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# AN APPROACH OF AGENT-BASED DISTRIBUTED SIMULATION FOR SUPPLY CHAINS: NEGOTIATION PROTOCOLS BETWEEN COLLABORATIVE AGENTS

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## KEYWORDS

Negotiation Protocols, Multi-Agent Systems, Supply Chain Management, Distributed and Proactive Simulation, Agent-UML, Modeling.

## ABSTRACT

The modeling languages of multi-agent systems are recently developing, mainly AUML (Agent Unified Modeling Language). This paper presents modeling work based on the AUML language for distributed architecture of simulation and decision-making in the supply chain. The environment of supply chain is rich in negotiation protocols; we propose and model with AUML some exchange and negotiation protocols for agents within the supply chain context. We show through an example that AUML language could be used for specifying and modeling real-world agent-based applications.

## INTRODUCTION

The economic and industrial communities worldwide are confronted with the increasing impact of competitive pressures resulting from the globalization of markets and supply chains (SC) for product fulfillment. More and more enterprises are being driven to pursue new forms of collaboration and partnership with their direct logistics counterparts. As a result, at a company level there is a progressive shift towards an external perspective with the design and implementation of new management strategies, which are generally named with the term of supply chain management (SCM). Adopting a SCM strategy means to apply a business philosophy where more industrial nodes along a logistic network act together in a collaborative environment, pursuing common objectives, exchanging continuously information, but preserving at the same time the organisational autonomy of each single unit. However, in order to conduct this concept in practice, several hurdles are still to overcome (Samii 2004) (Hieber 2002), mainly due to:

- The conflicts resulting from local objectives versus network strategies, because supply chain is a multi decisional context, so companies must make decisions collectively.
- The difficulty in making decisions in a collaborative manner. It observed in several supply chain cases.
- The need for sharing sensitive information of participants

in the SC. If the supply chain is composed by independent enterprises, sharing information becomes a critical obstacle, since each independent actor typically is not willing to share with the other nodes its own strategic data (as production capacity, internal lead times, production costs, sales forecasts, etc.).

- The need for sharing information technology tools.

In this paper, we focus on the modeling of agent-based distributed architecture of simulation in decision-making processes within the supply chain context. We propose mainly a set of negotiation protocols and model it within AUML modeling language.

The agent-based distributed architecture concerns two different kinds of simulation: classical simulation and proactive simulation. Classical simulation is a useful device to provide “what-if” analysis and to evaluate quantitatively benefits and issues deriving from operating in a cooperative and collaborative environment. It is a powerful technique to convince decision-makers to adopt a SCM process and to choose the most appropriate management strategies and practices for a given SC. Proactive simulation allows making decisions collectively in a short time (in particular, in case of disturbance). Also this distributed architecture allows simulating the future behavior of the supply chain participants.

This paper is structured as follows. In Section 2 we introduce the role of distributed simulation in the supply chain context. In Section 3 we show a generic model fixing and defining the group of participants in the supply chain. In Section 4 we present the class diagrams for agents. In Section 5 we propose a set of negotiation protocols and model it within AUML sequence diagrams. In Section 6 we present a case study which gives some tests of the negotiation protocols. Finally, we conclude the paper and give an overview of our future work.

## THE ROLE OF DISTRIBUTED SIMULATION IN THE SUPPLY CHAIN CONTEXT

Many software vendors (e.g. IBM in (Bagchi et al. 1998)), universities and companies (Telle et al. 2003) (Banks et al. 2002) have traditionally used a local simulation approach in the supply chain context. Only in recent years, more and more companies in supply chain adopt distributed collaborative simulation (Brun et al. 2002), because it

provides a connection between supply chain nodes that are geographically distributed throughout the globe, guaranteeing that each single simulation model is really linked to its respective industrial site. Moreover, companies in any supply chain must make decisions individually and collectively regarding their actions in *production, inventory, location, transportation and information* (Hugos 2003), then the distributed simulation can preserve at the same time the local autonomies and privacy of logistics data. In some cases, the execution of a distributed model allows to reduce the time spent for simulation, since separated models run faster than a single complex model (Fujimoto et al. 1999).

Despite the great use of simulation in SC and SCM, there are many additional opportunities for application of the methodology (Banks et al. 2002). However, many of these opportunities require that challenges be overcome (see Introduction). Aim of the agent-based distributed simulation presented in this paper is:

- To convince decision-makers to adopt a SCM process and to choose the most appropriate management strategies and practices for a given SC.
- To make decisions collectively in a short time. Mainly, in the case of operational planning (short term, for example: rush order) (Pinedo and Chao 1999) or in a situation where the supply chain partners negotiate a delivery dates modification due to a disturbance (for example: problem of production, problem of transport, etc.), because the decision system has to make its choice within a short time, and must be able to evaluate the consequences regarding various scenarios in distributed manner within a shorter time too.

In order to have a flexible and proactive model, we have chosen the Multi-Agent approach to develop our architecture. Clautier (Clautier et al. 2001), Maturana (Maturana et al. 1999) and Parunak (Parunak 1996) showed the main benefit to use this approach in the field of the supply chain. Thus, the complete architecture of simulation is made on a set of agents modeling the supply chain participants (figure 1). These collaborative agents communicate between them and negotiate using protocols. They seek the accurate and timely data that holds the promise of better coordination and better decision-making in the information systems of the supply chain participants (such as an ERP (Enterprise Resources Planning) system); this means every time the simulation starts, the model must be initialized with the current states of the supply chain participants.

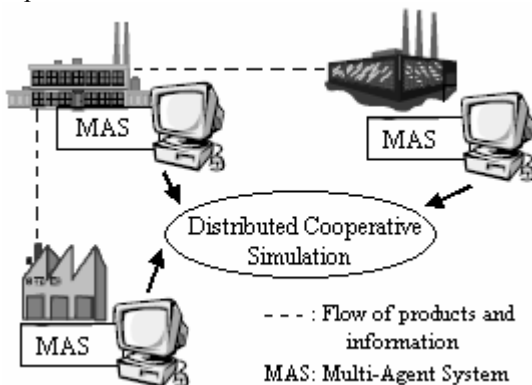


Fig. 1 – Agent-Based Distributed Simulation for the SC

## STRUCTURE AND PERIMETER OF SUPPLY CHAIN TO BE MODELLED

Two parameters are important in the process of the modeling of a supply chain, the perimeter and the structure. The first delimits the supply chain in a number of actors (companies), and the second defines the customer/supplier relationships. If the two aforementioned parameters are absent, it will be difficult to define the modeling boundaries (in term of levels). Indeed, a supply chain can use several tens, even hundreds of nodes geographically distributed throughout the globe. Then, is it really necessary to take into account all the actors? Moreover, a company can belong to several supply chains. Then, what are the levels of customers and suppliers that should be covered by the proposed model?

To answer these two questions, it is necessary to identify the product for which the supply chain is defined. Indeed, we define a supply chain for a product or a family of products. It is composed of all the companies involved in the design, production, and delivery of a product to market. Having a clear knowledge of the product, we better specify the central company of the supply chain, i.e. the one that assembles the finished product. Next, we propose to follow the steps below, they define a generic model for supply chain which delimits the boundaries of modeling and defines the customers/suppliers relationships:

### *Identifying the product:*

1. Identify the finished product for which the supply chain is defined. This automatically defines the central company of the supply chain.
2. Identify the bill of materials of the finished product.
3. Exclude from this bill of materials the raw materials not requiring a partnership or collaboration.

### *Suppliers:*

4. Afterwards, identify the remaining raw materials suppliers (distributors or factories having the activity of production). The same raw material can be bought from one or more different suppliers. In this last case, the percentage of the orders to place to each one of them should be determined.
5. For each supplier, the steps 2, 3 and 4 have to be renewed by considering, this time, the raw material as a finished product, and so on up to the upstream supplier.
6. Determine the type of the orders (stationary, random, etc.) of the customers (other than central company "EC") of the various suppliers identified in step 4.
7. Remake step 6 for the suppliers of the suppliers except for the last suppliers (upstream suppliers).

### *Customers:*

8. Identify the list of customers of central company "EC".
9. In this list, identify the potential customers acting on the supply chain of the product (customers requiring collaboration or a partnership) and those which do not require the collaboration. Then, determine the type of the orders for the latter (random, stationary, etc.) as well as the percentage of the orders which each potential customer places to central company "EC".
10. For each potential customer of central company "EC", remake steps 8 and 9 except for the final customers (for example, consumers).

*Agents-based Model:*

- Allot an Agents-based model (cf. Section below) to all the identified actors (central company, customers and suppliers).

**AGENTS-BASED MODEL FOR SUPPLY CHAIN AND SUPPLY CHAIN MANAGEMENT**

The shift from the proposed generic model to an agents-based model starts with the modeling of each actor (central company, customers and suppliers). To represent the three main functions of the company (*source, make and deliver*) and consider the control processes in the supply chain and its environment, each actor is modeled by seven agents, except the last suppliers and customers (retailers and consumers). These agents are: *AgentPRC* which plays the part of the processes related to the customer, *AgentDis* who manages the “stock of distribution”, *AgentPro* which plays the role of the “make” process, *AgentApp* for the “source” process, *AgentAch* which plays the role of the “purchase” process, *AgentSCM* for the “management” of the SC and *AgentPer* which handles the “disturbances”. This last agent makes it possible to the model to be open and extensible in order to consider a large variety of disturbances in order to cover various types of SC (world size, national size, branch of industry, etc.). In the case of an actor of the distributor type, the agents *AgentPro* and *AgentApp* do not exist. In order to represent the relationships between agents and to define its elements (their attributes, operations, roles, protocols, etc.) we use the AUML class diagrams (Huet 2002). Figure 2 shows the conceptual level of the class diagram of an actor and figure 3 illustrates, as an example, the implementation level for the agent *AgentSCM*.

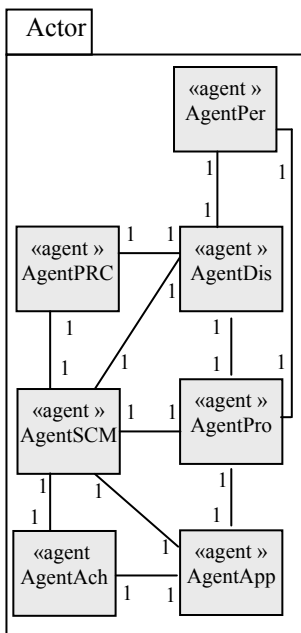


Fig. 2 - Class diagram: Conceptual level

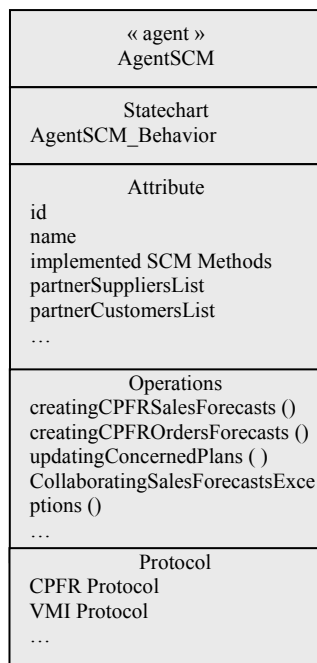


Fig. 3 – Implementation level for the “AgentSCM”

**NEGOTIATION PROTOCOLS**

The negotiation is the mechanism by which the agents can establish a common agreement. In the case of intelligent agents and of the MAS (Multi-Agent Systems), the

negotiation is a basic component of the interaction because the agents are autonomous (Jenning et al. 2001); there is no solution imposed in advance and the agents must find solutions dynamically, while solving the problems. To model the negotiation between the agents composing our system, we consider the following aspects:

- *The negotiation object*: an abstract object which includes the attributes that the agents want to negotiate. In our architecture, several objects are prone to be negotiated according to the situation. We find among others, the Order and its attributes (quantity and delivery date), the Contract of Continuous Delivery and its attributes (quantities and plan of delivery), the Forecasts and their attributes (quantities, dates and exceptions) and the acceptable scenario in the case of dysfunctions.
- *The decision-making process*: this is the model that the agent uses to make the decisions during the negotiation. The most important part of making decisions is the negotiation strategy which allows the agent to choose the most appropriate communicative intention (also called “performative”) at a certain time. The performative can be ACCEPT\_PROPOSAL, REQUEST, INFORM, PROPOSE, etc.
- *The communication language*: the language used by the agents to exchange their knowledge and information during the negotiation. We use the FIPA-ACL language (FIPA 2002) in our application.
- *The negotiation protocol*: the set of elements that governs the negotiation such as the possible participants in the negotiation, the legal proposals that the participants can make, the states of the negotiation. And finally a rule to determine when the negotiation should be stopped in case of agreement (or when it is necessary to stop the negotiation process because no agreement could be reached).

In the SCM process, the agents are co-operative, having the same goal (aggregation of the local objectives). They share and solve problems together. For this reason, the agents must provide useful reactions to the proposals that they receive. These reactions can take the form of a counter-proposal (refused or modified proposal). A counter-proposal is an alternative proposal generated in response to a proposal. From such reactions, the agent must be able to generate a proposal which is probably ready to lead to an agreement. Consequently, the agents of our system must use protocols respecting the criteria which have been stated above and that mainly depend on three parameters:

- The branch of supply chain sector (textile and clothing sector, consuming goods sector, etc.);
- SCM strategies and practices used for the companies’ co-operation and coordination;
- Objects to be negotiated: rush order, ordinary order, sales forecasts, orders forecasts; modification of delivery plans in case of trouble, etc.

We propose a set of negotiation protocols between agents peculiar to the supply chain management. They are:

- Protocols corresponding to the SCM strategies and practices (CPFR -Collaborative Planning, Forecasting and Replenishment-, Transshipment, etc.);
- Recursive heuristic negotiation protocol;
- Firm heuristic negotiation protocol.

We mainly focus in the following sections on the recursive and firm heuristic negotiation protocols, and the CPFRR negotiation protocol used between two agents “AgentSCM” of a distributor and his supplier. We also model these negotiation protocols with AUML sequence diagrams (Huget and Odell 2004).

**Heuristic Negotiation**

The heuristic negotiation is shown in figure 4 (Florea 2002). In this protocol several proposals and counter-proposals can be exchanged in various steps. Agent “A”, with proposal “pA”, is the initiator of the negotiation, whereas the agent “B” (participant) can reply with the answers “p1B”, “p2B” and “p3B” (to modify the request). The number of the counter-proposals is limited. Once this limit is reached, the agents arrive to a rejection. We propose to recapitulate the heuristic negotiation protocol using an AUML sequence diagram (figure 5).

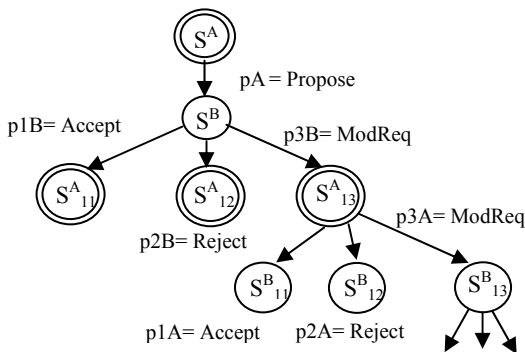


Fig. 4 - Heuristic negotiation

**Proposal for a Firm Heuristic Negotiation**

In some situations of negotiation, the cooperative agents must find an agreement; an example is the case of two agents “AgentSCM” that collaborate on the sales forecasts. For this reason, the heuristic negotiation (cf. figure 5) should include only ACCEPT-PROPOSAL or PROPOSE performatives (without the REFUSE performative). Thus, we propose the *firm* heuristic negotiation protocol which is a particular case of the heuristic negotiation. The word “firm” stands for this protocol since it always leads to an agreement. Figure 6 shows the sequence diagram that describes this protocol.

**Proposal for a Recursive Heuristic Negotiation**

The *recursive* negotiation protocol that we propose takes place at least between three agents, the initiator of the negotiation (sender), and the receiver who could become the initiator of a new heuristic negotiation with the third agent; hence the word “recursive” qualifying this heuristic protocol. Figure 7 shows the corresponding sequence diagram.

In our architecture of the simulation, the recursive heuristic negotiation either belongs to a protocol corresponding to a SCM practice and strategy or corresponds to the negotiation of a rush order or scenario to be adopted in the case of disturbance (production problems, disturbance of transport, etc.). In the general case, the negotiation takes place in the following way:

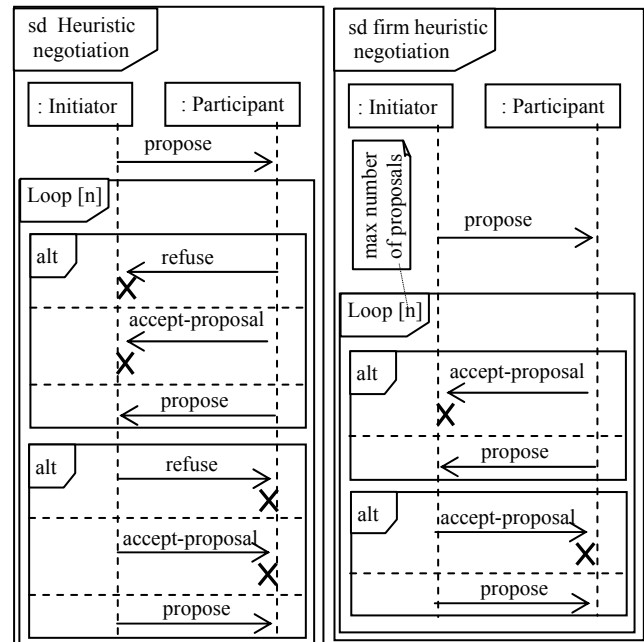


Fig. 5 - Heuristic negotiation

Fig. 6 – Firm Heuristic negotiation

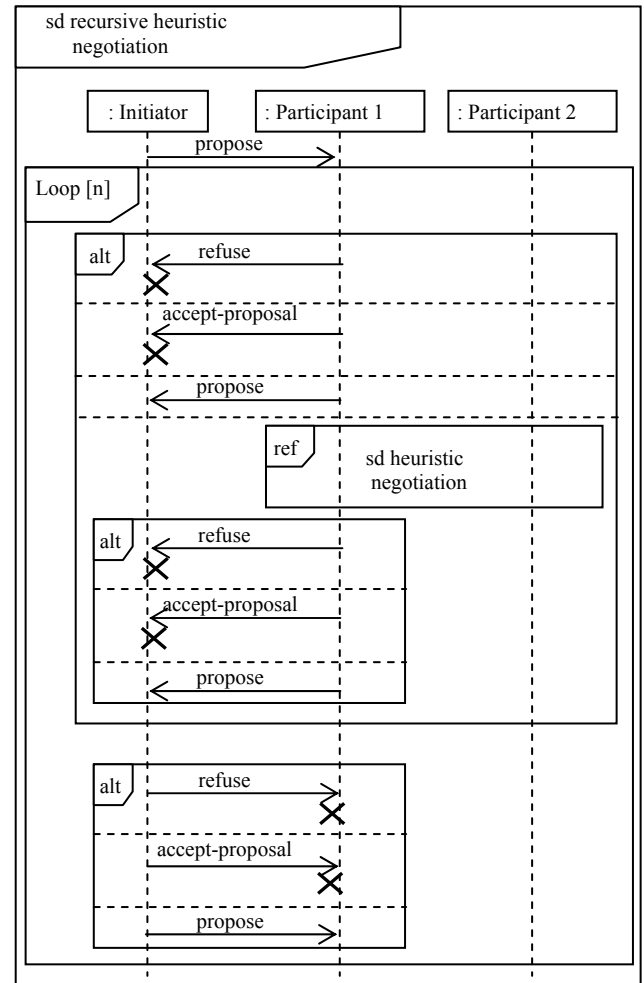


Fig. 7 - Recursive heuristic negotiation

- The initiator of the negotiation sends messages (not necessarily identical) of type PROPOSE to all the direct agents (upstream and/or downstream) whom he thinks could be candidates in a negotiation. So, the initiator launches several independent negotiations. It does not

wait for all the answers to make a decision. Moreover, according to the situation and the time interval, it can come up with the best solution by creating new proposals deduced from the received answers;

- Since the agents of our architecture are co-operative, each one of them - receiver of a message - can start a negotiation if necessary between other agents in order to find the best solution.

### CPFR Negotiation Protocol

The CPFR (Collaborative Planning, Forecasting and Replenishment) developed by the VICS Association (2006) (Voluntary Interindustry Commerce Standards) is a collaborative process that enhances VMI (Vendor Managed Inventory) and CRP (Continuous Replenishment Program) by incorporating joint forecasting. The CPFR negotiation protocol between a supplier and a distributor proceeds in the following way:

- The negotiation starts between the distributor agent “AgentSCM” and his supplier agent “AgentSCM” as soon as one of them creates sales forecasts and informs the other about them.
- The receiver agent consults and analyzes these forecasts, then sends a confirmation to the sender or initiates a *firm* heuristic negotiation with him if he does not agree in order to modify these forecasts. In all the cases, the sender and the receiver must agree on sales forecasts then share them.
- Each one of them can be the author of a heuristic negotiation which resolves an exception (changes/updates) concerning the created sales forecasts. This heuristic negotiation is prone to become *recursive* to involve other agents being able to contribute to the resolution. The negotiation finishes when all the exceptions are resolved or the dynamically fixed delay is expired.
- The agent “AgentSCM” of the distributor sends a message of type INFORM to the agent “AgentSCM” of its supplier containing information about the level of its stocks (orders quantities, inventory quantities...).
- The agent “AgentSCM” of the supplier also answers by a message of type INFORM indicating its capacity and history of production, its lead times...
- At this stage, the negotiation concerning the sales forecasts is finished. A new negotiation begins between the two agents (distributor agent “AgentSCM” and his supplier agent “AgentSCM”) as soon as one of them creates orders forecasts and informs the other about them.
- Each one of them can be the author of a heuristic negotiation which resolves an exception concerning the created orders forecasts. This heuristic negotiation is prone to become *recursive* to involve other agents being able to contribute to the resolution. The negotiation finishes when all the exceptions are resolved or the dynamically fixed delay is expired.
- Finally, according to the situation, one of them creates firm orders, and then immediately informs the other about them.

Figure 8 illustrates the corresponding sequence diagram when the supplier deals with the creation of the forecasts of sales and the firm orders.

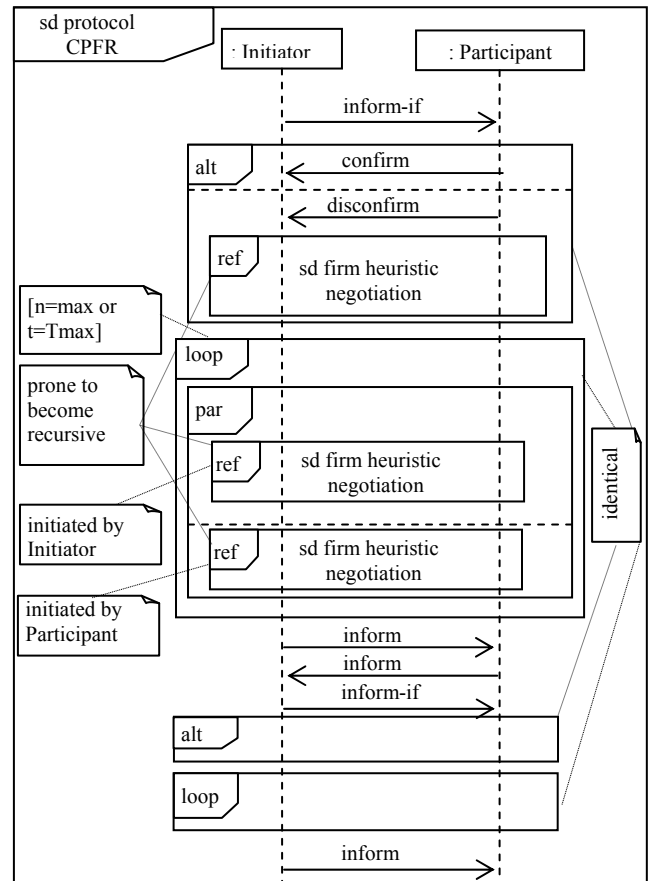


Fig. 8 – CPFR Protocol

### CASE STUDY

To test the proposed protocols, we considered a particular case (similar to the industrial cases) of SC in the textile and clothing sector including a central company (head office) located in a country and of two subsidiaries F1 and F2 located in two different foreign countries. The functions of supplying raw materials, manufacturing and delivering to stocks abroad are carried out by the central company. The functions of sales and delivery to the wholesalers are done by the subsidiaries. We have supposed that F1 distributes the products to two competitor wholesalers, while F2 distributes the products to two non-competitor wholesalers located in two different geographical areas. Each of the two non-competitor wholesalers uses CPFR protocol to collaborate with its distributor (subsidiary company F2). However, the two competitor wholesalers use a simple collaboration without sharing their data with their same distributor (F1), because they fear that their strategic information would be diffused. The final customers (retailers and consumers) have been represented by an agent that places two types of orders to the wholesalers:

- Pseudo-cyclic orders corresponding to a P1 product.
- Uniform random orders related to the stage of new fashionable product marketing, P2.

During simulation, we have chosen the performance indicator “Number of Backlogged Delivery” for the two subsidiary companies. It represents an out-of-stock for the wholesalers. Table 1 shows the results obtained throughout the period of simulation.

Table 1: Performance Indicator

	Subsidiary F1		Subsidiary F2	
	P1	P2	P1	P2
Number of Backlogged Delivery	4	11	1	4

Results comment:

- As to the product P2, we notice that the subsidiary F2's backlogged delivery number is only 4 while F1's number reached 11. The difference between the two numbers is relatively important in this case. This shows that the F2 subsidiary and its wholesalers got profit from determined sales forecasts and orders forecasts since they implement the CPFR process -especially as the nature of the P2 product orders is random uniform-. This kind of orders is difficult to control, because the actors (Head office, Subsidiary companies and Wholesalers) do not have the entire ability to predict the overall amount of sales and orders within a given market. It is the case of several fashionable products in the textile and clothing sector.

- Concerning the product P1, we notice that the subsidiary F2's backlogged delivery number is only 1 while F1's number reached 4. The difference is not relatively large, because the P1 product orders are pseudo-cyclic. I.e. these variations' orders are well known. It is the case of several products in the textile and clothing sector whose orders vary according to seasons of the year (tee-shirt for summer and coat for winter).

We deduce that the CPFR process used by the F2 subsidiary and its wholesalers reduced considerably the number of backlogged delivery. In effect, the wholesalers' out-of-stock will be reduced. This will have a good impact on the quality of the offered service within the satisfaction of the final customer policy.

This case study, which aims only at testing the proposed protocols, shows that more the level of collaboration increases, the better the performance indicator is. The level of collaboration can increase by choosing supply chain management strategies and practices based on the sharing of data (like CPFR) and by integrating several actors in the decision-making.

## CONCLUSION AND FUTURE WORK

In this paper, we presented the basis of a distributed architecture for proactive simulation to contribute to the collaborative decision-making in the supply chain. We proposed a generic model allowing a flexible modeling of the supply chain thanks to the multi-agent properties. The model, developed at this stage, makes it possible to test a set of negotiation protocols which we previously proposed and modeled with the AUML language. The given scenario shows that AUML diagrams offer effective solutions to specify and model real-world agent-based applications.

Considering the diversity of the platforms used by the industrial actors and the distributed nature of the SC, we have chosen the JADE development framework to develop the proposed agent-based distributed architecture.

The used tests are very promising and show that it is possible, by connecting the agents to the information systems of supply chain actors (APS or ERP, etc.), to bring an important help to the collaborative decision-making.

In the next stage of this work we will validate and enhance the components of the proposed architecture on some industrial cases from the textile and clothing sector.

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