé will also be used to specify the permissible value for a particular property/slot (property is named as a slot in protégé) which will be:

String: that is, if the value can only be alphabets and numbers.

Integer: if the property can take any integer number as its value.

Boolean: if the properties can only take two values (either true or false).

3.3.7 Step 7 Define Instances

The last step in the ontology creation will be to populate the ontology model created in steps one to six. Instances will be the most specific terms, which might have been listed in the list of terms created in step 2. For example, the company ABC may be a supplier located in China, but this is a specific instance of a class *supplier* and so will be listed as an instance of class *supplier*. Some basic steps included in this process will be choosing the class to which a particular instance will belong, selecting properties and the input to their values.

Ontology creation is an iterative process which means that at any stage, concepts or new terms can be added to the ontology based on their requirements in the ontology. As defined by Ahmad (2004), ontology generation can be considered as a waterfall approach. Each step takes place after the previous one is completed (the backward arrows signify the fact that ontology creation is an iterative process.

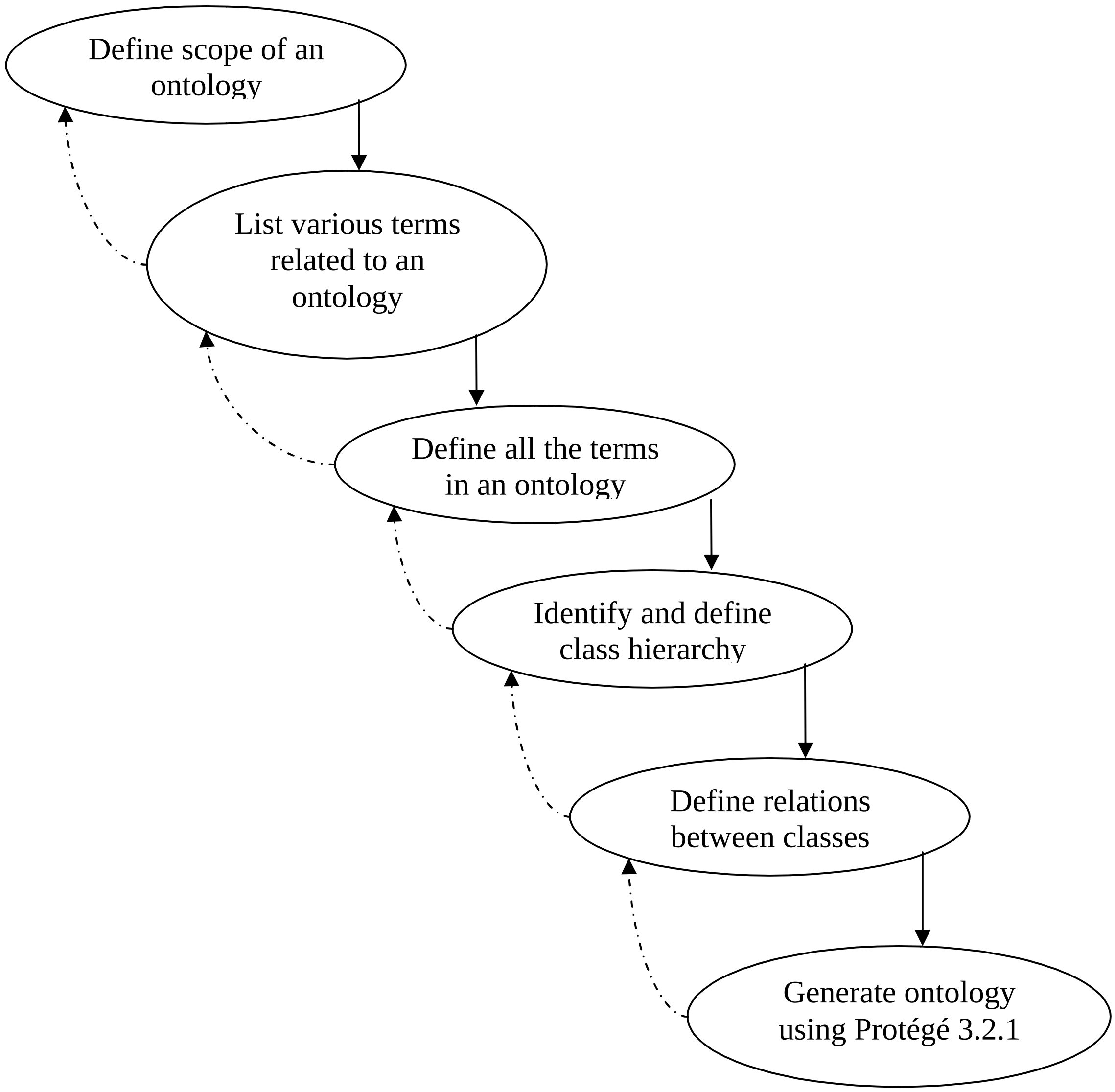

Figure 3.1 Iterative nature of an ontology generation process (Ahmad 2004)

3.4 Naming Convention

A large number of terms will be listed in step 2 of ontology creation. In order to make this ontology easy to use by everyone some rules need to be defined regarding the process of naming different classes and properties. For example ‘order’ can be listed as a class of orders. It will have its sub-classes as the different kinds of orders a customer can place. *Order* can also be used as a property, for instance if a customer places an order with its supplier. In this case, *order* defines a relationship between the class *supplier* and *customer*, therefore it can be listed as a property. Some rules regarding name convention are:

a) If a class has two words in it, two words will be combined by an 'underscore' symbol. For example if there is a property named order number, then two words will be combined and written as Order_number. This is done to avoid confusion regarding terms.

b) Plural names for classes and properties will not be used

c) If needed the same word will be used as the name for class and property at the same time. In order to avoid confusion, the names of classes will be capitalized and the names of properties will be in lower case. Protégé is case-sensitive; it will allow the same word being used to name a class and a property at the same time. But Protégé will not accept the same name for both class and property if both are capitalized or both are in lower case.

d) Some knowledge bases allow the use of prefixes and suffixes in the name of slots. In this ontology however, no prefixes or suffixes will be used in the names of classes and slots to avoid confusion and keep the names short.

3.5 Meta-Ontology

In the process of selecting terms included in the knowledge base and defining these terms in step 3, some basic terms will stand out and they need to be explained using any assumptions. Most other terms will use these basic terms to define their existence or their relations with other terms and concepts in the ontology. A meta-ontology will generally consist of terms like matter, quality, relation, and time. These terms can be defined without making any other assumptions (Mizoguchi, 2003).

In the case of complex ontologies for a large knowledge base, validating the usefulness of the knowledge base, its stability and application to a wider range of tasks becomes more important than its specific application. A meta-ontology is generally task independent, so it does not help in problem solving.

As defined by Uschold (1996) “the basic concept of meta-ontology is entity.” More or less all terms in the ontology will be some form of entity. These entities will sometimes play the role of relationships between different concepts, actors or agents that do or start an activity. Initially, no commitment should be made towards a meta-ontology, doing so may constrain the thinking and development of other terms and concepts (Uschold, 1996). Wrong and inadequate definitions in the beginning may lead to a lot of rework. A careful understanding and consideration of all the terms and their relations in the main ontology will correctly determine the requirements of a meta-ontology. Even in the lean supply chain ontology, a meta-ontology will be defined after defining the main ontology.

3.6 Protégé 3.2.1

The Protégé ontology editing tool is used for creating and editing the lean supply chain ontology. Protégé is a free and open source ontology editing tool which is widely used in creating knowledge bases, ontologies and various problem solving tools. Protégé was developed by Stanford Medical Informatics at the Stanford University School of Medicine to develop knowledge base systems in the field of medicine. Protégé can define different classes related to the knowledge base and then define instances for these classes.

It can simultaneously work with both classes and instances. Classes can also be added as properties or instances for other classes (Noy; Fregson, 2006). Protégé uses a graphical user interface for ontology creation and editing. This is helpful especially because researchers and experts in various other fields might not be very comfortable with advanced programming language hence Protégé is an easy tool for them to create an ontology.

Protégé is an Open Knowledge-Base Connectivity protocol (OKBC) compatible knowledge base creation and editing tool. OKBC is a common query and construction interface which makes is easy to export and import files from other knowledge base servers. Some of the other benefits as defined by Noy (2006) of using Protégé as an ontology creating tool over other ontology creating tools are listed below.

1. Protégé has a simple and easy to use graphical user interface
2. Protégé helps to graphically view the structure of an ontology
3. Protégé database loads frames only on demand and uses caching to free up memory when needed
4. Protégé is easily extensible and various plug-ins that enhance its capabilities can be added to Protégé

Summary

An ontology can be defined as “a specification of a conceptualization” (Gruber 1993). An ontology defines the vocabulary which is used to share information among researchers. It includes machine interpretable definitions of the concepts involved in the ontology (Noy, 2006). Three main reasons for ontology creation include:

a) Knowledge sharing

b) Better communication

c) Interoperability

The ontology creation method is an iterative process and there is no right way of defining an ontology. There can always be a more appropriate way depending on the scope and use of the ontology being created. The method adopted to create an ontology for a lean supply chain system includes following steps:

a) Defining the scope of ontology

b) Listing all the terms relevant to knowledge base

c) Defining the terms

d) Identifying classes and defining the class hierarchy

e) Defining properties for the classes

f) Defining constraints on the properties

g) Creating instances of classes.

A Meta-ontology is used to define basic terms in the ontology. A meta-ontology will generally consist of terms like matter, quality, relation and time. These terms can be defined without making any other assumptions (Mizoguchi, 2003).

Chapter 4

ONTOLOGY FOR A LEAN SUPPLY CHAIN

The ontology for a lean supply chain is developed in this chapter. The ontology generation process starts with defining the scope and domain. Steps for creating an ontology listed in the previous chapter are used to define the ontology. A hypothetical supply chain is used to define the flow of information and parts in the supply chain.

4.1 Domain and scope of the Ontology

Ontology generation is an iterative process that starts with defining the domain and scope of the ontology. It is important to define the intended uses of an ontology. The domain and scope help to identify the boundaries and the purpose for generating the ontology. A brainstorming session was used to develop a domain and scope for the ontology. Brainstorming is a tool to provide possible solutions to any unresolved problem. It is an effective way to generate ideas and set a framework that can lead to a possible solution to the problem. The brainstorming team consisted of Drs. Don Malzahn and Lawrence Whitman. For this purpose questions suggested by Noy (2006) are used to determine the scope and domain of the ontology.

- What is the domain that is covered by the ontology?
    - The primary focus of lean manufacturing is delivering value to the customer. This is achieved by eliminating waste from the processes. The lean supply chain looks at a broader goal of delivering value to the end customer by optimizing the entire supply chain. The best performance scenario for the entire supply chain may not be the best scenario for individual components.

    - The domain of the supply chain ontology will cover the application of lean principles across the supply chain. The lean supply chain looks at the process from the raw material stage to the finished good stage as an integrated enterprise. This lean supply chain identifies a hypothetical supply chain which extends from the supplier's supplier to the customer.
- Who will use the ontology and what purpose will it serve?
    - The ontology will serve as a reference model for researchers interested in developing lean supply chains. It will also act as a platform for further research in specialized fields like order tracking in a supply chain or simulation of a supply chain.
    - The goal of the lean supply chain is to achieve:
        - Shorter lead times
        - Increased on-time deliveries
        - Reduced costs
        - Improved quality

- What information should be included in the ontology?

    - The lean supply chain ontology will identify the key concepts and define the relationships between these terms. The list of the terms generated and their definitions will help to create a common shared knowledge base across the supply chain.
    - The lean supply chain will utilize supply chain management and lean concepts across various partners in a supply chain to achieve shorter lead-times, higher rates of on-time deliveries, lower cost of production and improved quality.

The supply chain consists of a HVAC (Heating ventilation and air conditioning) company called The HVAC Company. The company mainly makes three products AHU (Air handling units), CRU (Circulation units) and Fan assemblies. AHU is an engineer-to-order product while the CRU and fan assemblies are make-to-stock items. A brief product structure of these parts is given in figure 4.1. All engineer-to-order jobs need a new design each time an order is placed from the customer. Hence, it is difficult to forecast demand for such products, while the customer provides the forecast for make-to-stock items. Production is driven by forecast for make to stock items.

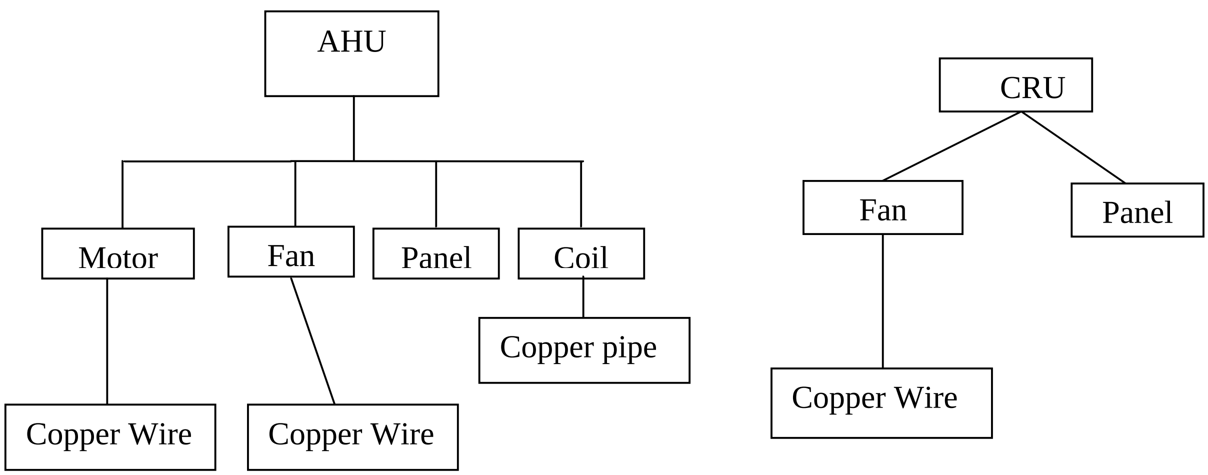

Figure 4.1 Product structure for AHU, CRU and Fan

The supply chain is established in this way; the HVAC Company has two tier one suppliers: the copper company that supplies panels and copper coils which are used in products manufactured by the HVAC Company and the electric company which supplies centrifugal fans and motors. Finished parts are supplied to one final customer, The Blue Moon Company. The supply chain also has a tier two supplier, The Nature Company, which supplies copper wire and copper pipe that are used for manufacturing coils, motors, and fans. VMI (Vendor managed inventory) and forecasting techniques are used to manage inventory among various partners in the supply chain. The products of the HVAC Company are classified under two categories ETO (Engineer to order) and MTS (Make to stock). To have a better understanding of the architecture of the interactions between various partners of the supply chain two models are proposed, one for managing ETO and other for managing MTS products. Lean and supply chain concepts are applied across each partner to make the overall supply chain lean. This is covered in detail later in this chapter once the important terms are listed and defined.

4.2 Important Terms in the Ontology

The terms in the lean supply chain ontology have been chosen as close to their natural meaning as possible. Some of the words in the lean supply chain ontology might not be the most common choice to represent the concept but it have been selected to avoid the confusion of mixing the term with other terms in the ontology. In some cases phrases have been used to represent concepts. This might not seem to be the best approach to define a concept but it is the selected approach in order to keep concepts clear in their meaning.

Two brainstorming sessions where held to create the list of terms. The first brainstorming team consisted of Drs. Don Malzahn and Lawrence Whitman. The second brainstorming team consisted of Jerry Kukuruda, supply chain planning manager at LSI Logic Corporation, Wichita, Kansas and Kevin Parker, supply chain analyst also at LSI Logic Corporation. During the brainstorming sessions, all the terms that were suggested were recorded. The main idea was to get to the terms that were important to the lean supply chain and the properties of these terms. For this reason a comprehensive list of terms was generated during the brainstorming sessions without consideration to the relations between these terms. As stated by Uschold (1997) a basic term is defined and then other related terms are defined. The terms can be more generic or more specific. The middle approach of listing the terms is used in generating this ontology. In this approach, the most prevalent term is defined first which can then be generalized and/or specialized. The complete list of terms generated during the brainstorming session is provided in the appendix. This unstructured list of terms was then divided into different categories based on its relation and importance to the lean supply chain ontology. The terms are divided into different categories based on its relevance to the lean supply chain ontology. The main categories under which the terms can be classified or grouped on the base of relations between the terms are: supply chain, lean, time, flow, cost, material and control. Terms that are more closely related to each other have been placed in one group. Table 4.1 lists the terms included in the lean supply chain. There is no relationship between the terms that are in the same row.

Table 4.1 List of Terms in the Lean Supply Chain Ontology

Supply chain	Lean	Time	Flow	Cost	Inventory	Control
3PL	5S	CT	Informational flow	Fixed cost	FGI	MRP
ASN - Advance shipping notice	Andon	LT	Customer order	Holding cost	RMI	Forecast technique
BPR	Autonomation	Response time	Shipment order	Shipping cost	Buffer	Inventory policy
EDI	Heijunka	Production lead time	Production order	Material cost	WIP	Point of use data collection
On-time delivery	JIT	Purchase lead time	Purchase order	Manufacturing cost	MTS	Lead time offset
RFID	Kanban	Shipping lead time	FGI shipment		MTO	BOM
Risk pooling	Kitting	Set up time	Replenishment order		ATO	Period order qty
Supplier development	Lean		Pull from VMI		Purchase part	Safety stock
CPFR	Level Load		Point of sale (POS)		ETO	MPS
supply chain partners	Line Balancing				VMI	Push pull control
Raw material	Once Piece flow					LTL

supplier						
Prime contractor	Pull					FTL
Customer	SMED					Forecast
Distribution center	Standard work					Planned order
Second tier supplier	Value					Planned work order
	Value Stream					Priority plan
	Value Stream Map					Allocate raw material
	Visual Controls					Production schedule
	Waste					Release order
	Cross functional team					MPS
	Bottleneck					
	Buffer					
	Setup time reduction					
	Cross docking					

The main groups, under which terms have been classified, are generic terms which will be used as the main building blocks for the lean supply chain ontology. These are some of the basic conceptual terms which will help to build the main lean supply chain ontology and these terms will constitute the meta ontology (i.e. the terms which will be used to define and build other terms in the ontology).

4.3 Ontology Terms Defined

The purpose of defining the terms in the ontology is to describe how a limited number of terms will be used for the concepts and relationship between these concepts in the ontology (Uschold, 1997).Whenever possible, the general term within each group will be defined first and will then be used to come up with other related terms. The APICS dictionary (2005) and Supply Chain Council definitions have been used to define all of the ontology terms.

3PL- “A buyer and supplier team with a third party that provides product delivery services. This third party may also provide added supply chain expertise.” (APICS, 116)

5S: Five terms beginning with “S” used to create a workplace suitable for lean production. Sort means to separate needed items from unneeded ones and remove the latter. Simplify means to neatly arrange items for use. Scrub means to clean up the work area. Standardize means to sort, simplify and scrub daily. Sustain means to always follow the first four Ss. (APICS, 43)

Andon- An electronic board that provides visibility of floor status and information to help coordinate the efforts to linked work centers. Signal lights are green (running), red (stopped) and yellow (needs attention). (APICS, 5)

ASN- (Advance ship notice) “An EDI notification of shipment of product.” (APICS, 3)

ATO: “Assemble-to-order a production environment where a good or service can be assembled after receipt of a customer’s order. The key components used in the assembly or finishing process are planned and usually stocked in anticipation of a customer order.”(APICS, 6)

Autonomation- automated shutdown of a line, process, or machine upon detection of abnormality or defect. (APICS, 7)

BOM: “Bill of material is a listing of all the subassemblies, intermediates, parts and raw materials that go into a parent assembly showing quantity of each required to make an assembly. It is used in conjunction with the master production schedule.”(APICS, 10)

Bottleneck- “A facility, function, department or resource whose capacity is less than the demand placed upon it. For example a bottleneck machine or work center exists where jobs are processed at a slower rate than they are demanded.”(APICS, 11)

BPR (Business process reengineering) **–** “A procedure that involves fundamental rethinking and radical redesign of business processes to achieve dramatic organizational improvements in such critical measures of performance as cost, quality, service, and speed. Any BPR activity is distinguished by its emphasis on (1) process rather than functions and products (2) the customer for the process." (APICS, 13)

Buffer-" A quantity of material awaiting further processing. It can refer to raw material, semi-finished stores or hold points, or a work backlog that is purposely maintained behind a work center." (APICS, 12)

Collaboration encompasses business planning, sales forecasting, and all operations required to replenish raw materials and finished goods."(APICS, 24)

Continuous process improvement- "A never ending effort to expose and eliminate root causes of problems; small-step improvement as opposed to big-step improvement." (APICS, 21)

CPFR (collaborative planning, forecasting and replenishment):"A collaboration process whereby supply chain trading partners can jointly plan key supply chain activities from production and delivery of raw materials to production and delivery of final product to end customers.

Cross-docking-"The concept of packing products on the incoming shipments so they can be easily sorted at intermediate warehouses or for outgoing shipments based on final destination. The items are carried from the incoming vehicle docking point to the out going vehicle docking point without being stored in the inventory at the warehouse. Cross-docking reduces inventory investment and storage space requirements." (APICS, 25)

Cross-functional teams- "A set of individuals from various departments assigned a specific task such as implementing new computer software."(APICS, 25)

Customer: a customer or organization in the supply chain who receives a good, service or information. (APICS, 26)

Customer order: “An order from a customer for a particular product or a number of products. It is often referred to as an actual demand to distinguish it from a forecast demand.” (APICS, 26)

Cycle time- “The time between completions of two discrete units of production. For example the cycle times of motors assembled at a rate of 120 per hour would be 30 seconds.” (APICS, 27)

Distribution center: a warehouse with finished goods or service items. When a warehouse serves a group of satellite warehouses it is usually called a regional distribution center. (APICS, 33)

EDI (Electronic data interchange)- “The paper less exchange of trading documents, such as purchase orders, shipment authorization, advanced shipment notices and invoices, using standardized document formats.” (APICS, 37)

ETO –“Engineer to order products whose customer specifications require unique engineering design, significant customization or new purchased material. Each customer order results in a unique set of part numbers, bill of materials and routings.”(APICS, 38)

FGI: “Finish goods inventory, those items on which all manufacturing operations, including final test, have been completed. These products are available for shipment to the customer.”(APICS, 42)

FGI shipment: A quantity of finished goods shipped to customer. (APICS, 42)

First tier supplier: a first tier supplier is a supplier that invoices the customer for goods and services rendered directly by that supplier (first-tier). (APICS, 113)

Fixed cost: “An expenditure that does not vary with the production volume. For example, rent, property tax.”(APICS, 43)

Forecast: “an estimate of future demand. A forecast can be constructed using quantitative methods, qualitative methods or a combination of methods, and it can be based on extrinsic or intrinsic factors.” (APICS, 46)

Forecast technique: the process of choosing appropriate forecasting method to predict sales and use of products so they can be produced and/or manufactured in appropriate quantities.

FTL: A truck load shipment that qualifies for a lower freight rate because it meets minimum weight and volume. (APICS, 118)

Heijunka: in the Just-In-Time philosophy, an approach to level production throughout the supply chain to match the planned rate of end product sales. (APICS, 50)

Holding cost: “The cost of holding inventory, usually defined as a percentage of the dollar value of inventory per unit of time. Carrying cost depends mainly on the cost of capital invested as well as such costs of maintaining the inventory as taxes and insurance, obsolescence, spoilage and space occupied.” (APICS, 50)

Information flow: The flow of data that have been interpreted and that meet the need of one or more managers. (APICS, 53)

Inventory: “Those stocks or items used to support production(raw materials and work-in-process items), supporting activities (maintenance, repair and operations) and customer service. Demand for inventory may be dependent or independent.” (APICS, 56)

Inventory policy: “A statement of company’s goal and its approach towards inventory management.”(APICS, 56)

JIT (Just-in-time): A philosophy of manufacturing based on planned elimination of all waste and on continuous improvement of productivity. It encompasses the successful execution of all manufacturing activities required to produce a final product, from design engineering to delivery, and includes all stages of conversion from raw material onward. The primary elements of just-in-time are to have only the required inventory when needed; to improve quality to zero defects; to reduce lead times by reducing setup times, queue lengths, and lot sizes; to incremental revise the operations themselves; and to accomplish these activities at minimum cost. (APICS, 58)
Kanban: a method of Just-in-time production that uses standard containers or lot sizes with a single card attached to each. It is a pull system in which work centers signal with a card that they wish to withdraw parts from feeding operations or suppliers. (APICS, 58)

Kit: the components of a parent item that have been pulled from stock and readied for movement to a production area. (APICS, 59)

Kitting: the process of constructing and staging kits. (APICS, 59)

Lead time off set: “A technique used in MRP where a planned order receipt in one time period will require the release of that order in an earlier time period based on the lead time for the time.”(APICS, 60)

Lean: A philosophy of production that emphasizes the minimization of the amount of all the resources used in the various activities of the enterprise. It involves identifying and eliminating non-value-adding activities in design, production, supply chain management, and dealing with customers. (APICS, 60)

Line balancing: the balancing of assignment of the tasks to workstations and minimizes the total amount of idle time at all station for a given output level. In balancing these tasks, the specified time requirement per unit of product for each task must and its sequential relationship with the other tasks must be considered. (APICS, 61)

Load leveling: Spreading orders out in time or rescheduling operations so that the amount of work to be done in sequential time periods tends to be distributed evenly and is achievable. Although both material and labor are ideally level loaded, specific business and industries may load to one or the other exclusively. (APICS, 62)

LTL: Either a small shipment that does not fill the truck or a shipment of not enough weight to qualify for a truckload quantity rate discount. (APICS, 118)

Manufacturing cost: the cost incurred on the part because of machine operation time and labor hours spent on it.(APICS, 23)

Material cost: the cost incurred on the part because of the material used.(APICS, 23)

MRP: "A set of techniques that uses bill of material data, inventory data and the master production schedule to calculate requirements for materials. It makes recommendations to release replenishment orders for materials."(APICS, 72)

MTO: "Make-to-order a production environment where a good or service can be made after receipt of a customer's order. The final product is usually a combination of standard items and items custom-designed to meet he special needs of the customer. Where options or accessories are stocked before customer orders arrive."(APICS, 64)

MTS: "Make-to-stock a production environment where products can be and usually are finished before receipt of a customer order. Customer orders are typically filled from existing stocks, and production orders are used to replenish those stocks."(APICS, 64)

One piece flow: A concept that items are processed directly from one step to the next, one unit at a time. This helps to shorten lead times and lines of communication, thus more quickly identifying problems. (APICS, 75)

On-time Delivery: “The number of orders / lines that are received on-time to the demand requirements divided by the total orders / lines for the demand requirements in the measurement period.” (APICS, 75)

Order: “A general term that may refer to such diverse items as a purchase order, shop order, customer order, planned order or schedule.”(APICS, 77)

Period order quantity: “A lot sizing technique under which the lot size is equal to the net requirements for a given number of periods, e.g. weeks into the future. The number of periods to order is variable, each order size equalizing the holding costs and the ordering costs for the interval” (APICS, 82).

Point of sale (POS): “The relief of inventory and computation of sales data at the time and place of sale, generally through the use of bar coding or magnetic media equipment.”(APICS, 84)

Prime contractor: the key supply chain partner which performs the final assembly and manufacturing to the finished goods product in the supply chain. The HVAC company is the prime contractor in this case. (APICS, 89)

Production lead time: “The total time required to manufacture an item, exclusive of lower level purchasing lead time. For make-to-order products, it is the length of time between the release of an order to the production process and receipt into inventory.”(APICS, 90)

Production order: “A document, group of documents or schedule conveying authority for the manufacture of specified parts or products in specified quantities.”(APICS, 90)

Purchased part: “An item sourced from supplier.”(APICS, 94)

Pull system: In production, the production of items only as demanded for use or to replace those taken for use. (APICS, 94)

Pull from VMI: A signal that indicates when to pull item from the inventory managed by the vendor. For example in a JIT environment kanban card is used as a pull signal to replenish used parts.(APICS, 94)

Purchase order: “The purchaser’s authorization used to formalize a purchase transaction with a supplier. A purchase order when given to a supplier should contain statements of the name, part number, quantity, description and price of the goods or services ordered.” (APICS, 94)

Purchase lead time: “Total lead time required to obtain a purchased item. Included here are order preparation and release time; supplier lead time; transportation time; and receiving, inspection, and put-away time.”(APICS, 94)

Replenishment order: Parts sent from supplier to the next partner in the supply chain to replenish the parts that have been used. (APICS, 99)

Response time: “The elapse of time or average delay between the initiation of a transaction and the results of a transaction and the results of the transaction.”(APICS, 100)

RFID: “Radio-frequency identification (RFID) is a technique for automatic identification and remotely retrieving data using radio frequency. It is used in supply chain for inventory accuracy and improved efficiency for inventory tracking.” (Huber, 2002)

Risk pooling: “The process of reducing the risk among customers by pooling stock in centralized warehouses. Statistically speaking when one customer, when one customer demands a large amount of a particular product, another customer demands only a little of the same product. The total inventory to maintain the customer service level is smaller on average with a centralized warehouse because the risk of a product stock-out is pooled across the customers.” (APICS, 101)

RMI:” Raw material inventory is inventory of material that has not undergone processing at a facility”(APICS, 97).

Safety stock: A quantity of stock planned to be in inventory to protect against fluctuations in demand or supply. (APICS, 102)

Second tier supplier: A Second-Tier supplier (referencing the customer) is a supplier that invoices the first-tier supplier for goods and services rendered. (APICS, 113)

Setup time: “The time required for a specific machine, resource, work center, process or line to convert from the production of the last good piece of item A to the first good piece of item B.”(APICS, 106)

Shipping lead time: “The number of working days normally required for goods to move between a shipping and receiving point, plus acceptance time in days at the receiving point, plus acceptance time in days at receiving point.”(APICS, 106)

Shipment: “A quantity of parts or goods shipped to customer” (APICS, 106)

Shipping cost: cost of shipping the part to the customer. (APICS, 22)

Shipment order: A document that authorizes shipments of products to the next partner in the supply chain.(APICS, 106)

SMED: Single-minute exchange of die, the concept of setup times of less than 10 minutes, developed by Shingo in 1970 at Toyota. (APICS, 108)

Supplier development: “Any effort from the customer or buying firm to work with its supplier in order to increase its capabilities and performance.” (Krause, 1996)

Supplier: Provider of goods or services. Seller with whom the buyer does business, as opposed to vendor, which is a generic term referring to all sellers in the marketplace.(APICS, 112)

Supply chain partners: The set of trading partners that define a complete supply chain (APICS, 113)

Standardization: The process of designing and altering products, parts, processes and procedures to establish and use standard specification for them and their components.(APICS 109)

Standard work: Standard work defines the most efficient way to produce a product using the existing equipment, men and material. (Lamming, 1996)

Value: “The worth of an item, good or service.” (APICS, 120)

Value stream: “The process of creating, producing and delivering a good or service to the market. For a good, the value stream encompasses the raw material supplier, the manufacture and assembly of the good, and the distribution network.”(APICS, 121)

Value stream map: An examination of all links a company uses to produce and deliver its products and services starting from the origin point and continuing through delivery to the final customer. (APICS, 121)

Visual controls: “The control of authorized level levels of activities and inventories in a way that is instantly and visibly obvious.”(APICS, 122)

VMI (vendor managed inventory): “A means of optimizing supply chain performance in which the supplier has access to customers’ inventory data and is responsible for maintaining the inventory level required by the customer. This activity is accomplished by a process in which re-supply is done by the vendor through regularly scheduled reviews of the on-site inventory.”(APICS, 122)

Waste:” Any activity that does not add value to the good or service in the eyes of the consumer.”(APICS, 123)

WIP: “Work in process a good or goods in various stages of completion throughout the plant, including all material from raw material that has been released for initial processing up to completely processed material awaiting final inspection and acceptance as finished goods inventory.”(APICS, 124)

4.3 Plan on Push and Execute on Pull

The prime contractor in the supply chain (i.e. the HVAC Company in our case) is releasing orders based on the customers forecast. Hence it is very important to understand that the driving force behind the supply chain is a push system. The forecast is primarily driving all the demand. Therefore it becomes critical to make the system pull right from the start. The process can be summarized in that the HVAC company uses a monthly forecast; that in turn, establishes the MPS based on the on hand inventory for each finished part. Raw materials are allocated based on a priority list created by calculating current days on hand of each finished part. Vendor managed inventory is used to achieve this goal.

The interaction between customer, prime contractor, and supplier is explained below with the help of figure 4.2.

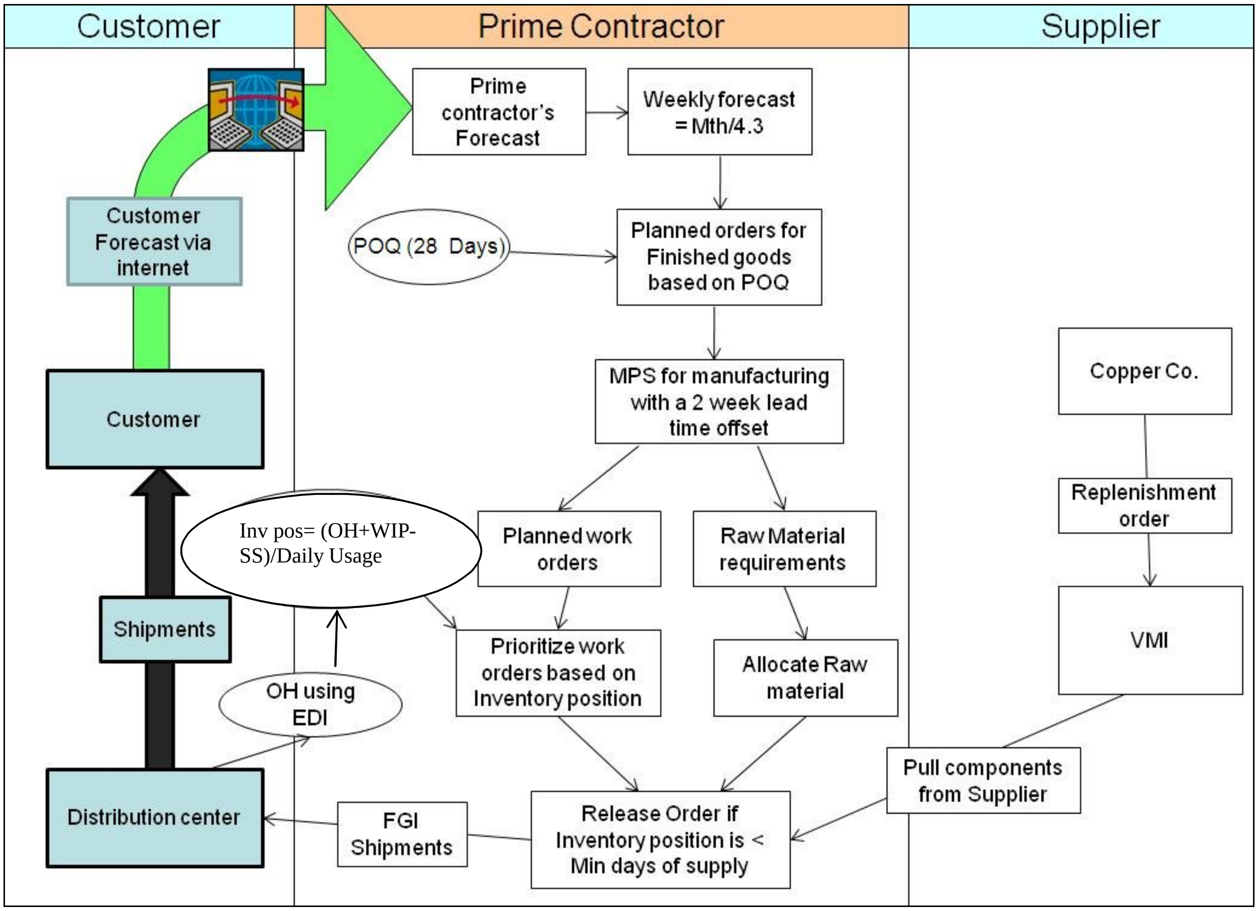

Figure 4.2 Plan on Push, Execute on Pull

The customer provides a monthly forecast to the HVAC Company via internet. This monthly forecast is used by the HVAC Company to come with its own monthly forecast along with the weighted average forecast method for a period of four weeks. Incase a weighted average forecasting technique is used, The most recent month's quantities are weighted more than the third month, which in turn is weighted more than the second and first week's actual quantities. The forecast is then generated once a month and reviewed weekly. This monthly forecast is then converted into weekly numbers by diving the monthly number by 4.33 the average number of weeks in a month. Another relevant concept used by the company is called the period order quantity (POQ), a simple lot sizing rule according to the net requirements is generated based on the requirements for a fixed number of periods in the future. The periods can be weeks, months, or days. The number of periods in the future can be variable (APICS 2005). To make the case simple, the ontology is restricted to the assumption that the HVAC Company uses a POQ of 28 days. The POQ helps to determine the aggregate requirements to maintain a supply for the next four weeks.

Once the requirements are established, planned orders are created. The planned orders created are based on the forecast demand from the customer. These planned orders serve as the master production schedule (MPS) for the manufacturing system. The MPS serves as an anticipated build plan. The MPS is then used to create a demand for raw materials and planned work orders based on a MRP run. MRP, or master production planning, uses bill of materials, inventory data, and MPS to calculate the requirements for the raw material and components. The MRP run then determines the requirements for the material in the future weeks. It also gives planned order release for the future weeks. Until this point, the system is push. The next step is to prioritize the raw material requirements and work order release based on inventory position. Vendor managed inventory (VMI) is used in the supply chain to establish the on hand inventory position, which in turn determines the priority for the work orders to release. The HVAC Company maintains the VMI at the customer company’s warehouse. The inventory position is calculated based on the on hand inventory, work in process and safety stock for a particular item. Safety stock is defined in terms of days on hand and not a fixed number. The inventory position (IP) is calculated as follows:

$$IP = (OH + WIP - \text{Safety stock}) / \text{Daily usage}$$

The on hand quantities are provided by the customer using electronic data interchange (EDI). The resulting value determines the number of days of inventory on hand. A negative number indicates that the number is below the safety stock quantity. Planned work orders are prioritized based on inventory position. The items with the worst (lowest) days of on-hand inventory are placed at the top of the list. Raw materials are also allocated based on this priority list. After inventory is allocated based on the inventory position, the next step is to decide which work orders will be released. Once the work orders are prioritized, a release time offset is used. This release time offset takes into consideration a three week manufacturing lead time offset and a one week offset for a shipping lead time. Hence any work order with an on hand inventory of more than four weeks is automatically dropped without considering the forecast. Work orders with too little inventory on hand are then released. Since nothing is built based on the forecast, the system is now a pull system as the customer forecast no longer drives the demand. Work orders are then released based on actual shipments to the customer. Inventory is pulled from the warehouse maintained by HVAC Company's supplier as soon as work orders are released. This ultimately triggers production at the supplier's site.

4.5 Production for Engineer to Order System

The HVAC Company also has engineer-to-order products. Engineer-to-order products, as defined by the APICS dictionary (2005), are products that need significant design to meet customer specifications. An engineer-to-order part also needs new products to be purchased. Each customer order can be drastically different from the previous order. Hence, each customer order will create an entirely new bill of materials and new part numbers too. The engineer-to-order product in this case is the AHU (air handling units). The customer company (Blue moon company) places orders for these AHUs to the prime contractor. Blue moon company installs these AHUs at various commercial sites like hotels, hospitals, etc. Since each project for the blue moon company is different than the previous one, each AHU needs to be designed different than the previous one. Therefore each order is different from the previous one. Since engineer-to-order products need special design specifications every time the company receives an order, they face long lead times and it is not possible to hold inventory for engineer-to-order products. Therefore a total pull based system is adopted and each part is produced based on Kanban card requirement. The entire production is triggered by an initial order from the customer company. Once this initial order is received from the customer company it triggers a production order at the prime contractor. This basically means determining the design and material requirements based on the bill of material. Once requirements are determined, an order is placed with the supplier. The supplier then issues a production order which in turn triggers a replenishment order to the prime contractor. The replenishment order to the prime contractor is offset by the manufacturing and shipping lead times. The production order at the supplier also triggers a pull from the tier two supplier for raw materials. The entire supply chain here works based on a pull system. Once the production is completed at the HVAC Company a shipping order is issued to the shipping company which handles the logistics for the shipment of finished goods.

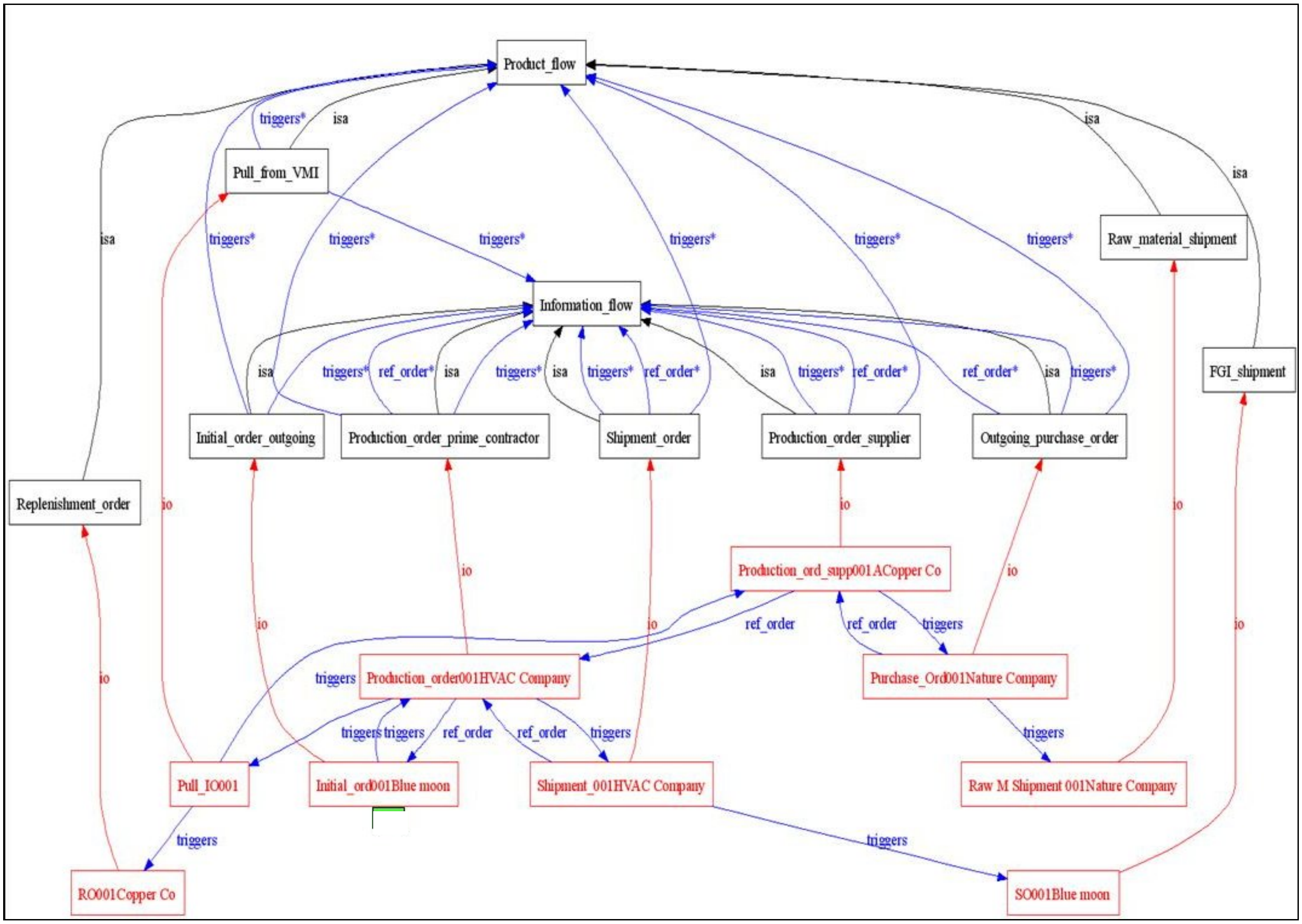

Figure 4.3 Production for Engineer to Order System

4.6 Classes and Class Hierarchy

As stated in chapter three there are several ways of defining the class hierarchy according to Uschold and Gruninger (1996). A top down approach starts with defining the most general concepts in the domain and by using these general terms more specific terms are defined. In a bottom up approach, more specific terms are defined first and once the specific terms are established, general concepts are then built based on these specific terms. The third approach, the combination process, is used in this ontology. A combination approach, as the name suggests, is a combination of both bottom up and top down approaches. A combination approach starts with defining the most common and salient terms. These terms can be general or specific. Neither method is better than the other. The combination approach is most effective in generating the terms in the ontology (Noy, 2006).

From the list of terms generated and defined in steps 2 and 3, classes are the terms that describe other terms and objects. Classes have independent existence (Noy 2006) and can be organized into a hierarchy. The final arrangement of the classes in the hierarchy is achieved by making sure that all the concepts of one class will be included in another class. For example, the instances of class A can be represented by class B, therefore class A is a subclass of class B.

The terms that are closely related to each other have been grouped together. The grouping of the terms is a pragmatic judgment. The relationship among these terms is a complex system and it is not possible to completely avoid reference among the terms across different groups. The groups are chosen based on their use in literature and common use in business houses. The groups were found to be valid as the ontology has developed. Table 4.2 list the class hierarchy.

Table 4.2 Class Hierarchy in Lean Supply Chain Ontology

Class	Sub-class	Sub-class
Supply_chain		
	Supply_chain_partner	Raw_material_supplier
		Prime_contractor
		Customer
		3PL
		Distribution_center
		Subassembly_supplier
	Supply_chain_concept	
		CPFR
		Supplier_development
		Risk_pooling
		RFID

		EDI
		BPR
		ASN
Flow		
	Information_flow	Shipment_order
		Production_order
		Purchase_order
		Customer_order
		POS
	Product_flow	FGI_shipment
		Replenishment_order
		Pull_from_VMI
Inventory		
	FGI	
	RMI	VMI
	Buffers	
	Material	
Time		
	Lead_time	Production_lead_time
		Shipping_lead_time
	Cycle_time	
	Response_time	
	Setup_time	
Lean_concept	SMED	
	5S	
	Standard_work	
	Line_balancing	
	Visual_control	
	Waste	
	Kitting	
	Andon	
	Autonomation	
	Heijunka	
	Kanban	
	Level_load	
	One_piece_flow	
	Value_stream_map	
	Cross_functional_team	
	Cross_docking	
	Setup_time_reduction	
Cost		
	Fixed_cost	
	Holding_cost	
	Shipping_cost	
	Material_cost	
	Manufacturing_cost	

Material_characterstic		
	MTS	
	MTO	
	ETO	
	ATO	
	Purcased_part	
Control		
	MRP_run	
	Forecast_technique	
	Inventroy_policy	
	Point_of_use_data_collection	
	Lead_time_offset	
	BOM	
	Period_order_quantity	
	LTL	
	FTL	
Push_pull_execution		
	Forecast	
		Customer_forecast
		Prime_contractor_forecast
		Supplier_forecast
	Planned_order	
	Planned_workorder	
	Priority_plan	
	Allocate_raw_materials	
	Production_schedule	
	Release_order	
	MPS	

4.7 Properties of Classes and Constraints on Properties

Properties are used to define classes in a better way. Properties are also used to define relations between different classes in an ontology. A list of all the properties used in the lean supply chain ontology is shown below in table 4.3.

Table 4.3 Properties of Classes

Property name	Type	Relates
Address	String	List address for supply chain partners and other terms
component supplied	Instance of class	Relates class sub-assembly supplier and material
converted into	Instance of class	Relates class customer forecast and weekly forecast
Created by		Relates supply chain partners with information flow
customer lead time		Relates classes time and material
delivery date	String	Gives a delivery date for production/purchase order
discount applicable	Boolean	Defines if discount is applicable from a supplier it is used in the class supply chain partner
forecast shared with	Instance of class	Relates various classes in the class supply chain partner
inventory policy	String	Define inventory policy
Issued by	String	Used in class product flow
Issued to	String	Used in class information flow
Material	String	List all material used in ontology
Name	String	Defines name for supply chain partners
order due date	String	Defines the due date for an order
order ID	String	Used to give unique number to each order
part no.	String	Used to give part numbers to inventory
pull from VMI	String	Define name for instances in class product flow
Quantity	Integer	Used in class product flow to list the product quantity
sent by	String	Relates class supply chain partner and class shipment order
sent to	String	Relates class supply chain partner and class shipment order
shipping cost	Float	Defines shipping cost related

		to any instance of class shipment order
time bucket	String	Defines if the instance of class forecast is weekly or monthly
Triggers	Instance of class	Relates classes product flow and information flow

4.8 Meta Ontology

Meta ontology consists of basic terms and concepts which are used to define the other terms in the ontology. As defined by Uschold (1996) "the basic concept of meta-ontology is entity." These terms can be used to define and develop other terms in the ontology. The meta ontology for a lean supply chain is defined in this section.

Supply_chain: A supply chain can be defined as "a web of autonomous enterprise collectively responsible for satisfying the customer by creating an extended enterprise that conducts all phases of design, procurement, manufacturing, and distribution of products" (Whitman et al., 1999). A supply chain can be assumed to be set of connected suppliers and customers with the free flow of product and information across boundaries. Supply chain partners can be defined as a set of trading partners that make up a complete supply chain (APICS 2005). They determine the structure of a supply chain and take decisions such as the capacity of warehouses and manufacturing facilities, products that will be produced, modes of transportation, and the information system.

Flow: The movement of products and information across the supply chain partners is termed as flow (Altarum 2003). In the case of the lean supply chain ontology, it will include the flow of products from suppliers to the customer and also the movement of information across various partners in the supply chain.

Inventory: According to APICS dictionary (2005), inventory includes items used to support production, maintenance, and customer service. This will include raw materials, finished goods, work in process, buffers and other service parts.

Time: The concept of time is not limited to the supply chain ontology but is used by other terms in it. Time here is synonym with the term time interval; it can be defined as an “interval of time specified as two time points and bounds on the distance between the two points” (Uschold 1997).

Lean concepts: As defined by the APICS dictionary (2005) lean is a philosophy of production that aims at reducing and minimizing the amount of resources used in various activities. It identifies the value added and non value added activities. Once the non value added activities are identified lean tools or concepts are used to eliminate these non value added activities.

Cost: Cost in lean supply chain ontology terms can be defined as the value associated with an activity to produce or assist production of a part. It can be classified into various types for e.g. fixed cost, production cost.

Material characteristics: Material characteristics is based on the manufacturing environment or whether a part is a purchased part. As defined by the APICS dictionary 2005 manufacturing environment is the framework a company selects regarding production strategy of parts. It often refers to whether a company plans to assemble, manufacture or buy the parts. Some of the common strategies are make-to-order, make-to-stock or assemble-to-order.

Control: Control consists of various activities and techniques which are used to maintain a desired level of inventory in the system be it raw materials, work in process or finished goods inventory. Some of the examples of control used in lean supply ontology are inventory policy, period order quantity and bill of material (APICS, 2005).

Push pull execution: An important concept that determines the boundaries for push and pull systems. It defines the interface between push and pull system. it divides the planning and production in push and pull system. Choosing the location of this interface helps to take advantage of both pull and push systems, while still driving the demand based on customer's forecast (Hopp & Spearman, 2000).

Summary

The lean supply chain ontology has been created based on the steps defined in Chapter Three. The scope of the lean supply chain ontology is defined first by the list of terms that are included in the ontology. Terms have been defined using the APICS dictionary and SCOR website. Class structure is presented along with the properties used to define the classes. The Meta ontology helps to define the basic terms in the ontology. These terms can be used to define other terms in the ontology. The Meta ontology is defined in the end.

CHAPTER 5

Conclusion and Future Work

5.1 Introduction

"A supply chain is a web of autonomous enterprises collectively responsible for satisfying the customer needs by creating an extended enterprise that conducts all phases of design, procurement, manufacturing, and distribution of products" (Whitman et al. 1999). Lean manufacturing can be defined as relentless elimination of waste. The concept of lean supply involves looking at the supply chain as a whole, from raw material stage to the finished goods (Lamming, 1996). An ontology can be defined as "a specification of a conceptualization" (Gruber, 1993). An ontology serves a knowledge base for particular domain of knowledge.

5.2 Thesis Summary

Emphasis of lean supply chain is on eliminating waste from the supply chain and not just transferring from the prime contractor to a supplier. The need for minimum inventory calls for a pull system right from the first step in the supply chain instead of building to the forecast, which essentially is making the system push from the start. The aim of this thesis is to propose a model for a lean supply chain with the help of an ontology. A hypothetical supply chain is identified in this thesis; a model is then proposed to make this supply chain lean. This ontology will serve as a reference model in developing further lean supply chains. The goal of lean supply chain model is to achieve shorter lead time, reduced costs, increased on-time deliveries and better quality.

5.3 Thesis Approach

a) The scope of the lean supply chain ontology is defined first with the help of brainstorming sessions.

b) The terms listed during the brainstorming sessions are then defined using mainly the APICS dictionary.

c) Lean supply chain terms are then arranged in a class structure a model is then presented along with the properties used to define the classes.

d) A model of lean supply chain is finally created in Protégé software.

5.4 Future Work

A model of lean supply chain has been proposed in this thesis. Further recommended future work includes.

a) Real time implementations of the lean supply chain model can help develop a common understanding of entire supply chain, across all supply chain partners. This means understanding the information flow, part flow across the supply chain. It will help to build a common understanding of the terms used across the supply chain.

b) Lean supply chain model can help identify desired inventory levels at various levels in the supply chain.

c) Lean supply chain model can be used to implement pull model across all partners of the supply chain.

d) The lean supply chain ontology can serve as a reference of interest for further research in specialized field like order tracking.

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APPENDIX

APPENDIX

Complete list of terms generated in brainstorming sessions

3pl	Cycle Stock	Lean
5S	Dance card	Lean accounting
ABC	DBRope	Level Load
Andon	Demand Plan	Line Balancing
ASN	DRP	Line of Balance
Audit	Echelons	Line stocking
Autonomation	ECN	LP
Autonomus maintenance	ECO	LT
Barcode	EDI	Mass customization
Batch	Effectivity	Min Max
BOM	Efficiency	Min order qty
Bottleneck	EOQ	Missing and action
BPR	Eproduct code	MRP
Buffer	ERP	MRP 2
Capacity	ETO	MTO
CMM	Flow control	MTS
CMMI	Focus Factory	Mura
Continous	Forecast	Muri
Contracts	Glossary from IDEF & Lean & SC model	Once Piece flow
Contribution	Heijunka	Ontime delivery
Cost estimation	Inventory	OP
CPFR	Inventory position	Order Qty
Critical WIP	IPPD	Pareto Analysis
Cross docking	JIT	Perfection
Cross function	Kanban	Perferct order
CT	Kitting	Pitch
Point of Views	Spaghetti chart	Risk pooling
Process time	SPC	Schedule
Production Smoothing	Sprint	SCOR
Productivity	Sstock	SDED
Profit	Standard work	Service Level
Pull	Standards	Shadow Boards
pull	Supermarket	Shipping
Push	Supplier development	SKU
Push - Pull Boundary	Swim Lane	SMED
Q,r	Taguchi loss function	Source
Quality	Takt	TPM
Reorder Point	TH	UPC
Response time	TH Accounting	Utilization

Revenue Sharing	TOC	Value
RFID	VAR atio	Value Stream
Risk	Variability	Value Stream Map
Visual Controls	Velocity	VMI
Waterspider	Vendor	Waste

WIP