A REVIEW OF APPROACHES TO SUPPLY CHAIN COMMUNICATIONS: FROM MANUFACTURING TO CONSTRUCTION

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SUMMARY: 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: to have the right products in the right quantities, at the right place, at the right moment and at minimal cost, supply chain management is situated at the intersection of different professional sectors. This is particularly the case in construction, since building needs for its fabrication the incorporation of a number of industrial products. This paper provides a review of the main approaches to supply chain communications as used mainly in manufacturing industries. The paper analyses the extent to which these have been applied to construction. It also reviews the on-going developments and research activities in this domain.

KEYWORDS: Information exchanges, knowledge sharing, ontology, supply chain management, construction, manufacturing.

1. INTRODUCTION

The supply chain management (SCM) literature offers many variations on the same theme when defining a supply chain. The most common definition, as proposed by (Houlihan 1985), (Stevens 1989), (Lee et al., 1993) and (Lamming 1996) 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 (SC) 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.

Traditionally, marketing, distribution, planning, manufacturing, and the purchasing of organisations along the supply chain operate independently. These organisations have their own objectives and they are often conflicting. Marketing's objectives of high customer service and maximum sales dollars conflict with the manufacturing and distribution goals. Many manufacturing operations are designed to maximize throughput and lower costs with little consideration for the impact on inventory levels and distribution capabilities. Purchasing contracts are often negotiated with very little information beyond historical buying patterns. The result of these factors is that there is not a single, integrated plan for the organisation. Clearly, there is a need for a mechanism through which these different functions can be integrated together. Supply chain management is a strategy through which such an integration can be achieved. Supply chain management is typically viewed to lie between fully vertically integrated firms, where the entire material flow is owned by a single firm, and where each channel member operates independently.

(Houlihan 1985) is credited with first coining the term "supply chain," but it seems that researchers have varying interpretations of exactly what managing a supply chain means. The common thread in any definition is that supply chain management seeks to integrate performance measures over multiple firms or processes, rather than taking the perspective of a single firm or process.

This paper is aimed at providing a broad review of the main approaches to SC communications, through the description of the main characteristics, techniques and research activities. If most of them have initially been developed for, and applied to manufacturing, it is important to analyse to what extent they have been applied to construction. This is one objective of this paper; another objective is to present some existing and on-going developments and research activities in this domain.

This paper is structured into five sections. First of all, we present some fundamental elements and definitions about supply chain, along with the objectives of supply chain management: this analysis is made both for manufacturing and construction. The last part of this section presents the concept of supply chain as a network of relationships among the different partners of the chain. This network structure logically leads to the identification of the communication system within the network: this is the subject of the following section, where some modelling approaches of the supply chain are described. Among them, we focus on simulation based methods. The section ends with the identification of some communication problems within the supply chain.

Given the importance of the communication problems faced, the question is how to solve them, how to improve communication among a so big and diversified set of actors, all of them speaking a different language, with different vocabularies, with different working habits and obeying different legal rules. To try to bring some kind of answer to this question, the next section presents the concept of supply chain re-engineering, in terms of methodology and models to be developed: business process models, flow models, decision process models. Improving the supply chain communication is still the subject of many research activities, some of the current tracks leading to this improvement are presented in the following section: among them, let us mention the agent-based approach, ontology-based approaches, the concept of virtual supply chain, and maybe one of the most recent, based on the integration of web services. Some construction specific approaches are also presented at the end of this section.

This paper ends with a discussion, and a final summary of the main ideas proposed.

2. SUPPLY CHAIN FUNDAMENTALS AND OBJECTIVES

In this section, some fundamental definitions and features about the concepts of "*supply chain*" and "*supply chain management*" are proposed, but also the objectives of supply chain management.

This paper being a review of existing approaches to supply chain communications, both for manufacturing and construction, the analysis is made here for the two sectors. Supply chain in manufacture is first presented, since this concept originated in the manufacturing industry. Some methodologies for managing supply chains are also presented, based on developments made for, and applied to industry.

The application of supply chain concepts to construction is relatively new. This new way of working has to be related to the current trend in construction to move towards a more industrial-like way of working – particularly for big construction sites and big companies. A particular attention has to be paid to the specificity of construction compared to manufacturing, discussed through the roles played by supply chain management in construction. Some problems, with possible remedies are presented about supply chain in construction.

The last part of this section analyses supply chain as a network of systems, sub-systems, operations, activities, and their relationships, given the members of the chain: suppliers, transporters, manufacturing plants, distribution centers, retailers and construction co- and sub-contractors.

2.1 Supply chain fundamentals

There seems to be a universal agreement on what a supply chain is, see (Teigen, 1997). (Swaminathan et al, 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 et al., 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 et al., 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.

Before analysing the concept of SCM and its application to different industrial sectors, it is interesting to present the objectives of the SCM function. The following section recall the objectives of supply chain management.

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*. More precisely, the objective can be translated into more precise areas of concern, which are: flexibility, delivery reliability, delivery time/lead time and inventory level. Delivery reliability and delivery times are both aspects of *customer service*, which is highly dependent on *flexibility* and on *inventory* (Teigen, 1997).

Once the fundamental concepts defined, it is interesting to see how they apply to two important economic sectors: manufacturing, and construction. The following sections will enable a better understanding of commonalities, but also of differences between the two sectors.

2.3 Supply chain in manufacture

We present here the concept of supply chain at it was initially developed and used in manufacturing industries. Since SC is a vast concept, including several aspects and methods, some of them are recalled here.

2.3.1 Origin of supply chain management

SCM is a concept that has originated and flourished in the manufacturing industry, according to (Vrijhoef et al., 1999). The first signs of SCM were perceptible in the JIT delivery system as part of the Toyota Production System, see (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, see (Bechtel et al., 1997), (Cooper et al. 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. For Van der Veen et al.,

the concept of SCM represents a logical continuation of previous management developments (Van der Veen et al., 1997). Although largely dominated by logistics, the contemporary concept of SCM encompasses more than just logistics, for (Cooper et al. 1997).

Actually, SCM is combining particular features from concepts including Total Quality Management (TQM), Business Process Redesign (BPR) and JIT, see (Van der Veen et al., 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", for (Christopher 1992).
We will come back to this concept of a network in the last paragraph of this section.

Information flow (orders, schedules, forecasts, etc.   )

| Suppliers | ⬌ | Manufacturers | ⬌ | Assemblers | ⬌ | Retailers | ⬌ | Customers |

| Materials | ⬌ | Parts manufacture | ⬌ | Product assembly | ⬌ | Sales | ⬌ | Use or consumption |

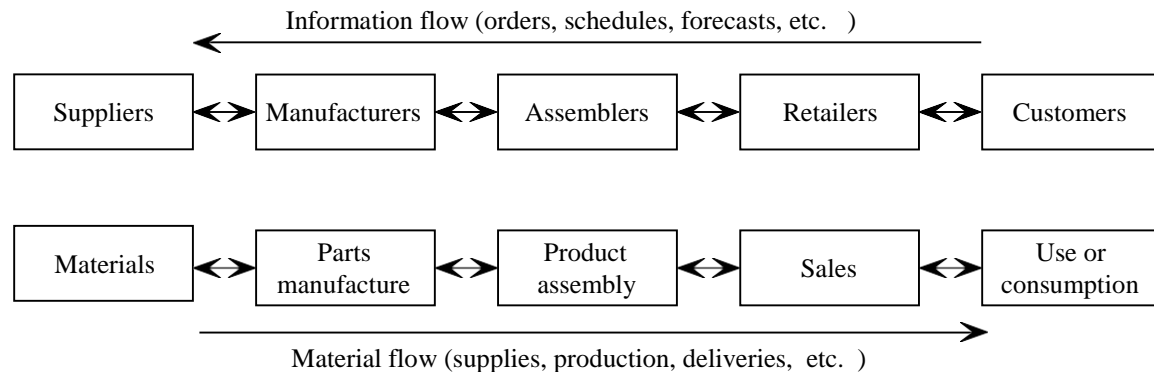Material flow (supplies, production, deliveries, etc.)

FIG. 1: Generic configuration of a supply chain in manufacturing (Vrijhoef et al., 1999)

Fig. 1 shows a generic configuration of a supply chain in manufacturing, with information flows (such as orders, schedules, forecasts), circulating between customers, retailers, assemblers, manufacturers and suppliers. Material flows (as supplies, production, deliveries, products of whatever kind) circulate from their manufacturing from raw materials or components, through to their use within the manufactured product.

SCM looks across this entire supply chain, 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 et al., 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, for Koskela, the flow view focuses on the control of the total flow of production (Koskela 1992).

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, see (Scott et al., 1991), supply chain modelling, for (Davis 1993) and logistics performance measurement, for (Lehtonen 1995) analyse stock levels across the supply chain. The LOGI method, see (Luhtala et al., 1994), (Jahnukainen et al., 1995) studies time buffers and controllability problems of the delivery process. For La Londe et al., supply chain costing (La Londe et al., 1996) focuses on cost build-up along the supply chain. Integral methods like value stream mapping, see (Hines et al., 1997), (Jones et al. 1997) and process performance measurement (De Toni et al., 1996) offer a "toolbox" to analyse various issues including lead time and quality defects.

Applied to construction, the fundamental aspects of supply chain remain the same, slight differences may however appear, due to the specificities of the two sectors. In the following paragraph, the application of SC to construction is highlighted.

TABLE 1: Characteristic differences between traditional ways of managing the supply chain and SCM, see (Cooper et al., 1993) mentioned in (Vrijhoef et al., 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

2.4 Supply chain in Construction

For analysing the application of SCM to construction, it is first necessary to present the characteristics of construction in terms of SC concepts: given the specificity of a construction "product", compared to a manufactured one, SC cannot be applied in the same way to the two domains.

According to the areas of focus of SC, it is possible to identify four roles that can be played by supply chain in construction. Those roles are presented in this section.

The last sub-section presents some problems specific to construction supply chains.

2.4.1   Characteristics of construction supply chains

In terms of structure and function, for Vrijhoef et al., the construction supply chain is characterised by the following elements (Vrijhoef et al., 2000):

- It is a converging supply chain directing all materials to the construction site where the object is assembled from incoming materials. The « construction factory » is set up around the single product, in contrast to manufacturing systems where multiple products pass through the factory, and are distributed to many customers.
- It is, apart from rare exceptions, a temporary supply chain producing one-of construction projects through repeated reconfiguration of project organisations. As a result, the construction supply chain is typified by instability, fragmentation, and especially by the separation between the design and the construction of the built object.
- It is a typical make-to-order supply chain, with every project creating a new product or prototype. There is little repetition, again with minor exceptions. The process can be very similar, however, for projects of a particular kind.

2.4.2   Areas of focus, and roles of supply chain management in construction

The characteristics discussed above have an impact on the management of supply chains. Four major roles of SCM in construction can be recognised, dependent on whether the focus is on the supply chain, the construction site, or both. They are:

- the focus may be on the impacts of the supply chain on site activities. The goal is to reduce costs and duration of site activities. In this case, the primary consideration is to ensure dependable material and labour flows to the site to avoid disruption to the workflow. This may be achieved by simply focusing on the relationship between the site and direct suppliers. The contractor, whose main interest is in site activities, is in the best position to adopt this focus.
- the focus may be on the supply chain itself, with the goal of reducing costs, especially those relating to logistics, lead-time and inventory. Material and component suppliers may also adopt this focus.
- the focus may be on transferring activities from the site to earlier stages of the supply chain. This rationale may simply be to avoid the basically inferior conditions on site, or to achieve wider concurrency between activities, which is not possible with site construction with its many technical dependencies. The goal is again to reduce the total costs and duration. Suppliers or contractors may initiate this focus.
- the focus may be on the integrated management and improvement of the supply chain and the site production. Thus, site production is subsumed into SCM. Clients, suppliers or contractors may initiate this focus.

It should be noted that the roles as identified above are not mutually exclusive, but are often used jointly. The focus here is on the supply chain of a main contractor. However, there is a fifth important role that lies in the management of the construction supply chain by facility, or real estate owners. They may well drive the management and development of the construction supply chain on which they are reliant for the continuation of their business, for instance when they exploit a number of facilities that need frequent new development and refurbishment.

2.4.3   Problems of the construction supply chains

Much research work and real test cases analyses have assessed that construction is ineffective and many problems can be observed. Analysis of these problems has shown that a major part of them are supply chain problems, originating at the interfaces of different parties or functions, as represented in Fig. 2, among which (Vrijhoef et al., 2001):

- client/design interface: difficulties in finding out client's wishes, changes of client's wishes, long procedures to discuss changes,
- design/engineering interface: incorrect documents, design changes, extended wait for architect's approval or design changes,
- engineering/purchasing & preparation interface: inaccurate data, engineering drawings not fitting the use,
- purchasing & preparation/suppliers interface and purchase & preparation/subcontractors interface: inaccurate data, information needs not met, adversarial bargaining and other changes,
- suppliers/subcontractors interface and suppliers/site interface: deliveries not in conformance with planning, wrong and defective deliveries, long storage period, awkward packing, large shipments,
- subcontractors/site interface: subcontracted work not delivered according to main design, contract and planning,
- site/completion of building interface: problematic completion due to quality problems,
- completion of building/occupation interface: unresolved quality problems, delayed occupation due to late completion,
- purchasing & preparation/site interface: inaccurate data, information needs not met, unrealistic planning.

We can notice from this list that communication problems (either described in terms of "data", or more generally in terms of information handled during the exchanges) form an important part of the problems faced in construction supply chains.

The current practice of supply chain management rightly suggests controlling the supply chain as an integrated value-generating flow, rather than only as a series of individual activities. Here, the term "supply chain" refers to the stages through which construction materials factually proceed before having become a permanent part of the building or other facility. It covers thus both permanent supply chains, that exists independent of any particular project, and temporary supply chains, configured for a particular project.
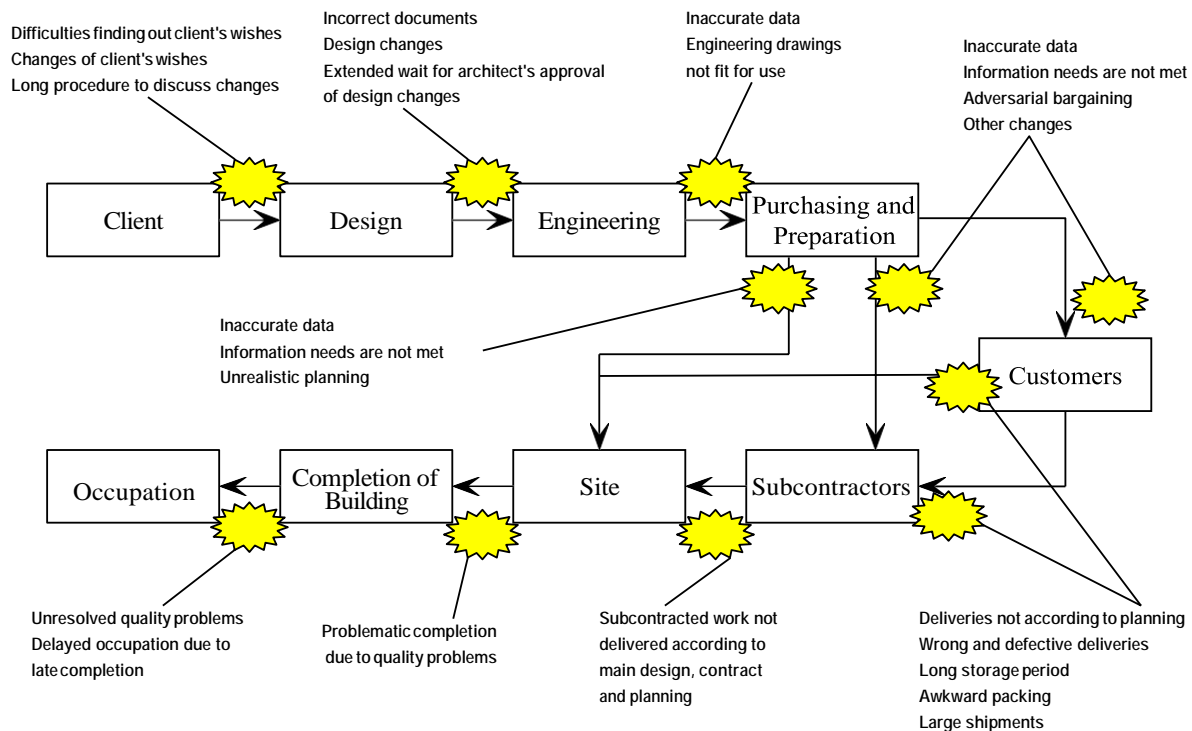
Difficulties finding out client's wishes
Changes of client's wishes
Long procedure to discuss changes

Incorrect documents
Design changes
Extended wait for architect's approval
of design changes

Inaccurate data
Engineering drawings
not fit for use

Inaccurate data
Information needs are not met
Adversarial bargaining
Other changes

| Client | Design | Engineering | Purchasing and Preparation |

Customers

Inaccurate data
Information needs are not met
Unrealistic planning

| Occupation | Completion of Building | Site | Subcontractors |

Unresolved quality problems
Delayed occupation due to
late completion

Problematic completion
due to quality problems

Subcontracted work not
delivered according to
main design, contract
and planning

Deliveries not according to planning
Wrong and defective deliveries
Long storage period
Awkward packing
Large shipments

FIG. 2: Generic problems in the construction process (Vrijhoef et al., 2001)

Given the role of communications within the supply chain, it is interesting to see if another approach of the SC, based on information management would be possible: this is the subject of the following section, where supply chain is now considered as a network, not only of *facilities*, but also of actors exchanging messages/information.

2.5 Supply chain as a network

In a systemic approach, supply chain can also be considered as a network of systems, sub-systems, operations, activities, and their relationships, where the members of the chain are: suppliers, transporters, manufacturing plants, distribution centers, retailers and construction co- and sub-contractors. We will see in this section that this approach is very interesting, since it focuses on the message, in terms of format and contents, but also on the way of managing the coordination and synchronising of the communication systems. It will also enable, as we will see in the following section, the identification, then the modelling of the information exchanged.

2.5.1 General features

A supply-chain network 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, see (Chandra et al., 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. 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, see (Lee et al., 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)". For other authors, an 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 et al., 1994). We will come back on this concept of CSC in the section on ontology-based approaches.

2.5.2 Construction supply chain: a network of firms

For London et al., following the decision to procure a construction project there are a number of identifiable phases: conception, inception and realisation (London et al., 1998). The main purpose of the conception phase is to assess the strategic need of the project and typically includes financial feasibility studies, future growth and market expectations. The inception phase is to clarify specific project objectives and involves determining the design brief and the method of procurement, developing a financial model and producing conceptual designs. Finally, the realisation phase involves resolving the detailed design, construction planning, tendering and construction. There is often considerable overlap between phases.

The simplification of conception, inception and realisation belies the variety and number of interdependent firms involved in the entire process. These firms form temporary organisations to provide specific productive capacity for a given project to satisfy client demands. They can be categorised into the specialist roles of consultants, contractors, subcontractors and suppliers. Within each of these categories there are networks of firms organised to supply products and/or services for the realisation of the project. Each of these firms have a significant role to play over the duration of the procurement process that is interdependent on the other firms within their own network in the supply chain.

During the early phases of conception and inception, services are purchased by various mechanisms ranging from open tender, selective tender to negotiation. At some point there is enough information to commit to a tendering process to manage the construction process and to 'realise' a building or infrastructure project. Again the various mechanisms to purchase the service, to manage the construction process, range from open tender to negotiation. This and similar processes is typically repeated for both the procurement of the services for constructing or assembling of the component parts on site and also the procurement of products/components ie materials or component suppliers.

In this section, we focused our attention on some fundamental aspects of supply chain management, but also on the objectives of the chain, in order to build the fundamental bases of our analysis. The study was made both for manufacturing and construction in order to see the analogies, but also the differences due to the specificity of the sectors.

Given the focus of the paper on the communications in supply chain management, a network-based approach of the SC is very interesting, since this kind of approach puts the emphasis on the message, in terms of format and contents, but also on the way of coordinating and synchronising the different messages exchanged.
In the following section, we focus on this communication aspect.

3. COMMUNICATIONS WITHIN THE SUPPLY CHAIN

Communications within the supply chain can be analysed from different points of view, based either on real approaches (test-cases), or built from the results of the application of simulation methods.

In the first part of this section, we present some supply chain modelling approaches, among which SC network design method, MIP (Mixed-Integer Programming) optimisation modelling, Stochastic Programming and Robust Optimisation Methods, Heuristic Methods and Simulation based Methods.

In the second part, the communications within the SC are simulated, then the results of the simulation are represented under the form of an information model. Of course, it is first necessary to identify the data requirements of the model.

The benefit of this approach is to enable a better identification of the communication problems met within the supply chain: those problems are discussed in the last part of the section.

3.1 Supply chain modelling approaches

Dong has categorised modeling approaches in SCM 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 et al., 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 analyzed by considering both its strategic and operational elements. This method can evaluate the effectiveness of a pre-specified policy before developing new ones.

We focus here on the informational aspect of supply chain modelling. This aspect has mainly been developed through simulation methods, representing the communication features of the supply chain.

3.2 Simulation based supply chain information modelling

There are several ways of modelling the information handled and exchanged in a supply chain seen in terms of communication and information exchanges. Given the complexity, the diversity of the chains and the number of possibilities of exchanges, one possible way is simulation. In that case, simple or complex scenarios can be developed, each of them proposing a possible version of a supply chain management situation. We discuss here the role of simulation, the role played by simulation models, but also the requirements in terms of data necessary for modelling supply chains.

3.2.1 Role of simulation

A poor plan can easily propagate to the whole supply chain areas, see (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 (ERP) 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 minimize the risk of changes in planning process: by what-if simulation, user can test various alternatives before changing plan.

3.2.2 Data requirements for supply chain modeling

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 et al., 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. Fig. 3 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.
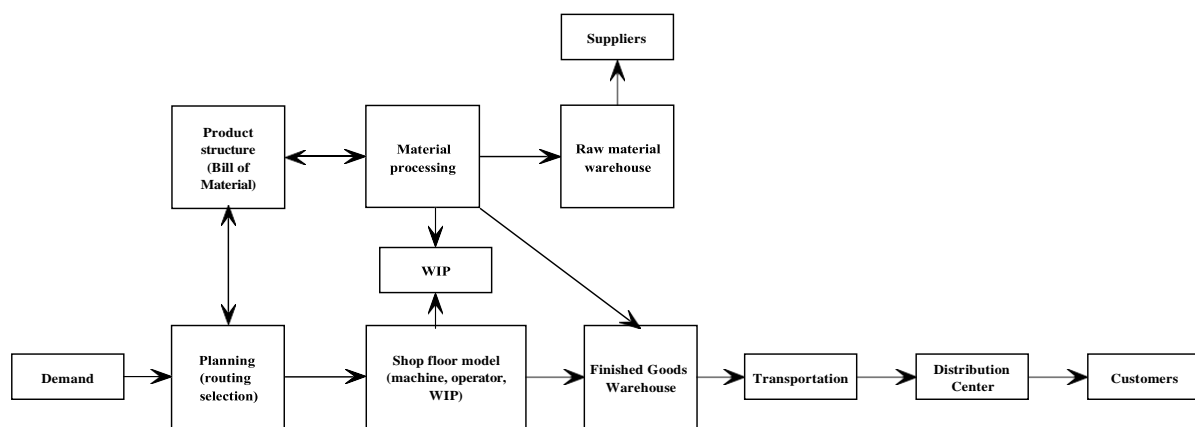

FIG. 3: Diagram of an example of supply chain simulation model (Chang, 2001)

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

Of course, the result of the simulation has to be related to the complexity of the simulation model. A complex simulation model, but well adapted to the needs of the problem will enable the identification of a big number of problems, and thus very useful!

3.3 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, see (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 re-entered 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;
- Organizations 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 unrealized.

In this section, we have presented the way of identifying, then modelling communication systems in a supply chain. SC can be modelled in different ways, according to the priorities and the concepts we want to put forward. In our approach, we focus on an informational modelling-based approach of SCM. Given the complexity of the informational approach in SC, simulation based information modelling methodologies are often used to highlight problems arising.

In some cases, some of these problems can be more or less easily solved, particularly when they come from local conflict situations. For more general problems, or problems related to more general situations, e.g. involving many actors of the chain, local solutions are not possible. It is thus necessary to re-build the chain, to re-engineer it.

In the following section, we will focus on the different possibilities of re-engineering a supply chain.

4. SUPPLY CHAIN RE-ENGINEERING

The term of re-engineering, applied to business processes, or to supply chain has many interpretations, has showed by (Stevens et al., 1997). Most of the authors classify a broad range of initiatives under this concept. Besides, it can be expected that the focus of re-engineering, or whatever term succeeds it, will continue to evolve.

The same authors consider that the evolution, in terms of re-engineering, has had three stages:

- At Stage 1, the efforts are department focused. Process improvement is conceived, developed, and managed at that level. The result is optimisation at the department level while perhaps doing damage in other departments or even in other enterprises beyond the walls.
- In Stage 2, enterprise-wide solutions emerge. Re-engineering begins to affect the entire company with top management sponsorship. Efforts such as cellular work groups and focused factories, organised around segmented customer requirements, are examples of enterprise-wide solutions.
- Stage 3 is supply-chain focused, going beyond the organisation to multi-enterprise processes. There are many reasons to pursue a supply chain strategy. The best is improvement in strategic positioning. (Porter 1996) believes that strategic positions are built on hard-to-copy activity systems. Sustainable competitive advantage derives not from cost cutting, but from excellence in executing activities that reinforce value to customers. For manufacturers, the supply chain is integral to these sustainable strategies.

Many research efforts have been put into optimizing the performance of supply chains (Teigen, 1997). The major part of the early work tends to focus on very limited segments (corresponding to the stage 1), e.g. only material procurement, manufacturing, or distribution, and treat these as separate systems.

In later years we have seen an increasing focus on the integration of different segments of the supply chain (corresponding to the stage 2). As for example Cohen and Lee (Cohen et al., 1988) and Chandra and Fisher (Chandra et al., 1994) who treat integration and coordination of production and distribution functions. These efforts are what Bhatnagar et al. (Bhatnagar et al., 1993), who have reviewed the existing works on coordination, refer to as *general coordination*. Bhatnagar et al. distinguish between two broad levels of coordination. General coordination is the integration of different functions, e.g. inventory and production planning, sales, and distribution.

The other level of coordination identified, is that on which production decisions are coordinated among the plants of an internal supply chain (stage 3). This is referred to as *multi-plant coordination*. The objective of multi-plant coordination is to coordinate the production plans of several plants in a vertically integrated manufacturing company so that the overall performance of the company is improved. Still according to Bhatnagar et al., in order for such coordination to be efficient, the effects of uncertainty of final demand, uncertainties in production process at each plant, and capacity constraints at each plant must be taken into consideration.

Before starting a re-engineering action, it is important to define a methodology. We present one of the possible methodologies, developed within the framework of the IPRODOC project (IPS-CT-2000-00029).
An important part of the work leading to process re-engineering lies in the development of models. The following sub-sections present some types of possible models, among those commonly built: business process models, material flow/logistics models and decision process models. All these models are aimed at improving the understanding of the current situation, first stage towards a real process re-engineering.

4.1 Re-engineering methodology

A re-engineering methodology has been proposed by (Echave et al., 2003), within the framework of the IPRODOC European project.

The IPRODOC project aims at supporting the re-engineering of SMEs supply processes in the mechanical sector, empowering flexibility in spite of complexity. The project intends to deploy, test and validate a specific methodology to help European SMEs in achieving high integration within inter-companies relationships, through the adoption of innovative ICT based tools and new business models able to take into account organisation management, new working methods and integration of knowledge.

The methodology followed in the project has the following features:

- it is focused on the introduction of new ICT tools;
- it considers technology as a significant factor on bringing about comprehensive change;
- it is able to integrate both *continuous process improvement and radical process change;*
- it affects one or more related processes;
- it is driven by organisational strategic objectives;
- it works on all components of the process: flow, organisation, personnel, logistics, information;
- it is flexible, adaptable to specific situations and scalable.

The re-engineering methodology highlighted three phases, each one being sub-divided into different steps. We only present here the main elements; for further developments, see (Echave et al., 2003):

PHASE 1: Definition of the field of application

1. **Identification of the area and level of intervention:** including the definition of the boundaries of the areas and processes within which it is intended to act and the identification of the personnel – internal and external to the company – involved in those processes.
2. **Outline of strategic context:** in-depth analysis of the reasons for the company reengineering, of the opportunities offered by new technologies and of the stimulus arising from the customer requests.
3. **Decision on strategic objectives:** definition of the strategic objectives to be reached through the re-engineering process.

PHASE 2: Priorities and critical issues diagnosis

4. **Identification of the real processes:** identification of the main processes and their description in terms of carried-out activities, input, output, actors, tools and constraints. Identification of relationships: processes/sub-processes, products/processes, processes/responsibility. This work leads to the development of a model.
5. **Definition of the metric for the whole process:** For each process a group of indicators that could help in the process total *performance evaluation* has to be identified and selected. In particular, the process performance evaluation needs to be focused on the parameters of efficiency (ratio between output and input) and effectiveness (ratio between foreseen and obtained results).
6. **Measurement of the gaps between strategic objectives and real context:** the strategic objectives identified during the first phase are put in relation to the processes and subprocesses identified in step 4 in order to measure the gaps between expected results and the company current performance, measured in terms of efficiency and effectiveness.

PHASE 3: Processes re-engineering

7. **Design of the possible different re-engineering projects:** the analysis of the critical processes and of their limitations could imply deletion, simplification and joining of some processes/sub-processes, as well as the design of new processes. All this should be taken into consideration when designing the possible reengineering projects, which implies first of all the choice of Information and Communication Technologies (ICT) tools suitable for the specific company/network situation.
8. **Design of the monitoring and control system:** although the indicators identified within the phase 2 are strictly related to the organisational structure prior to the re-engineering, a part of them could still be useful for monitoring the new processes.
9. **Setting and preparation of the organisational change:** the new organisational structure is intended to manage the new process scheme. The review of the technical and managerial skills includes a comparison between the skills of the existing human resources and those required by the new process/organisation, the evaluation of the gap and the elaboration of proposals in order to overcome the problem; e.g. training courses, hiring of new personnel, outsourcing.
10. **Implementation and test of the solution identified through the re-engineered process:** the identified solution inevitably requires to be tuned and adapted. There are two main methodological approaches that can be applied: partial realisation on a pilot group, simulation of the behaviour of the new process/processes.

If we go into further details about the models previously mentioned, we find: business process models, material flows and logistics models and decision process models. Let us give some indication about them in the following sub-sections.

4.2 Business process models

Business process models are needed to understand how operations are carried out both at individual suppliers and in the supply chain itself, according to Umeda and Jones (Umeda et al., 1997). They are basically functional models that describe what activities are performed, and relationships that exist among those activities. While there may be differences in how suppliers execute activities, the authors believe that a common set of operational activities does exist. This common set of activities forms the basis for a coherent production and operations management plan for the supply chain. Each of these operational activities contains a sequence of primitive activities. A primitive activity consumes both time and information and material resources. Both network flow and activity cycle diagrams are used to represent each business process flow. Each individual process can have its own internal decomposition into sub-processes. The top-level processes are generally design, process planning, material preparation, production and delivery.

4.3 Material flow/Logistics model

According to Umeda and Jones, Material flow models represent physical material flows of parts/products from suppliers to customers (Umeda et al., 1997). Usually, these models take a hierarchical network form with multiple levels. A typical three-level model might contain factory, line, and cell levels. The factory level captures material-flows among suppliers' factories. The second level model presents the line flows within a factory, which is composed of processes and transporters. The third level models physical movement within each manufacturing cell. Mathematically, the model at each level is a general queuing network model. Logistics models deal primarily with material flows at the factory level. It is at this level where the transfer of materials is accomplished using some sort of transportation such as trucks, rail, boat, or plane. The logistics model includes order planning, warehouse location planning, transportation planning, and inventory planning, among others. An integrated supply chain is only possible if there is a common understanding of these information flows. To achieve this common understanding, (Umeda et al., 1997) develop a collection of formal information models using OMT methodologies, developed by (Booch 1994). These models describe the entities which provide complete and detailed definitions for each of flows. They also identify all the relationships that exist among these entities.

4.4 Decision process model

Decision process models specify various production and operations management decisions that are made throughout the entire chain, see (Umeda et al., 1997). Examples include:

- Material selection: Which material is the best to choose for various products?
- Location selection: Which supplier is the best to produce and distribute?
- Inventory planning: Where and how much inventory should be stored?
- Load planning: How work load handled by each supplier?
- Capacity planning: How much production capacity do suppliers need to meet demand?
- Production scheduling: When and what suppliers should produce and associated due dates?
- Distribution planning: When and how much volume of end products or component parts should be transported?

It is possible to develop formal mathematical programming problems to represent most of these decisions. Typically, the objective functions in these formulations take into account several performance measures including: cost estimation, lead-time, highest utilisation of resources, throughput performance, and due date. This results in a multiobjective optimisation problem with multiple variables, generally considered as an NP complete problem, for which optimal solutions will be hard to find. Nevertheless, a number of commercial software packages on the market provide solutions to these problems.

Through this section, we have presented a re-engineering methodology, as developed within the framework of the IPRODOC European project.

An important part of the work leading to process re-engineering coming from the development of models, we have also presented possible types of models, among those which are commonly used, such as business process models, material flow and logistics models, and decision process models.

Process re-engineering has been, and is still the subject of many research actions – more generally, the improvement of supply chain, and SC management, whatever the point of view, is the subject of an important

research activity.

In the next section, we analyse some on-going developments and research aimed at improving the communications in the supply chain.

5. ON-GOING DEVELOPMENTS AND RESEARCH ACTIVITIES IN THE DOMAIN OF SUPPLY CHAIN COMMUNICATIONS

The domain of supply chain communications is the subject of numerous research actions. In this section, we present some of them, among the most important, or the most developed over the research community.

First, agent-based approaches of supply chain management, start with the definition of what "agents" are, and what is their use. There are some benefits to expect from the use of agents in SCM, they are analysed in this section.

Ontology based approaches are another important part of research activities about SC communications. They are used to provide 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.

Interesting work has also been done in the domain of virtual supply chains: we present here some results coming from the GLOBEMEN EU funded project.

The integration of web services to the management of supply chains is currently the subject of many research actions, particularly in the context of a semantic approach of the WWW. We propose in the next section an overview of the use of some web services in supply chain management.
Last section presents some research actions in the domain of construction supply chain management.

5.1 Agent based supply chain management

An agent is not easily defined. There is therefore no single definition that is recognised throughout the entire agent-based computing community. (Woodridge et al., 1995) identifies a weak and a strong notion of what an agent is (Teigen, 1997).

The weak notion is that of an agent denoting a hardware or (more usually) software-based computer system that enjoys the following properties:

- **autonomy**: agents operate without the direct intervention of humans or others, and have some kind of control over their actions and internal state;
- **social ability**: agents interact with other agents (and possibly humans) via some kind of agent-communication language. ("[Agents] communicate with their peers by exchanging messages in an expressive agent communication language." (Genesereth et al., 1994));
- **reactivity**: agents perceive their environment, and respond in a timely fashion to changes that occur in it;
- **pro-activeness**: agents do not simply act in response to their environment, they are able to exhibit goal-directed behavior by taking the initiative.

A stronger notion of the agent often ascribes human characteristics to it, such as knowledge, belief, intention, and obligation. And going even further agents can be said to have a degree of mobility (their capacity to move around in an electronic network), veracity (not communicating false information), benevolence (agents will do what they are asked), and rationality (acting to achieve goals).

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 formalized. One approach described in (Woodridge et al., 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 et al., 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 Benefits of the use of agents in SCM

One of the major advantages of the multi-agent approach is the ease it lends to the conceptualisation of a system (Teigen, 1997). This is most evident where the application domain is readily conceived in terms of naturally occurring entities, which is the case for a supply chain. A supply chain can be visualised as a set of entities and processes. Entities may be suppliers, plants, distribution centers, customers, etc, or it may be internal departments such as sales, planning, purchasing, materials, or research and development. A process is simply a series of actions. An entity is responsible for a set of processes, e.g. sales might be responsible for processes related to order acquisition, purchasing for processes related to supplier selection and material ordering, and R&D responsibility is processes related to introduction of new products in the supply chain.

Using this approach entities may be modeled as autonomous agent. There is only a *relatively* small step from describing a supply chain to designing it as a multi-agent system, reducing the danger of errors in the translation process.

A supply chain is a domain which is frequently subject to structural changes. Agents are autonomous, and often distributed, with very clearly defined interfaces, i.e. message passing. This gives a robust system that can undergo continuous adoption to the changes in the environment, both locally and globally, without the degradation of performance often met in other types of systems. Automated procedures can be developed to deal with adding and removing agents to the system, and changes within an agent will not affect other agents.

Another important issue is that of legacy software, i.e. systems that are already in use, for example a local inventory management system. A company wide multi-agent system can be implemented without having to redesign and implement all local systems. The agents can simply "use" the legacy systems through interfaces. Again changes can be made locally, e.g. by incrementally improving or replacing legacy software, without it affecting the enterprise wide system.

In a distributed domain such as the supply chain, integration and coordination are important aspects of any information and management system. A multi-agent system facilitates both multi-plant and general coordination. An agent may have *social ability* and a level of *reactivity*. These attributes of an agent make it well suited to assure a high level of coordination. An example would be when an agent is planning production. The agent may be planning for one site in a supply chain, but information can be passed to and received from other sites, allowing a coordinated production planning. Different "planning agents" could "talk" or "negotiate" to obtain a plan that is optimal not only locally, but also for the supply chain as a whole. This is multi-plant coordination.

When additional information is needed in the planning, e.g. inventory levels, current backlogs, etc..., relevant agents may be asked, e.g. a sales agent for current backlogs, or the databases may be queried directly. This is general coordination. Another example is that of customer ordering. When customers place orders, they want to know when their products arrive, see (Lee et al., 1992). It is a problem that the entity dealing with customer orders often lacks the necessary information to quote correct lead times. In a multi-agent system this agent (say a sales agent) will be able to query other agents for the necessary information, say on production, inventory, and current backlogs. Correct lead times can be deducted from the acquired information.

A multi-agent system would also allow a high degree of reactivity to unforeseen events. The occurrence of an unexpected event, e.g. an order cancellation, can be communicated to every concerned entity in a matter of a few minutes. Each agent receiving such an event warning must have the necessary tools to respond in a timely fashion. This may be as simple as printing a message on a monitor for a human user, or as complicated as rescheduling production. One important consequence of this is that customers could be informed on changes in delivery times caused by the unexpected events.

5.1.3 An example of application 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, for (Fox et al., 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 4 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.

In this section, we have seen to what extent agent based approaches could benefit to supply chain management. Another research approach consists in the use of ontologies to develop new approaches to the communication problem in supply chain management. This approach is presented in the following paragraph. Besides, there is a link between ontologies and agents, used together in an integration process based on knowledge management.
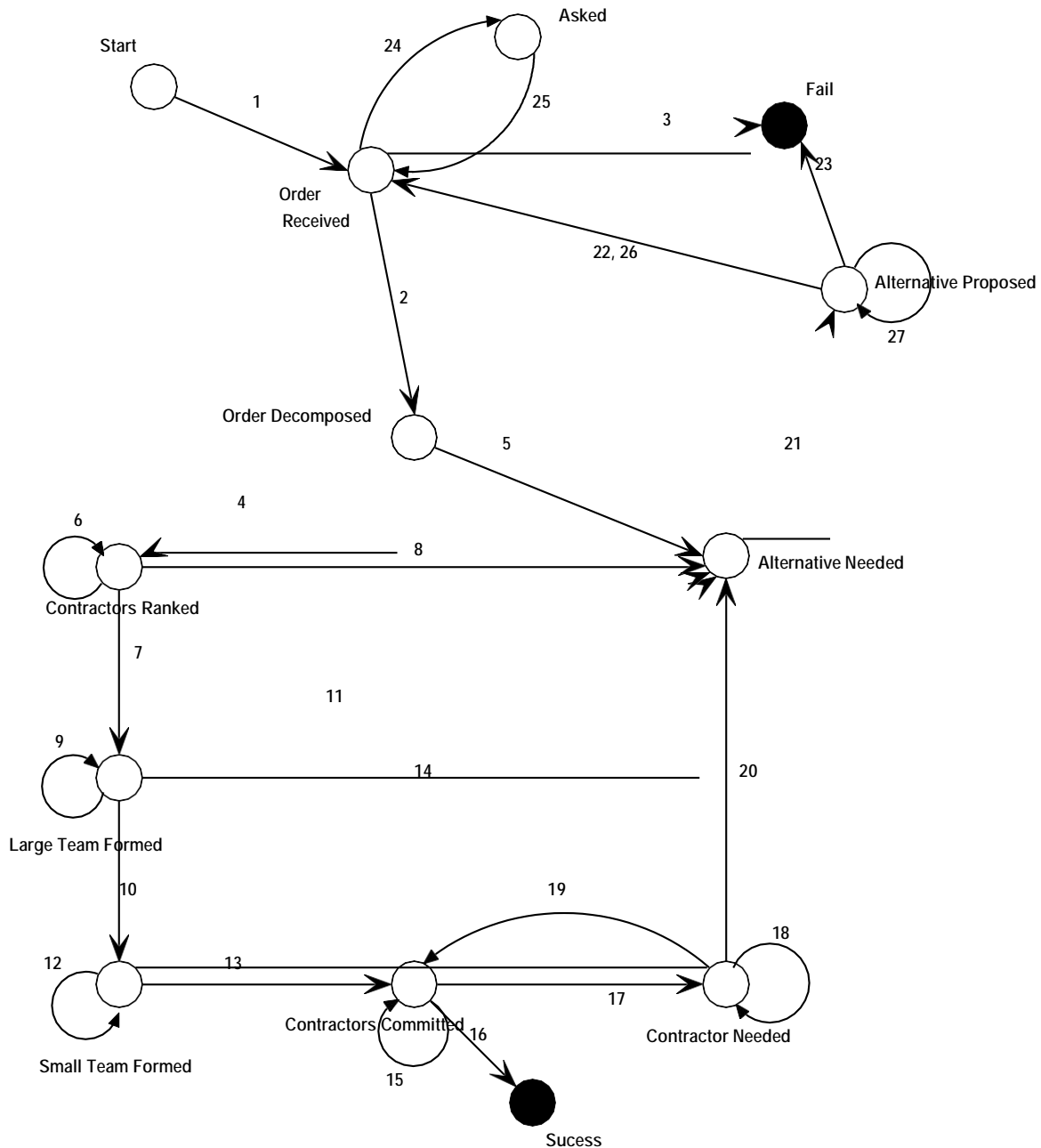

FIG. 4: Logistics execution conversation plan (Fox et al., 2000)

5.2 Ontology-based approaches

The word ontology first appeared in Aristotle's philosophical essays, where it used to describe the nature and organisation of being, see (Mansooreh Mollaghasemi and Rabelo, 2002). Artificial Intelligence (AI) practitioners use the word ontology to formally represent domains of knowledge. For Gomez-Perez, (Gomez-Perez, 1998), there are four main types of ontologies, which are: domain ontologies that provide a vocabulary for describing a particular domain, task ontologies that provide a vocabulary for the terms involved in a problem solving process, meta-ontologies that provide the basic terms to codify domain and task ontologies, and knowledge representation ontologies that capture the representation primitives in knowledge representation languages. Gruber (Gruber, 1995) states that formal ontologies need to be designed and provides a preliminary set of design criteria for the ontologies developed for knowledge sharing. These criteria are clarity, coherence, extendibility, minimal encoding bias, and minimal ontological commitment.

As a link to the previous section, the last paragraph proposes a relation between ontologies, and agents.

5.2.1 Role of ontologies in a cooperative supply chain

Supply chain management is the art and science of managing this complex network of interrelated systems and their components. A formal mechanism to organise them 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), as proposed by (Hillier et al., 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, see (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:

- *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

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, as mentioned in (Neches et al., 1991), (Patil et al., 1992). Knowledge management (KM) could be identified by four factors behind successful KM systems, see (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".

Smirnov et al. represent the SC configuration stage by the following relation (Smirnov et al., 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 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. For M. Grüninger, the development of ontologies is motivated by scenarios that arise in the applications (Grüninger et al., 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.

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, see (Sheremetov et al., 1997), (Smirnov et al., 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.

Another very active research domain is the development of virtual supply chains. Several European projects have been launched in this domain, we present here the results of one of them, GLOBEMEN, since it provides a typical representation of the most common features of a virtual supply chain.

5.3 Virtual supply chain

Companies today are facing increasing demands to be able to deliver more complex solutions, faster, cheaper and with higher quality (Globemen 2002). Many enterprises are moving from a more stable supply chain type of network towards a more dynamic and temporary virtual enterprise type of environment. The concept of Virtual Enterprises (VEs) has been given various descriptions, among which "a group of enterprises goes together to create a kind of formalised network (an existing enterprise will usually already have some kind of (informal) network)". This enterprise network then works as a breeding ground for setting up specific VEs based upon identified customer needs and requests.

The type of information and level of exchange between two enterprises depends on several aspects including the type of tasks that are being solved, the type of partnership, and the level of trust between the partners (Globemen 2002). Different trends occur for some enterprise more or less simultaneously:

- Many enterprises are in the process of *trimming their supply chain*, identifying key partners and establishing tighter, strategic type of relationships with them.
- Many enterprises face divergent demands from their customer, and an increasing competition, forcing them to *change their solution space faster* than before.
- Enterprises need to *focus more on their core competencies* and team up with partners possessing the remaining complementary competencies/capabilities needed to fulfil the customer requirements.

All this means that enterprises typically work with different types of partners:

- A set of *core strategic partners*, with a long-term relationship and with whom shared development work can be carried out, and a tighter integration can be established, e.g. shared ICT infrastructure, procedures, rules, etc.
- A group of *subcontractors* delivering standard components and simple subcontracting, some of

them with long-term relationships, other with shorter ones. The characteristics of those more standard subcontractors and suppliers are that the level of coordination is low, and accordingly the need for a shared infrastructure is not so prevalent.

Depending on the task various levels of information and integration are needed. For sub-contracting standard components, for example, the coordination needs are very low, essentially all what is needed is point-to-point contact where the contractor orders a certain quantum of one or more product numbers. The other extreme is a full integration, for example for carrying out concurrent inter-enterprise development with strategic partners of a highly innovative yet unknown product.

In the way they deal with the concept of information, of information exchanges and communications, virtual supply chains can be considered as a first stage towards a full web SC services integration. In the following section, we provide a rough overview of the integration of those services.

5.4 Supply chain management through web services integration

Web services are a better and more efficient version of distributed computing models. They are independent of underlying data, operating system and programming environment. Most modern languages have XML support and therefore work with web services. It is essential that the communication standards and protocols used in web services must be universally accepted – some of these standards are still emerging. In general, a web service is simply an application that exposes a Web-accessible program interface. This service can be requested by client applications – web-based, Windows or mobile devices. However, an additional requirement is that application data and format must be such that it can be understood by all kinds of client applications. Web services do not offer anything that was impossible before. Instead, they accelerate the implementation cycle, reduce development costs, and increase opportunities for system interoperability and reuse. Several industries, such as manufacturing, financial services, telecommunications, and utilities, are plagued with fragmented supply chains where standardized connectivity with business partners is limited. Web services can help improve supply chain efficiencies that are critical for competitive advantage.

The widespread acceptance of XML and other Web Services standards like SOAP (SOAP) and UDDI (UDDI) will ensure interoperability of supply chain members' applications. This will probably reduce the apprehension about launching complex business process integration projects across the supply chain.

For some typical cases, it is obvious that web services offer an easier and better solution than the use of traditional distributed computing methods, see (Murtaza et al., 2003). Let us mention here:

1. Large and dispersed client-base: if clients are located at various distant locations, it may be difficult to build traditional distributed computing applications as there may be proxy servers and firewalls to go through. In such a situation, building and deploying Web Services may be a more appropriate.
2. Exposing traditional applications: A large number of legacy and other non-web aware application
3. exist in the corporate world. Web Services offer one practical way to allow integration with modern web based systems.
4. Developing Extranet applications: The communication between business partners is not new. Electronic data interchange (EDI) has been around for a while – however, the time, cost and effort required for implementing EDI solutions made them inappropriate as far as most small and medium-sized business are concerned. On the other hand, web technologies are already there and relatively inexpensive to use and therefore business-to-business sharing of data and application through web services are rather easy to implement.

The area of supply chain management is one that falls in all of the above mentioned categories. Supply chain partners are often not in physical proximity of each other, have various legacy applications developed a number of years ago and do want to have better and more efficient information sharing for improving the business processes.

The construction sector is a very active research sector in SC management, particularly in the domain of the integration of web services and in the use of agent-based technologies. They are presented in the following section.

5.5 Research in construction supply chain

Construction sector is very active in research about supply chain management. Big construction sites all over the world, or companies (contractors, suppliers, transporters, retailers, …) in charge of a construction project, spread over big territories or across several countries have provided very good research and development platforms enabling full size experimentations of the most recent SCM concepts.

In this section, we mention the integration of web services, and the use of agent-based technologies, applied to construction.

5.5.1 Web services integration

A core concept of web service integration is the connectivity and interoperability of software components to perform different functions, described in (Min 2002), (Min et al., 2004). This idea can be applied to a business setting, especially to supply chain management, see (Castro-Leon 2002). In this framework, each of supply chain members plays a functionally decomposed role based on the set of predefined business rules. In addition to this basic rule-based web services, a web service can be composed by another web service. A composition of web services enables different enterprises to collaborate in order to perform business-to-business transactions. To develop automated web services, Semantic web has tried to transform the information of current web that can be manipulated automatically. In this approach, computer agents use the web ontology to find various web services and automate business-to-business processes, see (Hendler 2001). In this framework, McIlraith shows that computer agents perform automatic service discovery, execution, and composition to support automated web services (McIlraith 2001). Since a construction supply chain is complex and consists of sequential flows of activities and information as discussed earlier, we envision that dynamically and automatically composed web services can provide flexibility as well as visibility to construction supply chain management with minimum coding efforts.

The proposed research proceeded in three parallel tracks:

1. analysis of the construction supply chain focusing on material procurement and its detailed business practices,
2. development of a conceptual model and a framework for the roles of Web service integration,
3. prototype development and evaluation in terms of information transparency in construction supply chain.
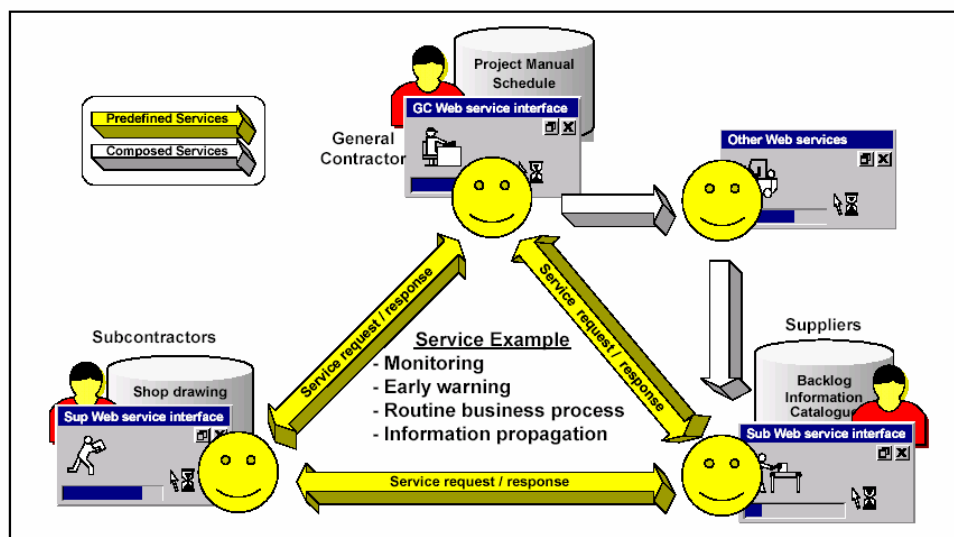

FIG. 5: Proposed framework (Min 2002)

In the Fig. 5, (Min 2002) illustrated a conceptual system structure of the proposed framework: each agent represents a supply chain member and communicates with other agents to request and provide services. Services can be performing routine business processes such as issuing purchase order and order confirmation, status monitoring, problem prognosis and early warning, problem propagation across the chain, and decision-support for problem solving. Each agent that holds information about corresponding business entities keeps monitoring its key performance data, such as inventory level, order status, delivery status, actual production status, etc.

Agents compare gathered information with schedule data so that they can forecast future problems. When an agent detects a problem, it propagates this problem to other agents across the chain and composes a new service to support decision makers to resolve that situation.

5.5.2 Multi-agent systems

For Min, while management of the supply chain is not new, more enterprises are beginning to give it the importance it deserves (Min et al., 2001). In the manufacturing industry, there has been much interest in SCM, distributed manufacturing planning and scheduling, and inventory control using agent-based systems, see (Shen et al.). In the case of construction supply chains, where one has to deal with thousands of products, numerous requirements, and many types of interactions, an agent-based system is suitable since no single person can handle these overall tasks. (Nwana et al., 1998) expected that agents would strategically form and reform coalitions, creating dynamic business partnerships. Most importantly, agents will help increase sales through the better matching of end user's needs with products offerings, as well as reduce transaction costs through the automation of business processes. Owing to its autonomous communication and negotiation ability, a computer agents system is also suitable for Internet pooled procurement in a supply chain, see (Taylor et al., 1999).

However, due to the short-lived nature of construction projects, a different approach is required to accommodate integrating SCM and production scheduling control. In terms of contents of information, (Lee et al., 1998) suggested that inventory level, sales data, sales forecast, and production/delivery schedule should be shared among participating trades to reduce the bullwhip effect. In the presented model, actual construction progress and updated construction schedule are shared instead of sales data and sales forecast. A project agent gathers information about actual construction progresses and sends it to a supplier and a sub-supplier agent. Based on this information, they update and modify the production schedule to meet changes in site demand flexibly.

As we have seen in this section, many research actions have been done in the domain of supply chain communications. We presented here some of the research tracks, such as agent-based and ontology-based approaches, the concept of virtual supply chain, and the new trends towards the integration of web services. Some construction specific approaches were described at the end of the section.

As we can see, research activities in the domain of SC communications have brought and are still bringing numerous results. Some of them propose what could be called "local" improvements to the problem of communications in supply chains, but others contribute to providing an enlarged view of the supply chain. This is particularly important now, while the integration of web services, the use of grid technologies and the development of new web-based languages are radically modifying the scale, the size and the capabilities of communication systems.

The last section tries to make a kind of synthesis, through elements of discussion and further issues that can be expected about this communication-based approach of the supply chain management problems.

6. DISCUSSION, ISSUES

In this paper we have discussed an approach of supply chain, of the way of managing a supply chain as a communication system, that is with the point of view of the management of the information stored, and, or exchanged among the different actors of the chain.

This paper was structured into sections, starting from the presentation of some fundamental elements and definitions about supply chain, along with the objectives of supply chain management. In order to set up the parallelism between the two sectors studied here, this analysis was made both for manufacturing and construction. Whatever the sector, it is obvious that the schema of several actors (that could also be called nodes) exchanging messages (items of structured information) looks like a network, whence the presentation, in the last part of the section, of the concept of supply chain as a network of relationships among the different partners of the chain. Those items of structured information exchanged among the actors logically lead to the possibility of building up a structured communication system within the network. This system was analysed in the next section. The development of a communication system, to be reliable, needs a model-based approach of the problem. In the next part, we gave a description of some modelling approaches of the supply chain; among them, we focused our attention on simulation based methods. As soon as we speak in terms of communication among people, or computer based systems, mis-understandings and problems of whatever kind are unavoidable. The section ended with the identification of some communication problems within the supply chain.
Given the importance of the problems faced, the question is how to solve them, how to improve communication

within so many actors, all of them speaking different languages, with a different syntax and semantics, with different working habits and legal rules.

Supply chain re-engineering, discussed in the next section, can be seen as a good way of solving problems. First of all, the concept needs to be defined, since the term itself covers several interpretations. Then, since they are different ways of re-engineering SC processes, it is necessary to provide a working methodology.
During the re-engineering process, several models can be developed, some of them were presented in this paper, such as business process models, flow models, decision process models.

Research plays an important role in the domain of supply chain management: lots of improvements still remain to be done, supply chain communication is still the subject of many research activities, some of the current tracks were presented in the paper. Among them, we mentioned the agent-based approach, ontology-based approaches, the concept of virtual supply chain, and maybe one of the most recent, based on the integration of web services. Research is also very strong in the construction domain, and some research approaches specific to construction were also presented at the end of the section.

This paper highlighted the important role played by communications in supply chain management. It also showed the number, but also the diversity of the approaches to this problem.

Some comments can be made at that stage: first of all, all the methods described here only deal with a part of the problem, all of them only providing a partial solution to the problem within the supply chain considered as a whole.

As a consequence of this, methods are often redundant, with sometimes important overlapping, but with also gaps. Sometimes also, they may be not compatible in between them, particularly in terms of integration and interoperability of the corresponding software tools! They can also lead to inconsistent results, notably when the behavior of the agents is not enough defined, or defined with not precise (or wrong) information.

What are now the next issues?

According to Kumar et al., design of a supply chain involves four design decisions (Kumar et al., 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, for (Moshowitz 1997). For the same author, 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, for Lee et al. and Tan et al., coordination in the supply chain is based upon the flow of coordinating information (Lee et al., 1997-2), (Tan et al., 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.

The design of a particular instance of the supply chain, *its surface structure*, is the consequence of deliberate or unconscious choices with regard to each of these four design decisions. The above discussion points out that the surface structure of the conventional supply chain can produce inefficiencies, unresponsiveness, and delays that need to be eliminated or reduced through a radical redesign of the chain. This redesign should include a rethinking of the supply chain governance, a choice of the supply chain actors, redesign of the supply chain structure, and redesign of information communication and coordination structures.
The widespread availability of highly flexible and inexpensive information and communication technologies (ICT) such as the Internet, intranets and extranets, intelligent-agents, global positioning systems, open-EDI standards, electronic markets, e-procurement, and broadband width are creating new possibilities for radical redesign of the supply chain.

Information systems development literature suggests that viewing the systems as abstract (or "logical") entities as opposed to concrete (or "physical") systems frees the designer from perceived constraints on their creative design processes that may arise due to the current physical structure of the system, see (DeMarco 1978), (McMenamin et al., 1984). The surface structure of the supply chain is a physical version of the supply chain. It embodies an implementation instantiation of the chain consisting of a preselected governance structure, a defined, usually fixed choice of actors, a relatively rigid predefined structure, and a defined set of coordination and communication structures. This physical structure may suffer design anomalies that need to be examined and redesigned in order to recreate supply chain designs that meet the customer's cost and value expectations. Consequently, we need "logicalisation" processes that help view the supply chain and its management at an abstract level unconstrained by existing physical implementation details, thereby creating a greater level of flexibility in redesign of supply chains. These logicalisation processes are built upon two concepts of separation: the separation of "abstract requirements for work" from "concrete satisficers" of the work requirements, for (Moshowitz 1997) and the concept of separation of "information flows" from "physical flows", for (Klobas 1998), (Sheombar 1992).

Both Klobas and Sheombar observe that modern information and communication technologies make it possible to detach information flows from physical flows. This makes it possible for information about a physical flow to arrive before the physical flow itself. This not only makes it possible to anticipate and prepare for the arrival of a physical shipment, it also makes it possible to process the information electronically, in parallel with the transportation of goods. While the former increases the coordination between physical processes, thereby reducing coordination costs and waiting time, the latter reduces the overall cycle-time for the supply chain and increases service quality by reducing information processing delays and information processing errors. For example, the literature on EDI recognizes that electronic messages arriving ahead of the physical shipment can be processed in parallel with the transportation time.

Furthermore, now that information flows are not physically attached to the physical goods (and therefore are not required to travel on the carrier of these goods), they can take different paths than the flow of physical goods. This reduces the constraints on information flow-paths, thereby increasing the variety of options available for communication and coordination structures. Taken together, the two principles of separation suggest a three-layer model for modeling a supply chain as shown by (Kumar et al., 1999) in Fig. 6 below.
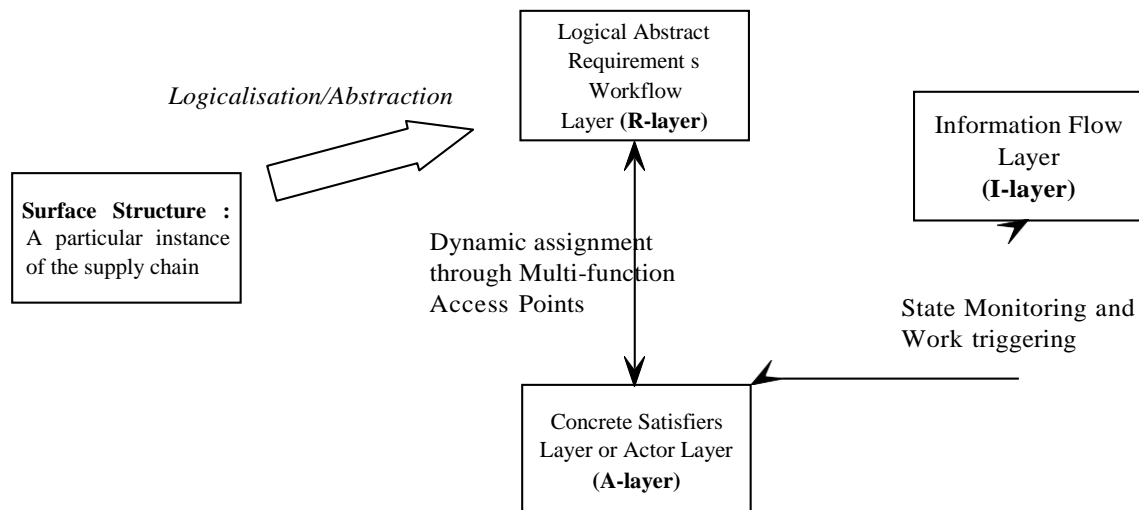
FIG. 6: Logical three-layer meta-model of a supply chain (Kumar et al., 1999)

In the three-layer model, a physical instance of a supply chain is first described in terms of its logical requirements. Logicalisation is a process of abstraction in which each activity or step in the chain is described in terms of what needs to be done rather than in terms of the actor or the department performing that activity. The logicalisation process includes removing historical, procedural, tool-related, political, and organisational details to arrive at an essential requirement model of the chain, see (Demarco 1978). This logical requirements model (the requirements layer or the R-layer) becomes the basis of a logical redesign of the physical part of the chain. At this level, the chain can be examined for natural sequences of workflow, possibility of parallelisation and/or combination of work-steps, and elimination of redundant steps leading to a radical reengineering of the entire supply chain structure, see (Hammer 1990), (Davenport 1993). The last design variable is the design of communication and coordination structures. The separation of physical flows from information flows makes it possible to design communication and coordination structures that are independent of the physical paths and the timing of the physical flows. The greater range and reach of information and communication technologies makes it possible to deliver monitoring and triggering information from any node of the chain to any other node of the chain, irrespective of the physical chain structure. This reduces arbitrary constraints on the design of communication and coordination structures, thereby leaving the designer with the freedom to design the most appropriate coordination and control mechanisms.

Supply chain communication management is a very complex problem, the analysis of the communication process was one of the objective of the X-SLANG project. The main purpose of the project was to explore the communication processes that occur within the supply chain and understand the related information structure and the process connectivity by considering an example of a business transaction, coming from a business scenario developed for the project. The example considered here is: the purchase order transaction initiated and executed by the Construction company of the supply chain. In our case, the term communication process means the flow of information from the sender to the receiver in order to enable the receiver to execute an activity. The objective of the project was to analyse to what extent it is possible to develop a supply chain communication language, based on the analysis of the main concepts of the exchange processes, and on the requirements of the PSL language. Given the results of the project, it appears that the approach followed within the framework of the X-SLANG project by (Das et al., 2004), (Cutting-Decelle et al., 2004), in terms of the development of a communication language for supply chain management can be considered as an important "glue" to link together the different methods described in this document.

The objective of this paper is not to present the results of the project (see Das et al., 2004 and Cutting-Decelle et al., 2006 for a more detailed presentation of the results of the project), but to propose a review of different approaches to supply chain communications in manufacturing and construction, since the identification of those approaches was one of the first – and fundamental – stages of the work done within the framework of the project. Given the number and the diversity of those approaches, it appeared important to review them and to propose an analysis framework.

7. ACKNOWLEDGEMENTS

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