3
Integration in Supply Chain Management

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3.1
Introduction

An introductory chapter (Section Three, Chapter 7) on the supply chain (SC) network has already presented the elementary principles and systematic methods of supply chain modeling and optimization. Here, the need for and integrated management of the SC is further emphasized and challenging solutions are presented. As seen, supply chain management (SCM) comprises the entire range of activities related to the exchange of information and materials between costumers and suppliers involved in the execution of product and/or service orders in an extremely dynamic environment (Fig. 3.1).

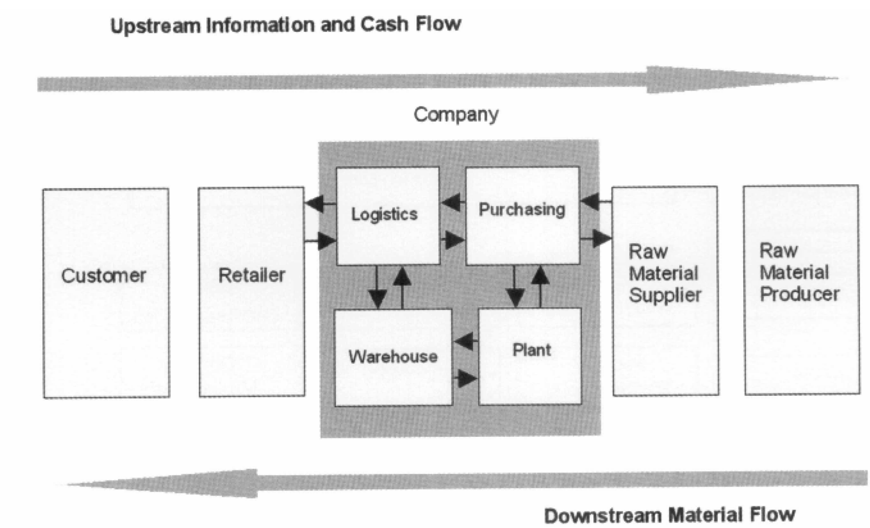

Figure 3.1 Flow of supply chain management information and materials

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A successful management of the supply chain management requires direct visibility of the global results of a planning decision in order to include this global perspective. This requires significant integration across multiple dimensions of the planning problem for nonconventional manufacturing networks and multisite facilities over their entire supply chain [1]. Objectives such as resources management, minimum environmental impact, financial issues, robust operation and high responsiveness to continuous needs must be simultaneously considered along with a number of operating and design constraints [2, 3].

Almost all the currently available SCM software suffers from several of the following demerits: product availability focus; reactive rather than proactive; long lead times; uncertainty treatment throughout; lack of flexibility in systems; performance measured functionally; poorly defined management process; no real partnership; insufficient performance measurement [4]. To overcome the above deficiencies and respond better to industrial demands facing a more dynamic environment (greater uncertainty of demand, shorter product life cycle, financial and environmental issues, fewer warehouses, new cost/service balance, globalization, channel integration and so on), there is a need to explore new strategies for supply chain management.

Moreover, an integrated solution is required for the next generation of SCM given the number and complex interactions present among supply chain main components in the global supply chain (Fig. 3.2).

This new scenario requires departing from current approaches that consider Supply chain optimization in a static way. Production-distribution-inventory systems that are now being used in manufacturing companies are static information systems. Periodically (typically weekly or monthly), all data (demand forecasts, available machine capacity, current inventory levels, desired inventory levels, etc.) are collected and fed into a huge optimization system (typically some type of linear programming system). After hours of computation a company-wide plan is obtained: this plan rep-

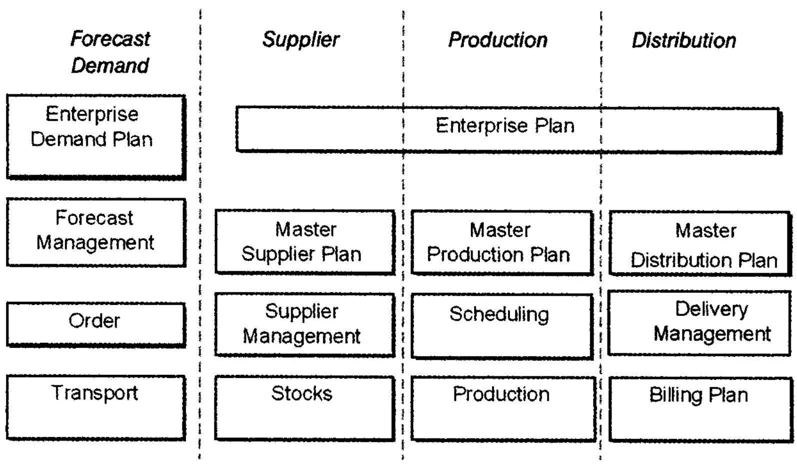

Figure 3.2 Current supply chain planning components

resents next week's (or month's) production schedule, the inventory levels at the various facilities and the distribution of the final goods. However, due to demand fluctuations or other unpredictable situations, the plan does not exactly meet the company's best course of action in length of changing conditions and data. So, production and plant managers adjust the plan to the best of their ability, given the frequent lack of data and their inability to compute the "best" course of action. Real-time adjustments in view of changing data are made manually and *ad hoc*. This situation is largely recognized and manifested in recent specialized forums of debate [5].

Therefore, new SCM solutions should be provided with the following main characteristics: interoperability, scalability, with open and flexible infrastructure; Web-oriented interface; autonomous, capable of self-organization and reconfiguration, coordination and negotiation, with optimization and learning mechanisms, so to evolve and adapt to the dynamic market environment; adaptive process modeling, rapid prototyping; involving production planning and scheduling; capable of making forecasts accurately and to incorporate e-commerce and w-commerce.

In this section, an open, modular-integrated solution is discussed that implements real-time supply chain optimization. The technology involved uses a network of cooperative and auto-associative software agents (smart agents) that constitute a decision support system for managing the whole supply chain in a real-time environment.

This chapter is organized as follows: First, a review of recent approaches to SCM integration is presented and the requirements for next generation of SCM integrated solution are identified. Then, a specific environment is presented that encompasses the SCM characteristics identified above. Finally, the integration of negotiation, environmental, forecasting and financial decisions is reported as an example of the new technology that may lead to better, fully integrated, easier to use and more comprehensive tools for SCM. A brief description of the architecture and functionalities of the solution implemented is also given.

3.2
Current State of Supply Chain Management Integration

Supply chain management (SCM) has been extensively studied in recent years. Lee and Billington [7] consider inventory handling as the central part of supply chain management integration. This work considers three areas of potential conflict:

- problems related to information and management of the SC;
- operational related problems;
- strategic and design problems.

Geoffrion and Powers [8] studied design aspects of the distribution network focusing on the storage location problem. The integration of production and distribution in the SC is examined in the work of Erengunc et al. [9]. The authors point out the necessary tradeoff between flexibility and quality on the one hand and product cost on the other in the SCM.

As the level of integration in supply chain management increases, the complexity of the resulting model limits some approaches to contemplate small academic examples. Some representative methodologies to represent the supply chain are summarized.

3.2.1
Methods Based on Deterministic Analytical Models

Heuristics methods were used by Williams [10] for planning and distribution of supply chain networks. The objective is to find the optimum production plan that satisfies the demand at minimum cost. Different models are used and compared with dynamic programming. In a later work, Williams [11] developed a dynamic programming model to determine simultaneously production and distribution lot sizing for each echelon in the chain. Inventory and operation costs associated to each mode of the chain are minimized.

A deterministic model was used by Ischii [12] to obtain the inventory levels and dead times associated to the solution of an integrated supply chain considering finite horizon and linear demand.

Cohen and Lee [13] presented a mathematical programming formulation (mixed-integer nonlinear programming) that minimizes net profit of manufacturing and distribution centers under management constraints (production resources) and logistics constraints (flexibility, availability and demand limitations). This work was later extended [14] to minimize fixed and transport costs along the chain subject to supply, capacity, assignment, demand and raw material constraints.

A combination of mathematical programming and heuristic models is used by Newhart et al. [15] to minimize the number of products in inventory through the network. A second step investigates the minimum inventory required to absorb demand delays and fluctuations.

Arntzen et al. [16] develop a "global" model for the supply chain (GSCM) that implies a formulation of the type mixed-integer linear programming to determine: (1) the number and location of distribution centers, (2) client assignment to distribution centers, (3) number of echelons in the SC, and (4) product assignment to production plants. The objective is to minimize the weighted sum of total costs (production, inventory, transport and other fixed costs) and active days.

The efficiency and response capacity of the SC can be improved by increasing its flexibility [17]. Here, flexibility is measured as the sum of the instantaneous difference between capacity and utilization of two types of resources: inventory and capacity resources. Given the necessary resources for manufacturing each product and bill of materials (BOM) information, the transport plan and delivery of each product is obtained and optimum inventory levels are achieved.

Camm et al. [18] developed an integer mathematical programming (IP) model to determine the best location for distribution centers of Procter and Gamble and its proper assignment to clients grouped by zones. The model developed uses a simple transport model and the allocation problem does not consider capacity constrains.

More recently, the design of multiechelon supply chain networks under demand uncertainty has been modeled mathematically as a mixed-integer linear programming optimization problem [19]. The decisions to the determined include the number, location and capacity of warehouses and distribution centers to be set up, the transportation links that need to be established in the network and the flows and production rates of materials. The objective is the minimization of the total annualized cost of the network, taking into account both infrastructure and operating costs.

3.2.2
Methods Based on Stochastic Models

A detailed presentation of uncertainty sources present in the supply chain that affects its operation performance can be found in Davis [20]. In the same work a method is developed to treat the uncertainty associated to the supply chain of Hewlett-Packard. According to Davis [20], three different sources of uncertainty can be found in the SC: (1) suppliers, (2) production, and (3) clients. Chain suppliers are characterized by their performance and their response can be predicted. Uncertainty problems related to production can be solved by reliability analysis maintenance techniques. Finally, client demand uncertainty can be dealt with specialized forecasting methods.

Stochastic models incorporate uncertain aspects of the supply chain and focus on certain parameters relative to its operation. For instance, in the work of Cohen et al. [21] a model is developed to establish a materials supply policy for each echelon in the SC. Four submodels are developed based on different costs for the control of materials, production, finished products storage and distribution. There are two probability distributions which are determined by the SC interactions, namely the materials' demand in manufacturing plants and clients demand in distribution centers.

Svoronos and Zipkin [22] consider a multiechelon SC distribution and estimate the average inventory level and the number of unfilled orders for a given base level of inventory. With these approximations, the authors build an optimization model to determine the inventory base level that implies minimum cost.

A mathematical programming model for three echelons SC (one product, one factory, one distribution center and a retailer) is developed by Pyke and Cohen [23]. The model minimizes the total cost subject to a service level constraint. A later work by Pyke and Cohen [24] considers the same network but with multiple types of products.

Lee et al. [25] present a mathematical model that describes the "bullwhip" effect (variance distortion along SC upstream). Although it is often impossible to know exactly the probability distribution functions of products demand, it will always be possible to specify a set of demand scenarios with high probability of occurrence. Scenario-based planning permits the capture of uncertainly by defining a number of possible future scenarios [26]. Thus, the objective consists of finding solutions that behave satisfactorily under all scenarios. Mobasheri et al. [27] describe a number of scenarios as possible states from the actual state. The authors claim that this is avoided forecasting, which is less reliable. The same approach is used to formulate and solve operational problems, like environmental impact along the chain [28, 29].

The midterm supply chain planning under demand uncertainly is addressed in a recent work with the objective to safeguard against inventory depletion at the production sites and excessive shortage for the customer [30]. A chance constraint programming approach in conjunction with a two-stage stochastic programming methodology is utilized for capturing the tradeoff between customer demand satisfaction and production costs.

The design of multiproduct, multiechelon supply chain networks under demand uncertainty is considered by Tsiakis et al. [31]. Compared to previous models, the model integrates three distinct echelons of the supply chain within a single, mathematical-based formulation. Moreover, it takes into account the complexity introduced by the multiproduct nature of the production facilities, the economics of scale in transportation and the uncertainty inherent in the product demands.

In a recent work [32], an optimization model is developed for the supply chain of a petrochemical company operating under uncertain demand and economic conditions. The proposed two-stage stochastic model succeeds in determining the optimum production volumes that maximize the volumes of products shipped for each scenario. However, the need for further investigation to study the dynamics of the petrochemical supply is recognized.

A novel approach to increase the supply chain competitiveness has been presented very recently [33]. The proposed strategy helps to coordinate the production/distribution tasks of the orders embedded in a SC by integrating the plant production scheduling with the transport scheduling to final markets. Uncertainty in the demand is considered and the problem is formulated as a two-stage stochastic optimization approach. The mathematical model looks for the detailed global schedule (production and transports) that maximizes the expected benefits.

3.2.3
Methods Based on Economic Models

The current trend of advanced planning and scheduling tools (APS) is to incorporate tools to model and change the current position of the financial and process managers during complex interconnected decision making in chemical process industries. Cash management models were considered in the supply chain following basically two stochastic approaches. Baumol's model [34] had an inventory approach assuming certainty. Cash was treated similarly as holding inventory and payments were assumed at a constant rate. On the contrary, the Miller and Orr cash management model [35] was based on the fact that perfect forecasts of cash were virtually impossible because the tuning of inflows depend on payments to customers. In consequence, lower and upper bounds of cash were calculated to create a safety stock. In an attempt to model the client-provider behavior, Christy and Grout [36] develop a supply chain economic model based on games theory. The integration of budgeting models into scheduling and planning models is also considered in a recent work [37]. A cash flow and budgeting model is coupled with an advance scheduling and planning procedure within the decision-making process for increased revenues across the supply chain.

A further step in integrating levels of decision making in the SC is contemplated in the work of Badell et al. [38]. This work considers business decisions and their impact in the SCM. It addresses the implementation of financial cross functional links with the SC operation and investment activities at the factory level when scheduling and budgeting in short term planning in batch processing industries. The target is to obtain tradeoff solutions preserving at most the profit and liquidity while satisfying customers.

3.2.4
Methods Based on Simulation Models

The fast development of new products and the increasing competitiveness of market agents have turned the SC system into a rapidly changing environment. Therefore, it becomes necessary to capture and characterize the dynamic behavior of enterprise systems and develop systematic procedures for decision-making support under these circumstances.

Although the interest in integrated dynamic approaches for SCM is recent, some studies were clearly reported during the last four decades. Forrester [39] performs dynamic analysis and simulation of industrial systems by means of discrete dynamic mass balances and linear and nonlinear delays in the distribution channels and manufacturing sites. Although this work contemplated small academic examples, it permitted the identification of the aforementioned demand amplification problem. Later, Towhill [40] reported some effects to control SCs based on a transfer function analysis and classical feed-forward control.

A changing environment is contemplated in the work of Back et al. [41]. They propose a strategy to cater for the dynamics of the environment and the disturbances, as well as for the dynamics of operations of the business. The same approach is used in the work of Perea-López et al. [42], but taking a step forward by considering a consumer-driven operation. They analyze the impact of heuristic control laws on the performance of the SC integrated by multiproduct multistage distribution networks and manufacturing sites. A more recent model, model predictive control (MPC), applied to the supply chain problem was reported by Brown et al. [43]. A comparison between these two control strategies can be found in Mele et al. [44].

A different approach is presented in the work of Mele et al. [45]. Here, a dynamic approach for SCM based on the development of a discrete event-driven system model of the SC contemplating several entities is reported. The interaction between these entities is explored through simulation techniques. The results obtained provide information about the tradeoff found in real systems and give valuable insight into SC dynamics. Thus, the proposed framework becomes a useful tool for decision-making support in real scenarios.

Present analytic approaches to decision making have severe limitations when dealing with the amount of computations, probabilities and nonanalytic knowledge. Thus, there is an increasing interest in decision theory with artificial intelligence tools. It is used to address important tasks such as planning, diagnosis, learning, and serves as the basis for the new generation of "intelligent" software known as normative systems. An emerging area is the utilization of multiagent systems, since decision making is the central task of artificial agents [46].

This chapter focuses on a multiagent viewpoint for SCM and design. The proposed approach is to consider each possible configuration and action advice as an independent agent provided with autonomous, interactive, cooperative, adaptive and proactive capabilities. This approach permits new levels of integration and additional functionalities in SCM (environmental issues, human factors, financial decisions) as it will be unveiled in the next sections.

3.3
Agent-based Supply Chain Management Systems

Since SCM is essentially concerned with coherence among multiple, globally-distributed decision makers, a multiagent modeling framework based on explicit communication between constituent agents (such as manufacturers, suppliers retailers, and customers) seems very attractive. Agents can help to transform closed trading partner networks into open markets and extend such applications as production, distribution, and inventory management functions across the entire SC, spanning diverse organizations [46].

Agents are autonomous pieces of software that are designed to handle very specific tasks. In the case of SCs, where one has to deal with thousands of products, numerous requirements in production quality control, and many types of interactions, no single agent can be designed to handle this overall task; therefore, we will have to design multiple specialized agents to guide the SC in its entirety. Multiagent systems may be regarded as a group of agents, interacting with one another to collectively achieve their goals. By drawing on other agents' knowledge and capabilities, agents can overcome their own limits of intelligence. Otherwise, knowledge is distributed among several intelligent entities, the agents.

Autonomous agents and multiagents represent a new way to designing, analyzing and implementing complex software systems [47]. A multiagent system uses cooperative agents towards a common goal. The agent is informed about the environment and/or can act on it. The agent has control of its own actions and internal state in a very flexible way, interacting when appropriate with other agents. Therefore, a multiagent system can emulate the behavior of distributed systems – like real world distributed supply chains – at a logical level, thus providing a resource for control of the real physical distributed systems.

3.3.1
Multiagent System Architecture

A multiagent system (MASC) built on an open, distributed, flexible, collaborative, and self-organizing architecture has been recently proposed for SCM [48]. Retailers, warehouses, plants and raw material suppliers are modeled as a flexible network of cooperative agents, each performing one or more SC functions following a client-server paradigm in an object-oriented fashion.

An agent must use all its knowledge about the SC to determine the most convenient values of each attribute that must be negotiated. According to the resulting set of interests and capabilities of the network, the agent translates the value of each attribute into its value of satisfaction. Since it may be expected that not all attributes are equally important for the agent, each attribute has a different weight according to the agent's scale of priorities. The total satisfaction that an agent obtains from a set of attributes is calculated taking into account the satisfaction given by each attribute and their respective weights. This final function, the utility function, gives an abstract value of the offers and counter-offers generated by both supplier and customer. Since objects of negotiation may be interdependent, the tradeoff between each pair of attributes considered is defined in a compensation matrix. This matrix is the element that enables the negotiation of all attributes at the same time, making the whole process faster and more similar to a human negotiation.

The steps of the negotiation are: an agent receives a message of his opponent and evaluates how much this offer satisfies his expectations. From this initial vector of satisfaction, the agent generates an improved counter-offer using his compensation matrix. Then the agent can generate several counter-offers with the same utility using its weights. The opponent must do all the same steps after evaluating all the counter-offers and choosing the one with the highest applicable utility. The negotiation process finishes when an agent launches two consecutive offers that are nearly equal. Obviously, different negotiation policies can be considered and compared.

Two types of agents are to be distinguished: the physical agent and management agent (Table 3.1). The physical agent represents the system's physical entities (distribution center, warehouse, plant, etc.) and is capable of simulating the behavior and decision making of the corresponding entity, while information handling between entities is carried out by the management agents. A central agent, which is a management agent, is also responsible for the overall network management optimization.

Table 3.1 Classification of the different entities in the MASC

Entities		
Agents	**Modules**	**Users**
Physical Management	Forecasting Scheduling ...	

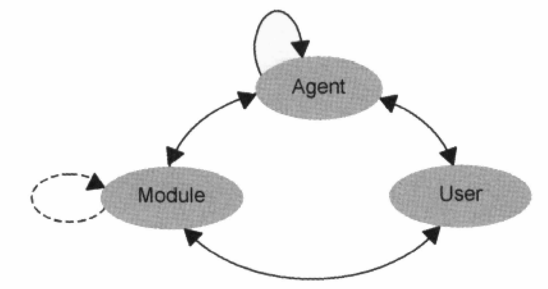

Figure 3.3 Communication types between entities

Module components (forecasting, scheduling, etc.) are information tools that act as servers to specific queries from other entity (agent, module, and user). These three types of entities define five types of communications as seen in Fig. 3.3 for illustration purposes.

The proposed MASC which contemplates a central agent (CA) as management agent offers a flexible architecture allowing representing real SCs with different policies of information control and decentralized decision making. The simplified structure of the MASC can be seen in Fig. 3.4.

The architecture proposed contemplates physical agents at each node of the supply chain network (client, warehouse, factory) while a central management agent communicates with all the other agents. Other management agents are also considered that may be subagents of these already enumerated. This flexible architecture should permit an easy adaptation to represent any real SC with its own level information sharing, from a centralized system to a wholly decentralized one. For instance, in a decentralized case every physical agent (manufacturer A and B, retailer) takes decisions on internal variables and negotiates with other physical agents within its own

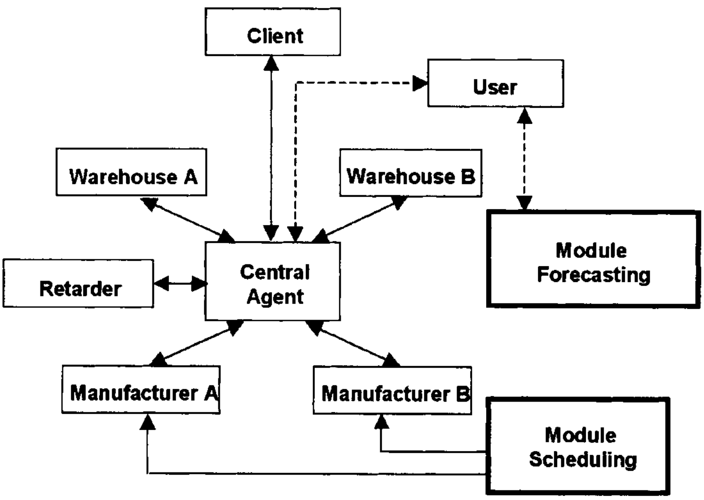

Figure 3.4 Basic multiagent system showing constituent entities (physical and management agents, modules and user)

SC. Here, the central agent plays the role of information handling without decision-making capacity. Otherwise, when a centralized control system is contemplated, the central agent is the only one to have the overall SC information and to make decisions, while every physical agent sends and receives information to and from him. In this case, the central agent is provided with improvement/optimization algorithms.

A fundamental aspect of this architecture is the traceableness required for a proper SC operation. Namely, all transactions carried out through the SC must be clearly registered to facilitate reproduction of the results obtained by simulation of a particular scenario.

The second important element of the framework is the agent modeling. A brief description of different physical and management agents contemplated is given below:

Physical Agents

As mentioned previously, physical agents represent the system's physical entities. Specifically, the following physical agents are considered:

- *Client agent.* The client agent initiates the system's information flow by placing an order to the central agent. Basically the information transmitted is related to the product type, the amount of it, the delivery date and acceptable price. The central agent receives this information and transmits it to potential suppliers (manufacturer/warehouse agents). Following their own internal logic, the potential supplier makes an offer to the central agent which is transmitted to the client. The client internal logic (amount of product, delivery, date and price) negotiates the selected supplier through the central agent. Final confirmation of the order by the supplier is received though the CA (Fig. 3.5).
- *Warehouse agent.* This agent models the material-handling of different kinds (raw materials, intermediates, final products) to be distributed through the SC. Clients of the warehouse may be manufacturers, other warehouses and product end-users. This agent mechanism has already been described (client agent), The internal logic for making an offer obeys to the following issues: (1) delivery date depending on distance, transport and preparation time; (2) available amount of

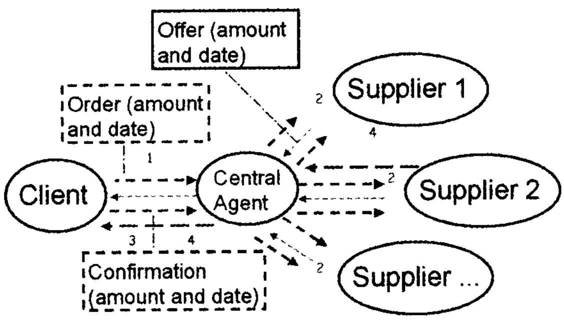

Figure 3.5 Client-system interaction

product that will depend on the stock and eventual delivery time, and (3) the product selling price which is dependent on production and storage cost plus warehouse expected profit. The warehouse behaves similarly to the client. However, complex inventory policies must be modeled that have to include demand uncertainty. Moreover, since the inventory control policy will influence the cost of downstream echelons in the SC, optimum negotiation at this point become very essential.

- *Manufacturer agent.* This agent models the actual manufacturing facility behavior in the SC producing intermediate and/or final products. It receives orders from clients/warehouses and makes an offer in terms of products amount, due date and price, which is calculated by using a production scheduling module. Manufacturers also operate like clients regarding raw materials supply. Planning tools are used to determine the amount of raw material needed. Production scheduling models will have into account the process type (continuous, batch, hybrid). Information provided by these models will be used at upper levels of manufacturing decision making (MRP, financial modules).

Management Agents

This type of agents does not represent a physical entity of the SC, but it rather simulates the SC operation in these aspects that are not necessary related to a physical entity of the SC. They could optimize the overall performance of the SC by modeling specific parameters associated to the other agents.

- *Central agent.* Coordination of the agent's network is achieved by means of the central agent. It essentially supervises and analyses the information flow between the other agents. As a result of information analysis, they may also have an active role by modifying adequate parameters looking for the optimum overall performance of the SC.
- *Other agents.* The architecture envisaged contemplates the existence of subagents operating within the agents already described. Namely, a manufacturer/warehouse agent contains coordinated subagents to simulate its real behavior. Typical examples of subagents are the sales/buy agents that simulate the corresponding department in a factory. These subagents negotiate transactions between physical agents (client, warehouse, manufacturer agents) and perceive their consequences. They follow the client-supplier logic described before. The architecture developed may consider the "multiowner" case where one SC competes with other SC. In that case, each SC has a partial view of the whole situation and therefore cannot manipulate variables belonging to a SC of a different "owner". Thus, negotiation between SCs is necessary; being the central agent of each SC the responsible for interchain negotiations mechanism to reach an agreement on multiple conditions (Fig. 3.6). Management agents are adaptive. Namely, they are able to learn from the operation of the SC. Otherwise, they must be provided with appropriate tools (modules) for internal optimization (vertical integration) and external optimum negotiation (horizontal integration).

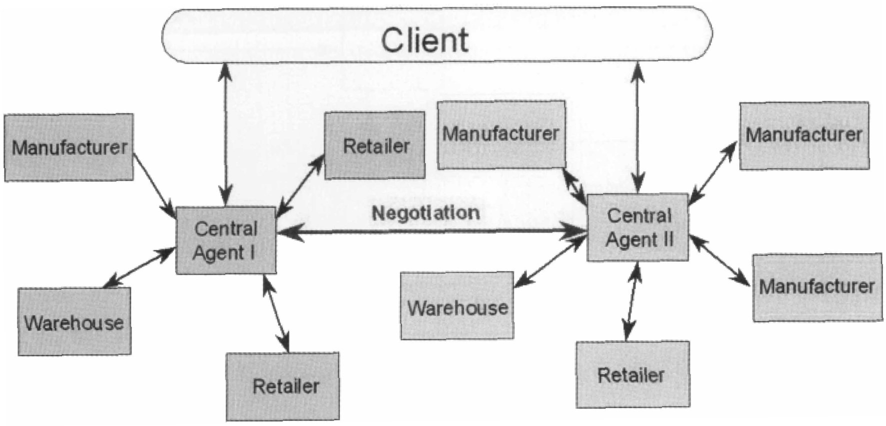

Figure 3.6 Interactions between two SCs through their central agents

Modules

Modules are not considered agents strictly speaking, but software tools needed to realize certain functionalities within the multiagent system. For instance, the warehouse physical agent model of inventory control may require demand forecasting tools to estimate the amount of future supply. Therefore, the warehouse agent will have to interact with the forecasting module to achieve proper inventory control.

Available modules are: forecasting, negotiation, planning and scheduling, financial, optimization (multiobjective), environmental and diagnosis. Other plug-in modules can be added in the future to contemplate further functionalities. The next sections focus on three of them (environmental, financial, negotiation) that provide a challenging insight into the level of integration achieved for the whole SC performance optimization.

3.4 Environmental Module

Environmental considerations in the SC are necessary because industrial products most often reach the client through a variety of steps that are subject to strict environmental regulations. Moreover, these requirements migrate upwards through the SC and create a need for flow of environmental information. An adequate methodology to systematize this information and provide a vehicle for environmental impact minimization is the life-cycle assessment (LCA).

The LCA approach has been adapted for the SC environmental assessment and improvement in this module [49]. The methodology used is summarized next.

Let us consider the elementary SC shown in Fig. 3.7. It contains all the basic constituents of a generic SC in a simplified way, but although simple permits the representation of a variety of scenarios. The assumptions made in this base case study will

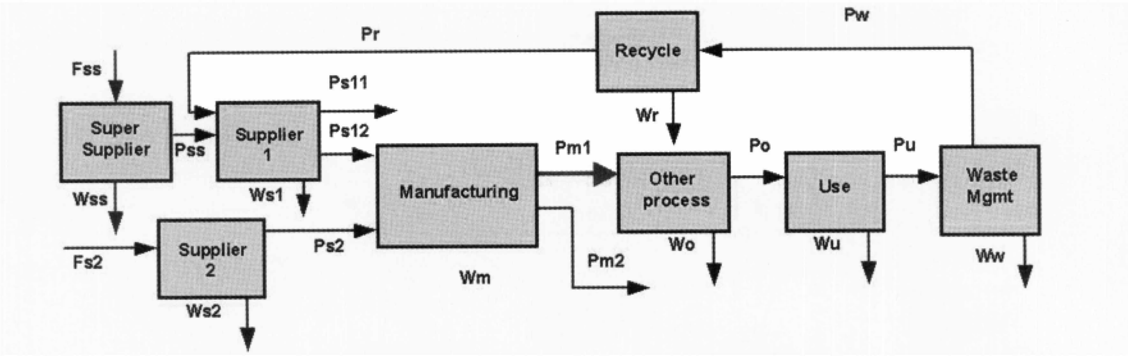

Figure 3.7 Elementary supply chain representation utilized in the environmental module base case study

give an insight into the characteristics of the model contained in the environmental module.

It should be observed that a high degree of aggregation is assumed in this SC representation so that energy and material streams are reduced to a minimum. This assumption implies that this SC representation is the result of a detailed modeling at the individual agent in the network, for instance, the manufacturer agent.

Now let us consider Pm1 as the selected product of interest for LCA evaluation. This product leaves the factory as seen in Fig. 3.7. Then, the purpose of this study is to obtain an eco-label for this product in terms of environmental burden emissions associated to it following the LCA methodology guidelines (goal and scope, inventory analysis, impact assessment, integration phases) applied to the SC system.

The first phase of LCA identifies the functional unit (product or process). This "functionality" can always be expressed as an equivalent product amount (in kg or MJ, according to the nature of the product) that will facilitate later calculations. The system boundaries are indicated in Fig. 3.7 (although in some cases it will be necessary to go deeper inside these boundaries to perform internal calculations to find environmental values for the global streams across the boundaries). Next, the inventory phase of manufacturing (the source block of product Pm1) takes place, where the input streams Ps12 and Ps2 data, the emissions represented by Wm and data related to the products Pm1 and Pm2 are tabulated. Additionally, inputs and emissions downstream the manufacturing agent (Wo, Wu and Ww) are also considered.

A key issue in inventory calculation is to establish the allocation policy for environment load associated to each product in each SC echelon. If causal relationship between inputs, outputs and emissions are known with certainty, inventory calculation can be easily done without need of an allocation procedure. Otherwise, the following general expression can be used for allocation at each SC echelon:

$$P_k \cdot v_k = f_k \left(-W \cdot v_w + \sum_s F_s \cdot v_s \right) - \sum_{p \neq k} f_{0p} \cdot P_p \cdot v_p \tag{1}$$

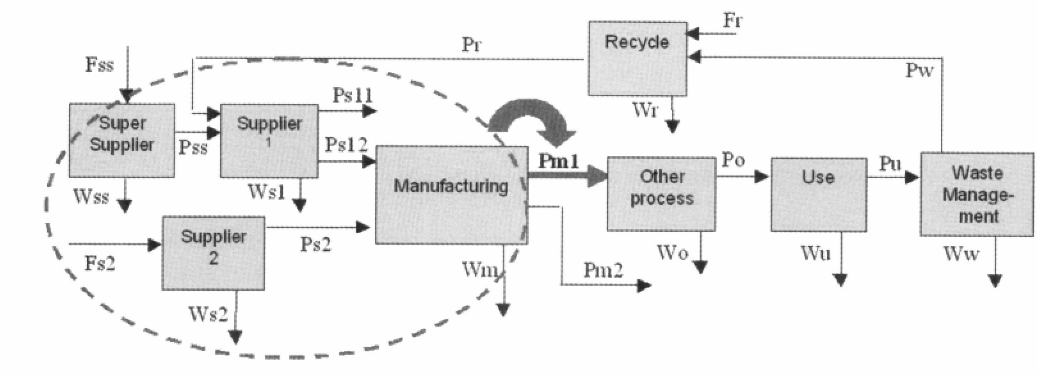

Figure 3.8 Forward allocation

where P_k represents the stream of product k and v_k is the corresponding eco-vector associated to product k. $W \cdot v_w$ is the waste stream weighted by its eco-vector, $F_s \cdot v_s$ is an input stream multiplied by its eco-vector and $P_p \cdot v_p$ is the corresponding output stream weighted by its eco-vector v_p. Finally, f_k and f_{0p} are allocation factors depending on the allocation policy (e.g., mass allocation, energy allocation).

Allocation to the chain left side of manufacturing (super supplier, supplier 1, supplier 2) is also analyzed in the same way as for the manufacturing case. This procedure is called forward allocation (Fig. 3.8) because environmental load is carried from left to right, that is in the same direction as the material flow in the SC.

Following the LCA philosophy, the environmental module also considers a backward allocation (Fig. 3.9) that is in the opposite direction to the SC material flow. For instance, the manufacturer is also responsible for the environmental impact generated by this product after manufacturing, that is, along other processes in which it participates, during its use, and finally, during the waste management and treatment of the generated residues.

Recycle processes and streams are treated by considering that the associated environmental load is included into the supplier LCA assessment. The model (Fig. 3.7) cuts the P_w stream, thus P_r and w_r now include the inputs and the emissions for the

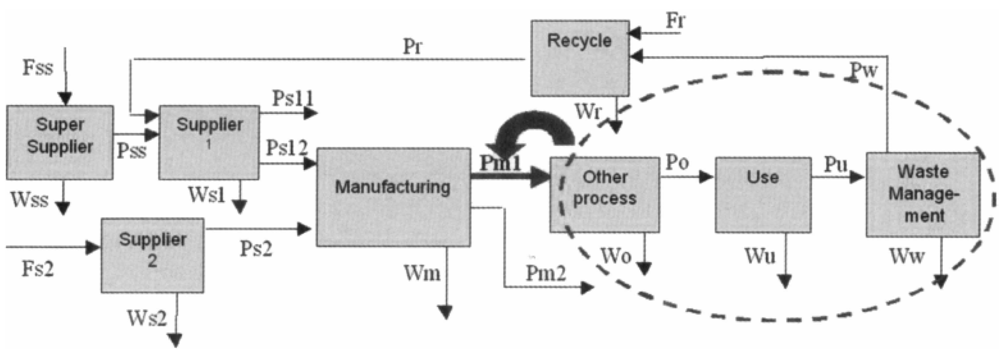

Figure 3.9 Backward allocation

recycling process plus the inputs and emissions for the supplier 1, respectively. The environmental load associated to stream P_w is considered to be zero.

3.4.1 Implementation Considerations

The user asks the system for an eco-label (ecological card). This eco-label can be expressed as a set of environmental loads as well as a set of environmental impacts. The system offers a table to enter data. These data belong to the following categories: inputs, emissions, products and functional unit, all referred to the main production process. This table would correspond to the manufacturing block in Fig. 3.7. Moreover, the system offers another table to introduce inputs and emissions associated to other processes such as those described as backward allocation.

According to the data entered, the system generates additional input data tables to be filled-up by the user with inputs, emissions, products and calculation basis for each new table. These new tables would correspond to the blocks on the left to the manufacturing block in Fig. 3.7.

Next, according to the kind of data entered in the tables, there are two types of calculation procedures. The tables whose inputs are all elementary flows must be calculated first. Otherwise, tables not having some elemental input have to be calculated afterwards. It is important to maintain the correct precedence in such a way that calculations follow the flow sheet from left to right.

Finally, a table that contains all the information entered to the system is built. With the final table, the life cycle assessment calculations are made using data saved in an impact category table and a coefficients impact table. The Unified Modeling Language (UML) representation [50] has been used to build the environmental module. The use case diagram shown in Fig. 3.10 summarizes the functionality of the module.

3.4.2 Industrial Testing

The environmental module has been tested in a real SC associated to automotive parts manufacturing. Specifically, the environmental impact associated to a certain component was evaluated and improvements were proposed to obtain the eco-labeling of the product.

Once selected the functional unit for the product chosen, the inventory analysis was carried out from the information collected on raw material consumption, emissions and product(s). In the impact assessment phase, with the inventory analysis results some impact indexes were calculated for the following categories:

- global warming
- stratospheric ozone depletion

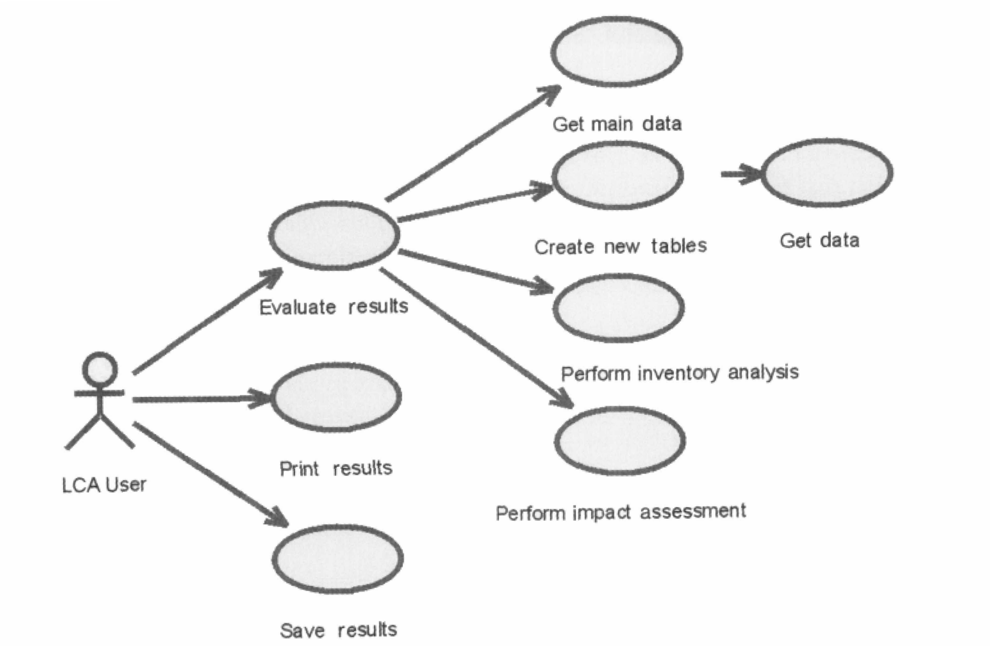

Figure 3.10 Use case diagram showing the functionality of the environmental module

- eco-toxicological impact
- photochemical oxidant formation
- acidification
- eutrophication.

Then allocation of environmental load was carried out satisfactorily backwards and forwards the supply chain. This permitted the maintenance of registers (eco-labeling) for each product. This register may give the manufacturer a substantial increase of penetration in the market. Moreover, the manufacturer can reduce the environmental impact of its products by selecting the "most ecological" supplier and/or modifying the process to reduce emissions. This could be done by incorporating other modules (planning, financial and optimization) in the final decision making.

3.5 Financial Module

The purpose of the financial module (FM) is to bridge the existing gap between supply chain financial decisions and production management by providing a common framework for integrated decision making that permits an optimum cash management thus avoiding "blind" financial/production disaggregated decision making occurring in industrial practice.

The methodologies currently used in production planning/scheduling try to optimize some performance measure without consideration of cash availability. Then, the output solution of the scheduling-planning model tries to fit the finances in an iterative trial and error procedure [51]. This procedure (called sequential procedure) usually incurs in substantial debt and has to pledge receivables (financial transaction of high cost to the manager). Moreover, the lack of synchronization between cash inflows and outflows results in cash balance fluctuations, which can be alleviated by considering the cash flows simultaneously with production decisions.

To achieve integration, the budgeting variables of liabilities and exogenous cash are calculated as a function of production planning and scheduling variables. Namely liabilities at a specific time period are a function of the cost of purchasing raw materials, the cost of materials processing and the cost of having to purchase part of the final product from another supplier or another plant. Exogenous cash flow incurred in every time period is due to the sale of products. The detailed formulation can be found in Refs. [51, 52].

In summary the proposed methodology contemplates:

- production expenses during the week consider an initial stock of raw materials and products,
- an initial working capital is considered,
- a short-tem financing source is represented by a constrained open line of credit,
- production liabilities incurred in every week period due to buy of raw materials,
- exogenous cash-flows due to sale of products,
- a portfolio of marketable securities is also considered.

3.5.1
Financial Module Interaction with the Multiagent System

The financial module constitutes the supporting tool for financial decisions within the multiagent system framework in a coordinated way with other decisions affecting the whole supply chain. This module permits coordination and integration of financial and operational decisions by exploiting the advantages offered by the multiagent system described previously.

The structure proposed for the integration of the financial module with MASC is shown in Fig. 3.11. The FM will be used by the SC central agent to identify the best opportunities for investment and financing the SC, as well as to evaluate the impact of operational decisions in the manufacturer's economy.

The real supply chain is modeled and represented by the multi agent system. The central agent interacts with the FM in order to maximize the net profit for a given budget provided by the budgeting model that uses the specific information given by the scheduling and planning model module for two sets of time periods. The first time period set corresponds to the scheduling and planning period, while the second set goes beyond the end of the planning horizon up to one year budgeting (see Fig. 3.12). It is important to note that the model incorporates a number of subjective constraints to allow for different profiles in financial risk management.

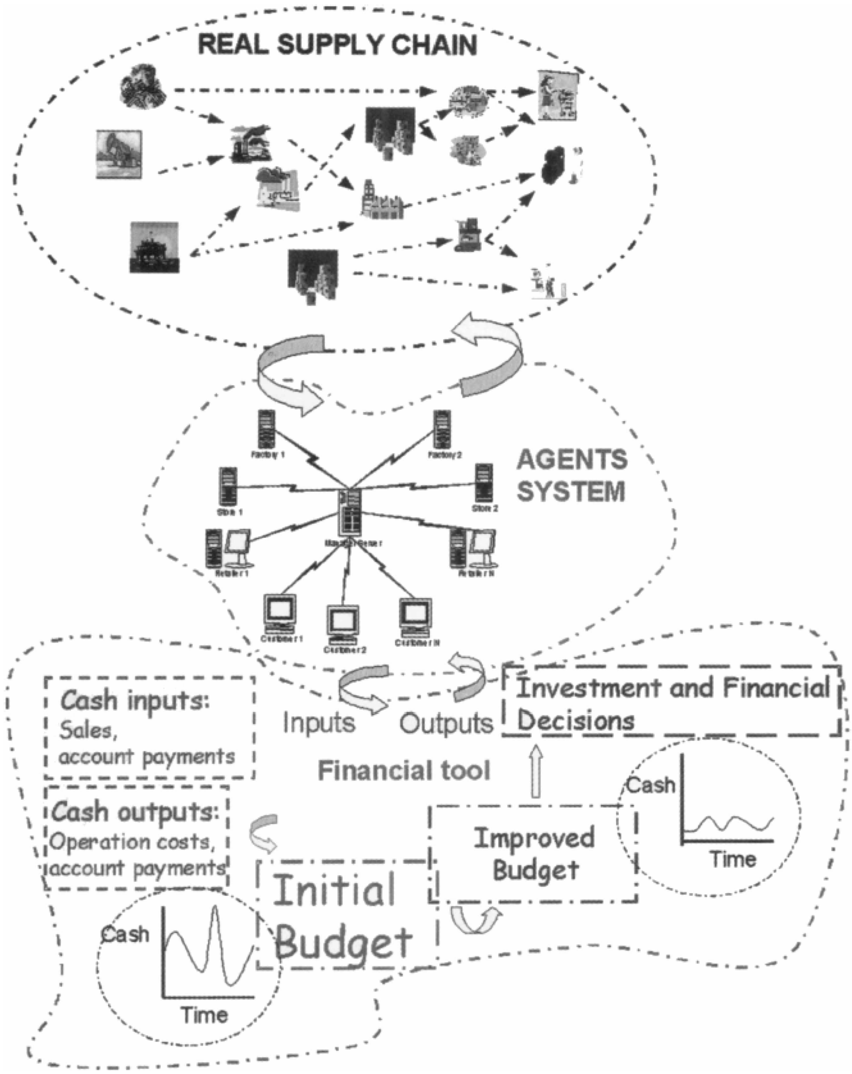

Figure 3.11 Integration of the financial module within the multiagent system

3.5.2
Testing Results in Industrial Scenarios

The benefits obtained by incorporating the financial module in the SC decision making have been assessed at different levels.

First, the use of an integrated model coordinating financial and operational decisions has been tested in a single manufacturer, specifically, a plant producing five different products and two different raw materials. Product switch-over basically

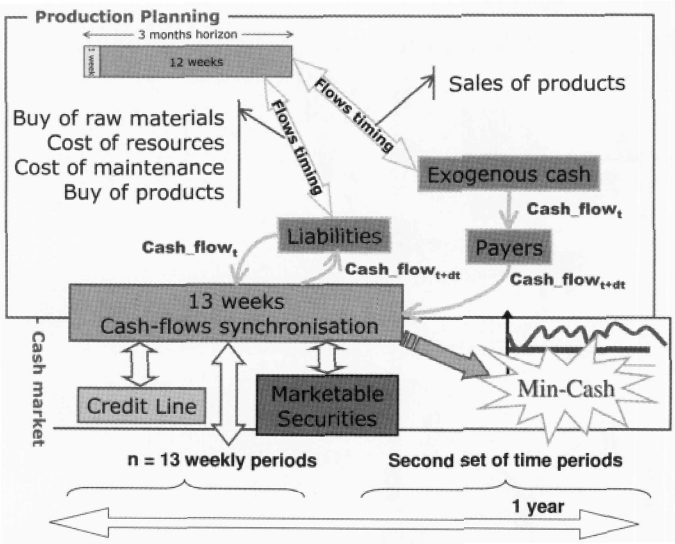

Figure 3.12 Budgeting horizons and its kink with operative planning model

depends on the nature of both substances involved in the precedent and following batch (precedence constraints). Cleaning times are constrained by the product sequence.

Comparative results obtained from the application of a sequential approach and those achieved with the FM are shown in Fig. 3.13. It can be seen that the integrated solution incurs less debt and avoids having to pledge receivables which means a 20 % savings for the firm.

The second case study deals with the SC of a large fruit cooperative made up of raw materials suppliers, manufacturing (fruit selection, clearing, and packaging), warehouses, distribution centers and clients. Here a deeper level of integration in the SC management was contemplated. Since this supply chain is driven by the raw materials arrival rather than by the customer demand, a main objective was to use the forecasting module (FOREST) to estimate the raw material arrival time thus reducing operational uncertainty. A second important objective was to integrate financial and production aspects linked to cash flow management across the supply chain. Both modules were used on-line through the Web, thus achieving high visibility (customer on-line information) and improved service (increased customer satisfaction). The net results were an increase of sales about 15 % and diminution of stocks about 20 % (saving of two million euro per campaign).

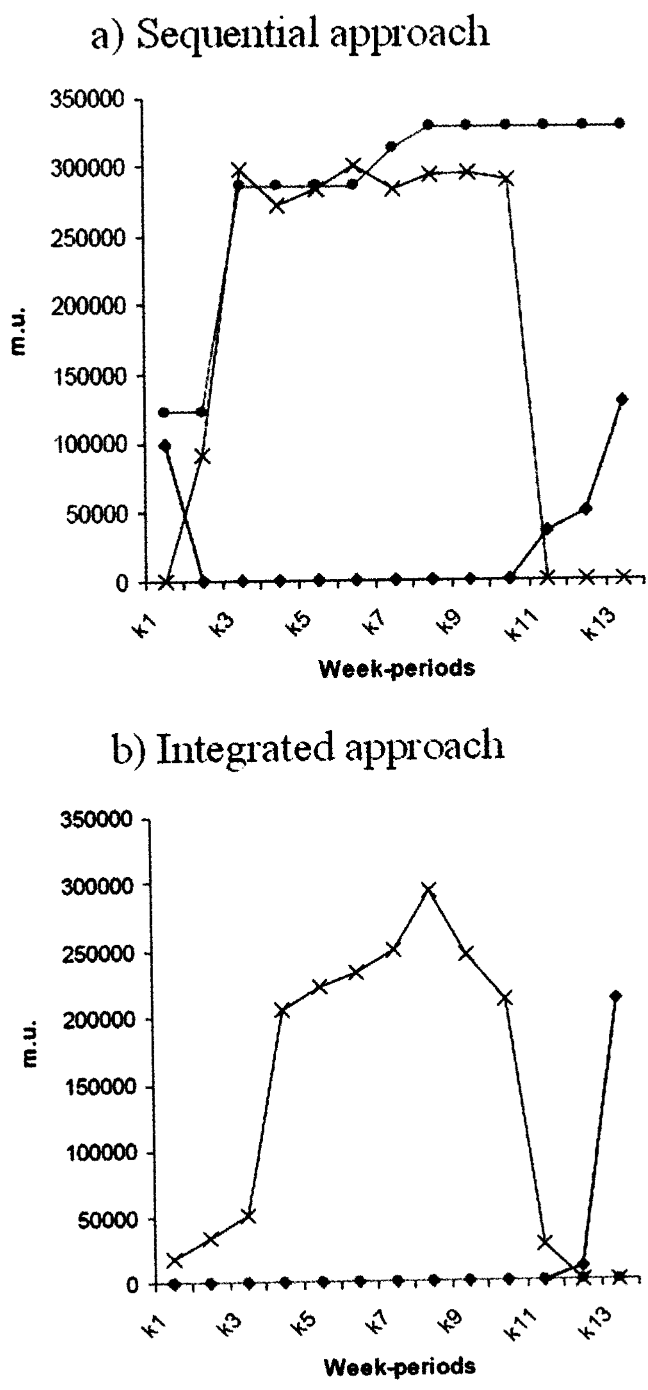

Figure 3.13 Comparative results between sequential and integrated approach: debt incurred, marketable securities and amount accumulated of pledged receivables at every week period (legend: —×— Marketable securities; —●— Debt; —◆— Receivables pledged)

3.5.3
Negotiation Module

When adopting an agent-oriented view of computation, it is readily apparent that most problems require or involve multiple agents as indicated before. Moreover, these agents will need to interact with one another, either to achieve their individual objectives or to manage the dependencies that follow from being situated in a common environment. These interactions can vary from simple information interchanges, to requests for particular actions to be performed and on to cooperation (working together to achieve a common objective) and coordination (arranging for related activities to be performed in a coherent manner). However, perhaps the most fundamental and powerful mechanism for managing interagent dependencies at run-time is negotiation – the process by which a group of agents come to a mutually acceptable agreement.

Automated negotiation among autonomous agents is needed when agents have conflicting objectives and desire to cooperate. This typically occurs when agents have competitive claims on scarce resources, not all of which can be simultaneously satisfied. These resources can be commodities, services, time, money, etc. Specifically, the main objective of the negotiation module developed is to enhance profitable partnerships in SCs. This goal is divided into the following steps:

- Identify the most profitable relationships and enhance them.
- Integrate supply contract negotiations into supply chain management.
- Evaluate different negotiation tactics according to the SC performance and partners behaviors.
- Develop learning techniques.

The proposed approach [53] takes into account the tradeoff between the quality of the offers made to customers, i.e., the level of satisfaction perceived by the client, and the expected profit to be achieved in the short term operation of the SC. Therefore, a two-stage stochastic formulation is derived that considers the uncertainty associated with reactions to future demand, in order to compute a set of Pareto optimal solutions to the proposed problem. Each of these solutions comprises an SC schedule and a set of values for the parameters of the offers. Through comparison of the Pareto curve and the solution that would be obtained without negotiation, a set of offers representing contracts that are desirable from the supplier's perspective is obtained. This set of values may be offered by the supplier in order to reach an agreement with the customer during the negotiation procedure. This approach facilitates a rational negotiation, in the sense that it enables the negotiator to simultaneously process much more data related to production and transport plans and customer preferences, thus avoiding having to rely exclusively on the negotiator's beliefs and interests.

3.5.4 Motivating Example

Inspired in a real industrial case, a relatively simple linear SC is considered to illustrate the performance and results of the negotiation module. It entails a batch plant which produces three different products. The manufacturer has a warehouse (W) at which the products are stored when they leave the plant. As the plant has a limited capacity and is imagined to be next to the factory, no transport is necessary. There is also a distribution center (DC) from which customers are served. Three occasional orders are met if the DC has some amount of the product requested in stock, provided that it is not planning to use that stock to satisfy contractual requirements. If an order has only been partially met, there is no penalization but that particular sale will not be able to be carried out at a later point, when the merchandise reaches the DC. Moreover, the possibility of signing a contract with a customer is considered.

The main objective of the proposed example is to observe how most of the activities executed by a SC can be integrated using the proposed negotiation model, rather than to study very complex structures involving many entities. The proposed approach provides a set of Pareto solutions to be used by the decision maker during the negotiation procedure (Fig. 3.14). There is a tradeoff between the expected profit and the quality of an offer sent to a customer, in this case the level of consumer satisfaction (CSat) attained by an offer, as well as the connection between customer relationship management (customer satisfaction) and production activities (schedules). For instance, for the stochastic Pareto solution the difference between the best-case and the worst-case values for CSat = 80 % is approximately 450 m.u. (20 %), while the deterministic solution, shows, this difference equal to 1140 m.u. (55 %). Therefore, the stochastic treatment of the negotiation problem minimizes the impact of the uncertain environment by both increasing the expected profit and reducing the variability of the solution compared with the deterministic solution, which makes it very attractive from the perspective of the decision maker.

Indeed more complex storage policies, plant flexibility, number of entities in the SC network and so on can be addressed using the same approach.

In addition, since future predictions related to market behavior cannot be perfectly forecasted, a number of the parameters in the associated scheduling problem, such as product demands and prices, were considered to be uncertain parameters. The two-stage stochastic formula developed has allowed this situation, commonly found in practice, to be handled properly, which thus reduces the impact of the uncertainty on what profit is achieved in short-term planning. The usefulness of signing contracts as a way of reducing uncertainty has also been shown by means of the aforementioned stochastic formulation.

The proposed strategy represents a method for facilitating rational negotiation, in the sense that it enables the negotiator to process a far greater amount of production, transport planning and customer preference data simultaneously and thus prevents beliefs and interests from being relied on exclusively.

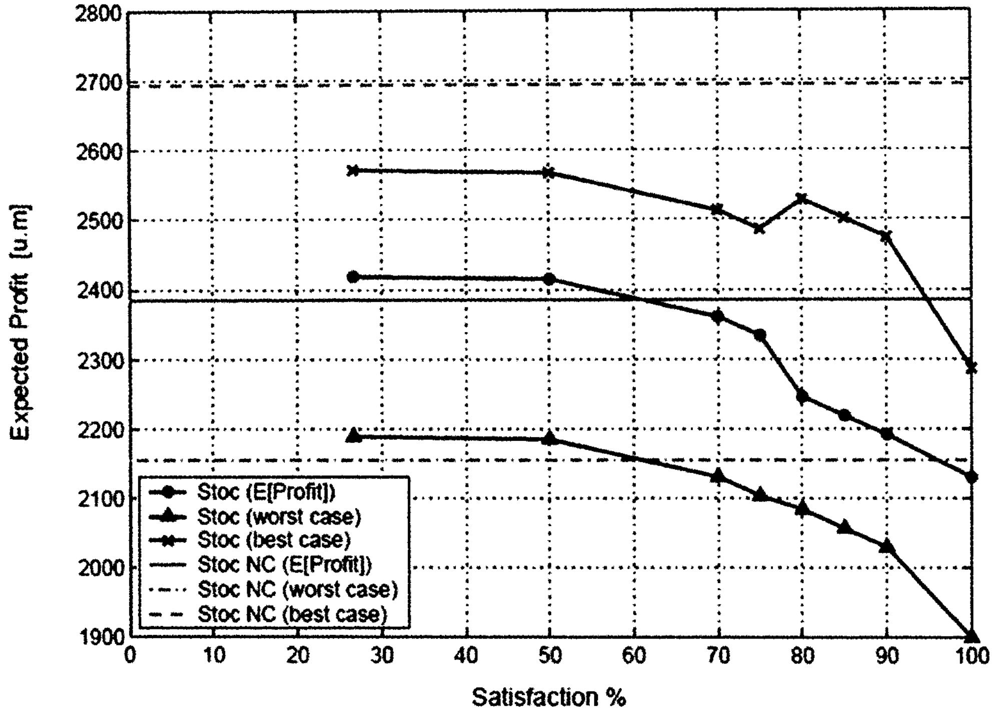

Figure 3.14 Stochastic Pareto curve

3.6 Multiagent Architecture Implementation and Demonstration

The multiagent system framework has been implemented as a Web service. Each agent receives and transmits relevant information for the optimization of the SC. All agents depend on a central agent that coordinates information handling and that may modify a particular agent's decision should it be necessary for the whole SC negotiation optimization. Web services (agents) are programmed in C# using the tools of Visual Studio.NET by Microsoft, while XML under the SOAP protocol is used for communication between them. Each agent may use distributed modules (forecasting, planning and scheduling, optimization, environmental, financial and diagnosis) to support his activities.

3.6.1 Manager Agent System

The manager agent system has a central agent that coordinates relevant information flow from/to the other agents in the network, and will eventually take decisions for the whole SC optimization. This way, the SC behavior can be accommodated to a full range of scenarios from a decentralized operation to a fully centralized management where the director (central) agent has the control on every individual SC activity. In general, the central agent will perform the following functionalities:

- decision support,
- real-time information on SC activities,
- SC performance optimization,
- simulation and performance indicators calculation,
- client/supplier selection,
- graphic representation (Pert, Gantt).

These and other functionalities (forecasting, environmental assessment, financial assessment, SC retrofit, etc.) will require the use of the appropriate module. Figure 3.15 shows the manager agent utility system.

Main performance indicators and expected ratio are indicated on Table 3.2. Obviously, the expected ratio will depend on the SC original situation and the type of SC. The table should be continuously updated once intermediate objectives are achieved.

A key component in the system architecture is the database that must be made available to each agent locally. For instance, the basic design of the database of the central agent is shown in Fig. 3.16 for the specific scenario contemplating retailers of four different items (computers, bakery, books, and furniture).

3.6.2 Graphic Interface

The graphic interface has a double objective. On the one hand a graphic user interface (GUI) is needed for the real client that requires interaction with the multiagent system (specific demand implementation, request of information). Otherwise, a graphic interface is needed for the SC manager. In this regard a client GUI is provided to perform the SC simulation.

The SC client makes the command through the Web application shown in Fig. 3.17, which enables him to communicate with the central agent who consequently

Table 3.2 Indicators range dashboard

Elementary indicator	Ratio expected (min. to max. %)
I1 Modeling time reduction	60–80 %
I2 Forecast accuracy	15–65 %
I3 Inventory reduction	20–85 %
I4 Means of production capacity utilization increase	5–60 %
I5 Cycle process time improvement	15–70 %
I6 Supply chain costs reduction	10–30 %
I7 Delivery performance improvement	15–45 %

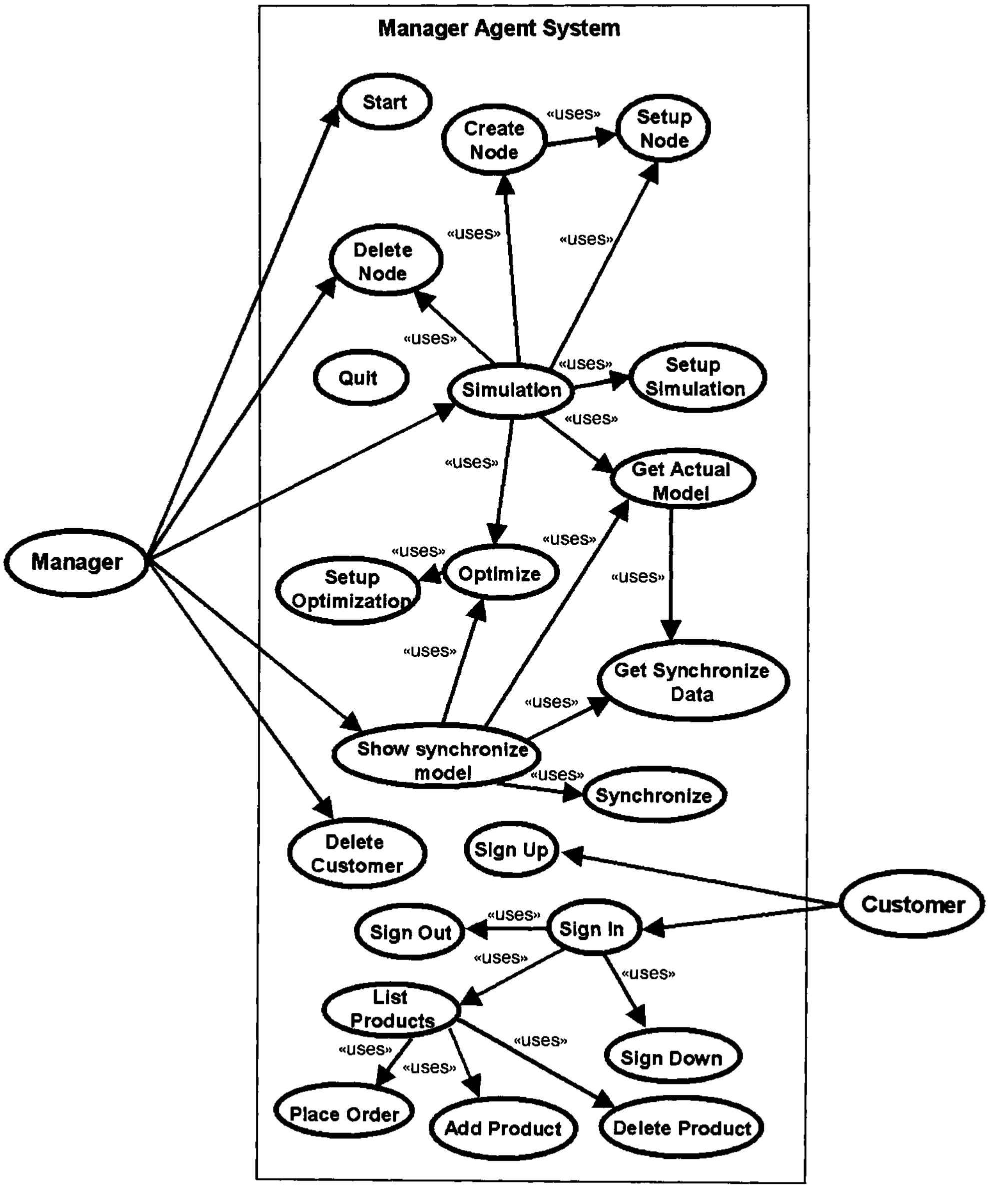

Figure 3.15 UML representation of the manager agent utility system

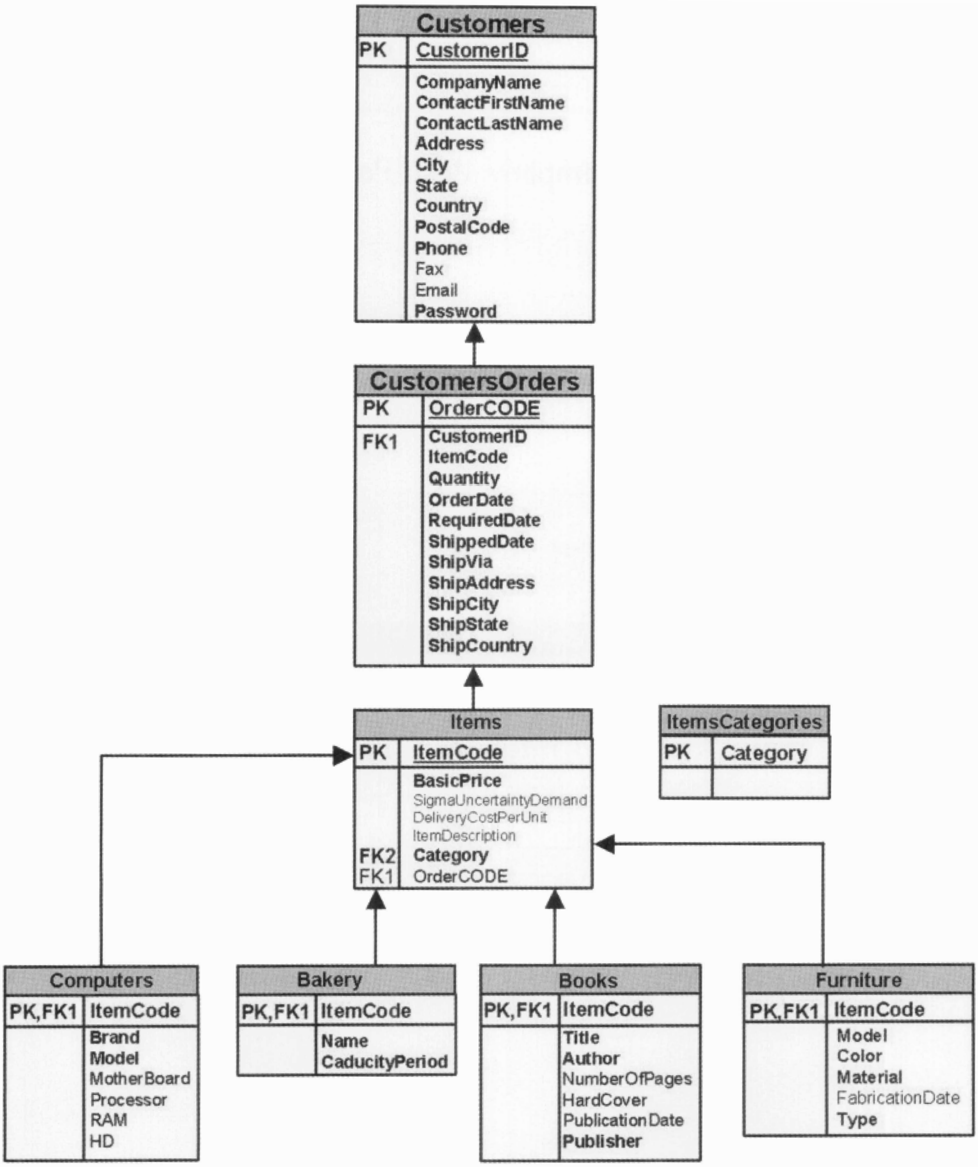

Figure 3.16 Basic design of the database of the central agent for the specific scenario contemplating retailers of four different items (computers, bakery, books, and furniture)

will update the database. Once the client signs up in the Web service and provides the information requested (Fig. 3.18) he has access to the services and information offered (Fig. 3.19).

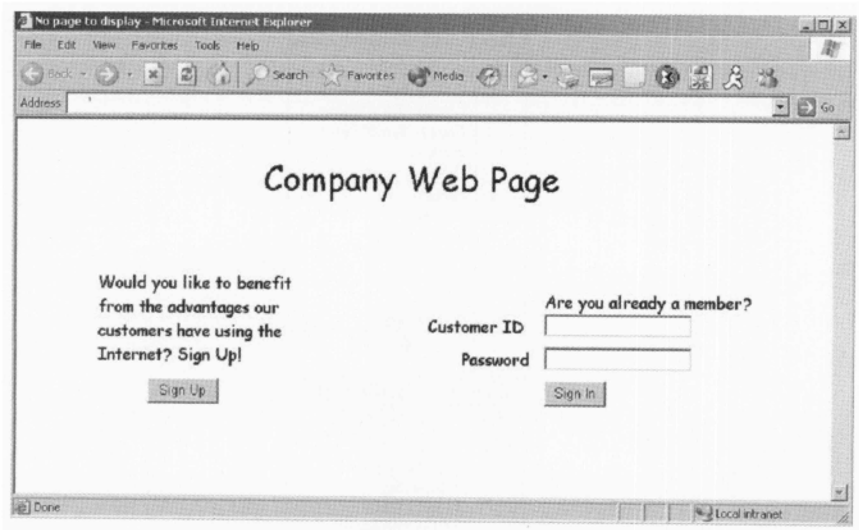

Figure 3.17 System access Web page

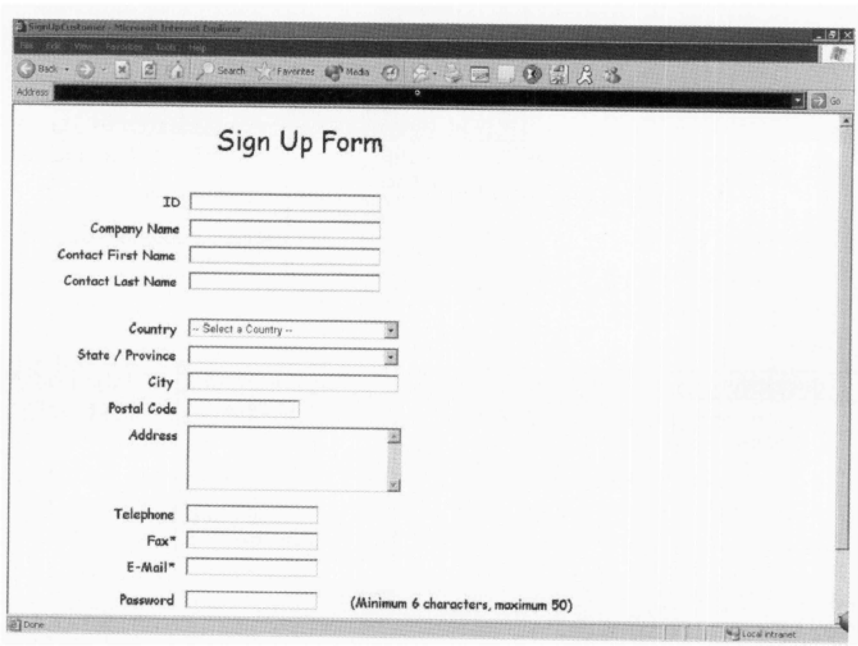

Figure 3.18 Client sign-up form

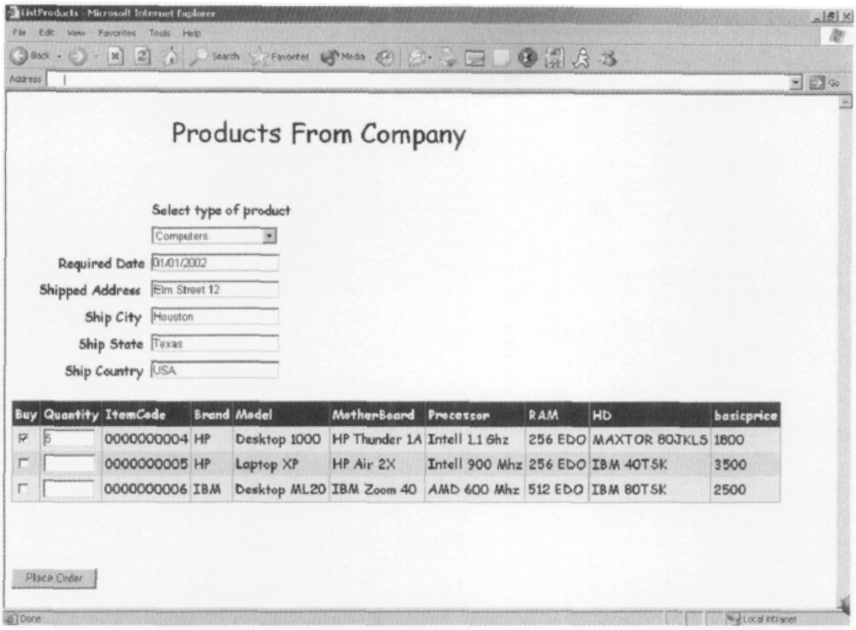

Figure 3.19 Example of information offered to the client

The client agent may be interested to know the real SC system behavior in front of new demand. In this case, a simulation of the real client is realized that analyzes alternative possible scenarios. Therefore, the client agent is provided with:

- *demand generator* supplied with different patterns (stochastic, probability distribution functions),
- *connectivity* with the central agent to receive/transmit messages,
- *graphic user interface.*

The interfaces created for the rest of the agents can be seen in the following figures. The central agent interface is shown in Fig. 3.20. It collects all information from the database (on products, transport, warehouses, factories, environmental impact, financial, etc.) and permits simulation (at the left panel) and optimization (at the right panel) of the SC: Multiobjective optimization is carried out using any of the solvers offered in the center panel. The forecasting module interface is shown in Figure 3.21 giving the demand forecast in terms of dates and amounts of specific products. The environmental module interface appears in Fig. 3.22. Here the left panel permits the input of raw materials needed for each specific product and the right panel has the commands to perform the life cycle analysis of the entire SC. Figure 3.23 shows the financial module interface. At the left initial assets, liability and equity can be introduced, which appear optimized at the right after optimization under the selected constraints at the center (minimum cash, debt, interest rate, etc). Finally, the negotiation agent interface can be observed in Fig. 3.24 for a certain product. It shows the evolution towards satisfaction for both, customer

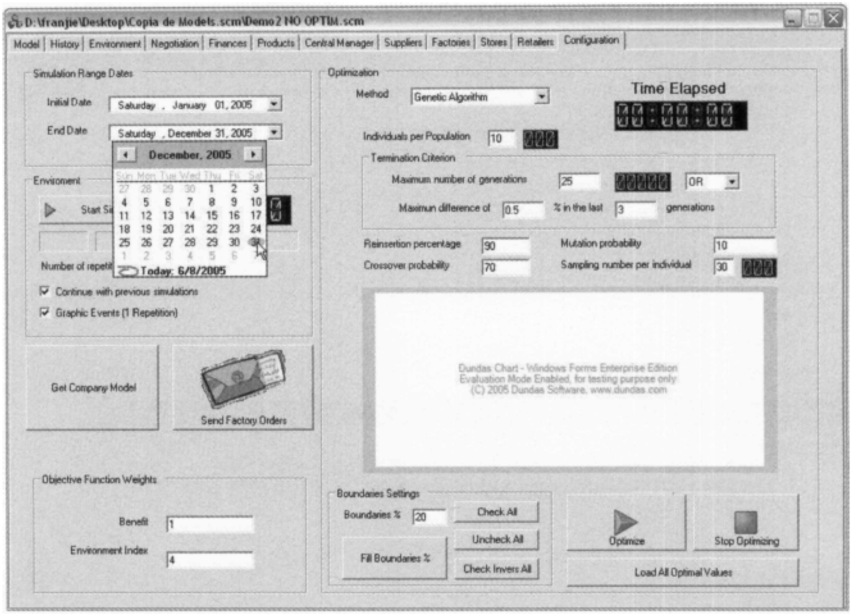

Figure 3.20 The Central Agent interface

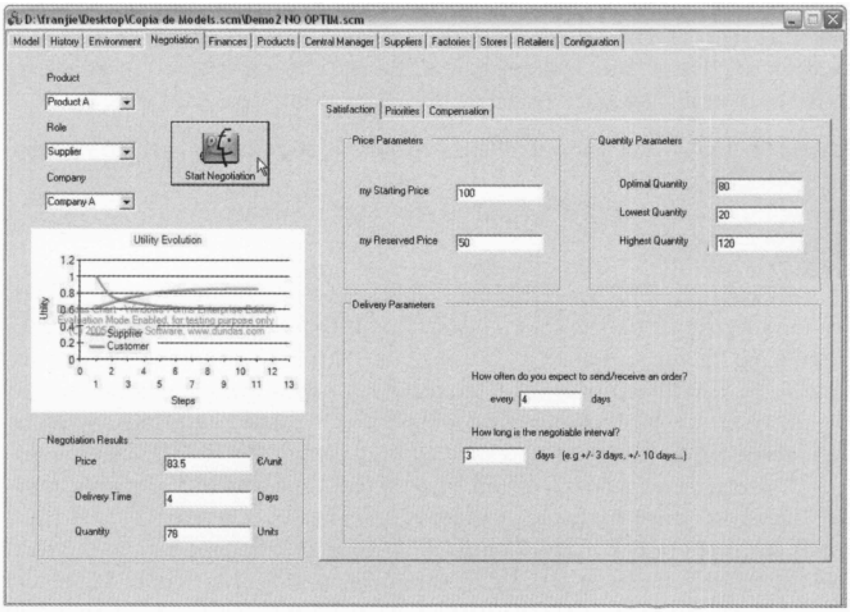

Figure 3.21 The forecasting module interface

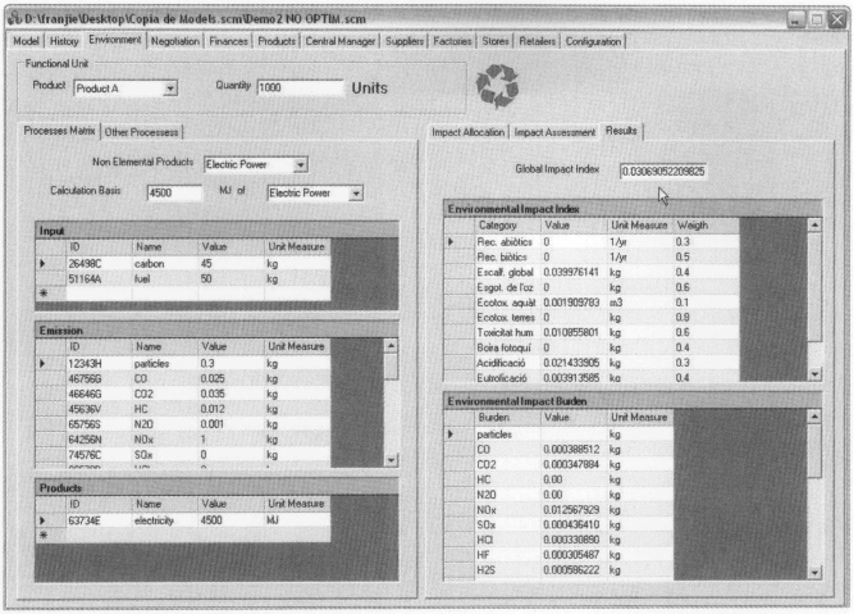

Figure 3.22 The environmental module interface

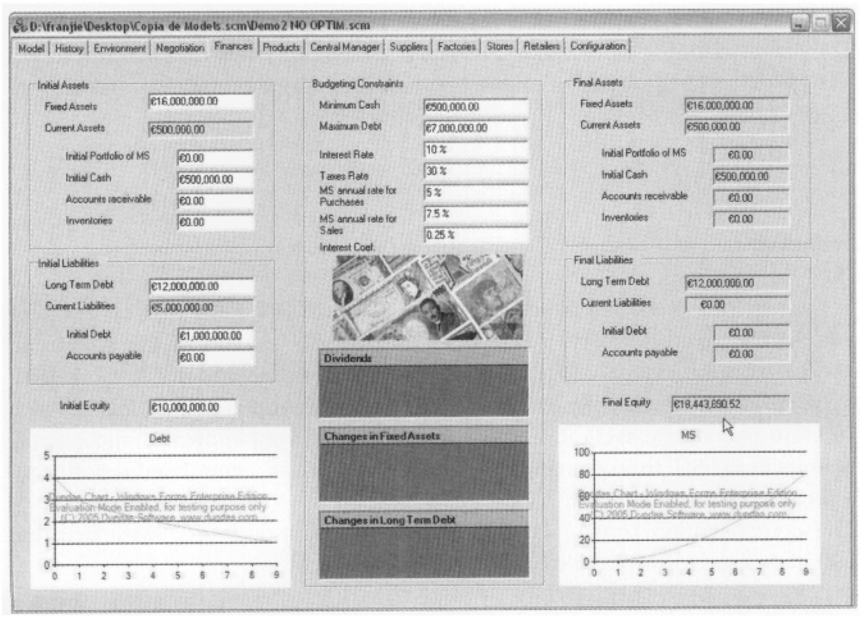

Figure 3.23 The financial module interface

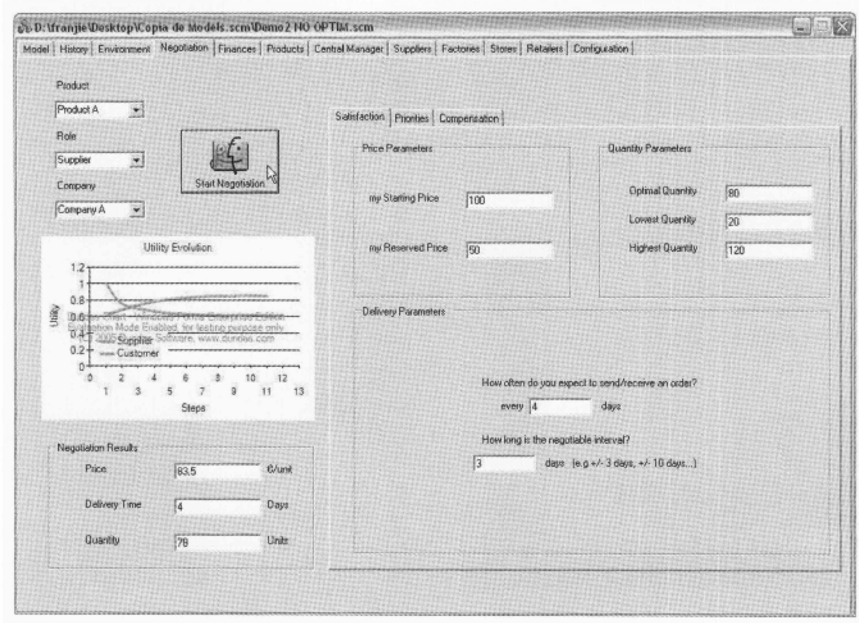

Figure 3.24 The negotiation agent interface

and supplier once the negotiation is initiated in terms of quantity, price and delivery time.

The planning and scheduling module is not shown, since it is fully described elsewhere [54, 55]. The same can be said regarding the real-time monitoring and diagnosis module [56].

3.6.3
Demonstration

The multiagent system described has been tested in industrial scenarios. Some of the scenarios have been partially presented in previous sections of this chapter to show relevant components of the SC system. A global on-line through the Web demonstration took place recently at the CHEM Users Committee held in Lille, France [57]. Here operational tactical and strategic activities were shown to successfully cooperate in the SC, from demand forecasting to diagnosis, control and retrofit considerations.

The demonstration contemplates the whole SC of a cosmetics manufacturing group of enterprises with the following characteristics:

- multiproduct manufacturing plants located in Europe (Oviedo, Tarragona in Spain and one in Italy), United States (California and Florida) and Mexico (Queretaro),
- warehouses for final products,
- distribution centers from which customers are served,
- transport system for distribution to retailers and clients.

The demonstration is initiated by forecasting from historical data the procurement needs of specific products at one of the warehouses in France. A robust demand is obtained using the forecasting module. Then, the following real-time sequence of decisions and activities is carried out by the multiagent system:

- The negotiation module is used to select and agree the most satisfactory provider (the factory situated in Tarragona) for the specific products and in the amounts, prices and due dates envisaged.
- The environmental impact is assessed for the complete life cycle of the products contemplated by means of the environmental module described before.
- Financial evaluation is carried out, taking into account budgeting, cash flow and additional considerations provided by the financial module.
- The central agent collects all the preceding information and requests additional manufacturing data from Tarragona plant. Simulation of the whole SC is then carried out checking for feasibility. Finally, multiobjective optimization (profit, cash flow, debt, environmental impact, due dates) is realized. Optimum values are transmitted over the Web to the plant in Tarragona for manufacturing.
- The production planning and scheduling module calculates the optimal production schedule for the forecasted demand, which is automatically performed in the plant.
- An incidence occurs during plant operation (the reactor heating system breaks down). The monitoring and diagnosis module detects and isolates the fault. An alarm is issued and diagnosed. As a consequence, a rescheduling procedure takes place to find an alternative production route which is implemented again in real-time.
- The operator repairs the reactor which comes back to operation. The monitoring system reacts sending a new plan, which coincides with the original since it was optimum, resuming the plant operation using the repaired reactor.

3.7 Concluding Remarks

The supply chain of a manufacturing enterprise is, nowadays, a world-wide network of suppliers, factories, warehouses, distribution centers and retailers through which raw materials are acquired, transformed and delivered to customers. In this sense, the whole supply chain can be considered as a dynamic virtual enterprise: by the adequate management of its supply chain, the manager can easily find adequate solutions to cope with the dynamics of its production scenario, which includes drastic and unexpected changes in materials or production resources availability, in the market conditions, or even in politics.

This chapter has presented recent advancement on integrated solutions for on-line supply chain management. Specifically, an environment is presented that encompasses the SCM characteristics identified in a preliminary review of the state of the art. It reported the integration of negotiation, environmental, forecasting and financial decisions in a reactive mode as an example of a new technology that may lead to better, fully integrated, easier to use and more comprehensive tool for SCM. A brief description of the architecture and functionalities of the solution implemented has also been presented.

Acknowledgements

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