BUILDING SUPPLY CHAIN COMMUNICATION SYSTEMS : A REVIEW OF METHODS AND TECHNIQUES

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ABSTRACT

With the increasing importance of computer-based communication technologies, communication networks are becoming crucial in supply chain management. Given the objectives of the supply chain, supply chain management is situated at the intersection of different professional sectors, each of them with its own vocabulary, its own knowledge and rules. This paper provides a review of the main approaches to supply chain communications through the analysis of different ways of modelling a supply chain and the presentation of new semantic-based approaches that have been and are being developed to improve the quality of the information exchanges within the supply chain.

Key-words : Information exchanges, Knowledge sharing, Ontology, Supply chain management, Modelling

1. INTRODUCTION

The supply chain management literature offers many variations on the same theme when defining a supply chain. The most common definition is a system of suppliers, manufacturers, distributors, retailers, and customers where materials flow downstream from suppliers to customers, and information flows in both directions. A supply chain is also a network of facilities and distribution options that functions to procure materials, transform these materials into intermediate and finished products, and distribute these finished products to customers. Supply chains exist in both service and manufacturing organisations, although the complexity of the chain may vary greatly from industry to industry and firm to firm. Realistic supply chains have multiple end products with shared components, facilities and capacities. The flow of materials is not always along an arborescent network; various modes of transportation may be considered, and the bill of materials for the end items may be both deep and large.

In the first part of this paper, supply chain definitions and main features are proposed. Those definitions are useful to build up the context for information system in supply chain management.Then, we analyse the information exchanges within the supply chain, through the development of a model of the supply chain, with the identification of the nodes and the information flows circulating between the nodes. At that stage, it is interesting to see if it is possible to merge all the components of the network into a single concept : the integrated supply chain. The analysis of the communication process within the supply chain is the backbone of this paper, supply chain communications are studied here from different points of view, real test cases, or simulation models. The following section is focused on the way of structuring the information exchanged during the communication process. Then we present high level approaches to supply chain communication, using semantic tools : agent-based approaches, ontology-based approaches and approaches based on the semantic web. The last part is a synthesis of the different ideas discussed.

2 SUPPLY CHAIN DEFINITIONS

In this section, some fundamental definitions and features about the concepts of “supply chain”, “supply chain management” are proposed. The objectives of supply chain management are also presented.

2.1 Supply chain fundamentals

There seems to be a universal agreement on what a supply chain is Teigen (1997). (Swaminathan, Smith, Sadeh, 1996) define a supply chain to be :

> a network of autonomous or semi-autonomous business entities collectively responsible for procurement, manufacturing, and distribution activities associated with one or more families of related products.

(Lee, Billington, 1995) have a similar definition :

> A supply chain is a network of facilities that procure raw materials, transform them into intermediate goods and then final products, and deliver the products to customers through a distribution system.

(Ganeshan, Harrison, 1995) have yet another analogous definition :

> A supply chain is a network of facilities and distribution options that performs the functions of procurement of materials, transformation of these materials into intermediate and finished products, and the distribution of these finished products to customers.

In this paper we use the term *supply chain* as it is defined by the last of the quotes above.

2.2 Objectives of supply chain management

The objective of supply chain management is to be able to have *the right products in the right quantities (at the right place) at the right moment at minimal cost*. Figure 1 (NEVEM-workgroup, 1989) translates this overall objective into four main areas of concern within supply chain management.

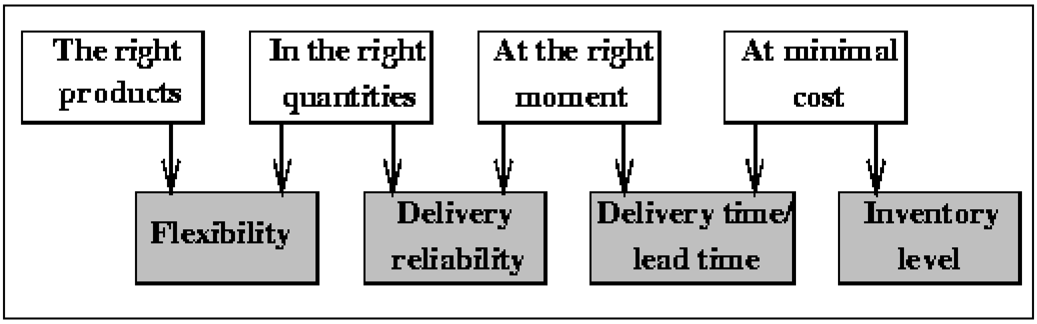

Figure 1. Hierarchy of Objectives (Teigen, 1997)

The two middle boxes in the lower row of Figure 1, delivery reliability, and delivery times, are both aspects of *customer service*, which is highly dependent on the first box, *flexibility*, and on the last box, *inventory*.

2.3 Supply chain : main features

2.3.1 Origin of supply chain management

SCM is a concept that has originated and flourished in the manufacturing industry (Vrijhoef, Koskela, 1999). The first signs of SCM were perceptible in the JIT delivery system as part of the Toyota Production System (Shingo, 1988). This system aimed to regulate supplies to the Toyota motor factory just in the right - small - amount, just on the right time. The main goal was to decrease inventory drastically, and to regulate the suppliers' interaction with the production line more effectively.

After its emergence in the Japanese automotive industry as part of a production system, the conceptual evolution of SCM has resulted in an autonomous status of the concept in industrial management theory, and a distinct subject of scientific research, as discussed in literature on SCM (Bechtel, Yayaram, 1997), (Cooper, Lambert, Pagh, 1997). Along with original SCM approaches, other management concepts (e.g., value chain, extended enterprise) have been influencing the conceptual evolution towards the present understanding of SCM. In a way, the concept of SCM represents a logical continuation of previous management developments (Van der Veen, Robben, 1997). Although largely dominated by logistics, the contemporary concept of SCM encompasses more than just logistics (Cooper et al., 1997).

Actually, SCM is combining particular features from concepts including Total Quality Management (TQM), Business Process Redesign (BPR) and JIT (Van der Veen, Robben, 1997).

2.3.2 Concept of supply chain management

Given the previous definitions, supply chain can be considered as "the network of organisations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer" (Christopher, 1992).

SCM looks across the entire supply chain (Figure 2), rather than just at the next entity or level, and aims to increase transparency and alignment of the supply chain's coordination and configuration, regardless of functional or corporate boundaries. According to some authors (Cooper, Ellram, 1993), the shift from traditional ways of managing the supply chain towards SCM includes various elements (Table 1). The traditional way of managing (Table 1) is essentially based on a conversion (or transformation) view on production, whereas SCM is based on a flow view of production. The conversion view suggests that each stage of production is controlled independently, whereas the flow view focuses on the control of the total flow of production (Koskela, 1992).

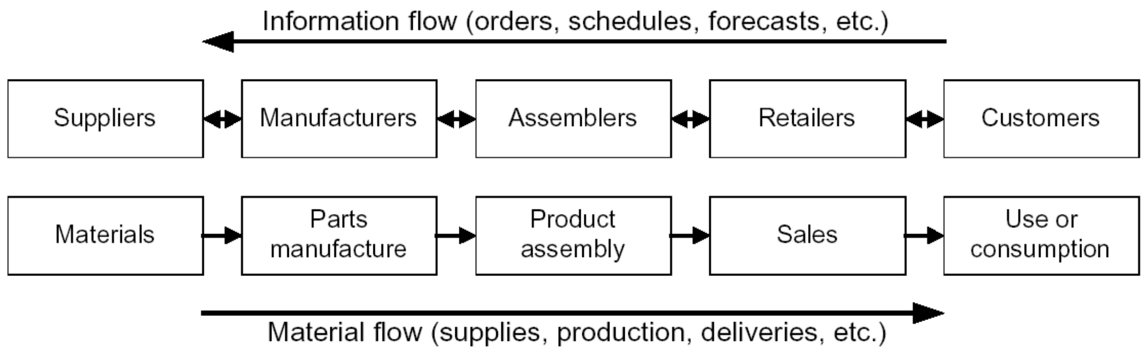

Figure 2. Generic configuration of a supply chain in manufacturing (Vrijhoef, Koskela, 1999)

2.3.3 Methodology of supply chain management

In the literature on SCM, many supply chain methods have been proposed. Most methods address logistical issues of the supply chain, e.g., quality rates, inventory, lead-time and production cost.

The methods of pipeline mapping (Scott, Westbrook, 1991), supply chain modeling (Davis, 1993) and logistics performance measurement (Lehtonen, 1995) analyse stock levels across the supply chain. The LOGI method (Luhtala, Kilpinen, Anttila, 1994), (Jahnukainen, Lahti, Luhtala, 1995) studies time buffers and controllability problems of the delivery process. Supply chain costing (LaLonde, Pohlen, 1996) focuses on cost build-up along the supply chain. Integral methods like value stream mapping (Hines, Rich, 1997), (Jones, Hines, Rich, 1997) and process performance measurement (de Toni, Tonchia, 1996) offer a "toolbox" to analyse various issues including lead time and quality defects.

Table 1. Characteristic differences between traditional ways of managing the supply chain and SCM (Cooper, Ellram, 1993) mentioned in (Vrijhoef, Koskela, 1999)

Element	Traditional management	Supply chain management
Inventory management approach	Independent efforts	Joint reduction of channel inventories
Total cost approach	Minimize firm costs	Channel-wide cost efficiencies
Time horizon	Short term	Long term
Amount of information sharing and monitoring	Limited to needs of current transaction	As required for planning and monitoring processes
Amount of coordination of multiple levels in the channel	Single contact for the transaction between channel pairs	Multiple contacts between levels in firms and levels of channel
Joint planning	Transaction-based	Ongoing
Compatibility of corporate philosophies	Not relevant	Compatibility at least for key relationships
Breadth of supplier base	Large to increase competition and spread risks	Small to increase coordination
Channel leadership	Not needed	Needed for coordination focus
Amount of sharing risks and rewards	Each on its own	Risks and rewards shared over the long term
Speed of operations, information and inventory levels	"Warehouse" orientation (storage, safety stock) interrupted by barriers to flows; localized to channel pairs	"Distribution center" orientation (inventory velocity) interconnecting flows; JIT, quick response across the channel

Given the objectives of supply chain management, it is easy to understand why particular attention has to be paid to the analysis of the information flows. This analysis must be precise and validated on real examples as often as possible.

In most cases, this analysis process can be decomposed into three stages, which are :

- building a model of the supply chain,
- management and structure of the information in a supply chain,
- identification of high level communication processes.

The following sections provide a review of methods, tools and approaches corresponding to those different steps.

3 BUILDING A MODEL OF THE SUPPLY CHAIN

3.1 Supply chain as a network

A supply-chain network depicted in Figure 3 can be a complex web of systems, sub-systems, operations, activities, and their relationships to one another, belonging to its various members namely, suppliers, carriers, manufacturing plants, distribution centers, retailers, and consumers (Chandra, Kumar, 2001). The design, modeling and implementation of such a system, therefore, can be difficult, unless various parts of it are cohesively tied to the whole.

3.1.1 Main characteristics

The concept of a supply-chain is about managing coordinated information and material flows, plant operations, and logistics through a common set of principles, strategies, policies, and performance metrics throughout its developmental life cycle (Lee, Billington, 1993). It provides flexibility and agility in responding to consumer demand shifts with minimum cost overlays in resource utilisation. The fundamental premise of this philosophy is synchronisation among multiple autonomous entities represented in it. That is, improved coordination within and between various supply-chain members.

Coordination is achieved within the framework of commitments made by members to each other. Members negotiate and compromise in a spirit of cooperation in order to meet these commitments, whence the use of “cooperative supply chain (CSC)”. Increased coordination can lead to reduction in lead times and costs, alignment of interdependent decision-making processes, and improvement in the overall performance of each member, as well as the supply-chain (group) (Chandra, 1997), (Poirier, 1999), (Tzafestas, Kapsiotis, 1994). We will come back on this concept of CSC in the section on ontology-based approaches.

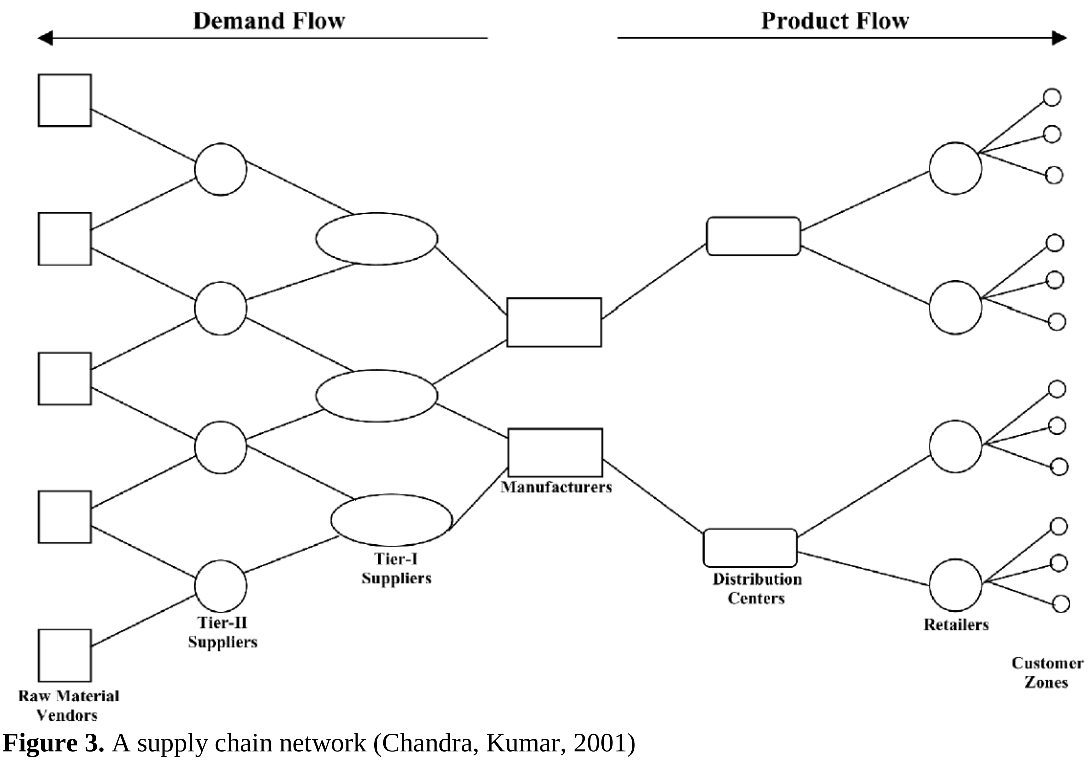

Figure 3. A supply chain network (Chandra, Kumar, 2001)

3.1.2 Network topology

The arborescent structure of the networks (Dong, 2001) treated by multi-echelon inventory networks and related models is appropriate for distribution networks. However, in a general supply chain network, the model involves not only distribution but also assembly, in which multiple components are required for the production of one part. Extending multi-echelon inventory networks into supply chain networks is not straightforward. See (Ernst, Pyke, 1993) and (Cohen, Lee, 1988) for research in this direction.

Supply chains may differ in the network structure (serial, parallel, assembly and arborescent distribution), product structure (levels of bill-of-materials), transportation modes, and degree of uncertainty that they face. However, they have some basic elements in common.

- Sites and Stores

A supply chain network can be viewed as a network of functional sites connected by different material flow paths. Generally, there are four types of sites (Dong, 2001) :

(1) *Supplier sites* : they procure raw materials from outside suppliers ;
(2) *Fabrication sites* : they transform raw materials into components ;
(3) *Assembly sites* : they assemble the components into semi-finished products or finished goods ;
(4) *Distribution sites* : they delivery the finished products to warehouses or customers.

All sites in the network are capable of building parts, sub-assemblies or finished goods in either make-to-stock or make-to-order mode. The part that a site produces is a single-level bill of materials (BOM).

All sites in a supply chain typically perform two types of operations : *material receiving* and *production*. A material receiving operation is one that receives input materials from upstream sites and stocks them as a stockpile to be used for production. A production operation is one in which fabrication or assembly activities occur, transforming or assembling input materials into output materials. Correspondingly, each site in the supply chain has two kinds of stores: *input stores* and *output stores*. Each store stocks a single stock keeping unit (SKU). The input stores model the stocking of different types of components received from upstream sites, and output stores model the stocking of finished-products at the site.

There are two special types of stores in this network topology: *source stores* and *end stores*. Source stores are those output stores that do not have any upstream input stores. They represent the upstream boundaries of the supply chain model. End stores are those output stores that have at least one customer demand stream associated with them. An output store could be both a supplier to downstream input stores and a supplier to external customer demand streams.

The external customer demand streams constitute the downstream boundaries of the supply chain model. The sites can be treated as the building blocks for modeling the whole supply chain.

Therefore, for the performance analysis of a supply chain model, the performance of each store is analysed first, then, the whole supply chain performance is analysed. It also can be seen that a supply chain network structure is closely related to the product structure (BOM) and process structures (serial, parallel, assembly and arborescent structures).

- Links

All stores in the supply chain are connected together by links that represent supply and demand processes (Dong, 2001). Two types of links are defined: *internal link* and *external link*. Internal links are used to connect the stores within a site, i.e. they represent the material flow paths from input stores to output stores within a site. Associated with an internal link connecting an input store i to an output store j is a usage count, u_{ij}, which indicates the number of SKUs in the input store i required to produce a SKU in the output store j. Along with the usage counts, the internal links connecting input stores and output stores constitute the single-level BOM for that output store.

A link connecting an output store of one site to an input store of another site is called an external link. This kind of link represents that the output store provides replenishments to the specified downstream input store. In the network topology, we define that a downstream input store has only one link between it and its upstream output store (see Figure 4).

The demand placed on SKUs at a downstream site is translated into a demand for components at the current site via the bill of materials, or equivalently, the usage count. The downstream demand, in turn, creates demand at the supplying site. Hence, the whole supply chain network behaves as a “pull” system in terms of material requirements. This is also called the *demand transmission process* (Garg, 1999).

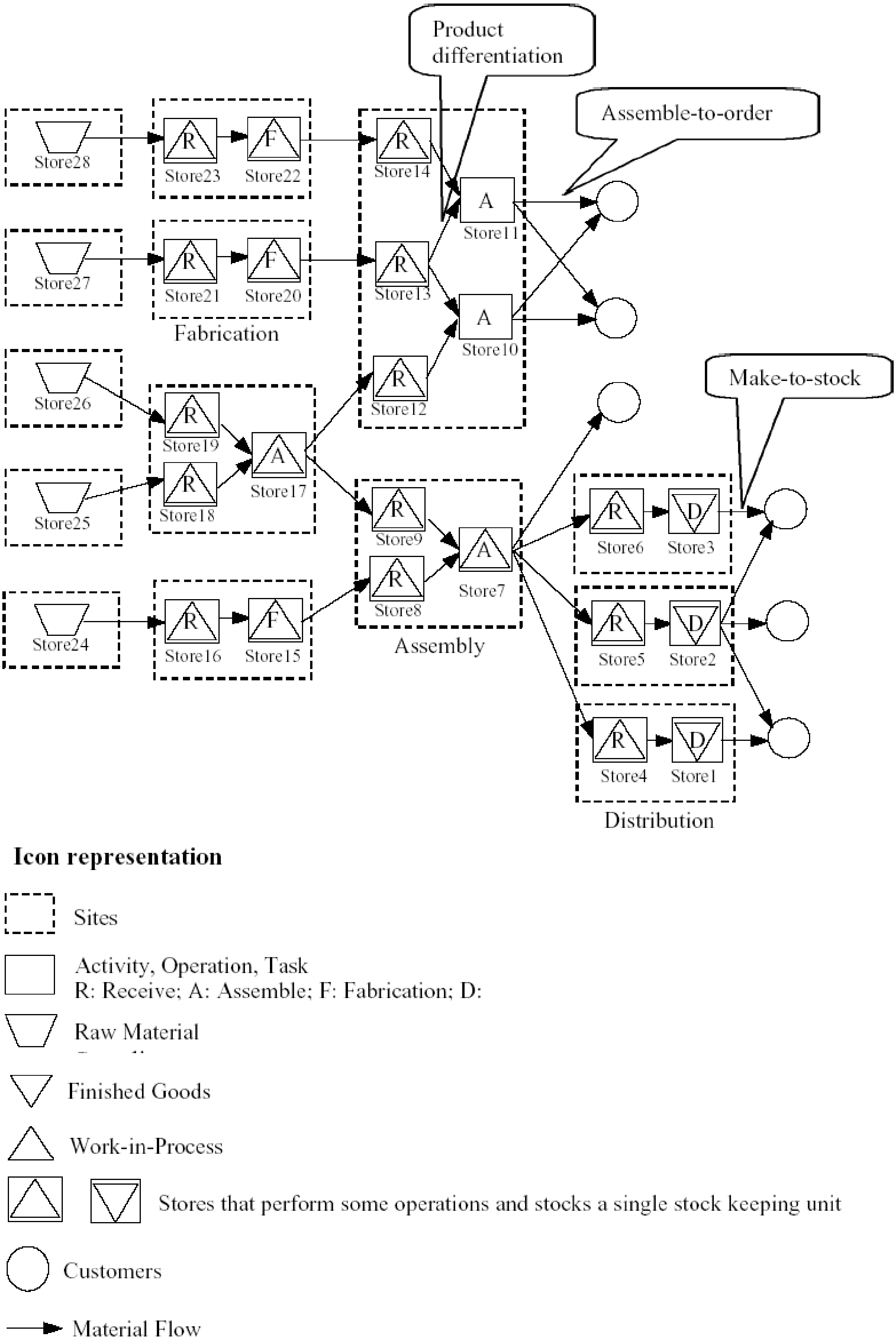

Figure 4. Network topology (Dong, 2001)

3.2 Flows within the network

Much has been written about the problems inherent with handling information in a logistics environment, and some of the main ones are summarised below (Hull, 2002). Demand information becomes increasingly distorted as it moves along a supply chain. This "bullwhip effect" has been established by the well-known beer game. The game was originally developed by (Sterman, 1989) and (Senge, 1990), and greatly extended by (Mason-Jones, Towill, 1997), (Mason-Jones, Towill, 1998). The main lesson of the game is that "structure determines behavior", meaning that distortions are closely linked to the supply chain structure.

Data Flow Diagrams (DFD) offer a general structure for supply-chain information, which readily differentiates between push and pull systems, and highlights the importance of synchronisation (Hull, 2002). Scheduling information can be pushed or pulled through the DFD as a line flow, while information on dispatching and real-world events move as intermittent flows. In a hybrid push/pull system, the point of transition from push to pull is shown as a weak point in the information flow. By focusing attention on a company' s primary data flows, one may improve the overall reliability of the chain. Similarly, one may develop metrics to aid in reducing distortions. The DFD representation provides for the information flow structure, a primary structural component of a chain – so understanding it is basic to reducing distortions.

(Chandra, Kumar, 2000) identify several types of self-reinforcing distortions. As an example, surplus inventory can lead to price reductions, which can artificially stimulate demand, which can cause further ordering, which can further increase the inventory surplus. Distortions can be intentional. (Lee, Padmanabhan, Whang, 1997) discuss "rationing and shortage gaming", where customers order too much, hoping to receive their requirements when product is in short supply or when transportation is bottlenecked.

Another problem is ensuring the timely, coordinated receipt of information by all relevant parties. Missed transportation connections in the middle of a supply chain may cause a customer outage or a supplier shutdown. If the problem is quickly communicated, though, an alternate carrier may be identified and further problems averted, or the customer and supplier may be able to devise alternate strategies. As an example, storms in the Gulf of Alaska can delay crude oil tankers from loading for extended periods of time. These delays can result in production shut-downs on the North Slope, and delay customer deliveries. Quickly relaying storm problems allows suppliers to prioritise the available volumes to minimise the overall impact, and allows customers as much time as possible to procure oil from other sources if they feel it necessary. LaLonde (1996) coined the phrase "information friction" for problems caused by last-minute orders and order changes, mechanical failures, picking and packing errors, coordination failures and data corrections. Information friction clearly needs to be identified, communicated and resolved quickly to defuse its impact. The challenge is to provide frictionless, undistorted information where it is needed in a timely fashion.

3.2.1 Addressing information flow problems

Information friction is reduced by bar coding, the Internet, EDI and point-of-sale systems. These techniques reduce data collection errors and move data quickly. Enterprise Resource Planning (ERP) systems further eliminate "double handling", and provide company-wide data visibility. But technology does not eliminate distortions or identify good information to flow routes. As mentioned above, "structure determines behavior" for a supply chain, and it is the structure of the chain which determines the magnitude of the bullwhip effect. Information flow is a key structural component. This section develops the information structure as a DFD, based on the description of an example. Once the flows have been diagrammed, they can be analysed and improved individually. One can also identify information flow "circuits" which contribute to the bullwhip effect, and develop metrics for each. Finally, information flows need coordination. The individual links need to synchronise their scheduling activities to minimise wasted time. Scheduling triggers the dispatching of vehicles and materials.

Dispatching problems (such as lack of inventory or vehicles) may require schedule modifications. Finally, with goods in motion, a large variety of real-world information (such as weather delays and order changes) needs to be incorporated into the flow as well.

Dispatches and schedules may need further revision. A DFD is of great use in determining how each of these events should be handled most efficiently.

3.2.2 A logistics DFD

Figure 5 shows an example of a DFD for the shipping activity (Hull, 2002). Shipping means that material, currently in a plant, warehouse, or distribution center, is staged for loading aboard an outbound transportation vehicle. Shipping must be both scheduled and dispatched. Scheduling is a planning (tactical) activity, which determines when items can be made available for loading, and when outbound transportation can be made available for loading. The items may not be in inventory currently and, if they are, they may be promised to other customers. Similarly, suitable transportation may not be available when the items are ready to go. Scheduling matches the availability of the items and the availability of transportation, and plans the loading date – which then is incorporated into the shipping schedule. The schedule typically plans activities for one week to one month. With scheduling set, dispatching begins. Dispatching is the operational activity that conveys formal orders to the plant or warehouse to release the items for loading, and to the carrier for pick-up. Dispatching communicates directly with warehouses and transportation companies, and is alerted of real-world problems if these entities cannot perform as planned. If necessary, dispatching conveys real-world information to scheduling, and the schedule may need to be modified.

Figure 5 shows an interchange of information with a customer. The customer might be the receiver of the items, the supplier of the items, or some intermediate party. The customer places/changes an order or makes an inquiry, and is informed of its status. Pushing product through a supply chain implies that attention is paid to keeping the product moving – i.e. the transportation and the shipping. Material must be available in a warehouse or plant when transportation vehicles are available to load to maintain continuous product flow. Such a focus highlights the shipping activity.

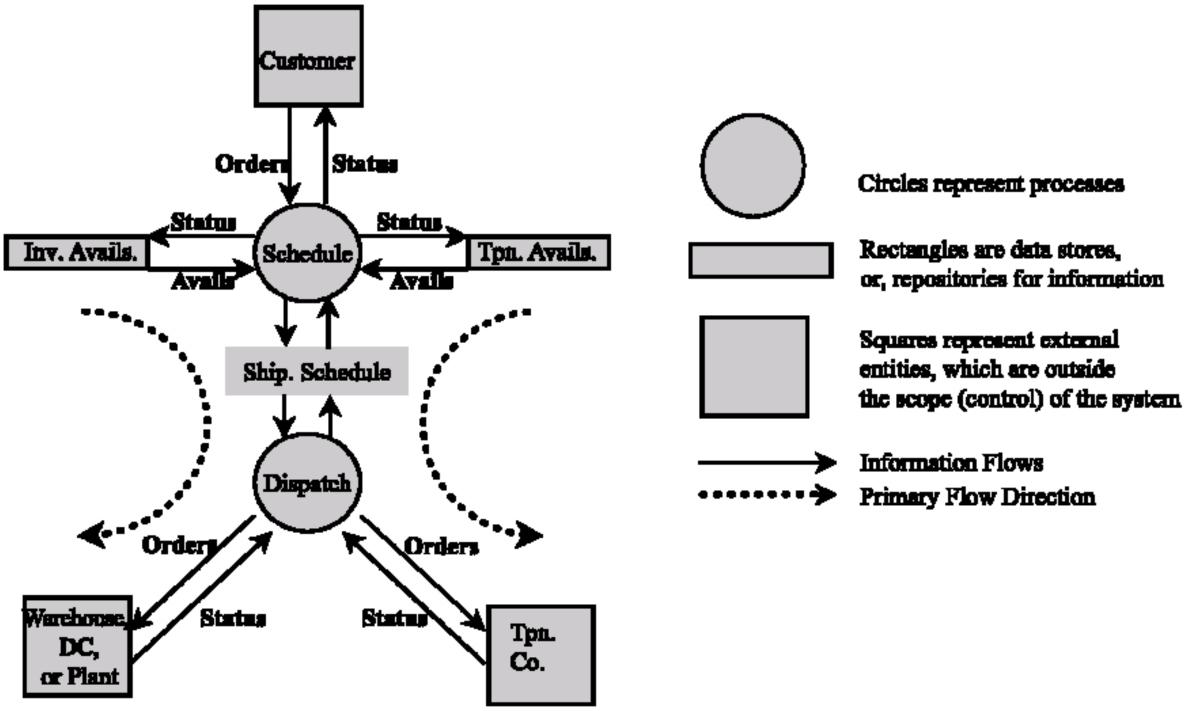

Figure 5. An example of Data flow diagram for shipping in a push-oriented chain (Hull, 2002)

Description: Inventory and transportation availability are determined simultaneously, and a shipping schedule defined. Then schedule events are dispatched to the appropriate parties for implementation.

3.3 Integration

Firms engaged in a supply-chain relationship, as customers, suppliers, or providers of services, need to share a great deal of information in the course of their interactions (White, 2004). These diverse data include descriptive information such as quantities, prices, dates, technical specifications, and quality attributes, and significant contractual and legal transactions, such as purchase orders, shipment authorisations, receipt acknowledgment, and payment processing. To understand the types of information flows, it is most convenient to break them down into functional categories.

Many different types of information must be exchanged for the supply chain to :

- product descriptions, specifications, and prices ;
- purchase order information such as quantities, required shipment dates and addresses ;
- planned and actual production, shipment, and delivery dates/times and status against such schedules ;
- technical and engineering data on products, components, and
- accounting information such as prices, discounts, allowances ;
- product quality data, such as test results, performance measurements, and warranties.

Over the years, companies have managed these information flows in a number of ways, including telephone calls, letters, telex, faxes, and electronics data interchange (EDI). Often firms will have several systems in place simultaneously, perhaps more sophisticated ones for normal, high-volume exchanges and manual systems for communicating schedule changes, quality problems, needs for expediting deliveries, canceled orders, or other emergencies. Redundancy is often built in to stop a system failure from leading to a business disaster, such as a plant shutdown or shipment of poor-quality product.

A perfectly efficient supply chain information structure does not exist in most industries today, and it is extremely unlikely that a fully optimised system could be implemented in any industry in the future. Nonetheless, it is useful to describe such a system to estimate the excess costs experienced in current operations, if for no other reasons than to quantify the size of the opportunity and allow more informed decisions about public and private investment in this area.

Supply chain information systems require a great deal of data input, both from automated sources (numerically controlled machines, scanned bar codes, sensors, analytical instruments) and manual interactions. In an ideal system, each piece of data would be entered only once and subsequently made available to any system in the information network that needs it. High-frequency, routine data input tasks should be made fully automated, with oversight on a periodic basis by skilled systems optimisers, such as planning or logistics personnel. In a similar manner, high-frequency information flows should be fully automated and transmitted in standard formats with common protocols.

Ideally, each firm would expend resources primarily on its own data, as well as on contributing to the maintenance and improvement of the standardised backbone. Information from supply-chain partners should "arrive" as needed (or be made available for query), without additional cost to the receiving firm. A set of agreements should exist to identify and empower the system optimiser, often the OEM, who would initiate the major changes to which other members must adjust (It is not necessarily the case that the OEM acts as the system optimiser; firms at a number of different places within a supply chain can play the key optimising role). These unusual events include the launch of new products or services, product termination decisions, production acceleration or slow-down, and sourcing changes.

In today's competitive environment, many medium and large firms set internal goals to approach this ideal state; integrated enterprise resource planning and internal networks can come close to this state within the boundaries of a multidivisional firm. Extended to the entire supply chain, however, this level of sophistication rarely occurs. A proper goal of supply chain integration, then, would be to extend these concepts to inter-firm interactions across the entire chain of industries. A piece of information is entered at the source and is instantly available to all members of the supply chain who need it, information flows to points of use without manual intervention, and standard protocols obviate the need for translation.

4 INFORMATION MANAGEMENT IN THE SUPPLY CHAIN

Communications within the supply chain can be analysed from different points of view, either from real approaches (test-cases), or else from simulation methods. In this section, we present simulation based supply chain information management, and the way information is modelled for this simulation. The benefit of such simulation methods is to facilitate the identification of communication problems.

4.1 Supply chain information management approaches

Generally, modeling approaches in SCM can be categorised into five broad classes (Dong, 2001) :

- **Supply Chain Network Design Method** : This method determines the location of production, stocking, and sourcing facilities, and channels the products take through them. The earliest work in this area, although the term "supply chain" was not then in vogue, was by (Geoffrion, Graves, 1974). They introduced a multi-commodity, logistics network design model for optimizing finished product flows from plants, to the distribution centers to the final customers.

- **MIP Optimisation Modeling :** Many important supply chain models fall into the MIP (Mixed-Integer Programming) class. This includes most models for vehicle routing and scheduling, facility location and sizing, shipment routing and scheduling, freight consolidation and transportation mode selection. Mixed-integer models are often difficult to optimize, as there can be an exponential number of possible decision alternatives. Some problems are nonlinear MIP.

- **Stochastic Programming and Robust Optimisation Methods :** Stochastic programming deals with a class of optimisation models and algorithms in which some of the data may be subject to significant uncertainty. Uncertainty is usually characterized by a probability distribution on the parameters. Such models are appropriate when data evolve over time and decisions need to be made prior to observing the entire data stream.

- **Heuristic Methods :** Heuristic is another important class of methods for generating supply chain alternatives and decisions. A heuristic is simply any intelligent approach that attempts to find good or plausible solutions. Generally, mathematical programming methods are used to solve strategic and higher levels of tactical supply chain planning. This method generally works only for solving linear- and some integer-based models, commonly used in strategic levels of planning. Heuristic methods used in supply chain planning and scheduling include the general random search approaches such as simulated annealing, genetic algorithms and tabu algorithms. Recently, the theory of constraints has also been used in supply chain operational planning.

- **Simulation based Methods :** This is a method by which a comprehensive supply chain model can be analysed by considering both its strategic and operational elements. This method can evaluate the effectiveness of a pre-specified policy before developing new ones.

This paper focuses on the informational aspect of supply chain modelling. This aspect has mainly been developed through the use of simulation methods, aimed at representing the communication features of the supply chain.

4.2 Simulation based supply chain information modelling

4.2.1 Role of simulation

A poor plan can easily propagate to the whole supply chain areas (Chang, 2001) (Lee et al., 1997), its impact on the overall business is huge. It causes cycles of excessive inventory and severe backlogs, poor product forecasts, unbalanced capacities, poor customer service, uncertain production plans, and high backlog costs, or sometimes even lost sales. Although the Enterprise Resource Planning and SCM solutions provide lots of benefits to industries, it is too costly to use those solutions for academic research.

Discrete event simulation permits the evaluation of operating performance prior to the implementation of a system. It enables companies to perform powerful what-if analyses leading them to better planning decisions ; it permits the comparison of various operational alternatives without interrupting the real system ; it permits time compression so that timely policy decisions can be made.

Most of simulation tools are designed as interactive tools to be used by a human planner not as real time decision-making tools, which are directly linked to control system to dispatch tasks. Simulation tools aid human planner to make a right decision by providing information. However, human planner should be able to interpret and modify the plan in order to achieve better supply chain performances.

Benefits of supply chain simulation are :

- to help understand the overall supply chain processes and characteristics by graphics/animation ;
- to be able to capture system dynamics : using probability distribution, user can model unexpected events in certain areas and understand the impact of these events on the supply chain ;
- to minimise the risk of changes in planning process : by what-if simulation, user can test various alternatives before changing plan.

4.2.2 Data requirements for supply chain modelling

In the supply chain, decisions taken are usually classified as strategic, tactical, or operational. Strategic decisions are related to the company's strategy and are long term (2-5 years) with involvement of the most partners in the supply chain. Tactical decisions are mid term (a month to 1 year). Operational decisions are short term, which are related to the day-to-day activities. Tactical and operational decisions are taken in individual area of the supply chain (e.g. plant and warehouse). They deal with issues in demand, procurement, production, warehouse and distribution. (Gunasekaran, Patel, Tirtiroglu, 2001) developed a framework on metrics for the performance evaluation of a supply chain. They also distinguished the metrics as financial and nonfinancial so that suitable costing method can be applied. Selection of performance measures depends on the organisational goal. Figure 6 and Table 2 show a simple supply chain model and example data requirements for the supply chain modeling, respectively.

Many researchers investigated the possibility of creating a simulation-based real time scheduling system that is able to monitor the system status and make decisions in real-time. To have the capability, it is desirable to have :

(1) capability to interface with legacy databases to obtain information ;
(2) hardware and software processing capability to run simulation within very short time- at least, pseudo in real time ;
(3) capability to interface with the control system to assign tasks and receive feedback on system status and performance.

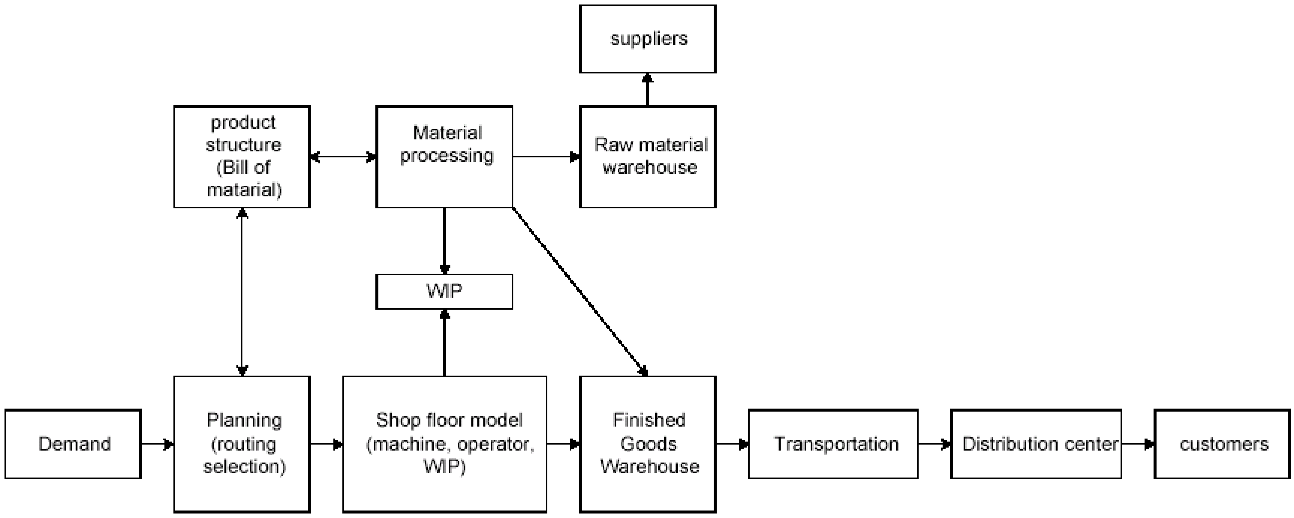

Figure 6. Diagram of an example of supply chain simulation model (Chang, 2001)

Table 2. Example of data requirements for supply chain model

Area	Data required
Manufacturing Process and time information	Manufacturing process data (process time, queue time, setup time, number of machine in each process, alternate route) Calendar data (shift information, holiday information, preventive maintenance information) Machine data (Number of machine, mean time to failure, mean time to repair, alternate resources data, preventive maintenance time) Bill of material structure
Inventory control policies information	Safety stock level, reorder point Inventory level of finished products, raw material and intermediate parts Any stock location in shop floor
Procurement and logistics information	Supplier lead-time Supply lot size Supplier capacity Procurement horizon Procurement time
Demand information	Due date Priority Start and end data Demand pattern
Policies/Strategies information	Order control policies, dispatch policies

In the following section, we present the example of an information model developed for the simulation of a manufacturing supply chain.

4.3 Information modelling for supply chain simulation

A prototype supply chain simulation has been developed as a test case for the MISSION project by the U.S. project team (Mission project, NIST) (Lee, McLean, Umeda, 2001). A major objective of MISSION was to enable the development of distributed supply chain simulations for globally distributed enterprises. The test case focuses on modules, data structures, and interfaces that require an information model.

There are several different information modeling methodologies, modeling languages, and implementation methods available to support the development of such a communication mechanism (Lee, 1999). The approach to developing this communication mechanism and the data specification are :

- Perform a case study to investigate a real supply chain system ;
- Identify the scope of the target application ;
- Identify core processes of supply chain management ;
- Design the prototype supply chain simulation ;

- Design the distributed simulation system ;
- Analyse communication data flow and identify data requirements ;
- Verify the data requirements using the prototype system and the distributed system ;
- Layout the data specification ;
- Implement the data specification.

The project team has been working on the development of a supply chain simulation as a test case for evaluating the quality of the supply chain model and validating interface specifications, leading to the development of a prototype.
The characteristics of the scope of the supply chain simulation were : Span across multiple businesses and organisations, Simulate multiple levels of manufacturing systems, Use a hybrid push-pull distribution system for product distribution, Include multiple software simulation modules in different geographical locations, Comprise multiple functional modules, such as simulation engines, display systems, and analysis tools.

The following manufacturing activities were within the scope of the supply chain simulation : Production planning, scheduling, and control, Transportation planning and scheduling, Materials/parts/products flow within the final assembly plant (and possibly suppliers), Inventory control, Cost control, Data communications between business functions.

4.3.1 Demonstration Scenario

The configuration is based on a previous case study of a U.S. power-tools manufacturing supply chain (Lee et al., 2001). The chain includes supply chain members, information flows, and product flows. There are seven major types of organisational units included in the supply chain: a supply chain headquarters, parts suppliers (3), warehouse, retailers (3), distributor, a final assembly plant, and a transportation network. Figure 7 shows the configuration of this supply chain simulation.

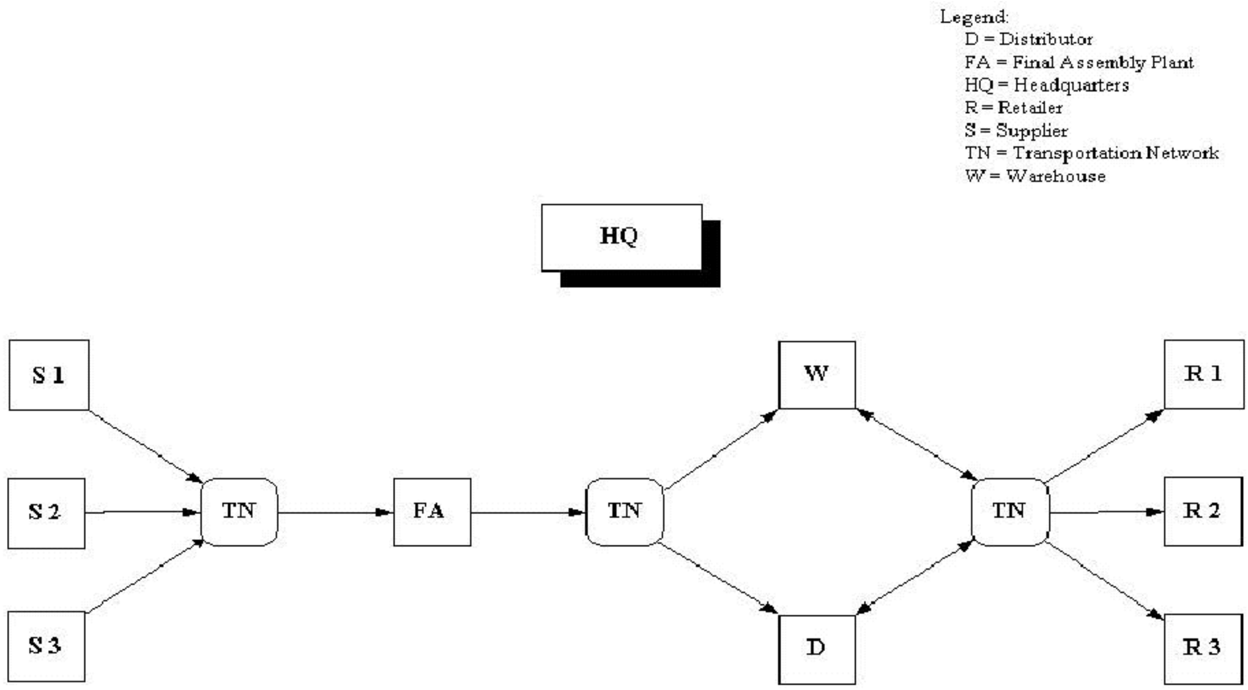

Figure 7. The configuration of the supply chain simulation (Lee et al., 2001)

The simulation system consists of suppliers, manufacturing centers, warehouses, distributors, and retailers, as well as raw materials, parts, finished products, and outsourcing companies, such as transportation providers. The headquarters manages the information flows and provides the products to the customers through the retailers. The final assembly plant assembles finished goods from the components provided by the suppliers. At least two production lines within the assembly plant have been modeled in detail. The final assembly plant manufactures products by using the parts provided from the parts suppliers; the finished products are then sent to the warehouse or to the distributor. The warehouse stores inventory and supplies products to the retailers. Other supply chain members, including the part suppliers, distributors, retailers, and transportation providers, may be independent firms. The part suppliers provide manufacturing parts to the final assembly plant. The distributors provide finished products to the retailers as required or according to other independent contracts. The retailers receive the finished products from the warehouses or from the distributors, and the finished products are then shipped to the customers. The transportation providers deliver the parts or finished products to the required destinations. This supply chain simulation uses a hybrid push-pull distribution system.

4.3.2 The Information Model

In this section, a high-level structure of the information model of the supply chain simulation system is presented in a graphical representation (Lee et al., 2001). The information model focuses on the minimal set of data that needs to be exchanged between members of the supply chain. Local data required by supply chain members is not contained within the model. A graphical representation of the model is made using the EXPRESS-G modeling language (ISO 10303-11, 2003). An overview of the structure of the information model and selected entities are shown here. The full model is not presented. For more detailed discussion of data contained in the information model, see Umeda, Lee (2002).

A communication data flow analysis of the supply chain simulation was performed. As a result, a set of data requirements used to communicate among the supply chain members has been identified. These data requirements are a set of messages or objects; they are grouped into five units of functionality : headquarters, manufacturing plant, warehouse/distributor, transportation network, and retailer. Figure 8 shows the overview of the information model of the supply chain simulation.

A transportation order is represented by an order identification (id), a pickup location id, an order originator id, a tracking number, a delivery location, a status code, a request delivery date, a request pickup date, and a set of shipment data including a list id, total weight, cost, container count number, and value. The status code is an enumeration of *On-time, Delayed,* and *Cancelled.* A transportation status is represented by a tracking number, an originator id, an originator order id, a shipment list id, a status code, a shipment cost, a truck id, a pickup location id, and a delivery location id. A truck dispatch is represented by a dispatch-action code, a routing id, a step number, and a status code. The dispatch-action code is an enumeration of *No-action, On-load,* and *Off-load*.

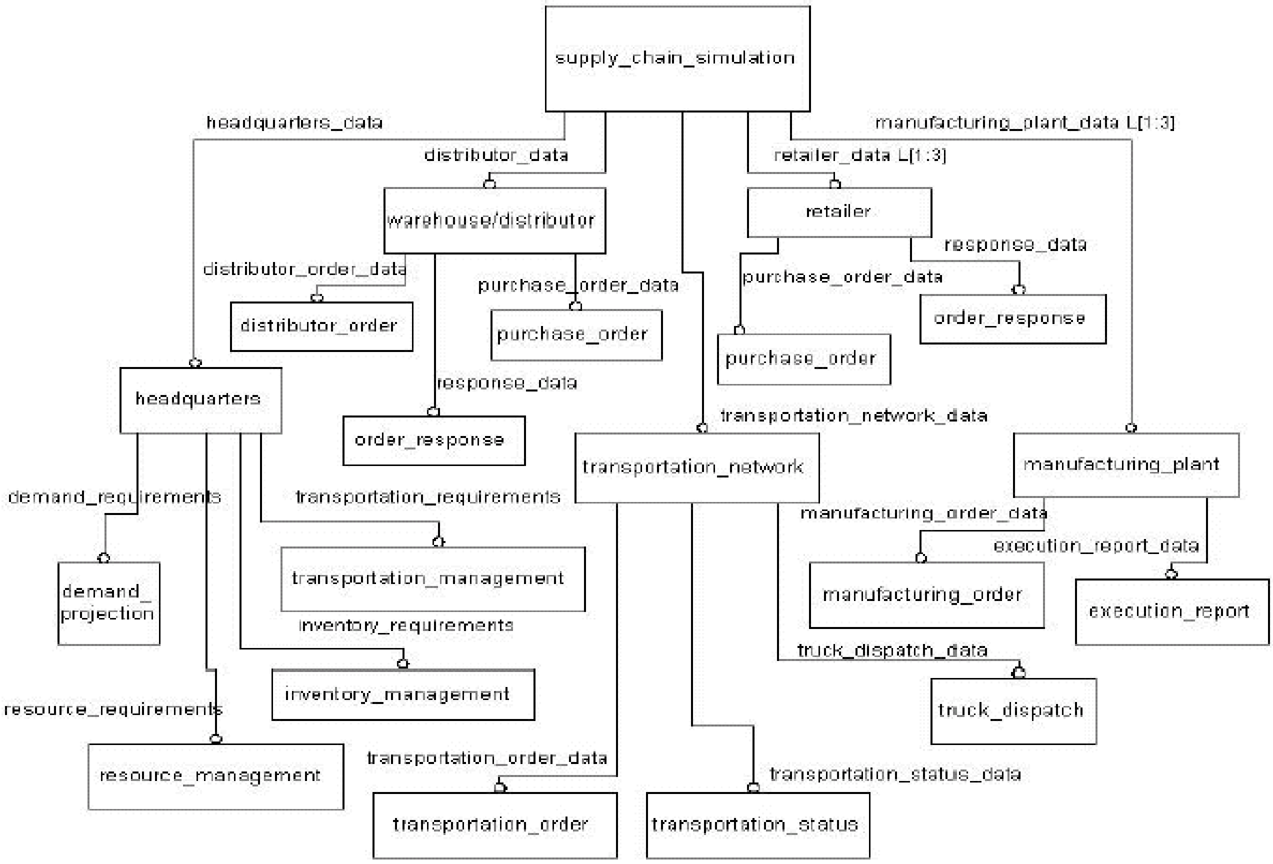

Figure 8. The high-level model structure of the supply chain information model (Lee et al., 2001)

4.4 Communication problems within the supply chain

Firms engaged in supply-chain relationships, as customers, suppliers, or providers of services, need to share a great deal of information in the course of their interactions (White, 2004). Over the years, companies have managed these information flows in a number of ways, including telephone calls, letters, telex, faxes, and electronic data interchange (EDI). More recently, firms have begun using the power of the Internet to create more effective and open transmission protocols for machine-to-machine communication of the same high-frequency data now handled by traditional EDI (It is the implementation of these Internet-based information systems that is most often referred to as Supply chain integration (SCI), even though EDI and telephone/fax are also ways of integrating supply chains).

Supply chain information systems require a great deal of data input, both from automated sources (software applications, control systems, bar code readers, sensors, analytical instruments) and manual interactions. In an ideal system, each piece of data would be entered only once and be available to any system in the information network that needs it. High-frequency, routine data input tasks should be fully automated, with oversight on a periodic basis by skilled systems optimisers, such as planning or logistics personnel. In a similar manner, high-frequency information flows should be fully automated and transmitted in standard formats with common protocols.

Much evidence is available that this ideal information system integration is not evolving within industry supply chains, since :

- Manual data entry is widespread, even when machine sources are available ; critical information is often manually reentered at many points in the chain ;
- Interventions from purchasing clerks, order processors, and expediters are required to maintain supply-chain information flows ;
- The use of translators to convert data from one format to another is almost universal, even between systems that are nominally compliant with established protocols ;
- Organisations of all sizes and across industry tiers use “informed” estimates rather than actual or production plan data in scheduling, materials management, and expediting ;
- Large numbers of firms, especially in the lower tiers, simply operate without essential data.

The business case for better integration has been evident in the automotive industry for several years and for more than a decade in the electronics sector. As a result, a number of companies in these industries have made efforts to provide partial or total solutions, almost all resulting in either inefficient or incomplete integration. Under *inefficient integration,* systems are put in place to automate information inputs and flows, but the unavailability of a suitable standards infrastructure leads to excessive capital investment, duplication of effort, higher than optimal staffing and support levels, and inadequate organisational flexibility. In the case of *incomplete integration*, key-elements of a comprehensive system are missing, or improved systems are only implemented for a subset of supply-chain partners. In the latter case, the supply chain as a whole still experiences costs well above optimal levels, and many of the gains from integration remain unrealised.

Another approach to supply chain communications consists in making the exchanges among the actors more “intelligent”. This can be obtained through the increase of the semantic level contained within the messages to be exchanged. In the following section, we present some of these semantic based methods.

5 SUPPLY CHAIN COMMUNICATIONS : SEMANTIC APPROACHES

Semantic approaches are new methods, some of them being still under development (research). They deal with knowledge representation and management in the domain of supply chain communications. We present below three of them, among the most important : agent-based approaches, ontology-based approaches and semantic web.

5.1 Agent-based approach to supply chain communications

5.1.1 Agent Theory

Agent theory focuses on what an agent is, what properties it may have, and on how this can be mathematically formalised. One approach described in Woodridge, Jennings (1995) is to represent the agent as an *intentional system*, “an entity whose behavior can be predicted by the method of attributing belief, desires and rational acumen” (Danial Dennett as quoted in (Woodridge, Jennings, 1995)). Almost any entity can be described in intentional stance. Describing a system in the intentional stance is more interesting for complex systems whose structure is not known.

There has not yet been developed an all-embracing agent theory. Such a theory should answer questions like how an agent's information and pro-attitudes (which guides the agent's actions) are related, how an agent's cognitive state changes over time, how the environment affects an agent's cognitive state, and how an agent's information and pro-attitudes lead it to perform actions.

5.1.2 Applications of agent technology in supply chain management

An example of supply chain application is proposed here, in which a coordination structure is designed to handle the dynamic formation and operation of teams. This example is relevant to the virtual enterprise approach to manufacturing (Fox, Barbuceanu, Teigen, 2000). A logistics agent coordinates the work of several plants and transportation agents, while interacting with the customer in the process of negotiating the execution of an order. Figure 9 shows the conversation plan that the logistics agent executes to coordinate the entire supply chain. The process starts with the customer agent sending a request for an order, according to customer-conversation. Once logistics receives the order, it tries to decompose it into activities like manufacturing, assembly, transportation, and the like. This is done by running an external constraint based logistics scheduler inside a rule attached on the order-received state. If this decomposition is not possible, the process ends. If the decomposition is successful, the conversation goes to state order-decomposed. Here, logistics matches the resulted activities with the capabilities of the existing agents, trying to produce a ranked list of contractors that could perform the activities.

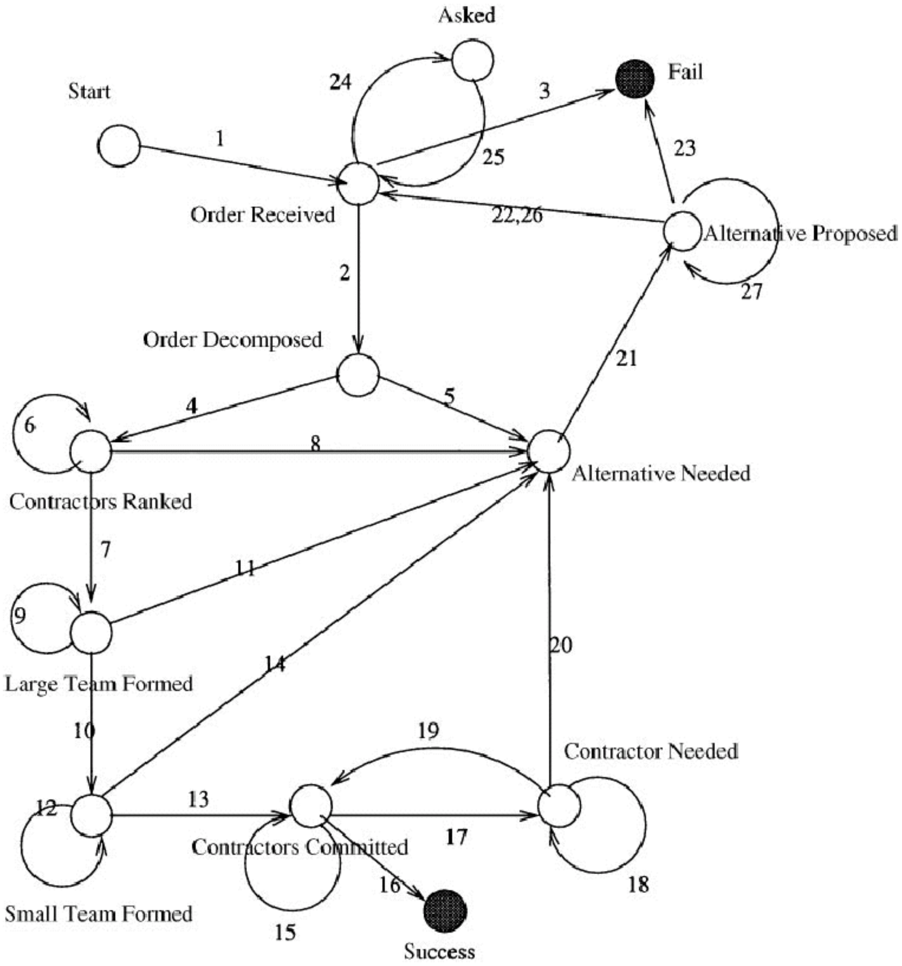

Figure 9. Logistics execution conversation plan (Fox et al., 2000)

5.2 Ontology-based approach to supply chain communications

5.2.1 A cooperative supply chain

Supply chain management is the art and science of managing this complex network of interrelated systems and their components. It encompasses identifying goals, and objectives of the supply chain and outlining policies, strategies, and controls for its effective and efficient implementation. A formal mechanism to organise these cohesively requires a systems approach. A decentralised cooperative supply chain (CSC) is a physically and logically distributed system of interacting components and elements of autonomous business entities (Members) (Hillier, Liebermann, 1990), and (Taha, 1987). In this distributed problem-solving environment, the task of solving a problem is divided among a number of modules or nodes (autonomous business entities and their systems).

Members co-operatively decompose and share knowledge on the problem and its evolving solutions. Interactions between Members in the form of co-operation and coordination are incorporated as problem-solving strategies for the system. Entity Group is responsible for coordination throughout the supply chain. Entity Member brings specialised expert knowledge and product and process technology(ies) to the supply chain. The decision making process is centralised for the Group. The Group enforces common goals and policies for the supply chain on Members. However, decision-making at Member is decentralised. Each Member pursues its own goals, objectives, and policies conceptually, independently of the Group, but pragmatically in congruence with Group goals.

A common knowledge base supports the CSC structure (Chandra, 1997-2). Knowledge is assimilated for an *activity* (the lowest level of information) in a specific domain and aggregated for various decision-making levels in the enterprise. Main concepts in *activity modelling* in a CSC decentralised enterprise are described below.

> *Activity* represents transformation of input (in the form of a technology) to an output (or product) through use of resources of an enterprise, such as a supply chain.

Process is a collection of activities representing various forms of technologies mobilised by the enterprise in generating an output.
Supply Chain Management comprises of activities or processes. These entities when associated to a user assume unique ontological forms.
Ontology is a unique form of representing knowledge applied in various domains. It is useful in creating unique models of a CSC by creating specialised knowledge bases specific to various supply chain problem domains.
Representation. An *activity* represents the lowest level of interaction in the supply chain model. It is synonymous with a "Member" for modelling business process, and an "agent" for knowledge management environment. It is classified into various *activity types* depending on unique *service*(s) they provide. Activity (ies) is used in relation to an aggregation. An activity possesses *attribute*(s), which describe its characteristics or features. An attribute assumes *parametric* values in relation to an aggregation model. Activities communicate with each other by exchanging *message*(s). Communication occurs based on a *protocol* whose boundaries are set by a *control* matrix prescribing level of *resource*(s) to be utilised by an activity, policies to be pursued, and objectives to be met in providing the service(s).
Aggregation. Aggregation represents a *system* form. It has seven components -- input, process sequence, output, mechanism, agent, environment, and function, described in (Nadler, 1970), which are defined by four matrices, namely, resource, performance, technology, and input/output. Each aggregation (system) has its own control matrix to define relationships between its components. Aggregation can take on many forms manifested by the orientation it is based upon, that is aggregation "within" system(s), or aggregation "between" systems. For example, a material-life-cycle flow and order-life-cycle represent horizontal aggregation between systems. Building decision models across the enterprise represents a vertical aggregation between systems. Similarly, aggregating all activities within a Member function represents "within" systems integration.
Protocol. Protocols for each aggregation (system) describe conventions governing communication between activities, services rendered by activities to one another, and controls for that system.
Communication between activities occurs in the form of *message*(s) exchanged to request a service.
Services are of resource and information types.

5.2.2 Supply Chain Knowledge Management (KM)

An important requirement for collaborative system is the ability to capture knowledge from multiple domains and store it in a form that facilitates reuse and sharing (Neches, Fikes, Finin, Gruber, Patil, Senator & Swartout, 1991), (Patil, Fikes, Patel-Schneider, MacKay, Finin, Gruber & Neches, 1992). KM could be identified by four factors behind successful KM systems (Donkin, 1998) :

1. An understanding by employees as to why knowledge sharing is important,
2. Recognition by employees,
3. Legacy of existing practices, and
4. Support mechanism or safety net that allows employees to experiment.

KM is 90 per cent people and 10 per cent technology. General functions of KM are : externalisation, internalisation, intermediation, and cognition (Delphigroup, 1998). These describe the relation "user –knowledge / databases".

The SC configuration stage is represented by the following relation (Smirnov, Sheremetov, 2000) :
"*configuring the product* (product structure, materials bill) ➔ *configuring the business process* (process structure, operation types) ➔ *configuring the resource* (structure of system, equipment and staff types)".

The implementation of an SC approach is based on the shareable information environment that supports the "product - process - resource" model (PPR-model) used for integration and co-ordination of user's activity. This model is studied from different viewpoints or user groups as depicted in Figure 10.

The development of ontologies is motivated by scenarios that arise in the applications (Grüninger, Fox, 1995). In particular, such scenarios may be presented by industrial partners as problems which they encounter in their enterprises. Motivating scenarios often have the form of story problems or examples which are not adequately addressed by existing ontologies, they also provide a set of intuitively possible solutions to the scenario problems. These solutions provide a first idea of the informal intended semantics for the objects and relations that will later be included in the ontology. Any proposal for a new ontology or extension to an ontology must describe the motivating scenario, and the set of intended solutions to the problems presented in the scenario. This is essential to provide rationale for the objects in an ontology, particularly in cases when there are different objects in different proposals for the same ontology. By providing a scenario, we can understand the motivation for the proposed ontology in terms of its applications.

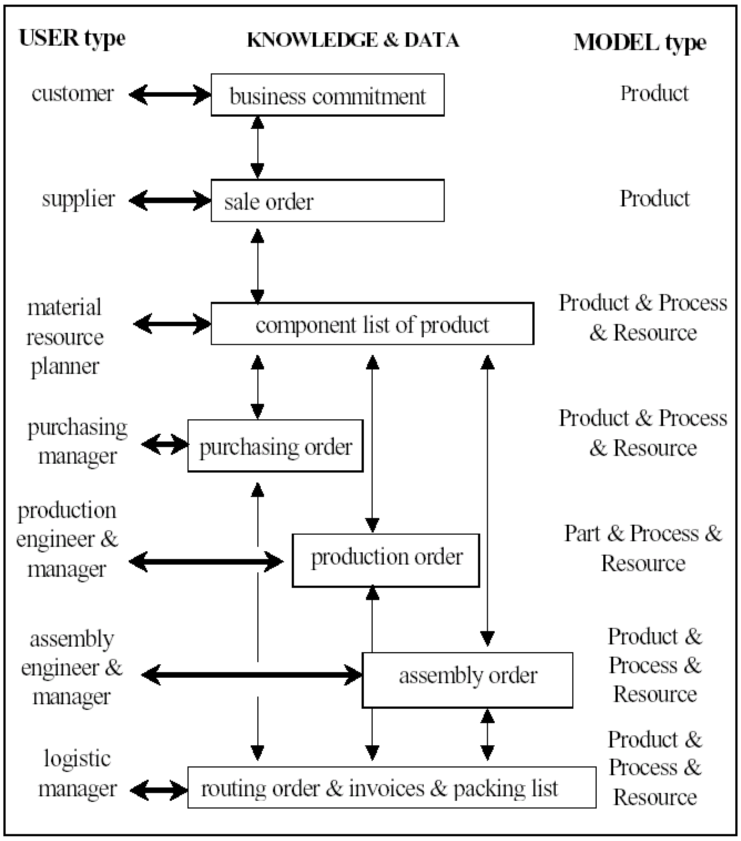

Figure 10. Links of users to knowledge and data in SC (Smirnov, Sheremetov, 2000)

- Informal Competency Questions : Given the motivating scenario, a set of queries will arise which place demands on an underlying ontology. We can consider these queries to be requirements that are in the form of questions that an ontology must be able to answer. These are the informal competency questions, since they are not yet expressed in the formal language of the ontology.

By specifying the relationship between the informal competency questions and the motivating scenario, we give an informal justification for the new or extended ontology in terms of these questions. This also provides an initial evaluation of the new or extended ontology ; the evaluation must determine whether the proposed extension is required or whether the competency questions can already be solved by existing ontologies. Ideally, the competency questions should be defined in a stratified manner, with higher level questions requiring the solution of lower level questions. It is not a well-designed ontology if all competency questions have the form of simple lookup queries ; there should be questions that use the solutions to such simple queries.

Ontological theories are formal models of concepts that are used in SC model representations. They capture rules and constraints of the domain of interest, allowing useful inferences to be drawn, analyse, execute, cross check, and validate models. Ontological translation of an enterprise, such as a supply chain is necessary because networks are multi-ontology classes of entities. Various ontologies for an entity describe its unique characteristics in context with the relationship acquired for a specific purpose or problem. For example, an entity “textiles” may have a multi-ontology representation for a user with a marketing perspective, and for another user with a design perspective, respectively. For the user interested in the marketing perspective of textiles, its attributes of size, denier, and style are important. However, the same textiles characteristics may be represented by size, quality, and finish for the user interested in its design specifications.

5.2.3 Integration of Ontology and Agents

The implementation of the basic principle for the SC, i.e., its collaborative nature is based on distribution of procedures between different users (or different agents). For this purpose, it is obvious to represent the SC configuration KM as a set of interactive autonomous agents. Different configuration problems are treated as separate agent-oriented tasks with embedded constraint satisfaction and consistency support facilities (Sheremetov, Smirnov, 1997), (Smirnov, Sheremetov, 1998).

Agent-based distributed constraint satisfaction problem is a problem in which variables and constraints are distributed among agents. Agents communicate by sending messages. The chart of co-operation cycle for agents has the following structure :

1. Application domain knowledge is shared between agents; knowledge about constraints (user requirements and artefacts) are transmitted to particular agents,
2. Agents solve local configuration tasks on the basis of shared knowledge, and

3. Results are collected and transmitted to all interested agents.

These stages are continuously repeated until the solution is globally confirmed or consensus cannot be reached, and constraint relaxation methods are to be applied.

5.3 Semantic web-based approach to supply chain communications

5.3.1 The concept of semantic web

In the short span of its existence, the World Wide Web has resulted in a revolution in the way information is transferred between computer applications (Horrocks, Patel-Schneider, 2003). It is no longer necessary for humans to set up channels for inter-application information transfer ; this is handled by TCP/IP and related protocols. It is also no longer necessary for humans to define the syntax and build parsers used for each kind of information transfer ; this is handled by HTML, XML and related standards. However, it is still not possible for applications to interoperate with other applications without some pre-existing, human-created, and outside-of-the-web agreements as to the meaning of the information being transferred.

The next generation of the Web aims to alleviate this problem : making Web resources more readily accessible to automated processes by adding information that describes Web content in a machine-accessible and manipulable fashion. This coincides with the vision that Tim Berners-Lee calls the Semantic Web in his recent book "Weaving the Web" (Berners-Lee, 1999).
If such information (often called *meta-data*) is to make resources more accessible to automated agents, it is essential that its meaning can be understood by such agents. For this to be the case there must be some common way of providing meaning for meta-data in the Semantic Web, or at least a common underpinning for providing such meaning. Otherwise agents will not be able to combine metadata from different sources in the Semantic Web.

A common underpinning is especially important for the Semantic Web as it is envisioned to contain several languages, as in Tim Berners-Lee's "layer cake" diagram (Figure 11) first presented at the XML 2000 Conference. The diagram depicts a Semantic Web Architecture in which languages of increasing power are layered one on top of the other. Unfortunately, the relationships between adjacent layers are not specified, either with respect to syntax or semantics.

The basis of a particular way of providing meaning for metadata is embodied in the model theory for RDF (Hayes, 2002), the language at the base of the Semantic Web. However, this basis is built on an unusual thesis of representation, one that is different from the representation thesis built into most logical languages. Moreover, the RDF thesis of representation has other unusual aspects that make its use as the foundation of representation in the Semantic Web difficult at best. In particular, RDF has a very limited collection of syntactic constructs, and these are treated in a very uniform manner in the semantics of RDF. The RDF thesis requires that no other syntactic constructs are to be used and that the uniform semantic treatment of syntactic constructs cannot be changed, only augmented.

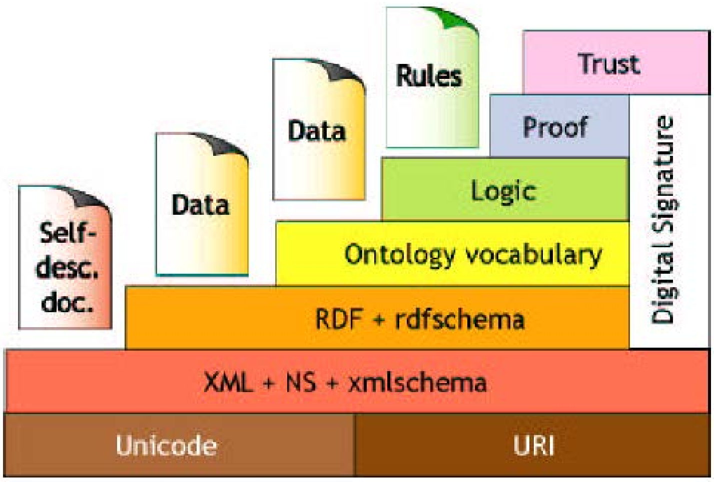

Figure 11. Semantic Web architecture (Berners-Lee, 2000)

5.3.2 Semantic web in supply chain management

The entire value network is an information flow when totally integrated and information sharing is possible for each company of the value network (Hemilä, 2003). Turquoise arrows at the bottom of Figure 12 mark the material flow. The material is going from the supplier to the manufacturer or from the manufacturer to the customer, depending on the role of the networked companies.

Figure 12 gives the hypothetical model for value network integration. It is possible to extend the model to include as many companies as the value network requires.

The model does not include more functionality in the Internet than the Intranet and Extranet. It is possible to make Internet-based marketplaces or create other kind of functionality. Integration could be achieved also on the hardware level. Every company in the network could have its own operator partner. The business processes can take place between other companies than those next to one another in the network. Value network integration could be one business opportunity for semantic web technologies.

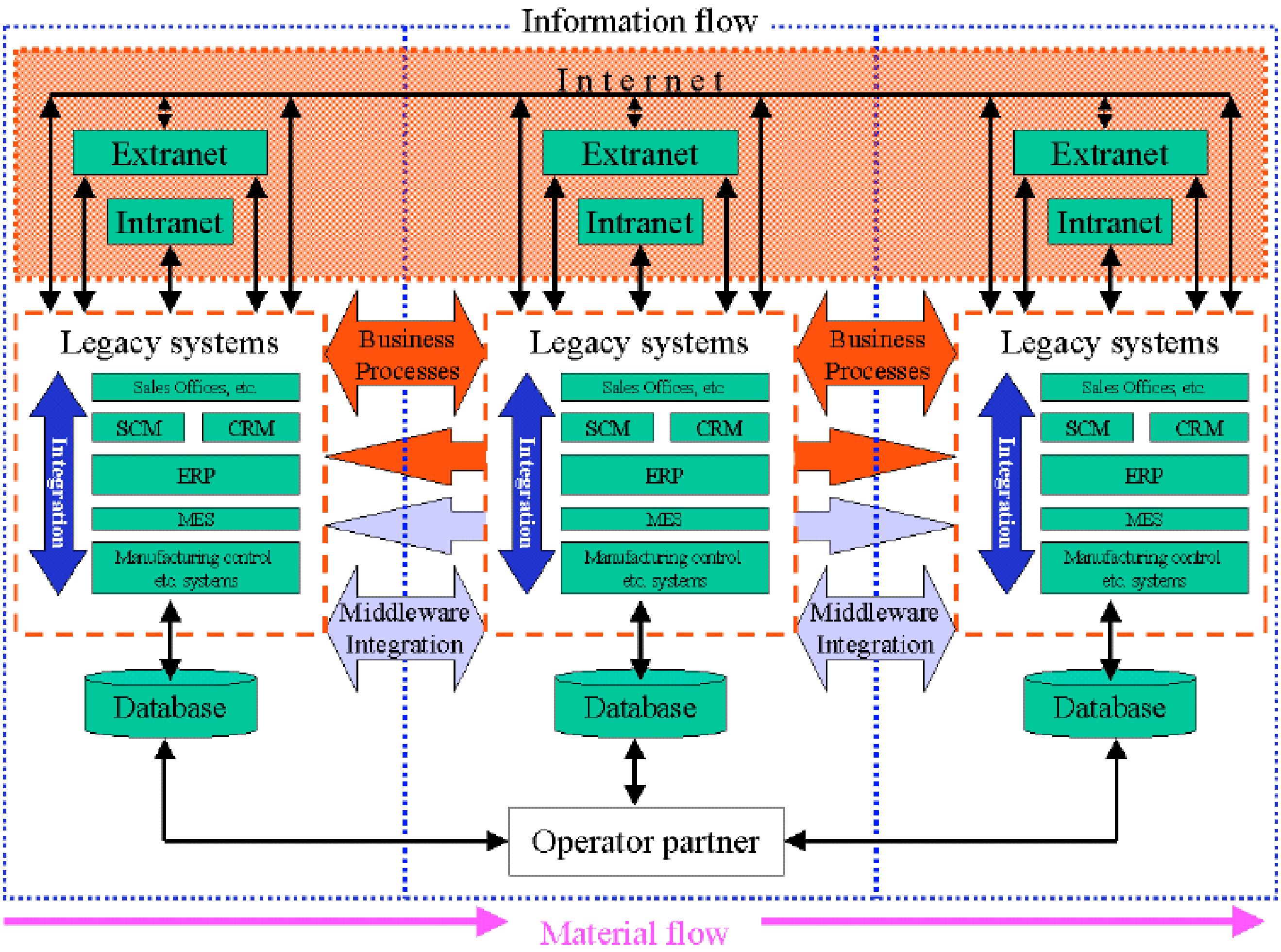

Figure 12. Integration in practice – the hypothetical model (Hemilä, 2002).

6 CONCLUSION

Design of a supply chain involves four design decisions (Kumar, Christiaanse, 1999). These decisions are the choice of actors in the supply chain, governance mechanisms in the chain, structuring (i.e., sequencing order) of the activities in the chain, and the choice of coordination structures in the chain. While some of these decisions are the consequence of the natural production and delivery processes or are strategically fundamental to the chain, other decisions are a matter of design and thus, at least theoretically, under the control of the designer of the supply chain. Moreover, these decisions are interrelated. For example, the choice of a totally vertically integrated governance structure precludes free choice of actors outside the ownership of the firm, while the choice of a market mechanism at every interface between the components of the supply chain would limit the design to dyadic coordination at the supplier-buyer interface.

The first design decision is the level of ***dynamism in the choice of actors*** in the chain. Static chains are chains where the partners in the chain are relatively established. On the other hand, in a completely dynamic chain the partners in the chain can vary from one market opportunity to another. Dynamism, however, results in increased coordination costs due to costs for actor selection, contract negotiation and specification, and increased monitoring (Moshowitz, 1997). Information technology, by supporting and/or enabling these activities can influence the dynamic selection and inclusion of various actors in the chain (Moshowitz, 1999).

The ***structure of the supply chain*** (i.e., its sequencing) is usually determined by the natural sequence of activities inherent in the manufacturing and logistics processes. However, often the structure is a consequence of chance, previous history, habit, limitations of the communication media, and limitations of the coordination mechanisms. For example, items such as computer systems may be assembled at the factory or warehouse before they are shipped out to the customer. However, in an alternate scenario, the components such as the monitor, the processing unit, and the printer may be shipped directly from the component supplier to the customer where the assembly may be performed by field technicians or the customer himself. In the former case, the component shipments in the supply chain converge at the factory or the warehouse, while in the latter case they converge at the customer location.

Finally, coordination in the supply chain is based upon the flow of coordinating information (Lee, Padmanabhan, Whang, 1997-2), (Tan, Shaw, 1998). Through long-established convention, information flows in traditional supply chains have been primarily dyadic (i.e., between the supplier-buyer) and follow the same path as the physical supply chain flows. Thus orders flow upstream from buyers to suppliers, while notification of shipments flow downstream from suppliers to buyers. Again, due to long established custom, as in the cases of bills-of-lading, loading manifests, or airway-bills, the information flows are normally bundled together with the physical flows and travel on the same carrier as the physical shipment. These customary information flow paths may impose delays, limitations, and constraints that may reduce the efficiency, effectiveness, and responsiveness of the supply chain. (Lee et al., 1997-2) show that information transferred in forms of sequential orders tends to become distorted and can misguide upstream members in their production and inventory decisions.

This paper showed the important role played by communication systems in supply chain management. However, comments can be made, since all the methods described here only deal with a part of the problem, they only provide a partial solution of the communication problem considered as a whole. Methods can be redundant, with overlapping, or gaps. They may also be not compatible in between them, particularly in terms of integration and interoperability of the corresponding software tools ! Semantic based approaches to supply chain management are aimed at providing a more general answer to these problems.

Supply chain communication management is a very complex problem, a lot of work still remains to be done in this domain. As such, the approach followed within the framework of the X-SLANG project (Das, Cutting-Decelle, Young, Anumba, Bouchlaghem, 2004), (Cutting-Decelle, Young, Das, Anumba, Baldwin, Bouchlaghem, 2004), in terms of the development of a communication language for supply chain management can be considered as an important phase of the development of relationships between the different methods described in this paper.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

Bechtel, C., and Yayaram, J., (1997) *Supply Chain Management: a Strategic Perspective*, Intl. J. of Logistics Mgmt., 8(1), 15-34

Berners-Lee T., (1999) *Weaving the Web*, Harper, San Francisco

Berners-Lee T., (2000) from the World Wide Web : http://www.w3.org/2000/Talks/1206-xml2k-tbl/

Chandra, C., (1997) *A formal system analysis methodology for a cooperative supply chain*, Proceedings of the 2nd Annual International Conference on Industrial Engineering Applications and Practice, San Diego, CA.

Chandra, C., (1997) *Enterprise architectural framework for supply-chain integration*, Proceedings of the Sixth Annual Industrial Engineering Research Conference, Norcross, Georgia : Institute of Industrial Engineers

Chandra, C. and Kumar, S., (2000) *Supply chain management in theory and practice: a passing fad or a fundamental change ?*, Industrial Management & Data Systems, 100(3)

Chandra C., Kumar S., (2001) *Enterprise architectural framework for supply chain integration*, Industrial management and data systems, 101(6)

Chang Y., Makatsoris H., (2001) *Supply chain modeling using simulation*, International Journal of Simulation, 2(1), 24-30

Christopher, M., (1992) *Logistics and Supply Chain Management: Strategies for Reducing Costs and Improving Service*, Pitman Publishing, London, UK

Cohen, M.A. and Lee, H.L., (1988) *Strategic Analysis of Integrated Production-distribution Systems : Models and Methods*, Operations Research, 36(2), 216-228

Cooper, M.C., and Ellram, L.M., (1993) *Characteristics of Supply Chain Management and the Implications for Purchasing and Logistics Strategy*, Intl. J. Log. Mgmt., 4(2), 13-24

Cooper, M.C., Lambert, D.M., and Pagh, J.D., (1997) *Supply Chain Management : More Than Just a New Name for Logistics*, Intl. J. of Logistics Mgmt., 8(1), 1-14

Das B.P., Cutting-Decelle A.F., Young R.I.M., Anumba C.J., Bouhlaghem N.M., (2004) *Towards the development of a language for cross-disciplinary interoperability for the construction supply chain*, International Conference FAIM04, Toronto (Canada)

Cutting-Decelle A.F., Young R.I.M., Das B.P., Anumba C.J., Baldwin A.N., Bouchlaghem N.M., (2004) *A multi-disciplinary representation of the supply chain information in construction : an innovative approach to project management*, TMCE Conference

Davis, T., (1993) *Effective Supply Chain Management*, Sloan Mgmt. Review

Delphigroup, (1998) from the World Wide Web www.delphigroup.com

Dong, M., (2001) *Process modeling,performance analysis and configuration simulation in integrated supply chain network design*, PhD dissertation

Donkin, R., (1998) *Disciplines complete for a newcomer*, Financial Times October 28:14

Ernst, R. and Pyke, D.F., (1993) *Optimal Base Stock Policies and Truck Capacity in a Two-Echelon System*, Naval Research Logistics, 40, 879-903

Fox, M.S., Barbuceanu M., Teigen R., (2000) *Agent-oriented supply chain management*, International Journal of Flexible manufacturing systems, 12, 165-188

Ganeshan R. and Harrison T.P, (1995) *An Introduction to Supply Chain Management*. Penn State University : from the World Wide Web : http://lcm.csa.iisc.ernet.in/scm/supply_chain_intro.html

Garg, Amit., (1999) *An Application of Designing Products and Processes for Supply Chain Management*, IIE Transactions, 31, 417-429

Geoffrion A., and Graves G., (1974) *Multicommodity Distribution System Design by Benders Decomposition*, Management Science, 29(5), 822-844

Grüninger M., Fox, M.S., (1995) *Methodology for the design and evaluation of ontologies*, Workshop on Basic Ontological Issues in Knowledge Sharing, IJCAI-95

Gunasekaran A., Patel C. and Tirtiroglu E., (2001) *Performance measures and metrics in a supply chain environment*, International journal of operations and production management, 21(1), 71-87

Hayes P., (2002) *RDF model theory*, W3C Working Draft, from the World Wide Web : http://www.w3.org/TR/rdf-mt/

Hemilä, J., (2002) *Information technologies for value network integration*. Espoo: VTT, Research Notes 2149

Hemilä J., (2003) *Semantic web applications in supply-chain management*, Postgraduate seminar on Information Technology in Automation

Hillier, F. S., and Lieberman, G. J., (1990) *Introduction to Operations Research*, New York: McGraw-Hill Publishing Company

Hines P., and Rich N., (1997) *The Seven Value Stream Mapping Tools*, Intl. J. of Operations and Production Management, 17(1), 46-64

Horrocks I., Patel-Schneider P.F., (2003) *Three theses of representation in the semantic web*, WWW2003, Budapest

Hull B., (2002) *A structure for supply-chain information flows and its application to the Alaskan crude oil supply chain*, Logistics Information management, 15(1), 8-23

ISO 10303-11, (2003) *Industrial automation systems and integration – product data representation and exchange – part 11 : the EXPRESS language reference manual*

Jahnukainen, J., Lahti, M., and Luhtala, M., (1995) *LOGIPRO : Towards World Class Make-To-Order Supply Chains*. Helsinki University of Technology, Espoo, Finland

Jones D.T., Hines P., and Rich N., (1997) *Lean Logistics*, Intl. J. of Physical Distribution and Logistics Mgmt., 27(3/4), 153-173

Koskela L., (1992) *Application of the New Production Philosophy to Construction*, Technical Report 72, Center for Integrated Facility Engineering, Department of Civil Engineering, Stanford University, CA

Kumar K., Christiaanse E., (1999) *From static supply chains to dynamic supply webs : principles for radical redesign in the age of information*

La Londe B.J., and Pohlen, T.L., (1996) *Issues in Supply Chain Costing*, Intl. J. of Logistics Mgmt., 7(1), 1-12

Lee H. L. and Billington C., (1993) *Material management in decentralized supply chains*, Operations Research, 41(5), 835-847

Lee H. L. and Billington C., (1995) *The Evolution of Supply-Chain-Management Models and Practice at Hewlett-Packard*. Interfaces 25, 42-63

Lee H. L., Padmanabhan, V. and Whang, S., (1997) *The bullwhip effect in supply chains*, SloanManagement Review, Spring Edition

Lee, H. L., Padmanabhan V. and Whang S., (1997) *Information Distortion in a Supply Chain : The Bullwhip Effect*, Management Science 43(4), 546-558

Lee Y. T., (1999) *Information Modeling : From Design to Implementation*, Proceedings of the Second World Manufacturing Congress, International Computer Sciences Conventions, Canada/Switzerland

Lee Y.T., McLean C., Umeda S., (2001) *A preliminary information model for a supply chain simulation*, EUROSIM ’01 Conference, Delft, NL

Lehtonen J-M., (1995) *Logistics Performance Measurement: an Application to Pulp and Paper Industry*, Proc. Intl. Federation for Information Processing Working Conf. On Reengineering the Enterprise, University College Galway, Ireland

Luhtala M., Kilpinen E. and Anttila P., (1994) *LOGI : Managing Make-To-Order Supply Chains*. Helsinki University of Technology, Espoo, Finland

Mason-Jones R. and Towill D.R., (1997) *Information enrichment : designing the supply chain for competitive advantage*, Supply Chain Management, 2(4), 137-149

Mason-Jones R. and Towill D.R., (1998) *Time compression in the supply chain : information management is the vital ingredient*, Logistics Information Management, 11(2), 93-104

MISSION Consortium, (1998) *Intelligent Manufacturing System (IMS) Project Proposal : Modelling and Simulation Environments for Design, Planning and Operation of Globally Distributed Enterprises (MISSION), Version 3.3*, Shimuzu Corporation, Tokyo, Japan

Moshowitz A., (1997) *Virtual Organisation*, Communications of the ACM, 40(9), 30-37

Moshowitz A., (1999) *The Switching Principle in Virtual Organisations*, Keynote address to Virtual Organisations Net Annual Workshop

Nadler G., (1970) *Work Design : A Systems Concept*, Homewood, Illinois: Richard D. Irwin

Neches R., Fikes R. E., Finin T., Gruber T., Patil R., Senator T. and Swartout W. R., (1991) *Enabling Technology for Knowledge Sharing*. AI Magazine, 12(3), 36-56

NEVEM-workgroup, (1989) *Performance Indicators in Logistics*. IFS Publications, Springer-Verlag

Patil R. S., Fikes R. E., Patel-Schneider P. F., MacKay D., Finin, T., Gruber T.; and Neches R., (1992) *The DARPA Knowledge Sharing Effort: Progress Report*, In Proceedings of the Annual International Conference on Knowledge Representation. Cambridge, MA.

Poirier C.C., (1999) *Advanced Supply Chain Management: How to Build a Sustained Competitive Advantage*, Barrett-Koehler Publishers, Inc., San Francisco, CA

Scott C., and Westbrook R., (1991) *New Strategic Tools for Supply Chain Management*, Intl. J. of Physical Distribution and Logistics Mgmt., 21(1), 23-33

Senge, (1990) *The Fifth Discipline, the Art and Practice of the Learning Organisation*, Doubleday, New York, NY

Sheremetov L. B. and Smirnov A. V., (1997) *A Model of Distributed Constraint Satisfaction Problem and an Algorithm for Configuration Design*. Computación y Sistemas, 2(1), 91-100

Shingo S., (1988) *Non-Stock Production*. Productivity Press, Cambridge, MA.

Smirnov A. V., and Sheremetov, L. B., (1998) *Agent & Object-based Manufacturing Systems Re-engineering: a Case Study*, In Proceedings of the Conference on Integration in Manufacturing, Göteborg, Sweden, IOS Press

Smirnov A.V., Chandra C., (2000) *Ontology-based knowledge management for co-operative supply chain configuration*, AAAI

Sterman J.D., (1989) *Modelling managerial behavior : misconceptions of feedback in a dynamic decision making experiment*, Management Science, 355(3), 321-339

Swaminathan J.M., Smith S.F., and Sadeh N.M., (1996) *A Multi Agent Framework for Modeling Supply Chain Dynamics*. Technical Report, The Robotics Institute, Carnegie Mellon University

Taha H. A., (1987) *Operations Research : An Introduction*, New York, New York : Macmillan Publishing Company

Tan G. W. and Shaw M. J., (1998) *Applying Component Technology to Improve Global Supply Chain Network Management*, Proceedings of the Nineteenth International Conference on Information Systems, R. Hirschheim, M. Newman, and J. I. DeGross (Eds.), Helsinki, Finland

Teigen R., (1997) *Information flow in a supply chain management system*, Diploma thesis

de Toni A., and Tonchia S., (1996) *Lean Organisation, Management by Processes and Performance Management*, Intl. J. of Operations and Production Management, 16(2), 221-236

Tzafestas S. and Kapsiotis G., (1994) *Coordinated control of manufacturing/supply chains using multi-level techniques*, Computer Integrated Manufacturing Systems, 7(3), 206-212

Umeda S., Lee T.L., (2002) *Management data specification for supply chain integration*, NIST report, NISTIR 6703

Van der Veen J., and Robben H., (1997) *Supply Chain Management: een Overzicht*. (Supply Chain Management: an Overview) Nijenrode Mgmt. Review, 6, 62-75

Vrijhoef R. and Koskela L., (1999) *Roles of supply chain management in construction*, IGLC-7

White W.J., O’Connor A.C., Rowe B.R., (2004) *Economic impact of inadequate infrastructure for supply chain integration*, Final report, NIST

Woodridge M., Jennings N., (1995) *Intelligent Agents : Theory and Practice*, Knowledge Engineering Review, 10(2), 115-152