20

COORDINATION OF SUPPLY CHAIN ACTIVITIES: A COALITION-BASED APPROACH

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Companies operate in an environment increasingly demanding in terms of flexibility and reactivity. The introduction of the entities resulting from Distributed Artificial Intelligence (DAI) and Multi-Agent Systems (MAS) in the management of enterprises prove to be an interesting technology to simulate and reproduce the collaborative and adaptive behaviors of enterprises. This article models the coordination of the various collaborative parties both inside and outside a supply chain using coordination methods of MAS mainly coalition formation mechanisms. In this paper, we present our agent modeling of supply chains, and then we detail the coalition formation algorithm. Lastly, we illustrate our approach with an example chosen in the industrial domain.

1. INTRODUCTION

A Supply Chain (SC) is a set of autonomous entities, internal or external to a company, interacting with each others in order to maximize a global wellbeing and this by searching a compromise regarding their own constraints and goals. This compromise is difficult to reach given the constantly dynamic environment in which these companies evolve. The characteristics of such systems, namely complexity, changing environment and autonomy of each entity implied in the *SC*, motivate researchers to use multi-agent techniques for modeling and studying their behaviors.

The aim of this paper is to propose a coordination method using a coalition formation mechanism for supply chain management. According to (Shehory and Kraus, 1998), a c*oalition* is defined as a group of agents which have decided to cooperate in order to reach a common goal. A shared utility is expected from the achievement to this goal. The aim is to model the possible partnerships that could be established between entities. In our approach we make a distinction between two abstract levels of coalitions:

- Internal coalitions: are the coalitions formed of the entities in the same company, i.e. a sort of alliances between plants of the same company in order to face huge orders.
- External coalitions: are the partnerships which could be established between internal and external entities in order to acquire missing resources and competences.

This paper is organized as follows: section 2 presents a review of existing approaches. Section 3 describes the coordination problem with an example and formalizes it. Section 4 proposes a coalition formation method adapted to this problem of supply chain management, and then we present our algorithm. Finally we conclude on this work.

2. RELATED WORK

Modeling of Supply Chains (SC) is one of the main topics in Operations research (OR) (Kok *and al.*, 2003), (Beamon, 1998), (Giard *and al.*, 2007), factories' localization, production planning, stock management, transport and distribution. Most of these works propose centralized approaches based on analytical models. Since the emergence of distributed techniques and multi-agent systems, several approaches studied the collaborative behaviors between supply chain entities using agent mechanisms (Dodd *and al.*, 2001). The advantage of these approaches consists in the possibility to explicitly model the behaviors of these entities as well as their interactions and their organization (Parunak *and al.*, 1998). (Swaminathan *and al.*, 1998) model supply chain dynamics using a multi-agent approach. The contribution of their work is the combination of both analytical and simulation methods in order to respectively model the static and dynamic aspects of supply chains. Other works studied the dynamics in supply chain using more specific techniques to multi-agent systems such as interaction languages and protocols. For example, (Fox *and al.*, 2000) have defined a coordination system using conversation structures while introducing a communication language (COOL) which is based on KQML[i] language and finite states automats. Other works have modeled only part of the supply chain (Hahndel *and al.*, 1994) which uses a negotiation protocol to coordinate activities of the production planning. To date, few works focus on the use of coalition formation techniques to model coordination in supply chains.

3. MULTI-AGENT MODELING APPROACH

We consider a company which manufactures and markets planes. We chose this industrial field because of the complexity of its supply chain which mainly manages the outsourcing of several parts and the multitude of entities that contribute to it. This company is localized mainly in France but it has several production sites (plants) on several continents. It has also various distribution centers in Europe which deliver various markets (Europe, Middle-East…). In addition, its suppliers are physically dispersed.

Inside of each plant (cf. figure 1), we can identify several other units which cooperate with each others. Such situation could be complicated due to relationships that might exist between these entities and the entities of other supply chains. Consequently a delay or dysfunction at a point of the chain could be propagated to all its connected points.

3.1. Agent identification

In our agent approach, we propose to model each entity in the supply chain by an agent (Barbuceanu *and al.*, 1996). We distinguish two abstraction levels for these agents: *internal* and *external agents*:

– ***Internal agents:*** are those located inside the company. In this category, we also distinguish two levels of agents: company agents and plant agents.

- *Plant agents:*
  - **'Plann'** agents: they deal with the production planning based on received demands and on communications with other agents of the plant.
  - **'Produc'** agents: they manage the production and stocks of the intermediate products. These agents have a perfect knowledge of the plant conditions in term of resources, machines and their sites
  - **'Exped'** agents: they handle the finished products of each plant and their expedition.
  - **'Mat'** agents: they supervise stocks of raw materials (RM*S*) and treat all information related to orders and raw material reception.
  - **'Info'** agents: they process all information related to the correct processing of the plant (capacities and breakdowns of the machines, information on stocks *RMS*, *IPS* and *FPS*).
- *Company Agents:*
  - **'Purchases'** agent: it represents the purchase function of the company including the selection and communication with suppliers.
  - **'Sales'** agent: this agent gathers the functions of marketing and sales. It ensures the forecasts of the demand by establishing communications with the customers.
  - **'Transport'** agent: this agent ensures products moving among plants and distribution centers.
  - **'Distribution Centers'** agents: they represent the different distribution centers of the company.
  - **'Logistic'** agents: they supervise the effective communication between the various agents (*purchase, sale, exped*, *plann* and *prod*).They also manage the events which may occur in the system such as an order modification by a customer, the out-of-stock event of some product, the change of a supplier…

– ***External agents:*** they represent the agents located outside the company.

  - **'Customers'** agents: these agents correspond to the customers of the company. In our example we have identified two agents: the European market, the Asian and Middle-East Market.
  - **'Supplier'** agents: each supplier is represented by an agent.
  - **'Econ-Part'** agents: they represent any other entity in the environment likely to have a relationship with the company (competitors, partners of transport…).

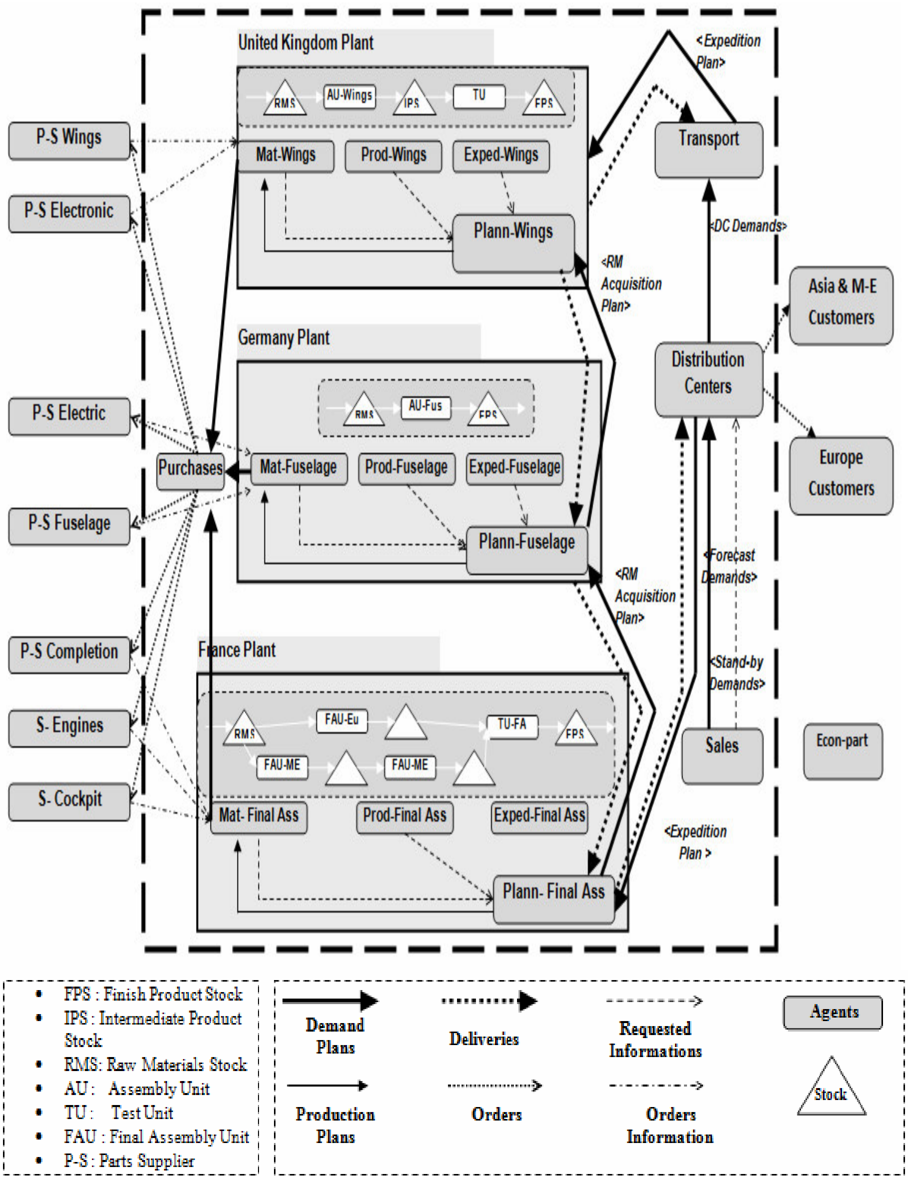

Figure 1 – Example of a supply chain and interactions among entities

4. COORDINATION OF SUPPLY CHAIN ACTIVITIES: COALITION FORMATION APPROACH

4.1. Definitions

We represent a chain of tasks by an acyclic directed graph <*TC, E*>, such that $TC = \{t_1 \cdots t_m\}$ represents the set of complex tasks for which an agent needs to initiate a coalition formation process to perform them. $E = \{(t_i, t_j)\}$ is the set of edges connecting the task t_i which precedes the task t_j with $(\emptyset, t_1) \in E$ as a beginning task, and $(t_m, \emptyset) \in E$ as an ending task. We define also the following concepts:

- Given $A = \{a_1 \cdots a_n\}$ the set of the agents in the system. This set is the union of two subsets $A = A^I \cup A^E$ including respectively the internal agents $A^I = \{a_1 \cdots a_k\}$ and the external agents $A^E = \{a_{k+1} \cdots a_n\}$.
- Given $T = \{t_1 \cdots t_c\}$ the set of tasks composing the chain such that $TC \subseteq T$.
- For the coalition formation, an agent determines, according to a preference model, a set of potential agents noted *AP* including itself.
- After coalitions are formed, we denote *AR* the set of agents do not participate to coalitions but contribute to one of chain tasks.
- Each agent a_i has a vector of capabilities $Q^i = \langle q_1^i \cdots q_p^i \rangle$.
- Each activity or complex task t_s has an execution cost denoted c_{t_s} which is the aggregation of several costs of all agents contributing to its execution. This cost represents the utility function of the agent. We suppose that this function could be defined by a linear function.
- We define also, $cp_{a_i,a_j}^{t_s}$, a cost of the output of an activity t_s from agent a_i to agent a_j, this parameter will be used in the total chain cost optimization.

The aim of each agent is to minimize its individual cost and consequently to minimize the cost of the whole chain. In the case of a coalition of several agents and in order to determine an activity cost, a binary variable is used:

$$Z_{t_s}^{a_i} = \begin{cases} 1 & \textit{if agent } a_i \textit{ is chosen to contribute to task } t_s \\ 0 & \textit{else} \end{cases} \quad \text{with } a_i \in AP \textit{ and } t_s \in TC$$

The objective is to minimize the total cost *T.C* by solving the following problem:

$$\text{Min.}T.C = \sum_{a_i \in AP} \sum_{t_s \in TC} z_{t_s}^{a_i} c_{t_s}^{a_i} + \sum_{(t_s,t_l) \in E} \sum_{a_i,a_j \in AP} z_{t_s}^{a_i} z_{t_l}^{a_j} cp_{a_i a_j}^{t_s} + \sum_{a_i \in AR} \sum_{t_s \in T} c_{t_s}^{a_i} \qquad [1]$$

$$\forall t_m, t_l \in TC \text{ , } (t_m, t_l) \in E \qquad \text{(a)}$$

$$\sum_{t_s \in T} q_{t_s}^{a_i} z_{t_s}^{a_i} \leq Q^i \qquad \text{(b)}$$

(a) To satisfy the constraint of tasks' order

(b) The sum of agent capacities invested in all tasks cannot exceed its total capacity.

The first two parts of [1] represent the cost of the activities for which the coalitions are formed. The third part describes the cost of the other activities of the chain. We define the preference of an agent to another by the following matrix of preferences:

$$\prod_{a_i}^{p} = \begin{pmatrix} y_{i1}^{1} & y_{i2}^{1} & \dots & y_{in}^{1} \\ y_{i1}^{2} & y_{i2}^{2} & \dots & y_{in}^{2} \\ y_{i1}^{p} & y_{i2}^{p} & \dots & y_{in}^{p} \end{pmatrix} \text{ with } \begin{cases} i \text{ index of agents} \in N \\ p \text{ index of criterea} \end{cases}$$

Each element y_{ij}^{k} of the matrix represents the preference of an agent a_i for the agent a_j according to criterion k. To obtain the multi-criteria preference of an agent for another, this matrix is reduced to a vector using an aggregation operator which can be *the balanced sum* or *the integral of Choquet* (Grabisch, 1996).We chose to use the second operator which has the advantage, contrary to the balanced sum, not to distort the result of aggregation when the criteria are not independent. It is based on the following principle: the agent a_i ranges by descending order the column of its preferences for an agent a_j according to specific criteria y_{ij}^{k}, according to given *individual* and *collective* weights of various criteria k noted $\mu(E_k)$ predefined by the system designer (with E_k a set including rather only one or several criteria).It calculates then its preferences' vector $\prod_{a_i} = (x_{ij})$ as follows:

$$x_{ij} = \sum_{0 \le k \le p} (y_{ij}^{k} - y_{ij}^{k+1}) \mu(E_k) \text{ with } y_{ij}^{p+1} = 0 \text{ and } y_{ii}^{k} = 0 \qquad [2]$$

We define another concept: ***attraction indices*** which can be ***unilateral* (U-Att) *or bilateral* (B-Att)*:***

- ***Unilateral attraction*** represents the force measurement of an agent to convince the other agents, not yet members, to join the coalition. To be able to determine it, the agent classifies the various values of the vector $\prod_{a_i} = (x_{ij})$ according to a descending order. This value is defined as follows:

$$\textbf{U-Att}\ (a_i) = \sum_{j=1}^{n} (x_{i,j} - x_{i,j+1}) \mu(A_j) \text{ with } i \neq j \qquad [3]$$

In [3], $\mu(A_j)$ is a predetermined weight for the agent a_i or for the set of agents $A_j \in A = \{a_1 \dots a_n\}$

- ***Bilateral attraction*** represents at the same time the desire of an agent to join a coalition and the desire of this coalition to integrate this agent. It is defined as follows:

$$\textbf{B-Att}\ (a_i, C_k) = \prod_{ki} \times \Re\,(a_i, C_k) \qquad [4]$$

In [4], $\Re\,(a_i, C_k)$ represents the preference of an agent a_i to the coalition C_k and $\prod_{ki}$ represents the preference model of the coalition C_k for the agent a_i.

4.2. Coordination mechanism steps

An agent a_i receives a new message from its environment; it analyzes using its *detection function* which transmits it to the decision function. Then the *decision function*, having the agent's objectives, its current state and knowledge, chooses which action to undertake. *The action function* is then activated to launch the coordination process by sending messages to other agents; after that it updates the state and knowledge of the agent. If it is question of a coalition formation process for carrying out a complex task, the agent a_i take the role *of initiator* and enters in communication with the other agents according to the following algorithm whose two principal steps are:

- *Step 1.*

The agent, after having built its preference model, it contacts the internal and external agents which it prefers i.e. having the maximum values in its preference model (cf. Figure 2). Note that each agent a_i builds its preference for an agent a_j according to various criteria such as time, distance, quality…these criteria are predetermined by the system designer.

- *Step 2.*

Each solicited agent a_j checks its capabilities in order to determine it can contribute to this activity and also checks its planned activities, then it answers the initiator agent by a temporary acceptance or refusal. If the initiator agent receives only a refusal, it has to decide if it continues or cancels the process. In the first case, it sends a message to the solicited agents so that they confirm their participation and thus if they accept definitively, the initiator agent adds them on the list of confirmed coalitions and determines the total cost of the coalitions.

Step 1: Agent identification by calculation of the preference model:

Each agent a_i in need to launch a coalition formation (CF) process has to:

- Identify, according to its knowledge on environment, the potential agents simultaneously internal $\forall a_j \in A^I$ and external $\exists a_j \in A^E$ and then add them to the set *AP*
- Build its preference $\prod_{a_i}^{p}$ according to predetermined criteria (*1…p)*
- Build its aggregated preference vector $\prod_{a_i} = (x_{i1}, \dots x_{ii}, \dots, x_{i|AP|})$ with $x_{ii}=0$.
- Send its model to other agents and wait in return their models. At the same time it adds these proposals to its list 'proposed coalitions'.
- When received other models : Calculate unilateral attraction indices

  U-Att (*a_i*) $= \sum_{j=1}^{|AP|} (x_{i,j} - x_{i,j+1})\mu(A_j)$ such that $\begin{cases} i \neq j \\ A_j \in AP \end{cases}$
- **<u>If</u>** the **U-Att** (a_i= initiator) is the highest

  (*) Block the CF process //one CF process at time.

  Calculate bilateral attraction indices **B-Att** (a_i, C_k) = $\prod_{ki} \times \Re(a_i, C_k)$

  <u>Else</u> The agent having the highest **U-Att** becomes the initiator and back to (*)

  $AP = AP \setminus \{a_i\}$ \\ in the case of a task outsourcing

  <u>End If</u>

Step 2: The coalition formation and calculation of the total cost

<u>While</u> the coalition objective not yet reached **<u>and</u>** $\{AP\} \neq empty$ **<u>do</u>**

- (**) Contact in the order the agent a_j having the highest **B-Att**

  <u>For</u> all t_l such that $(t_l, t_s) \in E$ **<u>do</u>**

  <u>If</u> $\sum_{t_s \in T} q_{t_s}^j < Q^j$ **<u>then</u>**

  // The accomplishment cost of a task is the sum of the preceding tasks costs.

  - $c_{t_s} = \sum_{(t_l, t_s) \in E} c_{t_l}$

  // The agent capacity is the sum of the actual capacity and the all capacities invested in preceding tasks.

  - $q_{t_s}^j = \sum_{(t_l, t_s) \in E} q_{t_l}^j$
  - Remove (t_l, t_s) *from* E
  - $Z_{t_s}^{a_j} = 1$ // The agent wishes participate to the coalition
  - $C_k = C_k \cup \{a_j\}$

  <u>Else</u> $Z_{t_s}^{a_j} = 0$ // The agent cannot participate to the coalition

  Back to (**)

  <u>End If</u>

  <u>End For</u>
- Send a message to the agent concerned by the coalition.
- Receive the answer (confirmation or refusal).

<u>End While</u>

Calculate the total cost of the chain:

$$\text{Min } T.C = \sum_{a_i \in AP} \sum_{t_s \in TC} z_{t_s}^{a_i} c_{t_s}^{a_i} + \sum_{(t_s, t_l) \in E} \sum_{a_i, a_j \in AP} z_{t_s}^{a_i} z_{t_l}^{a_j} cp_{a_i a_j}^{t_s} + \sum_{a_i \in AR} \sum_{t_s \in T} c_{t_s}^{a_i}$$

Figure 2- Algorithm of the coalition formation process

5. CONCLUSION

In this article, we showed that the multi-agent approach is well adapted to model the supply chain management. With the aim of improving and optimizing the management of the logistic chain, the agents resort on coordination mechanisms in order to achieve their common tasks. We have proposed a distributed coordination method: the coalition formation mainly used in multi-agent systems. Given that, in supply chains, the entities appear and disappear dynamically, multi-agent approach makes it possible to simulate open systems what guarantees flexibility, effectiveness and evolution of such systems. We have, in a second time, presented an algorithm of coalition formation. We illustrated our proposals with an example of a supply chain taken in the industrial field. A prototype implementing our algorithm of coordination and the protocol of agents' interactions is under development and tests.

As research perspectives, several assumptions made in our modeling could be improved: 1) once the coalition formation is chosen as a coordination method, *the choice and the definition of the corresponding protocol remains problematic*. This choice is actually very depend on the type of problem studied i.e. parameters to be taken into account such as the fact that *the agents have or not the same objective* even the same utility function, or *the fact that they trust each other or not,* or their ability to exchange their knowledge… all these parameters can generate totally different protocols which must be tested, 2) the suggested protocol is based on several principles which cannot usually be adapted to industrial reality in particular in the case of a competitive partners of a supply chain. They can also have radically opposed objectives as in the relation supplier-producer; all will then depend on the negotiation which should also to be modeled.

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[i] KQML : Knowledge Query and Manipulation Language