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Collaborative Information System for Managing the Supply Chain: Architecture Based on a Multi Agent System

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A B S T R A C T

Faced with new constraints of their environment, industries are forced to join together in collective entities and collaborate with their partners. These companies have realized the importance of collaboration between companies and have begun to adopt new patterns of behavior to improve their productivity, profitability and flexibility during market requests. Indeed, the collaboration between firms has become a major strategic choice. Companies have begun to think of how to cooperate, a new form of management must be developed to ensure coordination and information's sharing, in real time, between different stakeholders in the supply chain; suppliers, customers, subcontractors and carriers, etc. Faced with these issues, we truly believe that it is important to build a new information system; this one have to be modern, efficient and flexible in order to optimize and control the flow of information between supply chain actors. The approach presented in this paper is considered among the works that aim to propose solutions related to information systems based on multi-agent systems, in order to ensure coordination between services of various partners, sharing and traceability of information

1. Introduction

In a context of economic progress, industrial companies are confronted with an unstable environment and have less and less clear visibility on their market. This instability results from globalization, competition, technological development and the growing customers' requests [1]. In addition, companies seek to reduce logistics costs of supply, production and distribution. On the one hand, reducing stocks to a minimum and stock up just in time, on the other hand, being involved in an organization of time-to-market to achieve their goals and satisfy their customers. So, it becomes clear that an industrial actor must exceed its borders to engage partners in developing strategic plans that support the management of its business processes.

Several methods and approach are implemented for decision support between extended enterprise actors in order to meet firms' collaboration requirement. The main objective of our work is to develop a distributed architecture based on Multi-Agent Systems (MAS) and Services for supporting the collaborative process. This platform is an information system that

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is able to support inter-businesses processes beyond the boundaries of the firm. The MAS assigns to our collaborative system the characteristics of autonomy and intelligence to better manage exceptions, increase productivity and optimize the relationship of interconnection between the various services offered by supply chain partners. The present paper is organized as follows.

In the next section we give a short overview of different contribution linked to the collaboration concept and we explain our contribution, after that we present the approach multi-agent and we describe the types of agents used in our architecture. Then we present the general principle of managing customer request and our collaborative information system based on multi-agent systems. The article ends by describing the conception elaborated by AUML and realization of an example for testing the communication between the different entities, and finishes by conclusions and perspectives.

2. Result of the literature survey

Several related works on multi-agents and supply chain management proposed in the literature. We present the main works realized. Supply-chain agents were utilized in order to play different roles as retailers, manufacturers, and transporters for inventory control. One based framework simulation has been proposed for developing customized Supply Chain models using a library of software components [2]. A based functional agent's framework of negotiation has been described to let orders to automate or semi-automate [3]. Also, architecture for an Internet-based Multi-Agent System has been proposed. It is considered as a very suitable system for managing complex Supply Chains in large manufacturing enterprises [4]. In the same area S. D. Pathak [5] has proposed an agent-based software system for assistance in decision making of supply chain management and for effective usage of EDI. Some authors have developed a integrated model computing in order to allow creating models of software agents to simulate and control the actual on-line negotiation processes. E. Benaissa et al. [6] propose a distributed architecture based on Multi-Agent Systems (MAS) and Semantic Web Services (SWS) for assistance in collaborative decision-making in the context of the extended enterprise. In our study, we propose another form of collaboration in supply chain based on proposed approach Contextual Modeling of Collaborative System [7] for multi-agent modeling, designing and implementing. Our proposed architecture allows the collaboration and cooperation between partners in the Supply Chain and the adaptability of the collaborative process for integrating new stakeholders.

3. Multi-agents approach

The multi-agent systems, from the work of the Distributed Artificial Intelligence, provide relevant tools for modeling and simulation of industrial problems [8]. Indeed, Autonomy, proactivity, responsiveness and sociability are main ones which are considered as principal properties of an agent [9]. Also, to make the approach of multi-agent modeling suited particularly to the problem of modeling and simulation of supply chains [10]. In fact, a multi-

agent system is a set of agents who have some autonomy, a degree of intelligence, a representation of their environment with whom they interact. Also, they are able to take the initiative, communicate with each other and adapt to different situations [11].
The need for these concepts in our collaborative platform justifies, in some way, the choice of multi-agent approach.

3.1.Paradigm agent

An agent is defined as an intelligent entity independently, able to communicate with other agents, to perceive and to represent its environment. Each agent performs specific actions based on their perception of its environment. A set of interacting agents form a multi-agent system [12].

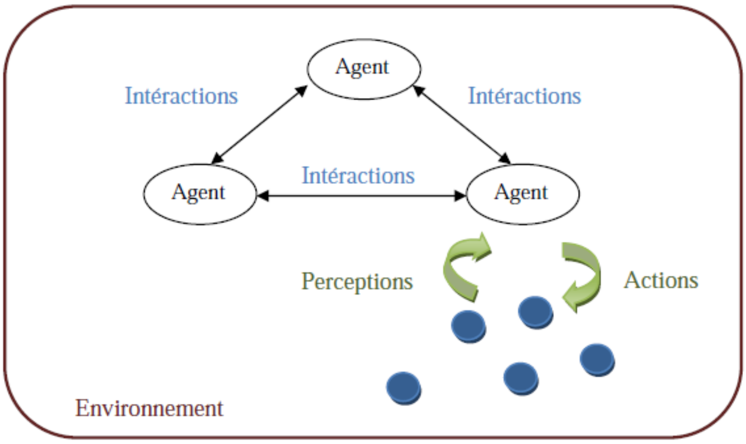

Figure 1. Representation of a multi-agent system by Ferber

Ferber defines an agent as a physical or virtual entity which [13]:

- is capable of acting in an environment,
- can communicate directly with other agents,
- has the own resources
- is able to perceive its environment,
- provides services.

We can therefore define a multi-agent system (MAS) as a system composed of a set of agents situated in an environment and interacting with each other to achieve a common goal. We distinguish in our model, two types of agents:
Cognitive agent: This agent has a global representation of their environment and other agents with whom they communicate [12]. On the one hand, they rely on their memory (history of their actions and tasks) to be able to act depending on the future (statuses and events). On the other hand, they rely on the principle of planning and collaboration among agents.
Reactive agent: This agent is only reacting to changes in the environment. They do not do deliberation or planning, they simply acquire perceptions and respond to them taking in reference some predefined rules [14].

We use, in our system, cognitive agent in order to decide, to negotiate, to communicate by sending messages. Otherwise, reactive agent is used because it has a very simple behavior in the system. Its capacity meets stimulus-action mode only that can be considered as a form of communication.

4. General context

4.1.Multi-Agent supply chain for a collaborative network (MASC-CN)

The concept of supply chain (SC) represents all companies involved in the manufacturing process, distribution and sale of its products to customers. A SC is the result of interaction processes between several companies. But this is only an external observer description, the SC in reality and in most cases, is a much more complex structure. It always integrates other smaller chains and often linked to other SCs.
Figure 2 depicts our proposed model of SC, called MASC-CN (Multi-Agent supply chain for a collaborative network), and based on the following principle: all the actors (customers, suppliers, factories, carriers, etc ...) are considered as agents with the ability to communicate and to analyze in order to take collectives decisions.

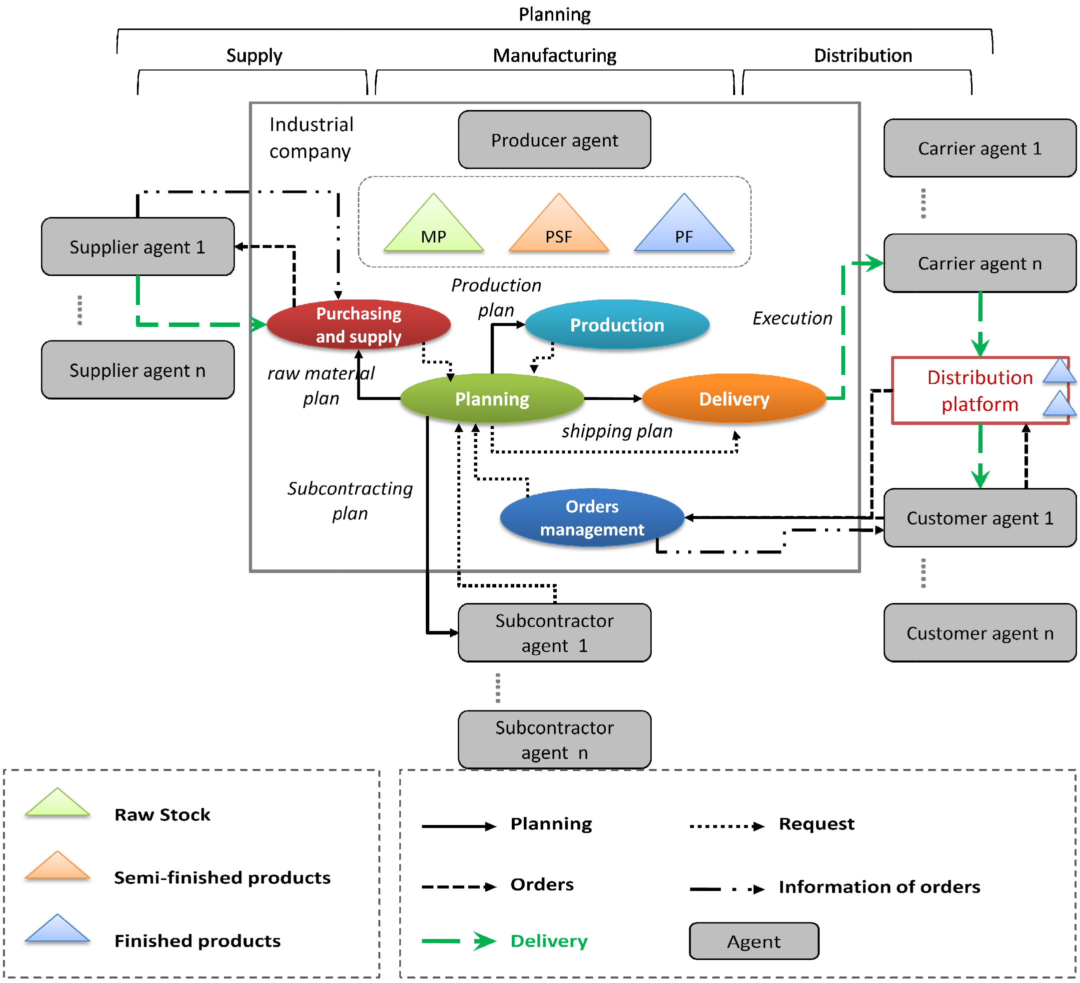

Figure 2. Multi-Agent supply chain for a collaborative network

Based on this design of Multi-Agent supply chain and many previous researches, we try to design a collaborative supply chain model, described via three types of levels: ‘Partners’, ‘Services’ and ‘Tasks’ (Figure 3).

4.2.Modeling Collaborative Supply Chain

Companies which make up the collaborative supply chain are represented by nodes 'P', see Figure 3. The flows processed at our study are characterized by information flows of the type "request". We define the collaborative supply chain as follows.

- The NETWORK has a set of partners Pr.
- Each logistic partner p ∈ Pr offers various services.
- The set of services Sr contains services S scheduled to process the customer request.
- Each service S ∈ Sr contains different tasks.
- The set of tasks Ts contains tasks T scheduled to get the response of the request.

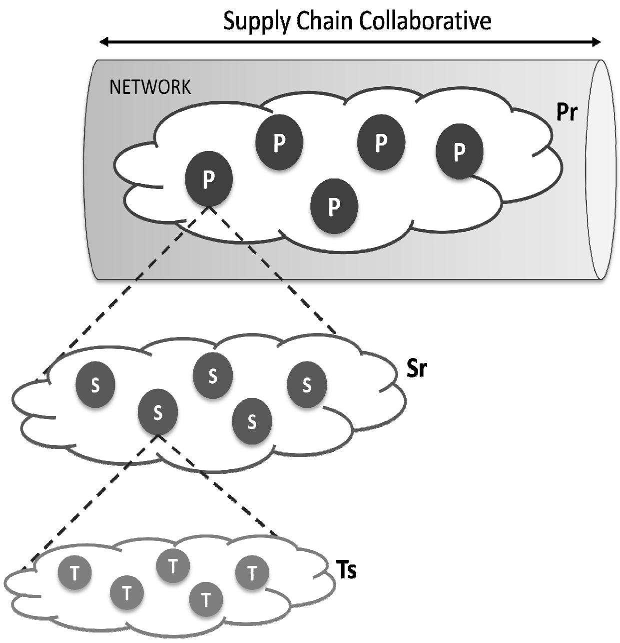

Figure 3. Modelling Collaborative Supply Chain

4.3.Multi-Agent Information System for a collaborative network (MAIS-CN)

In this section, we describe the behavior of the information system dedicated to manage the Collaborative Supply Chain. Called Multi-Agent Information System for a collaborative network, this system is composed of various resources which will be described on below.

4.3.1. Managing System

As shown in Figure 4, when system Manager receives a customer request from the interface resource, it sends messages (request) to the concerned Composers according to process this request.

After receiving messages, a composer resource processes the request and detects the appropriate services to achieve their tasks.

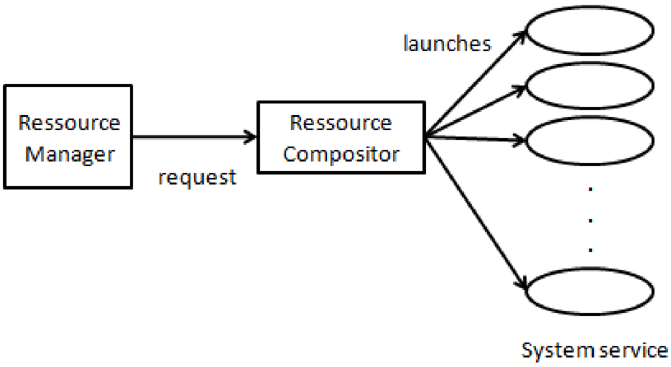

Figure 4. Request processing

As soon as the sub-queries processing is performed, Service resource sends a message of response to composer. If the answer is positive, the composer uses data to make a decision and send a message (inform) to the Manager. Otherwise, it undertakes new services to meet demand.

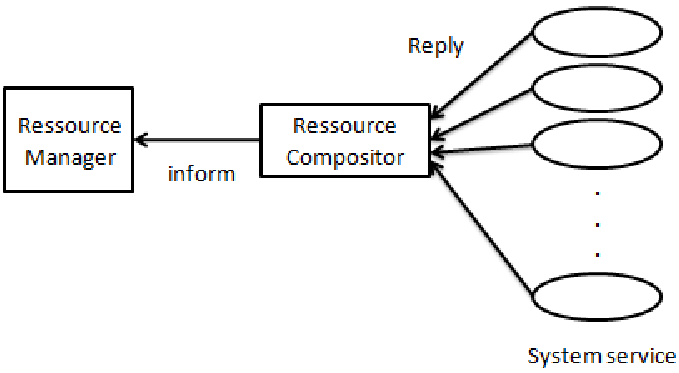

Figure 5. Response processing

4.3.2. Formulation of composer behavior

Composer resources determine the action plan describing services to be performed to reply user's request. This request is decomposed into a set of sub-queries. Each sub-request corresponds to an elementary task {Ţi}. So, each task can be processed by a partner type (supplier, carrier...).

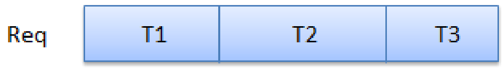

Figure 6. Example of request decomposition

At a time (tm), the formulation of a user request requires the creation of an Interface resource and triggers of the creation a Manager resource, Composers and a number of Services. We call these resources created at time (tm), the society of resources (Rs). So, the process described is presented by this algorithm below. Table 1 gives the explanation of notations used in the algorithm.

Table 1. Notations

Notation	**Signification**
Rt	Request at a time (tm)
$Ʈt = \{Ʈ_1, \ldots, Ʈ_i\}$	Tasks composing the request Rt
$Sr = \{Sr_1, \ldots, Sr_j\}$	Services offered by the collaborative system
N	Number of sub-queries (tasks)
$Ts = \{Ts_1, \ldots, Ts_k\}$	Tasks performed by a partner

```
Initialisation
Plan_Solution ← {∅}
Beginning
For i=1 à N do
  According to (Ʈi)
 Case 1: (Ʈi ∈ Ts (manufacturer))
        Load Composer Agent_Manufacturer
                    Detecting Service required
                    Solution_i  ←  Sr manufacturer (Ʈi)
 Case 2: (Ʈi ∈ Ts (carrier))
          Load Composer Agent_Carrier
                    Detecting Service required
                   Solution_i  ←  Sr carrier (Ʈi)
………..
………..
  End According to (Ti)
   Plan_Solution ← Plan_Solution +  Solution_i
End For
End
```

5. Proposed architecture

We propose architecture of collaborative information system for implementing our different processes. This collaborative environment will be the platform of communication and information exchange between the stakeholders in the supply chain.

5.1. Main expected properties of our architecture

Our collaborative information system is facing many constraints that lead us to define the following set of requirements: distribution, autonomy, intelligence, learning, adaptation, scalability and flexibility.

In the following, we define the properties that are required for our vision of a Multi-Agent System

Distribution: our collaborative system is considered as a distributed system because it contains a set of autonomous and independent entities, but it appears to the user as a single and coherent system.

Autonomy: Our distributed system consists of a set of agents that are able to organize their activities and to realize them without human intervention. Our collaboration platform is autonomous, it is able to interact with the environment, develop its own representations, make decisions and perform actions. The interactions with the environment can be the main basic way for a good selection of behavior and/or a choice of strategy.
Intelligence: Intelligence is characterized by a set of faculties to understand the facts and adapt easily to new situations. The intelligence consists, in our system, to analyze and adapt existing resources to make decisions appropriated to the tasks that lead achieving desired objective.
Learning: Learning is the process of acquiring skills and knowledge. The culmination of this knowledge is based on environment's perceptions, interactions of its components and relationships between its actions. The system uses typically a memory, known as the knowledge base, which represents a set of behaviors, conditions and constraints encountered during the execution.
Adaptation: the word refers directly to the adaptation process. It is a characteristic related to humans. It is the ability to change its organization facing a change in the environment. We can distinguish, in our system, several levels of adaptation; such a low level for a simple adjustment of parameters, another higher level can be a learning capacity.
Scalability: New partners can integrate the system and offer new services. Thus, scalability also refers to the faculty of adding easily new modules and new features.
Flexibility: Flexibility is the ability to adapt to the environment. Our collaborative system is faced with new technological changes, new business process or behavior scenarios.

5.2.Layers of collaborative system

Our system consists of five layers (see Figure below), application layer, coordination layer, communication layer, planning layer and resource layer.

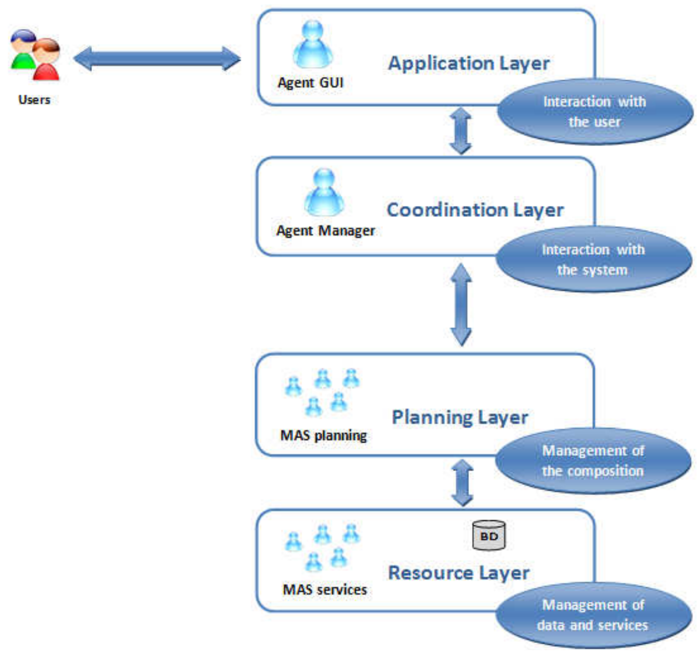

Figure 7. Layers of the system

Application layer: This layer contains interfaces that allow users to interact with the system. Its role is to capture the purpose of the user in order to meet his needs as well as possible. It includes a reactive agent, "the GUI Agent", interacting with the partner to help him to achieve a specific task. This interaction results in a transformation of requests to an objective understood by the system that will facilitate the coordination layer functioning.

Coordination layer: This layer mediates between users and the system. It is composed of a cognitive agent, "Agent Manager". It allows processing the user's request, to gather the results found in the form of a comprehensive response and transfer it to the Application layer.

Planning layer: this layer is used to establish an action plan composed of a succession of activities to achieve the target set by the coordination layer. It is run by "MAS planning" which consists of different cognitive agents known composers. At this level, and for each sub-goal, the system activates the dedicated composer agent.

Resource layer: this layer contains necessary elements (databases and services base) to perform the action plan defined by the planning layer.

5.3.Architecture of the system

Based on layers mentioned above, we propose a generic architecture of collaborative information system:

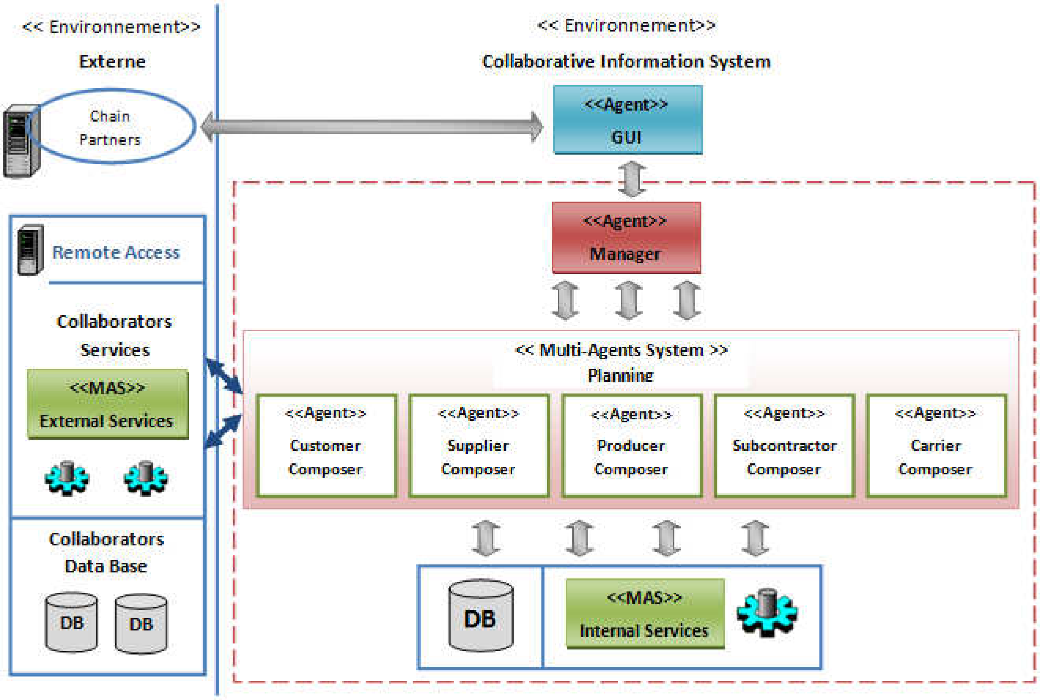

Figure 8. Architecture of the system

As follows, we detail the different agents that manage the layers mentioned above.

The Agent GUI: This agent can be seen as a wizard that allows users to interact with the system. It allows acquiring all user requests, transforming in understood goals by the system, communicating these requests to the Manager agent and displaying the results to users. It also checks the identification of users (authentication) and sends their profiles to the Agent Manager.

The Agent Manager: This agent is considered as the mediator of the system, the agent processes the target set by the agent GUI and it is able to reformulate this goal into sub-queries that are transferred to the MAS planning. When sub queries execution is completed, the Manager agent collects the results found in the form of a comprehensive response.
MAS Planning: This package itself consists of a multi-agent system; each agent is associated with a specified type of supply chain partners. We rely on the agents' decomposition of the supply chain proposed by Huget [15].
Thus, there is a customer agent composer, a provider agent composer, a carrier agent composer... For each sub-request sent by the Agent Manager, the system will load a set of composer agents in order to perform a series of processes and propose a solution plan. It communicates also with internal resources (databases / services base) and external resources (databases / remote services) to execute the established action plan.
MAS Services: This MAS loads the necessary services to perform the action plan produced by the MAS planning [16].

6. Implementing a platform

6.1.Design model

In this section we propose a design based on the Agent UML (AUML) language. AUML is an extension of UML to take into account the agent notion. Agent UML inherits representations proposed by UML [9]. The design of the proposed architecture is described through the class agent diagram. AUML allows representing several levels of abstraction in the design class diagrams. We will focus on the implementation level in order to give, in detail, the contents of the different agents. Figure 9 shows the class diagram for the agents' level implementation. The set of compartments is based on the generic architecture of AUML class [17].

6.2.Case study

We used the concepts explained in the previous sections to develop a demonstration application. The process realized concern the customer orders of a textile's chain. Three actors in the supply chain are involved in the example. In order to test the global operation of system, we implemented our architecture with the JADE platform. JADE is defined as a middleware oriented agents. It is often used to realize information systems oriented agents [18].

6.3.The scenario

- The customer wants to order some products. He uses "The dedicated interface" to choose product type, characteristics, quantity and delivery address.

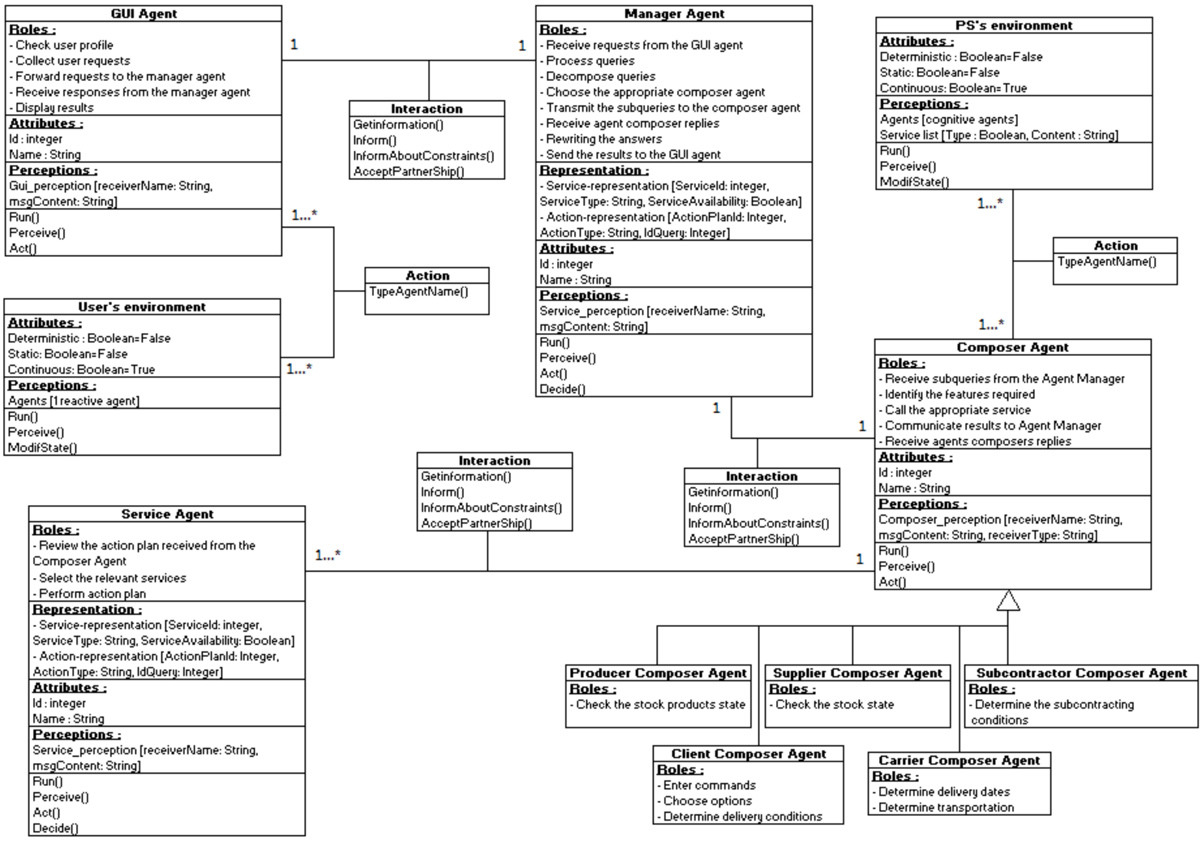

Figure 9. Implementation level of collaborative system

- The collaborative system receives the request and searches a suitable service in order to reply request customer.
- It decomposes the request into several tasks and sends them to suitable modules which then process these queries.
- After processing, the system proposes one reply to request customer and waits his confirmation.
- If the customer approves the response, he validates the command that will be saved.
- The system contacts the actors brought into play in the process by sending notifications.

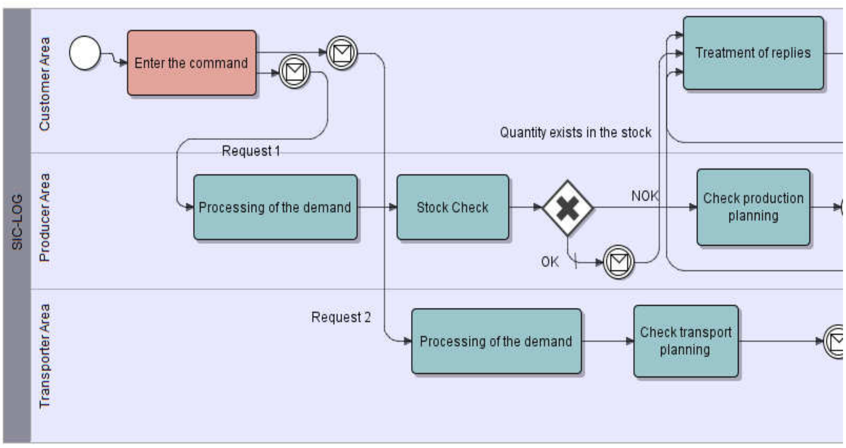

Figure 10. Sample of collaborative process model

- **Authentication**

Each user must authenticate to redirect to the management module concerned. The GUI agent calls the connection service to determine the user profile and display the interface for taking orders. At time T, only agent GUI, agent Manager and agent service "connection" are launched.

Figure 11. Workflow of authentication system

- **Order processing**

If the user has a profile "customer", the system shows the Figure 12. The user must specify the detail of the order and choose the delivery address.

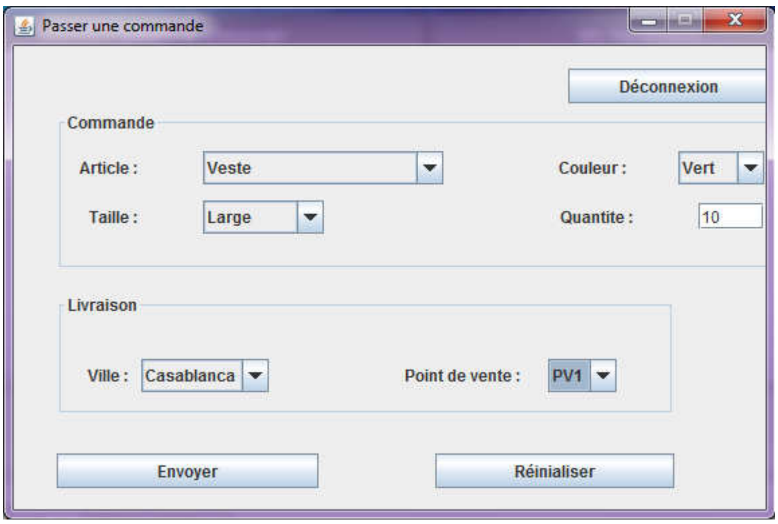

Figure 12. Interface to taking orders

The agent GUI collects customer demand and communicates this request to the agent Manager. This one processes the request, which will be divided into two sub-queries that are transferred to the Composer agents: agent "producer composer" for the order processing; agent "carrier composer" for the delivery processing.

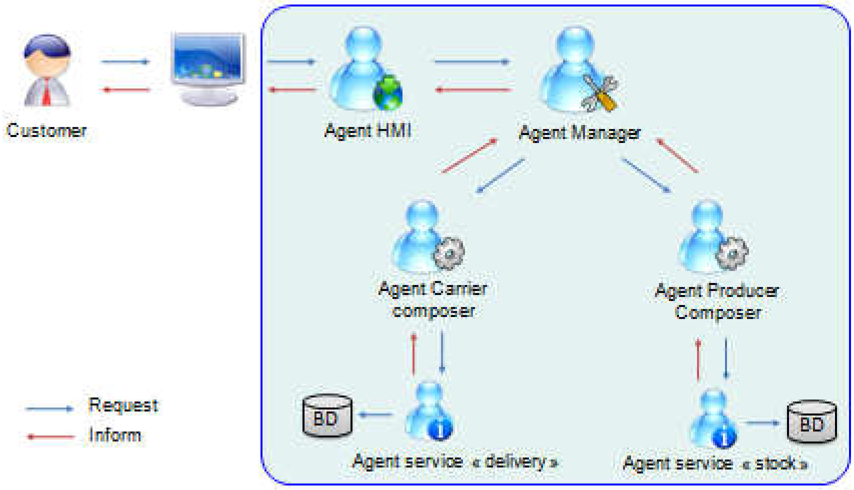

Figure 13. Workflow of orders processing

The agent producer composer charges the service "stock" to check the quantity of product requested. If the quantity is not enough, the agent producer calls another agent, agent service "production", and charges this one to check the production planning as first step. After this check and calculation, agent service "production", will communicate the client the delay to produce its articles. The agent carrier composer calls the agent service "delivery" to check the delivery time for the selected address. The Figure 14 concerns the case when quantity exists in the stock.

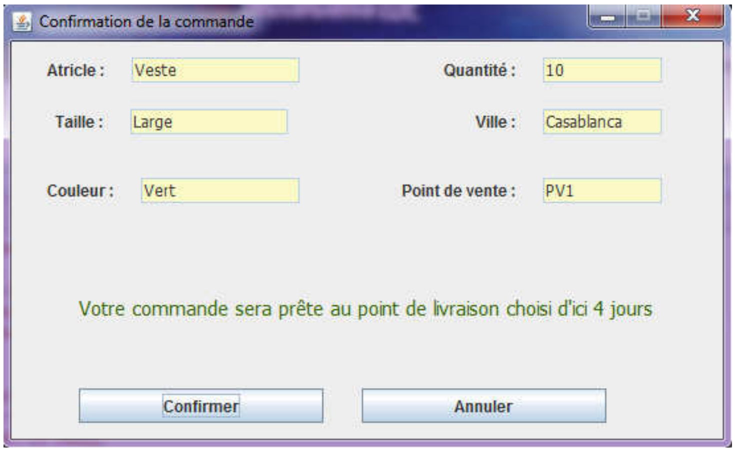

Figure 14. System response

The customer has the option to confirm or cancel the order. Once confirmed, a notification "new order" is sent to the producer.

The Figure 15 shows the agents communication flow in our prototype.

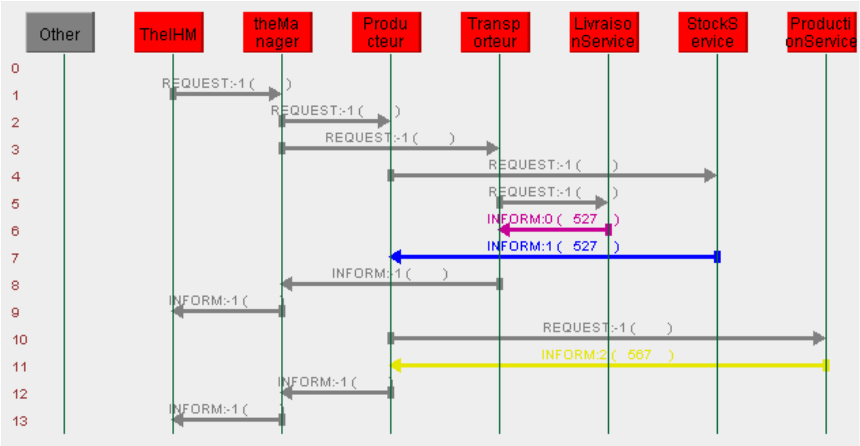

Figure 15. Example of communication agents SIC on JADE

- **Replenishment constraint:** Fixed date and variable order quantity

At fixed time, the system analyzes the stock and orders a quantity in order to meet the desired level. This replenishment method can be particularly applied on products whose consumption is regular or on expensive products. We use this method in our architecture because it allows mastery of stock. So, the variable quantity will be the difference between the replenishment level and the stock available at the time of ordering.

Different elements to consider are:

- *D:* Average demand
- *P :* The fixed period between two commands
- *L:* The replenishment period
- *Ss :* Safety Stock
- *Nr:* The level of replenishment expressed by the following expression

$$Nr = (P + L) \times D + Ss \qquad (1)$$

- *Sd:* stock available at time of ordering
- *Q :* replenishment variable quantity is calculated by the following expression

$$Q = Nr - Sd \qquad (2)$$

7. Conclusion

Information is one of the elements key of an effective supply chain management. Information is needed to master, manage, control, measure and optimize any kind of industrial activity. It needs to be captured, stored, analyzed, shared and transmitted in order to become the base for efficient decision-making, at every step of a supply chain (supplier, manufacturer, distributor...) [19]. In this paper we presented the architecture of the collaborative information system dedicated to manage the global supply chain based on multi-agent systems. This system is considered as a mediator who gathers information used by different systems of partners (ERP, WMS, TMS...).

Indeed, the main objective of our work is to develop a new approach that ensures the effectiveness and efficiency of inter-firm collaboration. For this, we used a set of reactive and cognitive agents in order to achieve the collaborative process. We have also presented an example of how to use the collaborative system between three actors of the supply chain (a customer, a manufacturing company and a carrier), by modeling the customer orders process. This example validates the behavior of our multi-agent system and our methodological approach CMCS (Contextual Modeling of Collaborative System) [7] for modeling and design of the collaborative information system. Moreover, the data are limited and do not allow to test the overall performance of the system. As short-term perspective, we are identifying models of collaborative practices in order to propose generics functionalities and performance indicators.

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