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A multiagent based-model for the collaborative planning process in decentralized supply chain networks

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1. Introduction

The supply chain management process encompasses all the necessary activities to satisfy final customer demand by commonly considering the distribution of components and raw materials among supply chain members and how they interact to also coordinate their activities and decision-making process. In fact, Chatfielf et al. (2009) emphasize how the main information elements to be considered in the supply chain management process must cover node actions (orders, order filling, shipping, receiving, production, etc.), node policies (inputs and outputs inventory policies), and the costs and rates involved. Therefore a collaborative process will emerge by sharing the proper information. In addition, collaboration in supply chains is important in terms of innovation as partners realize the various benefits of innovation, such as high quality, lower costs, more timely deliveries, efficient operations and the effective coordination of activities (Soosay et al., 2008). Thus, the level of collaboration in the supply chain will depend on whether supply chain members are willing to share and/or exchange the information required to support their planning process. In addition, collaborative planning can be defined as an interactive process in which customers and suppliers collaborate and share information about their demand plans (Alarcón et al., 2008). Moreover, and from a centralized point of view, collaborative planning (among supply chain partners) can be achieved by a simple form of coordination of upstream planning by providing the collaboration partners an opportunity to modify suggested order/supply patterns iteratively (Dudeck and Stadtler, 2005).

In many cases however, this perspective is scarcely applied in terms of, for example, information confidentiality despite centralized information processing generating optimal solutions at the supply chain level. Nowadays, therefore, the trend is to move toward decentralized information processing to ensure independent supply chain interaction. Thus as Sadeh et al. (1999) establish, one of the best technologies to support this decentralized view of planning in supply networks is multi-agent systems. Some recent contributions to this subject are: Akanle and Zhang (2008); De La Fuente and Lozano (2007); Jung et al. (2008); Lu and Wang (2008) and Hernández et al. (2009). Therefore in order to establish a real contribution for supply chain agent-based modeling under a collaborative environment, this paper presents a collaborative planning model for supply chain networks by considering a multi-agent system modeling approach supported by JADE 3.6 and ECLIPSE.

This paper is set out as follows: Section 2 briefly reviews the relevant literature on multi-agent systems in the supply chain management under a collaborative planning context. Section 3 extends the last idea of collaboration to the decentralized perspective where the complex supply supplier configuration is considered. Then, Section 4 provides some experimental results to validate the proposal. Finally, Section 5 provides the main conclusions of the paper and also establishes a brief description of our future work.

2. Multi-agent systems to support the collaborative planning process in supply chain management (SCM): a brief review.

For a good number of years now, architectures (from an enterprise modeling perspective) have been considered to define and represent complex systems, some of which are framed in the SCM field. In relation to this, architectures are oriented to identify and establish the main elements of the system and the representations of their relationships. Moreover from a conceptual viewpoint, and as already studied in Davis (1993), Hernández et al. (2008a), among others, there are three types of these representations: informal, semi-formal and formal. Therefore, the architecture will be composed of all the necessary elements from a formal point of view (or representation). Moreover, one of the representations that is becoming more widely accepted is that related to object-oriented programming, more specifically the UML (Odell et al. 2000) notation with the multi-agent-based model paradigm. Thus, in order to detect the main concepts and aspects, this subsection sets out to present the most relevant information considered in this field to carry out the architecture proposal of this paper. Full information about this field can be found in Bousqueta and Le Page (2004) and Shen et al. (2006) where full surveys and state of the arts can be found.

Thus in the SCM context, one of the first architectures was presented by Ba et al. (1997) in which a client-broker-server architecture is presented. This architecture considers five elements to support effective and coordinated operations by accessing and using the proper information at the right time (web clients, agents, directories, knowledge and a MIS broker). In this same way, Ulieru et al. (2000) propose an architecture to collaboratively support a recursive and multi-resolution process by considering multi-agents. Moreover, and as the authors establish, the agent as a coordination mechanism presents a solid foundation for the development of cooperative applications in global manufacturing processes. Furthermore, this architecture, as proposed by Ulieru (2000), comprises three main layers: the first supports the communication process, the second manages coordination and cooperation processes by considering intelligent communication mechanisms, while the third categorizes each agent in the system (interface, collaboration, knowledge management, applications and resources). Moreover in the knowledge management context (by considering the information exchange process), organizational memory involves knowledge being managed. Therefore, Chang et al. (2004) propose an architecture to facilitate organizational memory in supply chains which considered two layers; the storage layer and the facilitation layer; which represent the task and knowledge domain and harmony mechanisms, respectively, and use knowledge. In addition, these harmony mechanisms, as proposed by Chang et al. (2004), are supported by agents, collaborators, transactors, objects and registry facilitators. To support this, Ortiz et al. (2003), establish that virtual and/or extended enterprises should be considered to promote cooperation in exchanging flows of information and knowledge, material and services, etc. In the same context, Nahm and Ishikawa (2005) consider the robustness presented by the multi-agent system and proposed a novel architecture to support inter-enterprise functions/resources integration and collaboration in a networked context. Furthermore, the proposed architecture enables agents to display hybrid (continuous and discrete) behaviors and interaction. Another relevant contribution in this field for the proposed architecture is that by Chen et al. (2008)

who present a decoupled federated architecture to support facts like distributed simulation cloning, fault tolerance, interoperability and grid-enabled architectures. As a generic way in which reviewed architectures have been proposed, they can be presented as frameworks with which to develop other architectures in order to detect the main elements and relationships that might exist among them. Therefore, the following section considers all the valuable architecture elements of this section and uses a well-known and accepted enterprise framework to propose a multi-agent-based architecture to support the collaborative processes in the supply chain in a decentralized context.

3. The decentralized collaborative planning agent-based model for supply chains

By considering the review presented in the previous section, we may state that the collaborative process represented in Figure 1 as the STATE diagram aims to promote information exchange. In this context, the main purpose of the proposed architecture is to show the informational flows that might support collaboration among nodes. In this sense, we may say that collaboration involves many types of processes of which the most important are forecasting, planning and replenishment processes. In a collaborative context, these processes relate to the exchange of the demand plans which will eventually imply the consideration of a tactical perspective within the decision-making process. Additionally, and in a supply chain management context, there are other relevant processes that foster collaboration such as forward and reverse logistics, requesting management, inventory control, key performance indicators, and so on. Thus, in order to conceptually and graphically explain the collaborative process among the supply chain nodes, this architecture focuses on the planning process as the main information (demand plans) exchange engine in order to support the decision-making process.

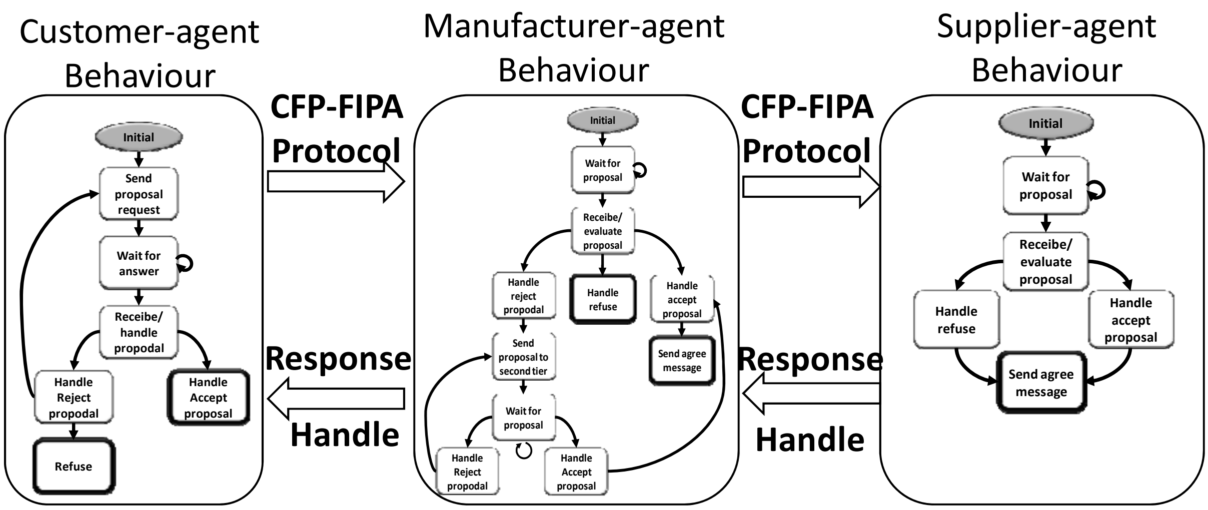

Figure 1. Decentralized multi-agent collaboration planning behavior in supply chains based on the state diagram.

Moreover and from the perspective of each node, it is possible to state that collaboration in the supply chain firstly considers the identification of collaborative and non collaborative nodes. Therefore, the relationship among the collaborative nodes will be supported by the demand plan exchanging process, which will collaboratively promote the negotiation of unfeasible values. Hence by considering a longer horizon plan, the capacity to react to some unexpected demand plan requirement will improve. Thus, by conspiring the advancement of orders or by changing the respective safety stock, respective suppliers will be able to react to the uncertainty in demand by avoiding an excess of orders or by maintaining a sufficient stock of materials in order to effectively and efficiently cope with changes in orders. Then in terms of the supply chain, the order may be accepted, negotiated or rejected. So, the negotiation process takes place when the supply chain configuration is in such a state that suppliers of suppliers will exist, and the information exchange (inherent in the decision-making process) will involve several supply chain several nodes which, in turn, will imply that the nodes will exchange the proper and timely information needed to cover possible backlogs in the production planning process from upper and lower supply chain tiers in a collaborative and decentralized manner.

4. Decentralized collaborative planning supported by the FIPA-ACL interaction protocol

In the supply chain modeling context, the agent-based model not only represents each node, but also the information sharing process among these nodes. Despite the complexity of the configuration, the agent-based model can be applied straightforwardly to support the collaborative planning process. Moreover, the proposed model (Figure 2) considers three supply chain agent-based nodes (customer, manufacturer and supplier) of decentralized distribution, whose logic process communication has already been defined in Hernández et al. (2008b). In addition, the communication process among the agents is supported by behaviors aimed to generate demands and firm orders to identify collaborative or non collaborative agents, and to also send and receive the corresponding messages by considering the FIPA standard communication protocols.

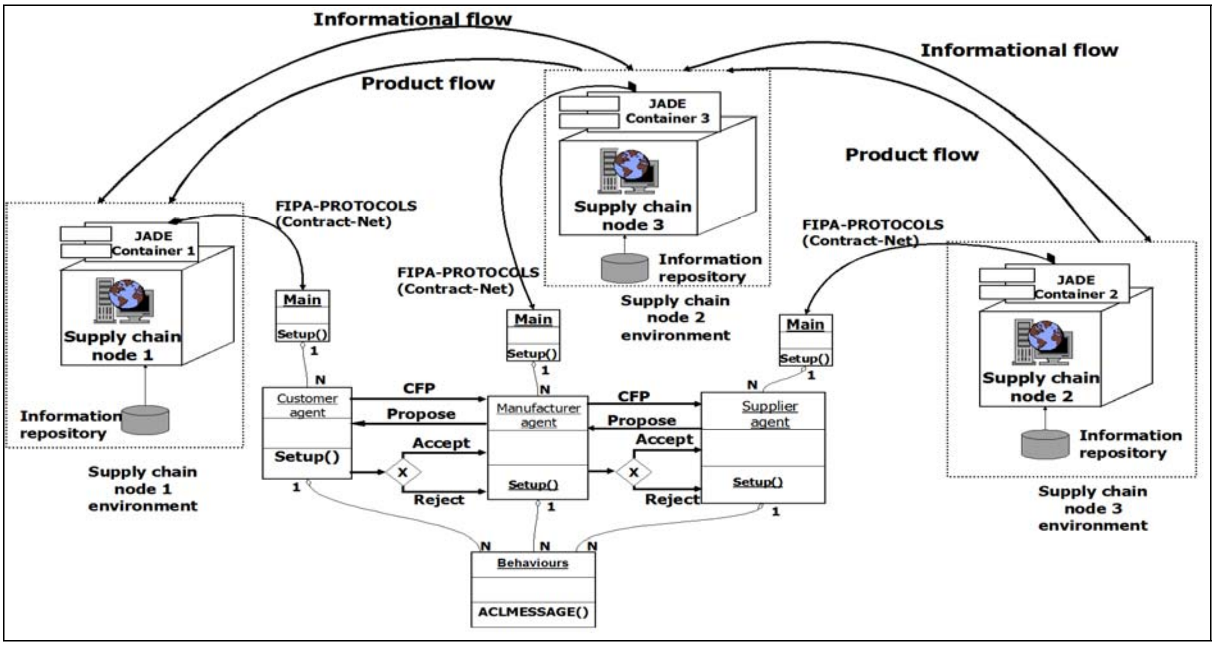

Figure 2. Particular decentralized supply chain network agent-based model (a UML-based model).

As Figure 2 illustrates, the decentralized process (supported by the multi-agent system) can be observed from three points of views. The first is a technical point of view oriented to consider different information repositories in order to share information properly. These repositories (or databases) will be accessed by the related agent which will merely search for the proper information to support the supply chain nodes' decision-making process. Therefore, this agent will be a class instantiated by the related supply chain agent. Figure 3 is an example of this implementation.

```
protected void setup(){
try {
Class.forName("com.mysql.jdbc.Driver").newInstance();
conextion = DriverManager.getConnection(url,“xxxx", “yyyy");
conextion.createStatement();
}
catch (Exception e) {e.printStackTrace(); }
this.addBehaviour(new BDBehaviour(this));
```

Launching the DataBase agent behaviour

```
⋮

public void action() {
ACLMessage message = blockingReceive();

if (message!=null){
switch(msg.getPerformative()){
case ACLMessage.QUERY_REF:
```

Accessing the database with messages

```
try {
String content = message.getContent();
//System.out.println(“DataBase content"+content);
if (contentcompareTo("getPedidos")==0){
ArrayList ordesr =(ArrayList) this.getPedidos();
ACLMessage reply = message.createReply();
reply.setPerformative(ACLMessage.INFORM);
reply.setContentObject(orders);
reply.setSender(getAID());
send(reply);
⋮
private ArrayList getDemandPlan(int i) {
ArrayList<Order> result = new ArrayList<order>();
```

Demand plan

```
try {
Statement stmt = content.createStatement();
ResultSet values = stmt.executeQuery("" +
"SELECT * " +
"FROM UPV.ExpectedRequest" );
⋮
while (values.next()){
Pedido PROC= new order();
aux.setIdProduct(values.getInt("idProduct"));
aux.setQuantity(values.getInt(“Quantity"));
aux.setDeliveryDate(values.getInt(“DeliveryDate"));
aux.setOrderDate o(values.getInt(“OrderDate"));
aux.setrange(values.getInt(“range"));
```

Process ontologies

```
result.add(PROC);}
}
catch (Exception e) {
e.printStackTrace();
}
return result;
```

Figure 3. JAVA/JADE DataBase Agent structure (example).

It is important to highlight that in order to promote the collaboration process, it is also important to consider common communication information. Figure 3 indicates the ontologies that the DataBase agent considers to access the related database.

The second point of view can be seen from the information flow. Thus, the information flow (from a decentralized perspective) will consider facts in relation to a certain necessity, the natural flow will be stopped until the initial request has been served and, therefore, the collaborative planning-related decision-making process will include the information from all the supply chain nodes concurrently. Finally, the last point of view is regarded as the implementation of each node that JADE carries out. In this context, each node will consider its own containers in order to carry out the related (or internal) processes which will support the security requirements of the related supply chain nodes, and the agents will interact with each other by negotiating orders, prices, dates, etc. by considering the two aforementioned points of view.

4.1. Simulation experiments

As explained in the previous subsection related to the decentralized collaborative planning process, supported by the multi-agent system, this section shows the current version of the multi-agent system process (See Figure 4) to support the decision-making process of automobile supply chain stakeholders. The prototype has been developed in a free open source tool, such as ECLIPSE, by considering the JADE 3.6 library to support the whole agent communication process, which is mainly supported by the Contract-Net protocol. Then, as agents consider their own thread, it is possible to use them to interconnect the different nodes from other supply chains situated in other geographical locations.

In this case, the model obtains its data from an MySQL database via connections with the agent systems. In this context, and in order to adequately support the data exchange process, we considered a database agent for the purpose of establishing a database connection that does not depend on other agents.

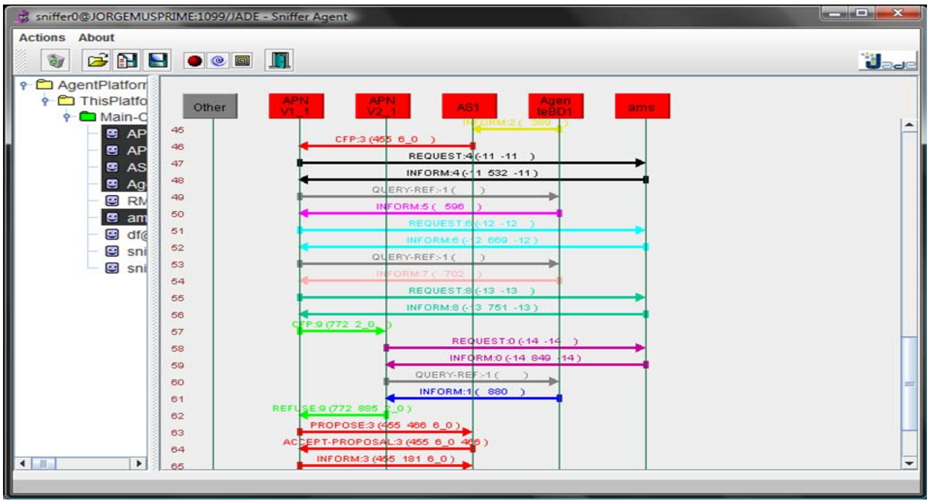

Figure 4. Structure/negotiation validation though SNIFFER/JADE 3.6.1.

The application calls the JADE RMA agent, which shows us the SNIFFER agent with some of the most relevant ACLMessages. These are relevant because SNIFFER shows a decentralized conversation among agents. This means that if we consider a dialog between two agents, the answers will sometimes not depend on the two agents themselves, but also on a third agent, for example. Finally to test some experiments, a simple supply chain configuration has been selected (customer, first-tier supplier and second-tier supplier). Hence, the idea is to contrast the impact which, via collaboration in the demand plans, the change in the demand plans implies at the service level. To carry out this experiment, random data between 20 and 80 have been considered. Moreover as both graphs display (Figure 5 and Figure 6), a clear impact exists at the service level, in which case 50% of demand visibility has been considered.

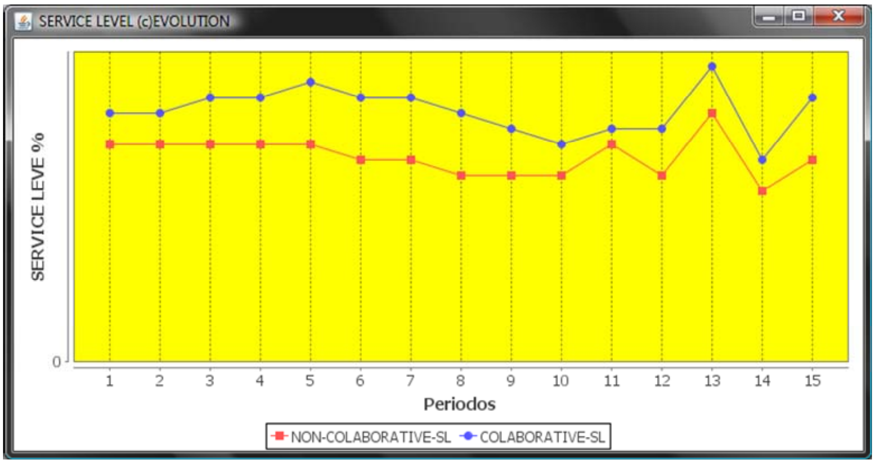

Figure 5. Service level evolution (example).

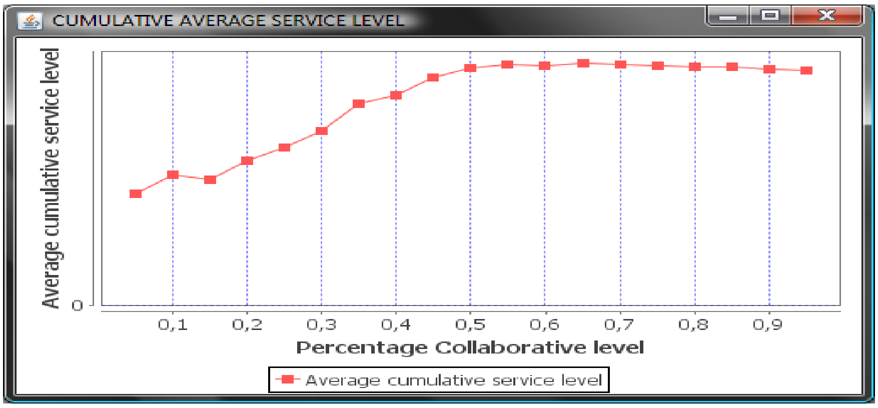

Figure 6. Cumulative average service level.

Since two options have been marked (collaborative and non collaborative) we may see how increased collaboration might finally have an impact at the service level. Since it is not possible to share all the information for the impact to become totally collaborative, it is important to find a minimum level of collaboration because this may increase the node's benefits.

4.2. Limitations

Simulation experiments were done with the enterprise network herein described. Thus, the main limitations are that no proposed model offering an economical impact has been shown and that a theoretical experiment sample has been defined. Therefore, the system should be tested further with the firm's results in order to observe the real impact or effect on the decision-making process.

5. Conclusions

The objective of collaborative planning is not only to improve the accuracy of the decision-making process but to also establish links between internal and external information to improve supply chain performance. Moreover, an agent-based model is presented as a robust and straightforward way to represent the collaborative processes in decentralized supply networks for the planning process. In addition, multiagent-based technology has been considered to support the experiments of a decentralized supply chain. Future research is expected to (1) test this decentralized collaborative planning proposal with other similar existing proposals in the scientific literature, (2) develop a robust negotiation function to consider the main fields of the negotiation process related to collaborative planning and (3) apply this architecture to a real supply chain.

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