AML MULTI AGENT MODELING OF TRUST FOR SUPPLY CHAIN

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ABSTRACT: Agent Modeling Language (AML) is a semiformal visual modeling language for specifying, modeling and documenting systems in terms of concepts drawn from Multi Agent Modeling (MAS) theory. Supply chain management (SCM) is the management of network of interconnected business which spans all movements of services and goods from the point of origin to the point of consumption. In SCM, Trust modeling is an important and crucial aspect from the perspective of sustainability of the supply chain and efficient performance in business. 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 using AML and proposed a MAS SCM model of trust in supply chain management. The proposed model is implemented using JADE and the simulation results demonstrated the impact of trust in supply chain along with the evolution of trust.

KEYWORDS: Agent Modeling Language, Multi-Agent System, Trust Simulation Model, Supply Chain Management

1 INTRODUCTION

With the globalization of markets, rapid development of technology, and the shortening life cycle of products, the importance of supply chain management has become more and more pronounced and goal centric. In a broad sense, a supply chain is a value-creating network consisting of suppliers, warehouses, manufacturers, wholesalers, and retailers through which material and products are acquired, transformed, and delivered to consumers in markets. In this entire scenario, the most difficult but critical issue is to improve the efficiency of supply chains in the perspective of the whole supply chain, not in the perspective of individual companies.

In order to sustain the supply chain in virtual organization form, trust has been identified as one of the ingredient. The general finding suggest that trust act as a buffer to facilitate the agreement and execution of transactions in the context of the virtual organization in the supply chain scenario. Trust fosters the willingness to cooperate and reduce the transaction costs, which in turn increase the value from virtual organization form (Kasper et al., 2001). Trust is also a vital component contributing to conflict resolution, global goal setting, and creation of shared values (Jarvenpaa et al., 2000). Trust involves within the interdisciplinary fields, including philosophy, computer science, economics and organizational behavior (Kasper et al., 2001). Incorporating trust into the supply chain requires synthesis of human science representation of trust in the computation model.

For the simulation of the supply chain based business model, multi-agent technology is increasingly regarded as a good solution. The features of multi-agent technology such as autonomy, distributed collaboration, and intelligence naturally fit well with the characteristics of supply chain management where geographically dispersed companies should collaborate with each other without central control. Besides, the agent systems possess the ability to form flexible collaboration networks through contract or negotiation which is helpful for dynamic supply chain configuration.

On the other hand, Agent Modeling Language (AML) is a new approach to model systems comprised of interacting autonomous agents. AML promises to have far-reaching effects on the modeling of multi agent system and thereafter implementation.

This research work is a joint effort of social and computer sciences toward the understanding of trust in supply chains. More precisely, we aim to understand the strengthening or weakening of trust as well as the effect on the performance of SC. The goal of this paper is to propose an AML model for modeling and simulation of trust in supply chains through transformation of trust model in MAS. Specifically, this paper uses Java agent development environment (JADE) which has been the
most successful foundation for intelligent physical agents (FIPA)-compliant multi-agent platform for research and commercial purposes. The system is implemented using JADE and tested for different levels of trust in supply chain and performance along with the evolution of trust has been experimented.

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

2 SUPPLY CHAIN MANAGEMENT AND TRUST

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 (Fox et al., 2000), (Nefaoui et al., 2008). The supply chain covers the full range of activities from the earliest level of incoming raw materials through the internal processes in an industry and on to the outgoing products through the distribution and marketing channels. Therefore, supply chain is the planned continuous improvement of processes and relationships that exist to support the movement of these products and services through the supply chain.

Trust is considered as a necessary antecedent of information sharing in a supply chain. Information sharing has always been considered to be beneficial in a supply chain. Lee and colleagues (Larzelere et al., 1980) 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. This phenomenon, called the “bullwhip effect” has been extensively analyzed (Cachon et al., 2004). Information sharing can also yield to other advantages such as reducing costs, improving service levels, and reducing lead times and stock outs (Anderson et al., 1992). However, it not the quantity of data exchanged in the supply chain that is most important but its quality to generate the highest benefits and performance in the supply chain (Premkumar, 2000).

Many scales exist for measuring trust in the management literature. Morgan and Hunt (Morgan and Hunt, 1994) for example, use the scale dyadic Larzerele and Huston (Larzelerere et al., 1980) scale that includes the major facets of trust (reliability, integrity, strong belief). Swan, Trawick and Silva (Swan et al., 1985), Swan, Trawick, Rink and Roberts (Swan et al., 1988), and Shurr and Ozanne (Schurr et al., 1985) also established scales, designed primarily to measure the trust of the Purchasing Manager to the seller. These scales are mainly Anglo-Saxon with a difference made between "trust" and "trust". It is possible to write that "trust" refers to the reliability and belief in something and that "trust" means the trust and honesty to an individual. Guibert (Guibert, 1996) and adapts its precise scales in the French context, and obtains information on honesty and loyalty, confidence and trust in your relationship with your supplier.

2.1 The Proposed Trust Model

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:

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)
16. Sharing information, type of information shared,

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

\[ C_c = (\alpha.H_o + \beta.C_r + \gamma.E_x + \delta.D_o + \epsilon.S + \zeta.P_r + \eta.T + \theta.B_v + \iota.E_n + \kappa.R_p + \lambda.H_a + \mu.P_r + \nu.R_s + \zeta.P_t + \omega.I) / (\alpha + \beta + \gamma + \delta + \epsilon + \zeta + \eta + \theta + \iota + \kappa + \lambda + \mu + \nu + \zeta + \omega) \]  

However, mobilized the literature does not attempt to define precisely the weights of each criterion. It is true, a
priori, each individual or entity has its own scale of values against the various criteria components of trust, i.e., the weight each set of weights for each criterion. In this research we consider that overall (alpha omicron) is a priori identical and equal to 1. In our present research behavior representing the trust is expressed as follows:

\[ Cc = \frac{(Ho + Cr + Ex + Co + S + Pr + T + Bv + En + Rp + Ha + Pv + Rs + Pt + I)}{15} \]  

(2)

where \( Cc \) = 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

Based on the calculation of trust behaviour \( Cc \), the level of trust is classified in the proposed scale as shown in the Figure 1 and relate to a phenomenon of sharing information.

\[ 0 < Cc < 0.5 \quad 0.5 \rightarrow 1.5 \quad 1.5 \rightarrow 2 \]

Non trust Moderate Trust

Figure 1: Classification of Trust Level

As seen from the figure, the trust behaviour between 0 and 0.5 is the behaviour of non-trust of the actor, between 0.5 and 1.5 is the behaviour of moderate trust and between 1.5 and 2.0 is for the trust. The trust behaviour within the supply chain network is influenced by multiparty engaged in the chain and the evolution of trust naturally requires modelling using multi agent systems.

3 MAS AND AML MODELING

Multi-agent systems (MAS) naturally models decision making when several decision makers interact. In fact, an agent may be defined as an autonomous program that is reactive, proactive and has social abilities (Wooldridge, 2002). The important feature in this definition is the social abilities of agents which provide them with beliefs about other agents, thus trust. Consequently, trust is important for multi-agent systems. For instance, Ramchurn and colleagues (Ramchurn et al., 2004) review the literature on trust in multi-agent systems and show that the purpose of trust is to minimise the uncertainty in interactions.

On the other hand, intelligent agents and MAS are an evolving paradigm of software system development. These are applied in a broad and increasing variety of applications (Chaib-draa et al., 2001), (Chaib-draa, 1995) and in many different combinations. The term “agent” denotes a hardware or more usually software-based intelligent computer system, that has the following characteristics (Wooldridge et al., 1995):

- **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.

During the past several years, methodologies and graphical modeling languages have been widely used by the designers in order to design systems, software and components. UML (Booch et al., 1999) 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 (Odell et al., 2000), (Bauer et al., 2000). 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 (Jennings et al., 2000). Even though, it seems to be important to capitalize on the skills of designers. Multiagent system designers are often software engineers who use UML (FIPA, 2005).

At the same time, software agents have some core and additional characteristics such as autonomy, proactivity, situatedness, interactivity, adaptability, learning, reasoning and mobility (Garcia et al., 2004) as outlined in this section earlier. The most well-represented characteristic is interactivity because AUMIL 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.

4 PROPOSED AML MODEL OF TRUST

This section presents an issue for modelling the dynamic behaviour of the proposed SC Trust model. Our aim is to design an efficient tool of simulation which can be applied to evaluate the global performance of the chain
based on the trust behaviours of its actors. The link between trust and performance will be obtained via the level and the quality of the information sharing. For that, we first implemented within the agents the trust variables and behaviours, and then we defined some strategic policies to simulate different relationships between the actors of the SC.

We introduced the Trust agent and used this agent in multi-agent systems to model SC in which trust impacts and is impacted by the performance of the companies. The trust agent with cyclic behaviour interacted with different agents within the proposed model. To shift from the proposed trust model to an agents-based model we started with the modeling of each actor of the supply chain (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 modelled by different agents in line with the trust model as outlined in the section 2.1. The TrustModelAgent implements the trust criteria with all the trust parameters and a cyclic behaviour for the collaboration with other agents to determine the level of the behaviour trust. All these agents are implemented using a JADE framework.

At every demand generation step in different agent, a cyclic call to calculateTrust() behavior of the agent TrustModel is made to ensure the level of trust and information sharing.

Agent Modeling Language (AML) class diagram is used in order to represent the relationships between these 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 Retailer along with the different behaviour and the TrustModel class. This TrustModel implemented the proposed human trust behavior formulation within the supply chain network and criteria for the trust level and calculation of the behaviour trust (cf. Section 2).

In the decision-making process within this SCM model, the agent decides on the demand generation based on level of behaviour trust. The demand generation strategy 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 3 describes the main behaviors of the agent "Retailer" in using the TrustAgent model as example. This interaction model demonstrates a situation where the level of trust is moderate and the information flows from different agents, based on the inventory and corresponding demand, is generated by the agents.
In Figure 3, different message interactions are shown among the agents with respect to the retailer. Another agent interaction model is shown in the Figure 4 when the level of trust is high and the information flows from different agents are on real time basis. As can be seen from the Figure 4, the demand messages are sent across different agents based on the validation of trust model on real time basis.

Figure 4: Dynamic Model of TrustAgent collaboration with the RetailerAgent when the level of trust is high

In the next section we present a case study with different scenario to validate the proposed model.

5 SIMULATION AND RESULTS

To validate the proposed multi-agent simulation model, we propose the Beer Game as the example of supply chain management. The MAS model of BeerGame employs four specific agent of the supply chain to represent Retailer, Wholesaler, Distributor and Factory and another agent Client along with this supply chain along with the TrustAgent.

In this game scenario, each player in the supply chain decides on the demand generation based on inventory, virtual stock, backlog and the demand of the tour. 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. Otherwise the demand level is equated to the sum of the demand of the previous week, the virtual stock, the inventory and the backlog of the week.

We conducted multiple rounds of experiments using our simulation model. In all the rounds, we tested supply chain performance under deterministic demand as set up in the Beer Game (the final customer demands 4 cases of beer in the first 4 weeks and then demands 8 cases of beer per week starting from week 5 and continuing until the end of the game 35 weeks).

In the first round, we have a behaviour of non-trust between the companies, so there is no communication and information sharing between them, excepting the orders from the customers to their supplier.

In the second round, the “behaviour of trust” is moderate (0.5 ≤ Cc <1.5), which means that the companies share not only the orders, but also information about their stocks (levels of stock are sent by the suppliers to their customers).

In the third and fourth scenarios, we have a “behaviour of trust” between the participants (1.5 ≤ Cc <2); so in this case, the companies 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 (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. The following Table shows the configuration of the four scenarios:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Information Shared</th>
<th>Information Flow</th>
<th>Physical Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>Orders</td>
<td>Delay: 1 week</td>
<td>Delay: 2 weeks</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>Orders + Stock Level</td>
<td>Delay: 1 week</td>
<td>Delay: 2 weeks</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>Orders</td>
<td>Delay: Real time</td>
<td>Delay: 2 weeks</td>
</tr>
<tr>
<td>Scenario 4</td>
<td>Orders + Stock Level</td>
<td>Delay: Real time</td>
<td>Delay: 2 weeks</td>
</tr>
</tbody>
</table>

Table 1: Overview of main parameters of experiments

Scenario 1: The goal of the first scenario is to test the SC performance in the worst collaborative case; after calculation by the agents, the behaviour of trust in this case is “no-trust” between the companies involved in the supply chain.

This behaviour corresponds to the classical Beer Game in which the players do not communicate with the others and take their decisions with no other information than the orders that they received from their customers. The delays of the different flows, information and product, are equal to 2 weeks for each.

The results of the simulation as shown in Figure 5 demonstrates that the generated demand is increasing from the first agent to the last one (the bullwhip effect), even if the demand of the final customer is not changing.

This scenario validates our multi-agent simulation model because, based on the non-trust behaviour, the global
performance of the supply chain: inventory levels (Figure 5) backlog levels correspond to that we have in the real Beer game.

Scenario 2: In the second round of experiments, we tested the case of a moderate “behaviour of trust”; the TrustModel Agent calculates the behaviours of trust based on the trust criteria, the results for the agents of the SC are in the interval: 0.5 ≤ Cc < 1.5. In this case, we simulate few information sharing; the companies share not only the orders, but also information about their stocks. Each agent will use the SendMessage() behavior to send information about the level of their stocks to their customer. We used a special parameter to represent this information about stock, the variable \( S2[Tour] \) in which \( i \) is the agent number in the SC and Tour is the number of the week. The agents use this new information to generate the demand of the week knowing the exact level of the stock of their supplier; they can like this optimize the value of the generated demand.

The result of the simulation is shown in Figure 6 which demonstrates that the generated demand is still increasing from the first agent to the last one, but we observe that the performance is better than in the first scenario: the maximum level for the stocks is equal to 168 (266 in the first scenario), and the maximum level of backlog is 154 (184 in the first scenario). The quantities are decreasing in this scenario because of the information sharing between the agents of the SC.

Scenario 3: In the third round of experiments, there is a behaviour of trust which allows the partners of the SC to collaborate. In this case, the companies share the orders and reduce the delay of information sharing (from one week to real time) by using integrated information systems; so they have in real time the information about the orders sent by their customer. As in the first scenario, the only information shared between the agents is the generated demand (order).

Reducing the delay of the information flow let the agents to better react to the SC demand variation as shown in the Figure 7. The results demonstrated a real decreasing of the average level of backlogs and inventory (Table 2); from 40 (avg inventory) in the two first scenarios to 13 in this one; and from about 15 (avg backlog) to 5 in the collaborative scenario. In terms of inventory the maximum level is equal to 65 (168 in the previous scenario); for the backlog, the maximum level is divided by three comparing to the last scenario (40 vs. 154). These results illustrate the fact that a behaviour of trust between the partners.

Scenario 4: The final experiment corresponds to the “best” collaborative scenario between the agents. Their behaviour of trust (Cc) calculated by the agent is comprised between 1.5 and 2.

The agents trust in each other, so they not only share orders but also information about level of stocks and integrate their information systems to reduce the information flow delay. They are in a real collaborative process. The different indicators of the simulation show an increasing of the global performance of the supply chain as shown in Figure 8 and the summary of the experiments are shown in Table 2.

<table>
<thead>
<tr>
<th></th>
<th>Inventory</th>
<th>Backlog</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Avg</td>
<td>Max</td>
<td>Avg</td>
</tr>
<tr>
<td>Scenario 1</td>
<td>42</td>
<td>263</td>
<td>18</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>40</td>
<td>168</td>
<td>13</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>13</td>
<td>65</td>
<td>5</td>
</tr>
<tr>
<td>Scenario 4</td>
<td>13</td>
<td>58</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 2: Overview of experimental results

The first analysis of these results is that, in this Beer Game 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 their company because of the delay. We have ob-
served 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.

6 CONCLUSION

In this work, we have proposed an AML model of trust in supply chain. Through different trust scenario we have validated the trust simulation model on the case study, the MIT Beer Game, which is an example of supply chain management that has attracted much attention from both the supply chain management practitioners as well as academic researchers. We also have reported multiple rounds of experiments conducted 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, which improve the performance of the companies by reducing the delay and let the companies anticipate the variation of the market demands.

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