AGENTS IN SUPPLY CHAIN MANAGEMENT: AN OVERVIEW

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1. Introduction

A supply chain is a network of suppliers, manufacturing plants, warehouses, and distribution channels that perform the functions of raw material procurement, transformation of these materials into finished products and the distribution of these products to customers. Supply-chain management is the strategic, tactical, and operational decision making that optimizes supply-chain performance. Tactical- and operational-level decision-making functions are distributed across the supply chain.

To optimize the performance, supply-chain functions must operate in a coordinated manner. But the dynamics of the enterprise and the market make this difficult and as a consequence the modifications of plans or schedules are done. The ability to manage the tactical and operational levels of the supply chain so that the timely expansion of information, accurate coordination of decisions, and management of actions among people and systems is achieved ultimately determines the efficient, coordinated achievement of enterprise goals.

In recent years, new software architecture for managing the supply chain at the tactical and operational levels has emerged. It views the supply chain as composed of a set of intelligent agents, where each agent is responsible for one or more activities in the supply chain and interacts with other agents in planning and executing their responsibilities. Agents are computational systems that inhibit some complex dynamic environment, sense and act autonomously in this environment, and by doing so realize the set of goals or tasks for which they are designed.

This overview was done to unify available information and researchers' works about agents and agents in supply chain into one paper for more profound research later on.

Section 2 reviews supply chain definition and basic positions. Section 3 presents agent's environment and architecture. Section 4 presents the use of agent-based system for supply chain management. Section 5 presents an example of the use of agents in supply chain proposed by Sardinha et al. [1].

2. Supply chain

A supply chain is a network of suppliers, manufacturing plants, warehouses, and distribution channels that perform the functions of raw material procurement, transformation of these materials into finished products and the distribution of these products to customers (Figure 1).

There are three participants in a supply chain, they are: suppliers, manufacturers, distributors:

- ✓ **Suppliers.** Suppliers are organizations that provide goods and/or services to a purchasing organization- manufacturer or distributor. They used to deal with vendors but may also refer to an internal company resource.

- ✓ **Manufacturers.** They are the companies engaged in the original production and assembly of products, equipment or services. They sometime refer to companies that purchase such products or services manufactured or assembled in accordance with company specifications.
- ✓ **Distributors.** Distributors are the external entities that sell for suppliers or manufacturers directly and often collect all payments from customers and maintain an inventory of the supplier's or manufacturer's products.

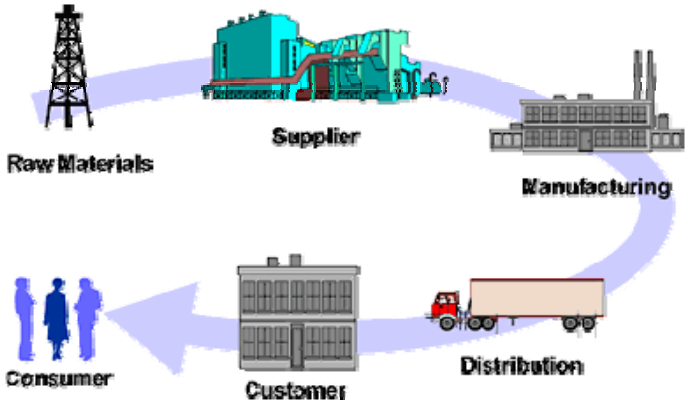

Figure 1. Supply chain

According to Simchi-Levi, supply chain management (SCM) is a discipline that focuses on the integration of suppliers, factories, warehouses, distribution centers, and retail outlets so that the items are produced and distributed to the right customers, at the right time, at the right place and at the right price. Importantly, this is done in a way that minimizes costs while satisfying a certain level of service. The focus is not on reducing inventory, but rather on minimizing system wide-cost. Supply chain management flows can be divided into three main flows:

- ✓ The product flow
- ✓ The information flow
- ✓ The finances flow

The product flow includes the movement of goods from a supplier to a customer mainly, and any customer returns or service needs as well. The information flow involves transmitting orders and updating the status of delivery. The financial flow consists of credit terms, payment schedules, and consignment and title ownership arrangements.

Supply-chain management is the strategic, tactical, and operational decision making that optimizes supply-chain performance. The strategic level defines the supply chain network- the selection of suppliers, production levels, manufacturing facilities, warehouses, and the like. The tactical level plans and schedules the supply chain to meet actual demand. The operational level executes plans. Tactical- and operational-level decision-making functions are distributed across the supply chain [2]. To optimize performance, supply-chain functions must operate in a coordinated manner.

The dynamics of the enterprise and the market instability make this difficult: the changes of rates and political situation, arrival of material not on time, the failure of production facilities, the illness of workers, the changes or cancellations of customer orders, and so forth, cause the deviations from the plan. In some cases, these events may be dealt with locally; that is, they lie within the scope of a single supply-chain function. In other cases, the problem cannot be “locally contained” and modifications across many functions of supply-

chain are required. Consequently, the supply-chain management system must coordinate the modification of plans or schedules across supply-chain functions. The ability to manage the tactical and operational levels of the supply chain so that the timely expansion of information, accurate coordination of decisions, and management of actions among people and systems is achieved ultimately determines the efficient, coordinated achievement of enterprise goals. [3]

3. Agents and their environment

Although the term "agent" is widely used, there is no single universally accepted definition of an agent. Some of definitions proposed by researchers are listed below.

Russel and Norvig proposed agent definition: "An agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through effectors". Maes proposed: "Autonomous agents are computational systems that inhibit some complex dynamic environment, sense and act autonomously in this environment, and by doing so realize the set of goals or tasks for which they are designed". Agent definition proposed by Wooldridge and Jennings: The term "agent" denotes a hardware or (more usually) software-based computer system that has the following characteristics:

1. Autonomy: agents operate without the direct intervention of humans or others, and has some kind of control over its actions and internal state;
2. Social ability: agents interact with other agents (and possibly humans) via some kind of agent-communication language;
3. Reactivity: agents perceive their environment, (which may be the physical world, a user, a collection of other agents in the Internet, or all of these combined), and respond in a timely fashion to changes that occur in it;
4. Pro-activeness: agents do not simply act in response to their environment, they are able to exhibit goal-directed behavior by taking the initiative. [4]

In order to exist and operate agents need an environment. It defines the properties of the world in which an agent will function. Agents perceive their environment and its effect on it through sensors. For example, a Stock agent can receive an event indicating that quantities of a particular part are low. The agent consequently decides whether more parts need to be ordered and, if so, put out a general call-for-proposal so that interested vendors can reply. When proposals arrive, the Stock agent will choose and notify the winning vendor. This model implies that agents interact via an environment. Even direct communications (such as vender notification) must occur through some medium. In other words, the environment provides the appropriate conditions that enable interaction among agents. [5] The agents' environment is typically complex, open and time-varying. Agents can be classified at least in these dimensions:

1) Quantitative (single, multi-agent);
2) Mobility (*static, mobile*) – the ability to move around the networks.
3) Responsiveness:
    a) *Deliberative agents* derive from the deliberative thinking paradigm: the agents possess an internal symbolic, reasoning model and they engage in planning and negotiation in order to achieve coordination with other agents.
    b) *Reactive agents* do not have any internal, symbolic models of their environment; instead they respond in a stimulus/response manner to the present state of the environment in which they are embedded.
4) Primary characteristics:
    a) *Autonomy* – agents can operate without human interference. A key element of their autonomy is their proactiveness, i.e., the ability to "take the initiative";

b) *Cooperation* – the ability to interact with other agents. The communication required to ensure cooperation generally involves high-level messages.
c) *Learning* – the ability to learn as they react and/or interact with the external environment. The learning may also take the form of increased performance over time.

5) Secondary attributes – these attributes provide a stronger definition of agenthood.

Some of them are: *versatility, benevolence, veracity, trustworthiness, temporal continuity, mentalistic and emotional qualities* etc. [6]

Four types of agents can be derived from the characteristics of primary attributes: *collaborative, collaborative learning, interface* and *smart* (Figure 2).

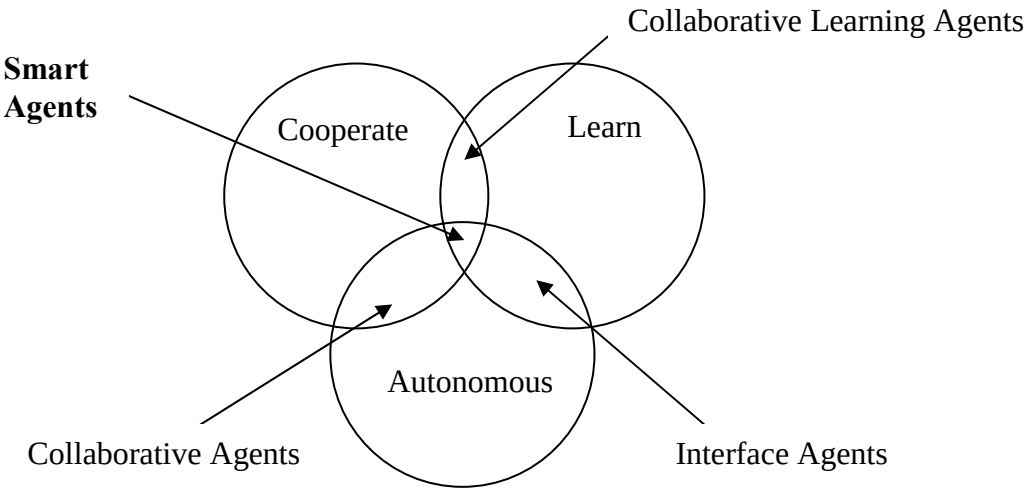

Figure 2: Typology based on primary attribute dimension [6]

According to Nwana [6], more common classification of agents involves eight categories (Figure 3):

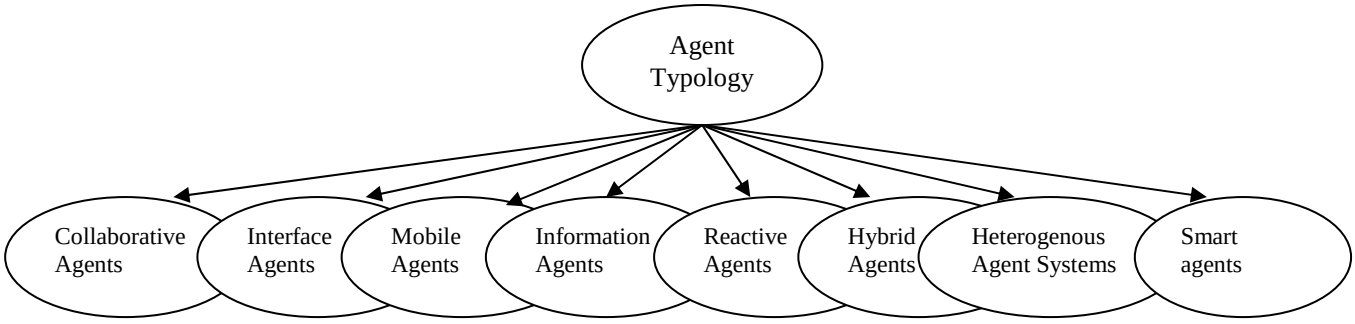

Figure 3. A classification of agents [6]

1. *Collaborative agents*: emphasize autonomy and cooperation with other agents (see Figure 2) in order to perform tasks for their owners. They may learn, but this aspect is not typically a major emphasis of their operation. In order to have a coordinated set up of

collaborative agents, they may have to negotiate in order to reach mutually acceptable agreements on some matters.

General characteristics of these agents include autonomy, social ability, responsiveness and proactiveness. Hence, they are (or should/would be) able to act rationally and autonomously in open and time-constrained multi-agent environments. They tend to be static, large coarse-grained agents. They may be benevolent, rational, truthful, some combination of these or neither. Typically, most currently implemented collaborative agents do not perform any complex learning, though they may or may not perform limited parametric or rote learning.

2. *Interface agents*: emphasize autonomy and learning in order to perform tasks for their owners (see Figure 2).

The agent observes and monitors the action taken by the user in the interface, learns new shortcuts, and henceforward suggests better ways to complete a task. These agents learn to assist their users by learning from the user (through receiving detailed instructions and positive and negative feedback from the user, by observing and imitating the user) or learning from other agent asking for advice.

Their cooperation with other agents is limited to asking for advice. The general benefits of interface agents are listed below:

a) Interface agents reduce user's efforts.
b) Agent can adapt to its user's preferences and habits
c) Know-how can be shared between different users.

3. *Mobile agents* are software processes capable of roaming wide area networks (such as WWW), interacting with foreign hosts, performing tasks on behalf of their owners and returning home with fulfilled duties that had been set. These duties may range from a flight reservation to managing a telecommunications network. Mobile agents are agents because they are autonomous and cooperative, although differently to collaborative agents.

4. *Information/Internet agents*: perform the role of managing, manipulating, or collating information from many distributes sources. The motivations for developing information agents are: there is an increasing need for tools that manage the information explosion of the WWW, where anyone would benefit from them, and there are also vast financial opportunities to be gained.

5. *Reactive agents*: there are three key ideas underpinning these agents. Firstly, *emergent functionality*: reactive agents are relatively simple and they interact with other agents in basic ways. There is no a priori specification of the behavior of the set-up of the reactive agents. No global model exists within any of the agents, meaning the global behavior has to emerge. Secondly, *task decomposition*: an agent is viewed as a group of modules that operate autonomously and are responsible for specific tasks. Communication between the modules is minimized and of quite a low-level nature. Lastly, reactive agents tend to operate on *low-level representations* that are close to raw sensor data, in contrast to the high-level symbolic representations that abound in the other types of agents discussed so far.

6. *Hybrid agents*: refer to those whose constitution is a combination of two or more agent *philosophies* within a singular agent. These philosophies include a mobile philosophy, an interface agent philosophy, collaborative agent philosophy, etc.

7. *Heterogeneous agent systems*: refer to an integrated set-up of at least two or more agents, which belong to two or more different agent classes.

8. *Smart agents*: advanced intelligent agents summing up the best capabilities and properties of all presented categories. [6]

According to [4] Russel and Norvig proposed the following classification of agent architectures:

1. Simple reflex agents: This type of agent is the simplest, because percepts are directly related to actions via some condition-actions rules. What has occurred in the past is ignored, because these agents have no memory.
2. Model-based reflex agents: As agents cannot perceive their whole environment, model-based reflex agents keep track of the part of their environment they cannot currently observe. To achieve this, they have an internal representation of their environment, called a "model of the world", to guess the evolution of the environment and the impact of the agent's actions on this environment. Like simple reflex agents, model-based reflex agents select their action according to condition-action rules, but now, the condition only depends on the model of the world, and not on the current perception of the environment.
3. Model-based, goal-based agents: This type of agent has goal information describing desirable situations, because the current state of the model of the world is not always enough to select an action efficiently. That is, the model of the world is used to elaborate some predictions on how the world would be if the agent executes an action and what is the price to pay for that. The action to carry out is chosen so that the goals will be satisfied according to such predictions.
4. Utility-based agents: Goals just differentiate wishable states from non-wishable states, without further details, such as, the speed, the price or the safety to reach a wishable state. As a result, in order to improve the quality of agent behavior, agents can be given a utility function mapping its state (or a sequence of states) in the model of the world, onto a real number describing the associated degree of agent's happiness. In comparison with goal-based agents, utility-based agents do not decide which action to do in order to achieve a goal, but which action to do to increase utility, utility-based agents find the best actions according to some given metrics.
5. Learning agents: Turing has noted the huge amount of work it takes to program an intelligent machine, and has concluded that it would be easier to build learning machines and then to teach them. Another advantage of learning agents is their adaptability to unknown environments, and the improvement of their behavior with time. Learning agents use the feedback from a critic to learn which perceptions of the environment are desirable, and in consequence, how to behave. Precisely, agents' learning consists in improving their future performance based on their past feedback from the critic, by optimizing their behavior such as to maximize their utility when the world continues evolving as it has been. This kind of learning makes agents discover that some kind of (but not exactly) condition-action rules always do the same thing, based on their current knowledge.

   Agent-enabling technologies:
   1. Java (language)
   2. CORBA/IIOP (infrastructure)
   3. KQML (protocol) [7]

4. Agents in supply chain management

Intelligent distributed systems, e.g. multi-agent systems, enable increased autonomy of each member in the supply chain. Each partner (or production subsystem) strives for individual goals while satisfying both local and external constraints. Therefore, one or several agents can be used to represent each partner in the supply chain (plant, warehouses, etc.). Moreover, the agent paradigm is a natural metaphor for network organizations, since companies prefer maximizing their own profit than the profit of the supply chain. In fact, the distributed manufacturing units have the same characteristics as agents:

1. Autonomy: a company carries out tasks by itself without external intervention and has some kind of control over its action and internal state;
2. Social ability: a company in the supply chain interacts with other companies, e.g. by placing orders for products or services;
3. Reactivity: a company perceives its environment, i.e., the market and the other companies, and responds in a timely fashion to changes that occur in it. In particular, each firm modifies its behavior to adapt to market and competition evolutions;
4. Pro-activeness: a company not only simply acts in response to its environment, it can also initiate new activities, e.g. launching new products on the market.

Thanks to agents adaptability, autonomy and social ability, agent-based systems are a viable technology for the implementation of communication and decision-making in real-time. Each agent would represent a part of the decision-making process, hence creating a tight network of decision makers, who react in real-time to customer requirements, in opposition to the flood of current processes, which is decided before customers place an order [4].

Agents in supply chain flows:

✓ *Material flows*: Messages in this category relate to delivery of goods by one agent to another. The processing semantics associated with material delivery messages minimally dictate adjustment to inventories of the posting and recipient agents by the quantity specified in the message. Material delivery messages can be either sent directly by a supplier agent to a consumer agent or may involve an intermediate transportation agent.

✓ *Information flows*: Messages for exchange of information between supply chain agents. It includes request for goods messages, capacity information, demand-forecast information, and supply-related information. Other messages that fall in this category include order cancellation messages and order modification messages.

✓ *Finances flows*: The movement of capital through the supply chain. This category includes a payment message sent by customer agents to their supplier upon delivery of goods. [8]

Supply chain activities using agent-based system:

1. *Order acquisition agent*. This agent is responsible for acquiring orders from customers; negotiating with customers about prices, due dates, and the like; and handling customer requests for modifying or canceling their orders. When a customer order is changed, this change is communicated to the logistics agent. When plans violate constraints imposed by the customer (such as due date violation), the order acquisition agent negotiates with the customer and the logistics agent for a feasible plan.

2. *Logistics agent*. This agent is responsible for coordinating the plants, suppliers, and distribution centers in the enterprise domain to achieve the best possible results in terms of the goals of the supply chain, including on-time delivery, cost minimization, and so forth. It manages the movement of products or materials across the supply chain from the supplier of raw materials to the customer of finished goods.

3. *Transportation agent*. This agent is responsible for the assignment and scheduling of transportation resources to satisfy interplant movement requests specified by the logistics agent. It can consider a variety of transportation assets and transportation routes in the construction of its schedules.

4. *Scheduling agent*. This agent is responsible for scheduling and rescheduling activities in the factory, exploring hypothetical “what-if” scenarios for potential new orders, and generating schedules that are sent to the dispatching agent for execution. It assigns resources and start times to activities that are feasible while at the same time optimizing certain criteria such as minimizing work in progress or tardiness. It can generate a schedule from scratch or repair an existing schedule that has violated some constraints.

5. *Resource agent*. The resource agent merges the functions of inventory management and purchasing. It dynamically manages the availability of resources so that the schedule can be executed. It estimates resource demand and determines resource order quantities. It is responsible for selecting suppliers that minimize costs and maximize delivery. This agent generates purchase orders and monitors the delivery of resources. When resources do not arrive as expected, it assists the scheduler in exploring alternatives to the schedule by generating alternative resource plans.

6. *Dispatching agent*. This agent performs the order release and real-time floor control functions as directed by the scheduling agent. It operates autonomously as long as the factory performs within the constraints specified by the scheduling agent. When deviations from schedule occur, the dispatching agent communicates them to the scheduling agent for repair [3].

Given degrees of freedom in the schedule, the dispatcher makes decisions as to what to do next. In deciding what to do next, the dispatcher must balance the cost of performing the activities, the amount of time in performing the activities, and the uncertainty of the factory floor.

The dynamics of the supply chain makes coordinated behavior an important factor in its integration. To optimize supply-chain decisions, an agent cannot by itself just make a locally optimal decision but must determine the effect its decisions will have on other agents and coordinate with others to choose and execute an alternative that is optimal over the entire supply chain. The problem is exacerbated by the stochastic events generated by the flow of new objects into the supply chain. These include customer orders, new customers, shipments of raw material from suppliers, and new suppliers themselves. Modifications to customer orders (at the customer's request), resource unavailability from suppliers, and machine breakdown all drive the system away from any existing predictive schedule. In dealing with stochastic events, the agents must make optimal decisions based on complex global criteria that

1) are not completely known by any one agent
2) may be contradictory and therefore require trade-offs.

An agent must be able to respond within the time allotted.

In summary, the next generation supply chain management system will be all of the following:

1. *Distributed*. The functions of supply chain management are divided among a set of separate, asynchronous software agents.
2. *Dynamic*. Each agent performs its functions asynchronously as required, as opposed to in a batch or periodic mode.
3. *Intelligent*. Each agent is an "expert" in its function. It uses artificial intelligence and operations research problem-solving methods.
4. *Integrated*. Each agent is aware of and can access the functional capabilities of other agents.
5. *Responsive*. Each agent is able to ask for information or a decision from another agent—each agent is both a client and a server.
6. *Reactive*. Each agent is able to respond to events as they occur, modifying its behavior as required, as opposed to responding in a preplanned, rigid, batch approach.
7. *Cooperative*. Each agent can cooperate with other agents in finding a solution to a problem; that is, they do not act independently.
8. *Interactive*. Each agent may work with people to solve a problem.
9. *Anytime*. No matter how much time is available, an agent can respond to a request, but the quality of the response is proportional to the time given to respond.

10. *Complete*. The total functionality of the agents must span the range of functions required to manage the supply chain.
11. *Reconfigurable*. The supply-chain management system itself must be adaptable and support the "relevant subset" of software agents. For example, a user who wants to schedule only a plant should not be required to use or have a logistics component.
12. *General*. Each agent must be adaptable to as broad a set of domains as possible.
13. *Adaptable*. Agents need to quickly adapt to the changing needs of the human organization. For example, adding a resource or changing inventory policy should be quick and easy for the user to do.
14. *Backwards compatible*. Agents need to have a seamless upgrade path so that the release of new or changed features does not compromise existing integration or functionality [3].

5. Agent-based system applied in supply chain management

The agent-based architecture for supply chain management proposed by [1] uses a multi-agent approach in order to build a flexible and general design for a dynamic supply chain. Each agent can be implemented with a different AI technique, which permits a system designer to test many diverse strategies and decide the optimal combination of these techniques. The agents also use a distributed knowledge base as a key component for collaboration. Agents store results and information in the knowledge base so that other agents can use it to solve their problems. Figure 4 presents the architecture of the multi-agent system.

The main focus of the proposed design is to tackle separately important sub-problems of a supply chain:

1. Procurement of components,
2. Production and delivery of finished goods,
3. Direct sales of finished goods to customers.

The customer agents typically represent real customers and firms that are willing to buy finished goods. The supplier agents are responsible for selling materials/components to the manufacturers, and it directly influences the procurement sub-problem. This agent is normally a manufacturer and could also use the design of the manufacturer proposed in Figure 4.

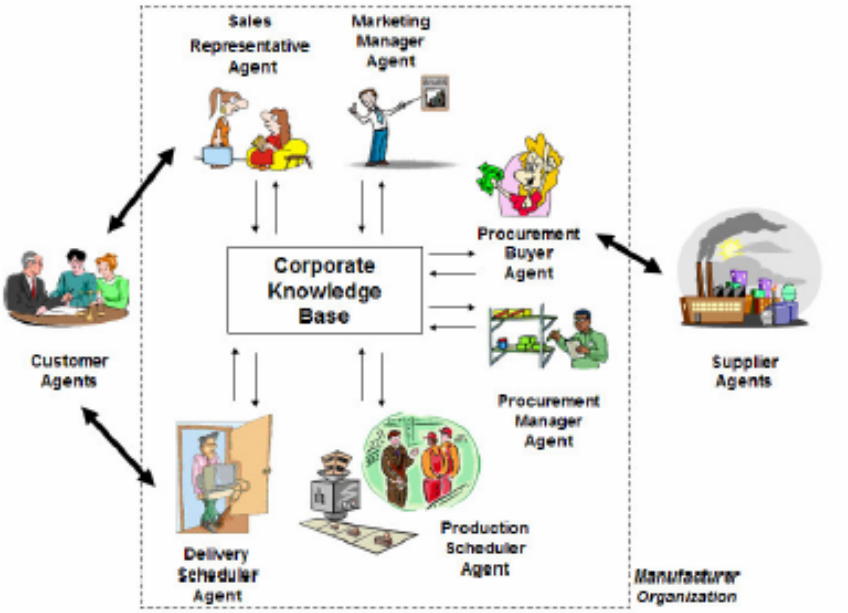

Figure 4. The multi-agent architecture [1]

The manufacturer of finished goods, also called manufacturer organization, is composed of the following agents:

1. Sales Representative agent – is responsible for fulfilling customer orders. Typically, this agent has to decide the price of finished goods based on current demand and the probability of winning customer orders. There, these decisions are based on a stochastic programming model;
2. Marketing manager agent – has to select the best customers and market segments in order to maximize the manufacturer's profitability. There, this agent uses a greedy strategy that chooses the most profitable Request-For-Quotes (in terms of its profit per factory cycles) and allocate them on the earliest date possible;
3. Production scheduler agent and Delivery scheduler agent – have to optimize the schedule of the production and delivery of finished goods respectively. Both production and delivery are decided at the same time in [1];
4. Procurement buyer agent – negotiates components with supplier based on attributes such as price and delivery time. This agent uses a simple heuristic that selects a component with the cheapest price after receiving responses from suppliers' Request-For-Quotes in [1];
5. Procurement manager agent – decides when to buy components based on the current inventory and component demand. A multiresolution procurement model is used in this agent in [1].

The design of the manufacturer tackles the sub-problems mentioned above with the following agents:

1. Procurement of components - Procurement buyer agent and Procurement manager agent,
2. Production and delivery of finished goods - Production scheduler agent and Delivery scheduler agent,
3. Direct sales of finished goods to customers - Sales representative agent and Marketing manager agent.

These agents use the corporate knowledge base to exchange important information for decision making purpose. This collaboration has the ultimate goal of achieving the maximum profitability for the manufacturer organization.

They [1] implemented their architecture in Trading agent Competition. This system completed against 32 entries, and was able to classify to the quarter-finals of the 2005 competition.

6. Conclusions

The implementation of agents in supply chain management is on a strong track and nowadays this is a topical question for researchers.

The next generation supply chain management system will be complete and dynamic with divided functions among intelligent, reactive agents, which in their turn can adapt to market changes and solve the problems at any time.

This work was done to unify available information about agents and agents in supply chain into one paper. Many works of researchers were investigated and used. The proposed information open up opportunities for more profound research. This paper can be used for initial study of agents in supply chain management.

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Rudenko Darja, Borisovs Arkādijs. Aģenti piegādes ķēdes vadībā
Piegādes ķēde ir tīkls, kas savieno piegādātājus, ražošanas uzņēmumu, noliktavas un izplatīšanas kanālu, kas nodarbojas ar tādām funkcijām kā izejvielu iepirkšana, to pārstrāde galā produkcijā un produktu izplatīšana līdz gala patērētajiem. Nesen tika atrasta jauna programmatūras arhitektūra piegādes ķēdes vadībai taktiskajā un operatīvajā līmenī. Tā apskata piegādes ķēdi kā intelektuālo aģentu grupu, kur katrs aģents atbild par vienu vai vairākām darbībām piegādes ķēdē, kā arī sadarbojas ar citiem aģentiem, plānojot un izpildot savus pienākumus. Šajā darbā ir īsi izskatīta daudzaģentu sistēmas izmantošana piegādes ķēdes vadībā.

Rudenko Darja, Borisov Arkady. Agents in supply chain management
A supply chain is a network of suppliers, manufacturing plants, warehouses, and distribution channels that perform the functions of raw material procurement, transformation of these materials into finished products and the distribution of these products to final consumers. In recent years, new software architecture for managing the supply chain at the tactical and operational levels has emerged. It views the supply chain as composed of a set of intelligent agents, where each agent is responsible for one or more activities in the supply chain and interacts with other agents in planning and executing their responsibilities.

Руденко Дарья, Борисов Аркадий. Агенты в управлении цепями поставок.
Цепь поставо к – это сеть поставщиков, завода - изготовителя, складов и каналов распределения, которая выполняет такие функции как приобретение сырья и его преобразование в готовую продукцию, а также - распределение этой продукции до конечного потребителя. В последнее время появилась новая архитектура программного обеспечения для управления цепями поставок на тактическом и оперативном уровне. Она рассматривает цепь поставок как группу интеллектуальных агентов, где каждый агент отвечает за одно или несколько действий в цепи поставок, а также сотрудничает с другими агентами в планировании и выполнении своих обязанностей. В работе даётся краткий обзор использования многоагентной системы в управлении цепями поставок.