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► **To cite this version:**

Yacine Ouzrout, S. A. Hossain, Olivier Lavastre, Ludivine Chaze-Magnan, Carine Dominguez-Pery. Multi-Agent Model of Supply Chain Management Trust in PLM. 7th International Product Lifecycle Management Conference (PLM'10), Jul 2010, Bremen, Allemagne. 10 p. <halshs-00641242>

**HAL Id: halshs-00641242**

**<https://shs.hal.science/halshs-00641242v1>**

Submitted on 8 Mar 2019

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## Multi-Agent Model of SCM Trust in PLM

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**Abstract:** A supply chain management (SCM) is the management of network having interconnected business nodes which spans all movements of services and goods from the point of origin to the point of consumption through chaining the services within the network. In the context of SCM within PLM, Trust modeling is an important and crucial aspect from the perspective of sustainability of the supply chain and to gain efficient performance in management of product life cycle. In the supply chain, the more we trust, the more we exchange information on demand and on forecast of the last customer so as with the level of stock and on the forecast of the suppliers. In this work, we attempted to model the Trust in SCM for using Agent Modeling Language (AML) and proposed a Multi Agent System (MAS) SCM model of trust in supply chain management for PLM. The proposed model is implemented using Java Agent Development Environment (JADE) and the simulation results demonstrated the impact of trust in supply chain along with the evolution of trust.

**Keyword :** PLM, Supply Chain, SCM, MAS, Trust Model, JADE

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### 1 Introduction

The Product Lifecycle Management (PLM) broadly defined within the information system that support the management of a portfolio of products, related processes and services from initial concept, through design, launch, production and use with maintenance to the final disposal. The interactions across the systems co-ordinate products, projects and process information throughout new product conceptualization, introduction, production, service and retirement among the different players, internal and external to the Original Equipment Manufacture (OEM) who collaborates to bring the concept to product [1].

The information system maintains a vault, which may be physically distributed, but has a single logical index within the context to all the documents containing product, project and process information. The PLM information systems use workflow and authorization

rules to give authenticated access to the protected information. The various processes of new product concept, introduction, production, service and retirement use a single source of product information. Most often Internet browser based access with viewer plug-ins provides access to the information through a authorised profile on an extranet at any place and any time. The granularity of access is by file or document or even higher defined hierarchy of the modules [1].

Besides, the PLM information systems contain sub-systems which provide necessary product information to the supply chain to facilitate the production as well as end of life management. A supply chain interface to PLM information system is undoubtedly an value-creating network that comprises suppliers, warehouses, manufacturers, wholesalers, and retailers as well as the product information system PLM.

The supply chain in virtual organization form requires trust as one of the core ingredient to sustain and the general finding suggest that trust act as a buffer to facilitate the required agreements and execution of transactions in the context of the virtual organization in the supply chain scenario. The trust fosters the willingness within the parties to cooperate and reduce the transaction costs and this in turn increase the value [1].

Agent Modeling Language (AML) is a well known approach used for the flexible implementation of multi-agent interactions, which comprised of interacting autonomous agents having behaviour intelligence. This research work is a joint effort of social and computer sciences toward the understanding of trust in supply chains. More precisely, we did research to understand the strengthening or weakening of trust as well as the effect on the performance of SC in PLM. The goal of this paper is to propose an AML model for modeling and simulation of trust in supply chains for PLM through transformation of trust model in MAS.

This paper is organized as follows: Section 2 reviews related research on the issues of supply chain management in PLM. Section 3 introduces modeling using AML for MAS. Section 4 presents the case study of SCM in PLM and the trust model and simulation experiments are illustrated in Section 5. Section 6 gives results and discussion and conclusion.

## **2 PLM and Supply Chain Management**

The PLM addresses the product's life cycle which is a period usually consists of five major steps or phases: Product development, Product introduction, Product growth, Product maturity and finally Product decline. These life cycle phases exist and are applicable to all products or services from a certain make of automobile to a multimillion-dollar lithography tool to any electronic parts. All these phases can be split up into smaller ones depending on the product and must be considered when a new product is to be introduced into a market since they dictate the product's sales performance [2].

Product development phase begins when a company finds and develops a new product idea. This involves translating various pieces of information and incorporating them into a new product. The introduction phase of a product includes the product launch with its requirements to getting it launch in such a way so that it will have maximum impact at the moment of sale. The growth phase offers the satisfaction of seeing the product take-off in the marketplace. This is the appropriate timing to focus on increasing the market

share. If the product has been introduced first into the market, (introduction into a “virgin”<sup>1</sup> market or into an existing market) then it is in a position to gain market share relatively easily. A new growing market alerts the competition’s attention. When the market becomes saturated with variations of the basic product, and all competitors are represented in terms of an alternative product, the maturity phase arrives. In this phase market share growth is at the expense of someone else’s business, rather than the growth of the market itself. This period is the period of the highest returns from the product. The decision for withdrawing a product seems to be a complex task and there a lot of issues to be resolved before with decide to move it out of the market. Dilemmas such as maintenance, spare part availability, service competitions reaction in filling the market gap are some issues that increase the complexity of the decision process to withdraw a product from the market [3, 4].

On the other hand, a supply chain is defined as a network of suppliers, factories, warehouses, distribution centers, and retailers through which raw materials are acquired, transformed, and delivered to customers [3], [4] within the network. This covers different activities from the earliest level of incoming raw materials from different suppliers through the internal processes in an industry and on to the outgoing products through the distribution and marketing channels. This leads to supply chain as the planned continuous improvement of processes and relationships which exist to support the movement of these products and services through the supply chain.

Since the production phase has all the actors of supply chain management, there is a great emphasis on the integration of PLM and SCM. This integration facilitates the product information sharing of OEM with the suppliers and other partners of SCM. As a result of this integration, PLM life cycle activities collaborate closely with the SCM which reduces the lead time as well as the performance of the product marketing.

Trust is considered as a necessary prerequisite to product information sharing of PLM within the supply chain network. The research review indicates that Lee and colleagues [5] were the first to identify information asymmetry as the main reason for the amplification of the demand signal and fluctuation of inventory level along a supply chain network. Besides, information sharing can also yield to other advantages such as reducing costs, improving service levels, and reducing lead times and stock outs and other related PLM and SCM performance factors [7-8].

### **3 Trust Model of SCM in PLM**

In general, a trust is a relationship in which one person holds title to property, subject to an obligation to keep or use the property for the benefit of another. Trust plays the most critical role in a committed and collaborative relationship between supply chain partners. If trust is present, it can improve the chances of a successful supply chain relationship; if not, transaction costs can rise through poor performance.

Based on the literature survey and from a critical review of literatures of a qualitative survey of supply chain management, we figured out different variables (or criteria) of the trust as the following [9] :

1 - Honesty (ex: the supplier's compliance with contract); 2 - Credibility (ex: the supplier always keeps its commitments); 3 - Experience (ex: the supplier is aware of good practices and has the knowledge necessary to meet my needs) ; 4 - Jurisdiction (ex: the advice we give our partner

we are useful.); 5 - Sincerity (ex: the supplier is frank and honest); 6 -Predictability (ex: the supplier has no opportunistic behavior); 7 - Transparency (ex: what we shared provider of comprehensive information on its processes); 8 - Goodwill (ex: the supplier is prepared to take extraordinary measures to respond as appropriate to our needs); 9 - Commitment (ex: the supplier invests in the relationship); 10 - Respect the confidentiality of information exchanged (ex: the provider respects the confidentiality of information that I provide it); 11- Communication skills (ex: the supplier meets our needs through effective communication) ;12 -Shared values (ex: suppliers that share the same moral values as us);13 - Similarity (ex: the supplier and we belong to the same network); 14 - Sharing working methods (ex: the supplier and we agreed on all processes that are common or individual); 15 - Influence in the network (ex: the supplier is recognized in the work network) -Sharing information, type of information shared

The trust calculated using a weighted average of all the defining criteria as shown in equation 1.

$$C_c = (\alpha.Ho + \beta.Cr + \gamma.Ex + \delta.Co + \varepsilon.S + \zeta.Pr + \eta.T + \theta.Bv + \iota.En + \kappa.Rp + \lambda.Ha + \mu.Pv + \nu.Rs + \xi.Pt + o.I) / (\alpha + \beta + \gamma + \delta + \varepsilon + \zeta + \eta + \theta + \iota + \kappa + \lambda + \mu + \nu + \xi + o) \quad (1)$$

where  $C_c$  = Trust Behavior;  $Ho$  = Honesty;  $Cr$  = Credibility;  $Ex$  = Experiment;  $Co$  = Competence;  $S$  = Sincerity;  $Pr$  = Predictability;  $T$  = Transparency;  $Bv$  = Goodwill;  $In$  = Commitment;  $Rs$  = Respect the confidentiality of information exchanged;  $Ha$  = Communication skills;  $Pv$  = shared values;  $Rs$  = Resemblance;  $Pt$  = Sharing working methods;  $I$  = Influence in the network. In this research we considered for simplicity all the coefficients are identical and equal to 1.

The calculation of trust behaviour  $C_c$  is associated with the level of trust in three different levels. The value of  $C_c$  between 0 and 0.5 is classified as 'Non-Trust', between 0.5 and 1.5 is classified 'Moderate' and between 1.5 and 2.0 is classified 'Trust'. Since the trust behaviour within the supply chain network is influenced by multiple-party engagements and thereafter the evolution of trust naturally requires modelling using multi agent systems to represent these multi-party engagements.

#### 4 AML Modeling for Multi-Agent Systems

The modelling of trust using Multi-agent systems (MAS) bring the real life essence of models in decision making while several decision makers interact in a particular business process. The multi-agent carries important characteristic like the social abilities of agents having beliefs about other agents and thus trusts as the end results. As a reality, an important ingredient for multi-agent systems interaction is trust.

Besides, intelligent agents and MAS are an evolving paradigm of software system development and applied in a broad and increasing variety of intelligent applications [10-12] and in many different combinations. In this case, the term "agent" denotes a hardware or more usually software-based intelligent computer system, that has the following characteristics [13]:

*Autonomy*: agents operate without the direct intervention of humans or others, and has some kind of control over its actions and internal state; *Social ability*: agents interact with other agents (and possibly humans) via some kind of agent-communication language; *Reactivity*: agents

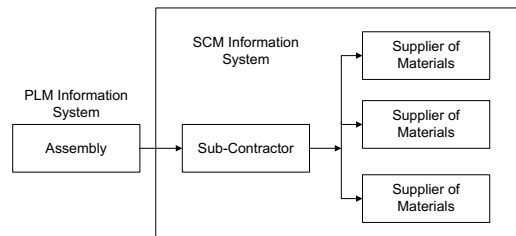
perceive their environment, (which may be the physical world, a user, a collection of other agents, the Internet, or perhaps all of these combined), and respond in a timely fashion to changes that occur in it; *Pro-activeness*: agents do not simply act in response to their environment, they are able to exhibit goal-directed behaviour by taking the initiative. Jennings [14] pointed out in his research that the flexible, high-level interactions of agents make the engineering of complex systems easier. This author indicates that complex systems are always distributed, and from this point of view, agent decomposition is very important to manage complexity.

During the last couple of years, methodologies and graphical modeling languages have been widely used by the designers in order to design systems, software and components. UML [17-18] is certainly the best known graphical modeling language amongst. During these years, multiagent system designers have the same possibility with some modeling languages like Agent UML [19], [20]. Agent UML is based on UML and now particularly known as AML. As Odell and Bauer quoted it, it is not possible to directly use UML since several differences exist between agents and objects like the autonomy or the ability to cooperate [21]. Even though, it seems to be important to capitalize on the skills of designers. Multiagent system designers are often software engineers who use UML [22].

At the same time, software agents have some core and additional characteristics such as autonomy, proactivity, situatedness, interactivity, adaptability, learning, reasoning and mobility [23] as outlined in this section earlier. The most well-represented characteristic is interactivity because AUML emphasizes too much Interaction Protocols. Adaptability and situatedness can be noticed while looking at Statecharts and Activity Diagrams: an agent may realize and change its plans if another delivered a message that affects the “environment state”. On the other hand, concurrent threads of interaction in Sequence Diagrams may represent that an agent is able to choose an action, showing a certain level of reasoning.

## 5 Case Study of SCM in PLM

This section presents the case study of trust for supply chain in PLM (see Figure 1). In this process, an efficient tool of simulation has been planned which can be applied to evaluate the global performance of the chain based on the trust behaviours of its actors. In this process of simulation, we implemented within the agents the trust variables and required behaviours, and defined strategic policies to simulate different relationships between the actors of the supply chain in PLM.

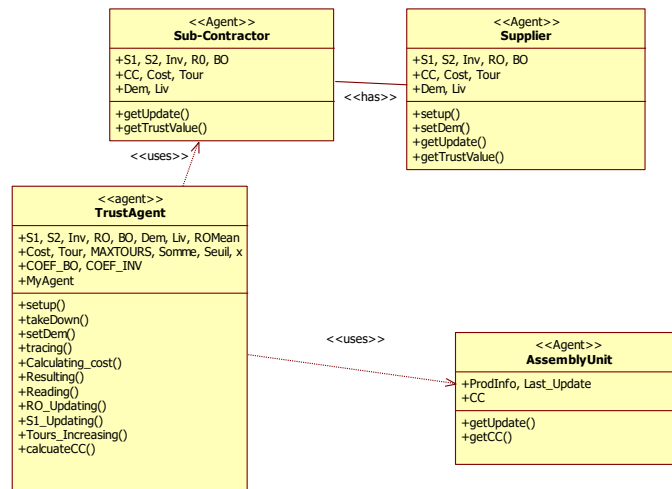


**Figure 1** The case study model of SCM in PLM

The case study model is shown in the Figure 1. In this case study, we developed scenario based on Assembly unit of PLM information system and Sub-contractor with a number of suppliers as the SC components. The trust issues are entirely covered within

this framework and primarily based on information sharing from the Assembly unit to the sub-contractors as well as suppliers of raw materials.

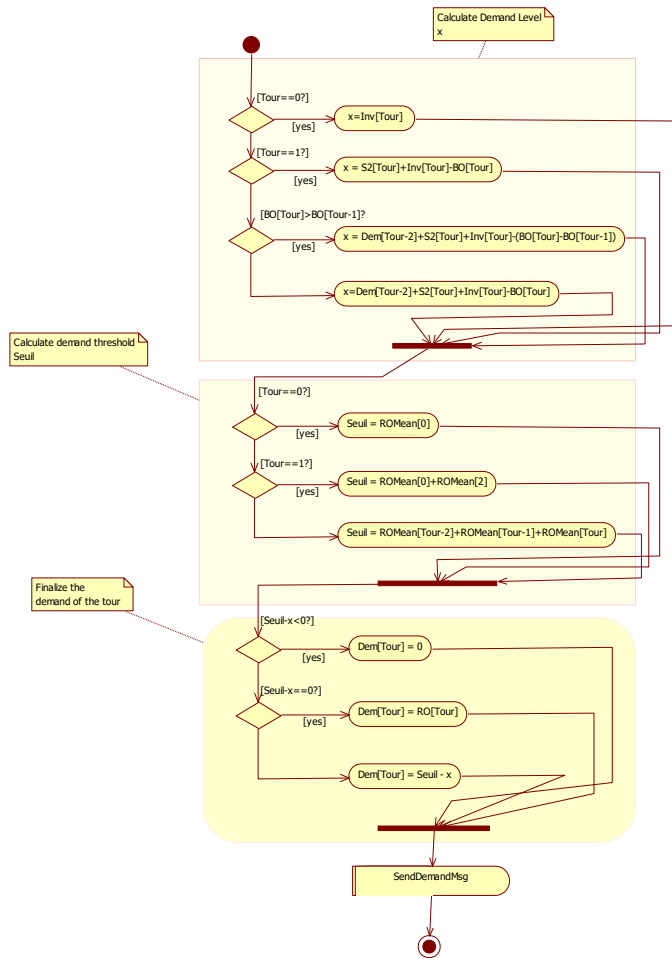
Agent Modeling Language (AML) class diagram is used in order to represent the relationships between different agents and TrustAgent and to define attributes, operations, roles, protocols, etc for the simulation of trust in supply chain as shown in Figure 2. Figure 2 shows the conceptual level of the class diagram of an actor which illustrates, as an example, the implementation level for the agent *AssemblyUnit* along with the different behaviour and the *TrustModel* class.



**Figure 2** The AML State diagram of TrustAgent interacting with other agents

As seen from the Figure 2, in the AML state diagram, the TrustAgent is interacting with agents for coefficient loading which implements one shot behaviour and creates the initial environment for the simulation to run. The AssemblyUnit agent interact with the TrustAgent to share product information based on the level of trust. The Sub-Contractor agent is associated with the Supplier agent and interact with the TrsuAgent.

In the decision-making process within this SCM model of PLM, the agent decides on the demand generation to the sub-contractors depends on the needs of the assembly unit and based on level of behaviour trust. The demand generation strategy shown in Figure 3 which allowed the agent to choose the most appropriate demand based on the level of trust. As the communication language used by the agents to exchange their knowledge and information during the negotiation, the FIPA-ACL language is used in this application. The agents are transformed from a given state to another according to the actions occurred in the environment or according to the received messages. The state diagram shown in the Figure 2 describes the main behaviors of the “TrustAgent” with other agents.



**Figure 3** The flow map of the demand generation based on the level of trust

As shown in the Figure 3, the demand generation involves level of stock, inventory and the back order information. Since the level of trust impacts on this basic information, the demand characteristic changes due to the successive changes in stock, inventory and back orders. In the next section we presented a case study with different scenarios to validate the proposed AML model.

## 6 Results and Discussion

The proposed model employed four specific agents based on the scenario shown in Figure 1 to represent Assembly Unit, Sub-Contractor, Supplier of material goods and TrustAgent.

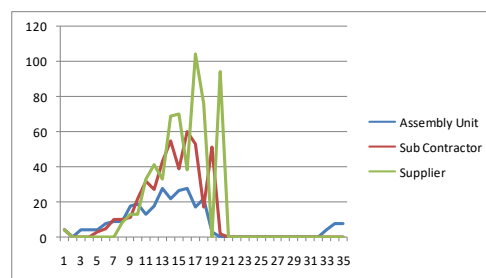
In this experiment, each actor in the supply chain decides on the demand generation based on inventory, virtual stock, backlog and the demand of the run. The demand level is calculated based on week. For effective demand level calculation, we compared the

backlog of the week with the previous week and in case of greater backlog of the week the demand level is equated to the sum of the virtual stock, demand of the previous week, inventory and the difference of the backlogs between week and the week before.

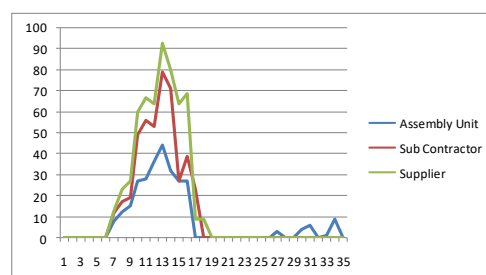
We have experimented using our simulation model and in all different experimental setup, we tested the performance of supply chain. In the first setup of experiment, we exposed a *behaviour of non-trust* between the parties. This results in no communication and information sharing between the parties except the orders from the sub-contractors to their suppliers. In the second scenario of experiment, the moderate “behaviour of trust” is exposed and the parties share not only the orders, but also information about their stocks as the levels of stock are sent by the suppliers to their sub-contractors. In the third scenario of experiment, we expose a complete “behaviour of trust” between the parties and as a result, the parties share the orders, the levels of stocks, and reduce the delay of information sharing from one week to real time by using integrated information systems as we simulate the fact that the companies connect their ERP’s for example, so they have in real time the information about the orders sent by their customer.

This simulation scenario validates the proposed multi-agent simulation model for the non-trust behaviour (Figure 4) backlog levels (Figure 5).

**Figure 4** The generated demand variations

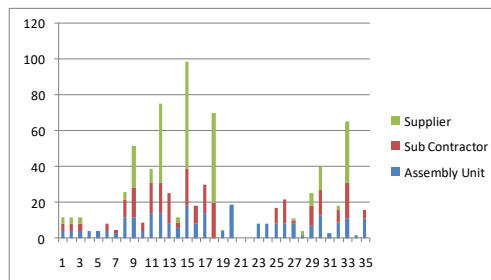


**Figure 5** The generated backlog level



In this case study, the different delays (information and physical flows) do not allow the partners of the supply chain to be reactive. In fact, even due to anticipation the ordering process does not really change the performance of the parties because of the delay. We have observed that a reduction of the delay of the information flow (from 1 week to real time) increased the global performance of the chain. The level of trust

impacted directly the level and the quality of information sharing, which improved the performance of the companies by reducing the delay and let them anticipate the variation of the market demands as well. The overall demand characteristics under the behaviour trust is shown in Figure 6.



**Figure 6** The overall demand characteristics on behaviour trust

## 7 Conclusion

In this work, we have proposed an AML model of trust in supply chain for PLM. Through different scenario we have accomplished the simulation on the case study. We also have reported multiple rounds of experiments using this simulation model. We tested different scenarios, focusing on the “behaviours of trust” of the agents in the supply chain; the first analysis of the results is that, in a supply chain, the level of trust impact directly the level and the quality of information sharing.

In the next level of research, we would like to extend the proposed AML model of SCM in PLM for multi level supplier selection based on trust behaviour and information sharing.

## Acknowledgment

The authors thank the collaborative effort of laboratories, human science and informatics on the relationship of agent modelling and trust model. The work is supported by a regional project “COPILOTES2” from the cluster GOSPi of the Rhone-Alps area. Besides, the detailed model is available in a book published by ISTE Ltd titled “Collaboration, Alignment and Coordination for Supply Chain Performance”.

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