A Supply Chain Architecture Based on Multi-Agent Systems to Support Decentralized Collaborative Processes

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Abstract. In a supply chain management context, the enterprise architecture concept to efficiently support the collaborative processes among the supply chain members involved has been evolving. Each supply chain has an organizational structure that describes the hierarchical relationships among its members, ranging from centralized to decentralized organizations. From a decentralized perspective, each supply chain member is able to identify collaborative and non collaborative partners and the kind of information to be exchanged to support negotiation processes. The same concepts of organizational structure and negotiation rules can be applied to a multi-agent system. This paper proposes a novel supply chain architecture to support decentralized collaborative processes in supply chains by considering a multi-agent-based system modeling approach.

Keywords: Enterprise architecture, Supply chain management, Multi-Agent Systems, Collaborative decision-making.

1 Introduction

Nowadays, market trends move toward a clean and natural business integration, which means that companies (according to both their current behaviour and own initiative) head toward establishing coordination/collaborative mechanisms in order to improve those aspects which, for example, are not as competitive as they used to be. Moreover, [3] consider that this integration may be achieved in terms of the knowledge that companies acquire from the environment, and vice versa. Therefore, as companies tend to work together by considering a specific matter, supply chain management (SCM) concepts emerge with a view to considering, in the first place, the perspective of each company and, in the second place, the perspective from the whole system (the supply chain). This management process involves planning at every decision-making level (strategic, tactical and operative [22]), and also aims to find the best possible supply chain (SC) configuration [13].

Thus at the tactical-operational planning level, the master planning (MP) task plays a crucial role (coordination problem). The coordination process of autonomous, yet inter-connected, tactical-operational planning activities refers to collaborative planning (CP) in whatever follows [8]. This CP means that the decision-making process will be supported by the exchange of demand plans in order to timely conduct and set possible future problems related to, for example, the capacity availability or to the defined inventory level in order to meet any sudden changes in orders at all times. In this context and from a decentralized collaboration viewpoint, each node considers their collaborative and non collaborative partners (customers and suppliers) [18]. In this way, we may state from the study of [6] that information fields can be used as the basis to coordinate an organization, which can be seen as a collective agent composed of other individual collective agents that may encompass multiple embedded information fields. Moreover, [9] view a SC as a composed set of intelligent (software) agents (responsible for one or more activities and for the interaction with other related agents in planning and executing their responsibilities). In addition, [10] explains the relationship between inter-firm coordination mechanisms and the interdependence characteristics among the actors involved in implementation based on a multi-agent approach. In this context, and as will see in Section 2, most of the current contributions to support collaboration in supply chains consider a centralized approach to manage the information exchange process. Hence the contribution of this novel architecture is the reason for considering a decentralized information exchange process representation in a collaborative manner in which multi-agent system technology has been considered to support this enterprise architecture, which not only considers the related negotiation process among the SC nodes, but also the objectives and constraints from the upper SC level to lower N-tier supplier levels.

Therefore, this paper is set out as follows: Section 2 briefly reviews the relevant literature on architectures in the SC in a collaborative context. Section 3 shows the main elements of the proposed architecture using the Zachman enterprise framework in which an N-tier SC supplier configuration is considered. Finally, Section 4 provides the main conclusions of the paper and also establishes a brief description of our future work.

2 Background

In the SCM context, enterprise architectures have been considered to define and represent complex systems by considering, in many cases, the different points of view within the same problem or the configuration that may be considered. In addition and in relation to [7], [11], among others, there are three types of representations from a conceptual viewpoint: informal, semi-formal and formal. Therefore, the proposed architecture will be composed of all the necessary elements from a formal point of view (or representation), such us the conceptual, logical and physical elements. Hence a modeling language that is currently being widely considering is the UML [16], which has been enriched with the multi-agent-based model paradigm. Thus this sub-section presents the most relevant literature in the SCM modeling field in order to carry out the architecture proposal of this paper. Further detailed information on this field can be found in [2] and [19] where full surveys and state of the arts can be seen.

In this context, one of the first SC architectures was presented by [1] which considers five main elements to support effective and coordinated operations (web clients, agents, directories, knowledge and an MIS broker). In the same way, [21] propose an architecture that collaboratively supports a recursive and multi-resolution process by considering multi-agents. Furthermore, this architecture proposed by [21] also considers three main layers which aim to support communication, manage the coordination and cooperation processes and categorize each agent within the system. Likewise, [4] propose an architecture that facilitates the organizational memory in SCs. To go about this, two layers are considered (storage and facilitation). Thus, these harmony mechanisms, as proposed by [4], are to be supported by agents, collaborators, transactors, objects and registry facilitators. In relation to this, [17] establish that virtual and/or extended enterprises should be considered to cooperatively support information exchange, material and services. In this same context, [14] propose a novel architecture to support the inter-enterprise functions/resources integration and collaboration under a networked context by considering the robustness of the multi-agent system which enables agents to exhibit hybrid (continuous and discrete) behaviours and interactions. Finally, another contribution in this field is that of [5] who present a decoupled federated architecture to support distributed simulation cloning, fault tolerance, inter-operability and grid-enabled architectures. Hence as the way in which the reviewed architectures have been proposed is generic, they can be presented as frameworks from which other architectures are developed in order to detect the main elements and relationships that may exist among them. Therefore the following section not only considers all the valuable architecture elements obtained from this section, but also the main existing frameworks in the literature, as well as the Zachman enterprise framework to support multi-agent-based architecture which takes into account the collaborative processes in the SC in a decentralized context, mainly regarding their multi-dimension perspective.

3 A multi-agent-based architecture to support the collaborative processes in supply chains

As we have seen in the last section, most of the authors suggest considering a framework to carry out the enterprise architecture development process. Moreover, the right selection of a framework will depend on the modeler's experience and how robust it can be in the environment to which is to be applied. In this context, the Zachman Framework [23] has been chosen to represent the main elements of the architecture based on multi-agent systems which will support the collaborative processes in the SC. In this context, an X node will represent the upper level (customer), a Y node the first-tier supplier and a Z node the supplier at the lower level (second- or N-tier supplier).

Moreover, the Zachman framework considers a total of thirty cells to represent different views of an enterprise architecture that primarily aims to identify aspects of the people involved in the process such as what, how, where, who, when and why, as well as those aspects related to the representation of processes such as: context, concepts, logic, physical, performance and content. In this way, only the five most representative cells are taken into account to represent the decentralized collaborative process in SCs with a view to favoring the simplicity of the representation and to not overextend the proposed architecture.

Therefore, the cells selected from the Zachman framework grid [20] have been chosen to collect and transmit the related information from the SC nodes which are intended to participate in a collaborative process as collaborative or non-collaborative nodes. The information flow takes place in this context, firstly at the upper level of the Zachman grid (Enterprise model/Why) to identify the main motivation (Model 1) and the collaborative process goals. Because they are supported by these flows, the related models are developed to obtain the business process (Model 2, Enterprise model/How), logical data (Model 3, System model/What), role (Model 4, System model/Who) and the control structure model (Model 5, Technology-constrained model/When). Thus, the following subsections show the model representation related to each selected cell by considering, on the one hand, the representation proposal of [15] and, on the other hand, the collaborative UML-based framework by [12].

Thus, the collaborative process, represented in the Figure 1 as BPMN diagram, is oriented to promote the exchange of information. In this context, the main purpose of the proposed architecture is to show the informational flows which supporta the collaboration among the SC nodes. In this sense, it is possible to say that the collaboration involve much type of processes, being ones of the more important the forecasting, planning and replenishment processes. These processes, under a collaborative context, will be related to the exchanging of the demand plans which, at the end, will imply to consider a tactical perspective in the decision-making process. In addition important to highlight is that, under a SCM context, there are many relevant processes in order to foster the collaboration such as forward and reverse logistic, requesting management, inventory control, key performance indicators among others. Thus, in order to explain in a conceptual and graphical manner the decentralized collaborative process (among the nodes of the SC), this architecture will be focused in the planning process as the main information (demand plans) exchange engine in order to support the decision-making process.

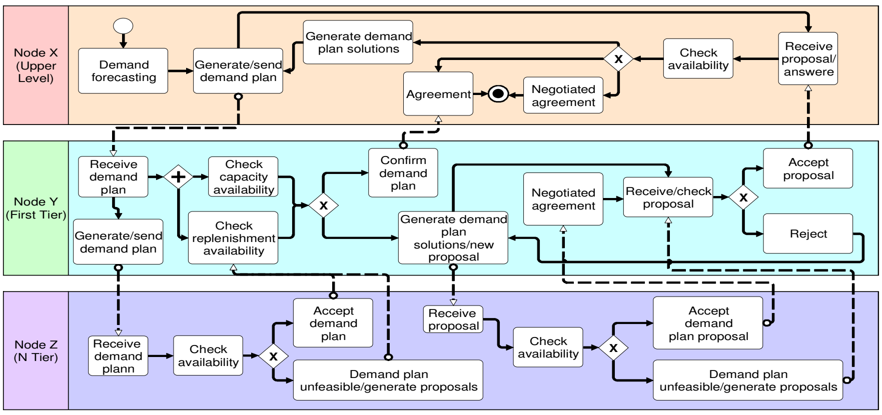

Figure 1. Generic decentralized collaborative process (BPMN – Model 1).

Moreover from the perspective of every node, it is possible to state that the collaboration in the SC firstly considers the identification of the collaborative and non collaborative nodes. Therefore, the relationship among the collaborative nodes will be supported by the demand plan exchanging process (Figure 1), which will promote the negotiation of the unfeasible values in a collaborative manner. Hence by considering a a longer horizon plan, the capacity to react to some unexpected demand plan requirement will be improved (and example of this may be found in [13]) Thus by conspiring the advancement of orders or by making changes in the respective safety stock, the respective suppliers will be able to react to uncertainty in demand by avoiding excess orders or by maintaining a sufficient stock of materials to effectively and efficiently cope with changes in orders. Under the SC terms, the request may be accepted, negotiated or rejected. So the negotiation process takes place when the SC configuration is such that suppliers of suppliers will exist. Then the information exchange (inherent in the decision-making process) will involve several SC nodes which will, in turn, imply that the nodes will exchange information properly and timely to cover possible backlogs in the production planning process from the upper and lower SC tiers in a collaborative and decentralized manner (Figure 2).

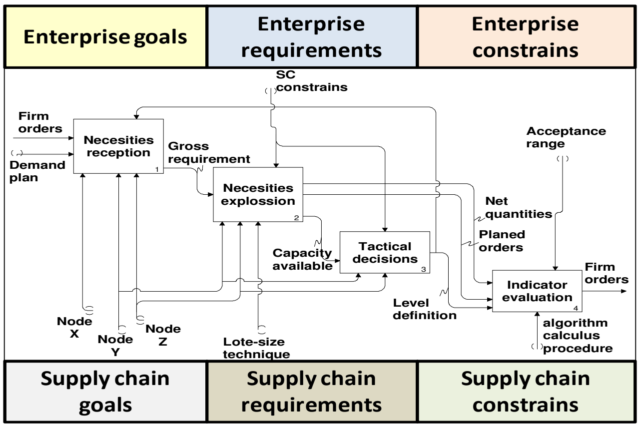

Figure 2. Business process model (IDEF0 – Model 2).

3.1 Agent-based model specification to support decentralized collaborative planning

Based on the previous subsection, the specification of the model is firstly defined by the agent role in the SC. Thus it is possible to define three roles from Figure 2: the “X node” role which will only generate a demand pattern and will receive offers; the “Y node” role which will receive proposals and, depending on the condition, will generate another demand at a lower level node that will be identified by the “Z node” role. Each agent, with their related roles (Figure 3), will interact and negotiate according to their own capacities with a view to solving order requirements.

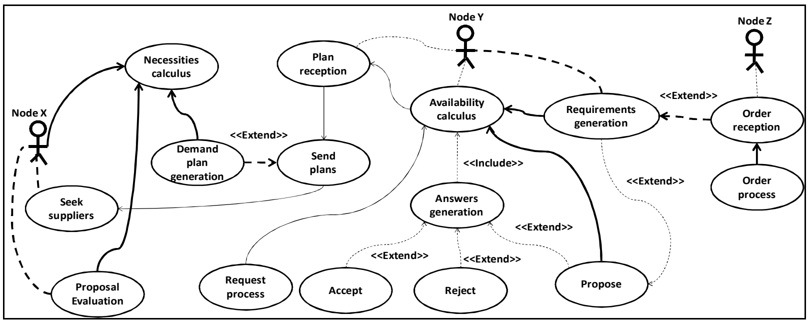

Figure 3. Agent role interaction (UML Use Case – Model 3).

This interaction process is supported by the corresponding methods and attributes that each agent considers as they are instances of the agent class (Figure 4). Hence, from one side, the supply chain nodes consider (under a one-to-many relationship oriented) the related ontology's in order to support the planning process (delivery time, request, product and stock register). In addition, from the other side, each node considers their behaviours (under an agent-based model approach). Thus, as the decentralized collaboration and negotiation, the behaviours considered are supported by the FIPA-ACL-Protocol to model each agent class. In this context, the classes consider behaviours to support the related protocol communication and ontologies which promote the interoperability among them by considering the Knowledge Query and Manipulation Language (KQML) standard (Figure 5). Therefore, decentralized collaboration, which in many cases will require a negotiation process, is supported by (Figure 6) the ContractNet FIPA-Protocol (CFP) that has been implemented in ECLIPSE and validated through the SNIFFER agent of the JADE 3.6.1 platform (Figure 7).

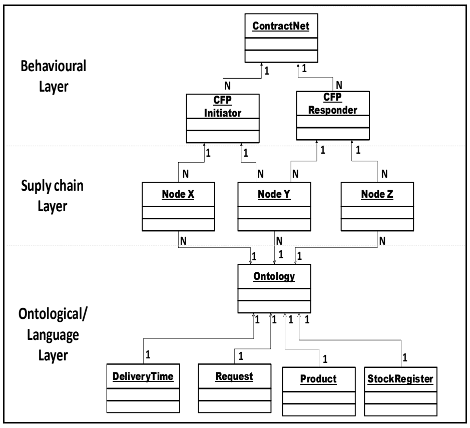

Figure 4. UML class diagram (Model 4)

```
(CFP
 :sender Node Y
 :receiver Node Z
 :content sr idProductoI sr
 :reply-with R1239169453235_0
 :reply-by 20090408T054418223Z
 :protocol fipa-contract-net
 :conversation-id C20275290_1239169453235 )

(PROPOSE
 :sender Node Z
 :receiver Node Y
 :content quentity
 :reply-with Node_Y@JORGEMUSPRIME:1099/JADE1239169453331
 :in-reply-to R1239169453235_0
 :protocol fipa-contract-net
 :conversation-id C20275290_1239169453235 )

(CFP
 :sender Node Y
 :receiver Node Z
 :reply-with Node_Z@JORGEMUSPRIME:1099/JADE1239169453368
 :in-reply-to Node_Y@JORGEMUSPRIME:1099/JADE1239169453331
 :protocol fipa-contract-net
 :conversation-id C20275290_1239169453235 )

(ACCEPT-PROPOSAL
 :sender Node Y
 :receiver Node Z
 :reply-with R1239169453372_0
 :in-reply-to Node_Y@JORGEMUSPRIME:1099/JADE1239169453331
 :protocol fipa-contract-net
 :conversation-id C20275290_1239169453235 )

(INFORM
 :sender Node_Y
 :receiver Node_X
 :reply-with Node_X@JORGEMUSPRIME:1099/JADE1239169453446
 :in-reply-to Node_Y@JORGEMUSPRIME:1099/JADE1239169453439
 :protocol fipa-contract-net
 :conversation-id C27532487_1239169452680 )
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Figure 5. CFP KQML code (extract)

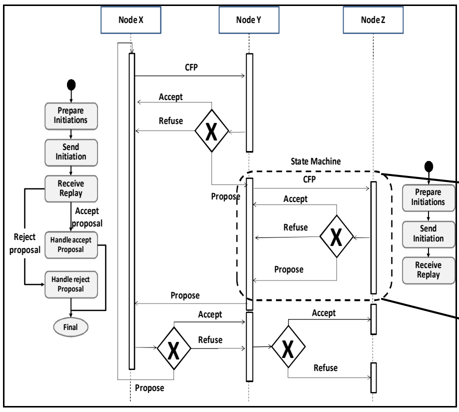

Figure 6. Sequence and state UML diagram of decentralized SC collaboration (Model 5)

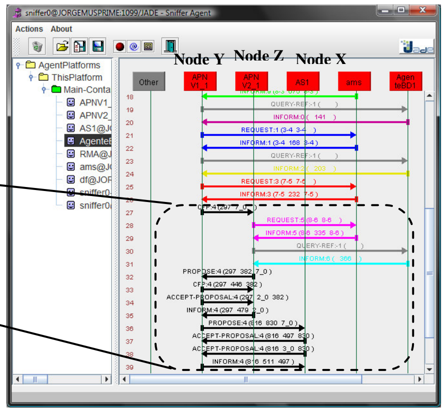

Figure 7. Structure/negotiation validation through SNIFFER/JADE 3.6.1

4 Conclusions and further research

This paper has presented a novel architecture proposal based on multi-agent systems to support the decentralized collaboration process in SC networks which also considers the Zachman enterprise framework. Furthermore, we may conclude that agents are an appropriate tool for collaborative process modeling from a decentralized perspective which has been defined by considering the information coming from the collaborative and non-collaborative SC nodes. As further research objectives, we expect to (1) apply this architecture to study the collaboration in SC with another modeling approaches such us mathematical models, discrete event-based simulation, among others and (2) apply this architecture to a real SC.

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