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AN APPROACH OF DECISION-MAKING SUPPORT BASED ON
COLLABORATIVE AGENTS FOR UNEXPECTED RUSH
ORDERS MANAGEMENT

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Abstract

Decisions at different levels of the supply chain can no longer be considered independently, since they may influence profitability throughout the supply chain. This paper focuses on the interest of multi-agent paradigm for the collaborative coordination in global distribution supply chain. Multi-agent computational environments are suitable for a broad class of coordination and negotiation issues involving multiple autonomous or semiautonomous problem solving contexts. An agent-based distributed architecture is proposed for better management of rush unexpected orders. This paper proposes a first architecture validated by a real and industrial case.

Keywords: Supply chain management; Demand uncertainty; Rush unexpected order; Multi-agent systems; UML; Global Distribution;

1 INTRODUCTION

The Supply Chain (SC) is increasingly interest for many business enterprises and a challenge for logistics management in the 21st century. Supply chain is defined as the chain linking each entity of the manufacturing and supply process from raw materials through to the end user (New and Payne, 1995). A supply chain comprises many systems, including various manufacturing, storage, transportation, and retail systems (Han et al., 2002). Supply Chain Management (SCM) has commanded attention and support from the industrial community. It consists in the coordination of production, inventory, location, and transportation among the participants in a supply chain to achieve the best mix of responsiveness and efficiency for the market being served (Hugos, 2003a). The optimal deployment of inventory is one of the principal goals of SCM. Indeed, Many collaborative processes (e.g. CPFR: Collaborative Planning, Forecasting and Replenishment (VICS Association, 2007), VMI: Vendor Managed Inventory (John Taras CPIM, 2007), CRP: Continuous Replenishment Program and ECR: Efficient Consumer Response (ECR, 2006) and software systems (e.g. APS: Advanced Planning Systems (Simchi-Levi et al., 2000), ERP: Enterprise Resource Planning (Baglin et al., 2001) are used for management and control of inventory in order to reduce the total system cost of inventory as much as possible while still maintaining the service levels that customers require. Literature shows that the common objectives of these practices is to avoid the surplus inventory, reduce the inventory shortage, minimize the safety stock, produce and deliver products in the right quantities and at the right time. However for the distributor centers, it is difficult to achieve this goal, because the rush unexpected orders placed by the wholesalers always present a challenge. This challenge will vary from one company to another and from one supply chain to another. In fact, the distributor can not predict the date and the ordered quantity of this type of orders since it is a random one whose causes are multiple and depend closely on the branch of industry. In addition, this type of orders has a very short delivery date. In this emergency case, the distributor is not able to wait for the next planned delivery of products from the supplier. Therefore, generally the order can be cancelled or can cause an inventory shortage if the ordered quantity is large. This will have a bad impact on the quality of the offered service within the satisfaction of the final customer policy.

Some suppliers allocate an additional human resources and logistics for delivering the rush unexpected orders of their distributors. The disadvantage of this solution is that the costs suggested are generally very high.

In multi-echelon networks, which is a common distribution model for many distributors and manufacturers, the distributors can deliver the rush unexpected orders. The echelon inventory includes the sum of local stock and

the stock of all the forward distribution centers (Calvin, 2003) (Siala et al., 2006). However, multi-echelon inventory management is more coherent to the centralized decisions and it requires that all locations must be submitted to the relevant control of a single enterprise. In addition, it requires a high degree of information sharing between the various actors of the SC, but if the supply chain consists in independent enterprises, information sharing becomes a critical obstacle, since each independent actor is typically not willing to share with the other nodes its own strategic data (as inventory levels). Also, it monitors his inventory levels (by using autonomous action and policies) and places the orders to its suppliers in order to optimize its own objective (Siala et al., 2006).

This paper focuses on unexpected swings in demand and on unexpected exceptions (problem of production, problem of transportation, etc.), which are important coordination and communication issues in SC management (Giannoccaro et al., 2003) (Reutterer and Kotzab, 2000) (Zhao et al., 2002). Both events can engender the presence of a rush unexpected orders in a node of supply chain; in particular, at the wholesalers and the distribution centers levels. In this context, we propose a collaborative process which presents an effective solution (to the distributors) for better management of the rush unexpected orders for which the quantity of product cannot be delivered partially or completely from the available inventory. This process includes the distributors of the same or equivalent products and their wholesalers. The participants in the process can be competitors. To implement the process, we apply an agent-based distributed architecture in order to guarantee the autonomy and the strategic data confidentiality of all participants. Agent technology provides to the distributed environment a great promise of effective communication (Swaminathan et al., 1998). An agent is a program that performs a specific task intelligently without any human supervision and can communicate with other agents cooperatively. Therefore, agent technology is suitable to solve communication concerns for a distributed environment. Recent researches also show that the multi-agent approach plays a significant role in supply chain management, for example (Wu, 2001), (Fu et al., 2000), (Kimbrough et al., 2002) and (Swaminathan et al., 1998).

This paper is organized as follows; in Section 2, the literature on supply chain coordination and agent technology is reviewed; in Section 3, the rush unexpected order is presented. The collaborative process and system architecture are proposed in Section 4. In Section 5, a set of negotiation protocols are presented and modeled within UML sequence diagrams. A case study is presented in Section 6 to validate the proposed architecture. Section 7 concludes the paper.

2 BACKGROUND REVIEW

To improve the supply chain's performance under demand uncertainty and exceptions, various levels of collaboration techniques based on information sharing were set up in real supply chains. These techniques are essentially, VMI, CRP and CPFR. VMI and CRP are very similar, but are used in different industries. The idea is that retailers do not need to place orders because wholesalers use information centralization to decide when to replenish them. Although these techniques could be extended to a whole supply chain, current implementations only work between two business partners. In fact, many customers are attracted to these techniques, because they mitigate uncertainty of demand. Moreover, the frequency of replenishment is usually increased every month or every week (or even daily), and from which both partners benefit. CPFR is a standard that enhances VMI and CRP by incorporating joint forecasting. Like VMI and CRP, current implementations of CPFR include only two levels of a supply chain, i.e., retailers and their wholesalers. With CPFR, companies electronically exchange a series of written comments and supporting data, which includes past sales trends, scheduled promotions, and forecasts. This allows participants to coordinate joint forecasting by focusing on differences in forecasts. Companies try to find the cause of such differences and agree on joint in order to improve forecasts.

In the literature, various researches to compensate for the uncertainty that exists in a supply chain have been reported. Cohen and Lee (Cohen and Lee, 1988) have developed a planning model to optimize material supply, production and distribution processes. Arntzen et al. (1995) have proposed a resource allocation and planning model for global production and distribution networks. Kimbrough et al. (2002), McBurney et al. (2002), Chen et al. (2000a; 2000b) focused on demand forecasting. Most of these researches suppose that companies in the supply chain share the information and coordinate the orders. But if the supply chain consists of autonomous enterprises, sharing information becomes a critical obstacle, since each independent actor typically is not willing to share with the other nodes its own strategic data (as inventory levels) (Terzi and Cavalieri, 2004); An example is the case of several competitor wholesalers (located in the same or different geographical areas) which source of the same distributor.

Various projects applied the multi-agent system paradigm to solve different problems in Supply Chain (as inventory planning, demand and sales planning, distribution and transportation planning, etc). DragonChain was implemented by Kimbrough et al. (2002) at the University of Pennsylvania (Philadelphia, PA, USA) to simulate supply chain management, and more particularly to reduce bullwhip effect. For that, they base their simulation on two versions of the Beer Game, the MIT beer game (i.e. the original game) and the Columbia Beer Game, and they

use agents that look for the best ordering scheme with genetic algorithms. Maturana et al. (1999) have developed a hybrid agent-based mediator-centric architecture, called MetaMorph, to integrate partners, suppliers and customers dynamically with the main enterprise through their respective mediators within a supply chain network via the Internet and Intranets. In MetaMorph, agents can be used to represent manufacturing resources (machines, tools, etc.) and parts, to encapsulate existing software systems and to function as system or subsystem coordinators/mediators. Swaminathan et al. (1998) have proposed a multi-agent approach to model supply chain dynamics. In their approach, a supply chain library of software components, such as retailers, manufacturers, inventory policy, and so on, has been developed to build customized supply chain models from the library. Sadeh et al. (2001) have developed an agent-based architecture for a dynamic supply chain called MASCOT. The MASCOT is a reconfigurable, multilevel, agent-based architecture for a coordinated supply chain. Agents in MASCOT serve as wrappers for planning and scheduling modules. Petersen et al. (2001) have proposed a multi-agent architecture, called AGORA, for modeling and supporting cooperative work among distributed entities in virtual enterprises. We have already proposed (Nfaoui et al., 2006) an agent-based distributed architecture of simulation in decision-making process within the supply chain context. Agents in this architecture use a set of negotiation protocols (such as Firm Heuristic Negotiation, Recursive Heuristic Negotiation, CPFR Negotiation Protocol) to make decisions collectively in a short time. Chehbi et al. (2003) have proposed multi-agent supply chain architecture to optimize distributed decision making. Moyaux et al. (2004) have developed an agent simulation model for the Québec forest supply chain.

3 THE RUSH UNEXPECTED ORDER AND SAFETY INVENTORY

Safety inventory is necessary to compensate for the uncertainty that exists in a supply chain. Retailers and distributors do not want to run out of inventory in the face of unexpected customer demand or unexpected delay in receiving replenishment orders so they keep safety stock on hand. As a rule, the higher the level of uncertainty is, the higher the level of safety stock is required.

Safety inventory for an item can be defined as the amount of inventory on hand for an item when the next replenishment EOQ (the Economic Order Quantity) lot arrives. This means that the safety stock is inventory that does not turn over. In effect, it becomes a fixed asset and it drives up the cost of carrying inventory. Companies need to find a balance between their desire to carry a wide range of products and offer high availability on all of them and

their conflicting desire to keep the cost of inventory as low as possible (Hugos, 2003b). That balance is reflected quite literally in the amount of safety stock that a company carries.

In practice, the safety stock is not enough to cover all types of unexpected swings in demand and the unexpected exceptions. As an example, the case of a customer (retailer, wholesalers, etc) who contacts his supplier (distributor) and asks for a product quantity as an immediate request, and the supplier discovers that his safety stock is lower than the ordered quantity at that moment. If this happens after the item has been logged in as a confirmed order, will the supplier be able to respond within a suitable timeframe to the customer?

We propose hereafter an agent-based distributed architecture to solve this problem of rush unexpected orders. The rush unexpected order is an object which is characterized by two attributes, the ordered quantity and the short delivery time. Multiple causes of rush unexpected order exist, they closely depend on the branch of supply chain sector. For distributors, the main interest got from such rush unexpected order delivery depends on the customer's profile and other additional criteria such as:

- It allows interesting benefit;
- The distributor does not look for benefit, but he only interests to attract and retain the customer. It is the case for a wholesaler strategic customer for example.
- It helps increasing the number of customers. It is the case of a wholesaler who is a customer of another distributor or a regular customer who is in hurry, which will appreciate the offered service and may become a new customer.

4 AGENT BASED APPROACH

In this section, the agent-based approach is presented, the multi-agent system architecture is described and different agents, as well as their specific roles, are defined.

4.1 Main idea

Figure 1 shows the typical structure of a global distribution supply chain. Systems that are defined as distribution systems can be of important varying structure. Nonetheless, such systems need to contain a number of common properties. A distribution system needs to include one or more customers who are defined by having a demand on a given product. In addition, the system needs to include one or more sources, which are defined by producing or containing the product demanded by the customer(s). Finally, the system needs a connection between

the source(s) and customer(s), which can accommodate a flow of the product from the source(s) to the customer(s) in order to obtain fulfilment of the demand.

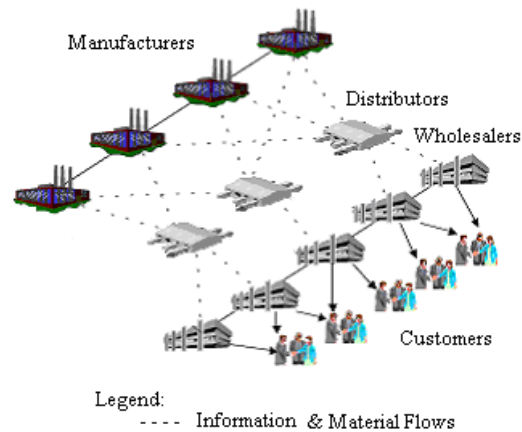


Figure 1. Overview of a global distribution supply chain

Let us suppose that a wholesaler or a particular customer had placed a rush unexpected order which is characterized by two attributes:

- The ordered quantity OQ which cannot be delivered partially or completely from the distributor's available inventory;
- The delivery time DT.

Two cases are then possible:

- a. The distributor does not have any part of the ordered quantity OQ;
- b. It has a part of the ordered quantity and must complete the rest.

In both situations:

$$OQ = DisQ + RQ$$

Where DisQ: available quantity which can be delivered by the distributor. Two situations are possible:

DisQ = 0 (a) or DisQ < OQ (b).

RQ: required quantity which must be looked for.

The problem can be then summarized as follows:

Find the required quantity RQ in order to deliver the rush unexpected order while respecting the delivery time DT.

One of the practices of the distributors (see other solutions in introduction) consists of seeking the required quantity from another wholesaler or distributor. In general, the distributor will be limited to some close and faithful

wholesalers or to distributors of the same company. This shows that the chosen solution (if it is found) can not be the best. Moreover, it takes enough time since the negotiation is carried out generally by phone. Within the context of SCM, we propose to extend this practice by involving (into collaboration) several wholesalers, same products distributors and equivalent products distributors. So, the distributor will be supplied from three different actors:

- 1st type (distributor and its wholesalers)
 - Wholesalers belonging to the same area as the customer;
 - Wholesalers belonging to different areas from the customer;
 - Both cases above.
- 2nd type (distributor/same products distributors)
 - The same products distributors and/or their wholesalers.
- 3rd type (distributor/equivalent products distributors)
 - The equivalent product distributors and/or their wholesalers.
- 4th type
 - Hybrid Solution: two or three types at the same time.

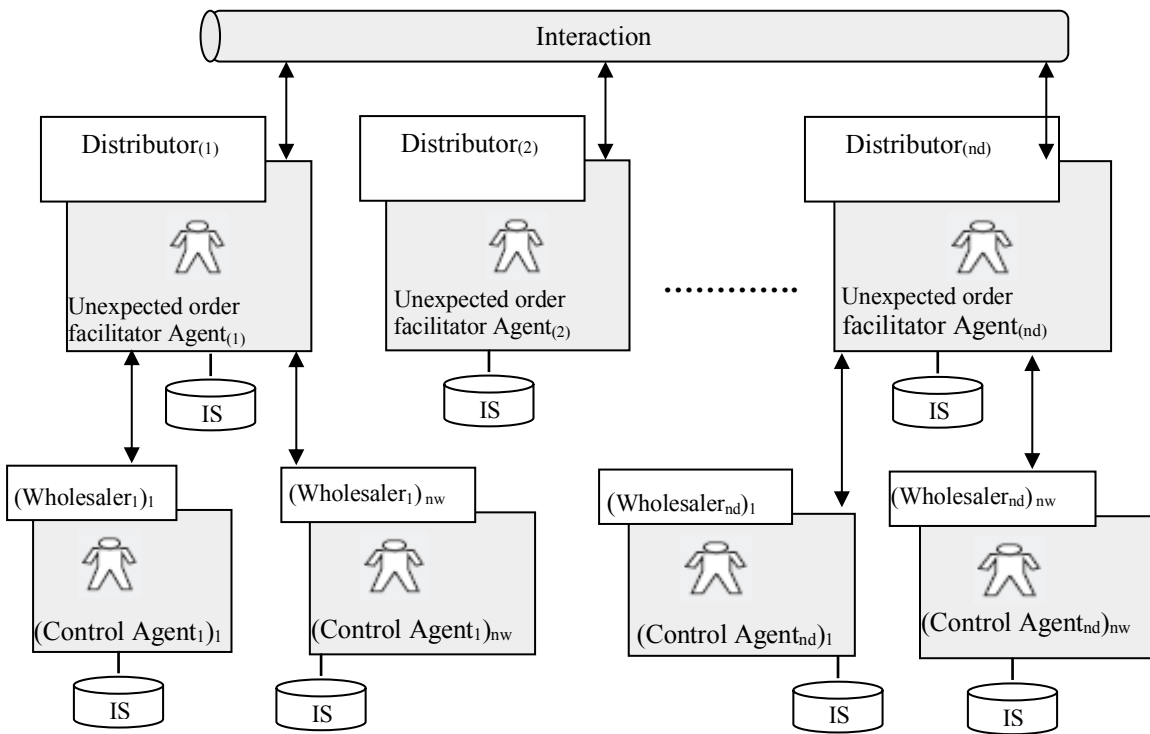
In practice, to implement this process in the industrial cases, and in order to satisfy the distributors' needs, three conditions must be checked:

- Quick and automatic solution. The manager contacts the collaborative participants only to confirm the solution.
- Autonomy and data confidentiality of each participant must be guaranteed since they can be independent.
- Transportation costs should be minimized, which will be added to the basic high purchase price since the products will not be delivered directly by the distributor.

As shown in the background review (section 2), the agent technology is more suitable for this type of problem. In this respect, we propose in the section below an agent-based distributed architecture which implements this process.

4.2 Agent-based solution approach

The proposed system does not substitute the existing tools and the SCM strategies and practices, but it can be used as a complement which improves them in the case of the presence of a rush unexpected order. The system architecture is shown in Figure 2.



nd: the number of collaborative distributors

nw₁: the total number of collaborative wholesalers of the distributor₍₁₎

nw_{nd}: the total number of collaborative wholesalers of the distributor_(nd)

IS: Information System (such as an ERP Enterprise Resources Planning system)

Figure 2. System architecture

The main purpose of this system is to coordinate all collaborative participants in order to find the OQ quantity and minimize total cost of transportation when a rush unexpected order is presented. The complete architecture includes two types of agents: control agents “*WhoAgent*” for wholesalers and the unexpected order facilitator agents “*DisAgent*” for distributors. Each distributor is modeled by a *DisAgent_i* (where $i \in [1, nd]$ and nd is the number of collaborative distributors) and each wholesaler is modeled by a *(WhoAgent)_j* (where $j \in [1, nw_i]$ and nw_i is the total number of collaborative wholesalers of the distributor_(i)). These coordinated agents have the ability to specify both static and dynamic characteristics of various supply chain entities (Lee, 1997); in particular, the level of distributors and their wholesalers.

The control agent plays a liaison role between a supply chain manager and the system. It collects strategies from managers, seeks the accurate data and aims at building a rule-base for better coordination and better decision-making process. When an unexpected order facilitator agent *DisAgent_i* asks a control agent *(WhoAgent)_j* (where $j \in$

$[1, nw_i]$ and nw_i is the total number of collaborative wholesalers of the distributor_(i) for possible quantity of product that it can deliver, control agent (*WhoAgent_i*)_j sends information about possible quantity and costs, and transportation costs. The agent system is autonomous because it allows any manager to change strategies of that node. Also, it allows overcoming the hurdle which consists of need for sharing sensitive information of participants in the SC, because the agents do not exchange information about inventory levels and strategies. In real world coordination, sharing information truthfully is problematic since intra-organizational trust cannot be easily developed. Next, if the collaborative participants (wholesalers and their distributors) are independent and operate within the same sector (same or equivalent products); information sharing becomes a critical obstacle, since each independent wholesaler/distributor is typically not willing to share with the other nodes its own strategic data (as inventory level for example). On the real global distribution cases, and especially in the same distribution sector, it is easy to implement the interaction between a distributor and its wholesalers. However, it is difficult, even impossible, to implement it between a distributor and the wholesalers of another distributor. Indeed, the participants are confronted to the increasing impact of competitive pressures. Also, each distributor tries to increase the number of its customers. To represent the real global distribution cases, each agent *DisAgent_i* can interact with other agents $\{DisAgent_k / k, i \in [1, nd], k \neq i\}$ and control agents $\{(WhoAgent_i)_j / j \in [1, nw_i]\}$, but a control agent can interact only with its distributor agents.

The unexpected order facilitator agent *DisAgent_i*, which communicates with control agents and other unexpected order facilitator agents, plays the same role of control agent. In addition, it provides the best solution of solving the rush unexpected order, which tries to minimize the total transportation costs. When a rush unexpected order (which characterized by: OQ and DT) is presented at the distributor_(i), the manager asks the unexpected order facilitator agent *DisAgent_i* to search the best solutions. At this moment, the agent carries out the algorithm “search_OQ” for solving the problem which can be summarized as follows:

- Search the RQ: It can be delivered completely by only one wholesaler or gathered from several wholesalers (1st type).
- Find and classify a series of possible paths in an ascending order depending on transportation cost (which depends closely on the distance) to transport OQ while respecting the delivery time DT.
- Propose quantity Q_j to be supplied by each participant belonging to a path.

Algorithm search_OQ

Constants

- $(d_{k,j})$ distances (D matrix) and $(t_{k,j})$ times (T matrix) between wholesalers (where $1 \leq k,j \leq nw_i$ and nw_i is the total number of collaborative wholesalers of the distributor_(i)).

$$D = (d_{k,j}) = \begin{bmatrix} 0 & d_{1,2} & d_{1,3} & \dots & d_{1,nw_i} \\ d_{2,1} & 0 & & & \\ \cdot & & 0 & & \\ \cdot & & & 0 & \\ d_{nw_i,1} & & & & 0 \end{bmatrix}$$

$$T = (t_{k,j}) = \begin{bmatrix} 0 & t_{1,2} & t_{1,3} & \dots & t_{1,nw_i} \\ t_{2,1} & 0 & & & \\ \cdot & & 0 & & \\ \cdot & & & 0 & \\ t_{nw_i,1} & & & & 0 \end{bmatrix}$$

- (dd_j) distances (DD matrix) and (td_j) times (TD matrix) between distributor_(i) and its wholesalers.

$$DD = (dd_j) = (dd_1 \quad dd_2 \quad \dots \quad dd_{nw_i})$$

$$TD = (td_j) = (td_1 \quad td_2 \quad \dots \quad td_{nw_i})$$

- The Minimal quantities $(qm_{k,j})$ (QM matrix) of product which can be transported in the segments connecting the wholesalers.

$$QM = (qm_{k,j}) = \begin{bmatrix} 0 & qm_{1,2} & qm_{1,3} & \dots & qm_{1,nw_i} \\ qm_{2,1} & 0 & & & \\ \cdot & & 0 & & \\ \cdot & & & 0 & \\ qm_{nw_i,1} & & & & 0 \end{bmatrix}$$

- The Minimal quantities (qmd_j) (QMD matrix) of product which can be transported in the segments connecting the distributor_(i) and its wholesalers.

$$QMD = (qmd_j) = (qmd_1 \quad qmd_2 \quad \dots \quad qmd_{nw_i})$$

- (ccp_j) coefficients of collaborative proximity (trust, levels of seniority,...) of each (wholesaler_i)_j towards the distributor_(i) :

$$CCP = (ccp_j) = (ccp_1 \quad ccp_2 \quad \dots \quad ccp_{nw_i})$$

Begin

// determine the customer's place

If (the customer is a collaborative wholesaler) **Then**

Its distances are defined (D , DD , T and TD matrices)

Else

Use the distances of the wholesaler nearest to the customer

End If

Read DT // the Delivery Time

Read OQ // the Ordered Quantity

Read $DisQ$ // the available quantity which can be delivered by the distributor_(i)

$RQ = OQ - DisQ$ // Deduce the Required Quantity

Send a message of performative $QUERY-REF$ to control agents $\{(WhoAgent)_j / j \in [1, nw_i]\}$ (where $j \in [1, nw_i]$

and nw_i is the total number of collaborative wholesalers of the distributor_(i)) to ask them for its maximum quantities of product which they can deliver. The agents use the FIPA-ACL language (FIPA 2002) for communication. $QUERY-REF$ is the act of asking another agent to inform the requester of the object identified by a descriptor. Each control agent $(WhoAgent)_j$ replies by a message of performative $INFORM$ indicating the maximum quantity $Qmax_j$ which can deliver (or a message of performative $REFUSE$ in case of rejection).

Construct an empty list LWC // the list of wholesalers candidates

Do //loop 1

Do //loop 2

Read N // N is the maximum number of wholesalers including in a path. $N \in [1, nw_i]$.

Determine the list LWC of wholesalers candidates: $\{(WhoAgent)_j / j \in [1, t] \text{ and } t \leq nw_i\}$.

/* If (N=1) then: $(WhoAgent)_j$ is candidate if it satisfies the constraint below :

$$Q_{max_j} \geq RQ$$

If (N ≥ 2): $(WhoAgent)_j$ is candidate if there exists at least N-1 $(WhoAgent)_{k \neq j}$ which belong to *LWC* and satisfy the constraints below :

- (The sum of the quantity Q_{max_j} and quantities $Q_{max_k} \geq RQ$)
- $Q_{max_j} < RQ$
- Each Q_{max_k} is less than RQ

*/

While ((*LWC* is empty) AND (N < Nu)) // Nu is the unacceptable value of N. Nu depends on RQ.

//End loop 2

If (N ≥ Nu) // the unacceptable value of N is reached

Then

Break and start a new research in same products distributors or equivalent products distributors (2nd type, 3rd type or 4th type).

End If

Construct an empty list *LPP* // the list of possible paths

At this step, the agent must found a list *LPP* of possible paths and order it by transportation costs (in case of close solutions, the manager will use the coefficients of collaborative proximity (CCP_j)). It must also propose the quantity Q_j ($Q_j \in [Q_{min_j}, Q_{max_j}]$) for each wholesaler belonging to a path. A possible path is characterized by:

- Starting point ;
- Destination point (customer) ;
- It includes N wholesalers. Each wholesaler belongs to the list *LWC* and can deliver Q_i .
- It must satisfy the constraints below :

If (the distributor_(i) is included in the path) **Then**

- The sum of the quantity $DisQ$ and quantities Q_j must be equal to OQ .
- The time of path (*TP*) must be less or equal to the delivery time (*DT*).

Else

- The sum of the quantities Q_j must be equal to OQ .
- The time of path (TP) must be less or equal to the delivery time (DT).

End If

While ((the list LPP is empty) AND ($N < Nu$))

// End loop 1

If ($N \geq Nu$) // the unacceptable value of N is reached

Then

Break and start a new research in same products distributors or equivalent products distributors (2nd type, 3rd type or 4th type).

End If

End //algorithm Search_OQ

Figure 3 shows the UML (Unified Modeling Language) sequence diagram (Bauer and Odell, 2005) that expresses the exchange of messages through the interaction protocol between the unexpected order facilitator agent $DisAgent_i$ and the control agents $\{(WhoAgent)_j / j \in [1, nw_i]\}$. These agents use other negotiation protocols (cf. section 5).

If no solutions are found (whenever an unacceptable value of N is reached) or the manager is not satisfied by the proposed solutions, the agent can interact with the unexpected order facilitator agents $\{DisAgent_k / k, i \in [1, nd], k \neq i\}$ of other distributors in order to find the best solution. In this case, the agent $DisAgent_i$ sends a message of performative $QUERY-REF$ to all the collaborative unexpected order facilitator agents to find the RQ . Each agent applies his decision-making process in order to deliver the RQ . They can interact if necessary with the control agents to get the best solution. At the end, the unexpected order facilitator agent $DisAgent_i$ sorts all the received solutions. Figure 4 shows the UML sequence diagram that expresses the exchange of messages through the interaction protocol between the unexpected order facilitator agents of several distributors. These agents use other negotiation protocols (cf. section 5).

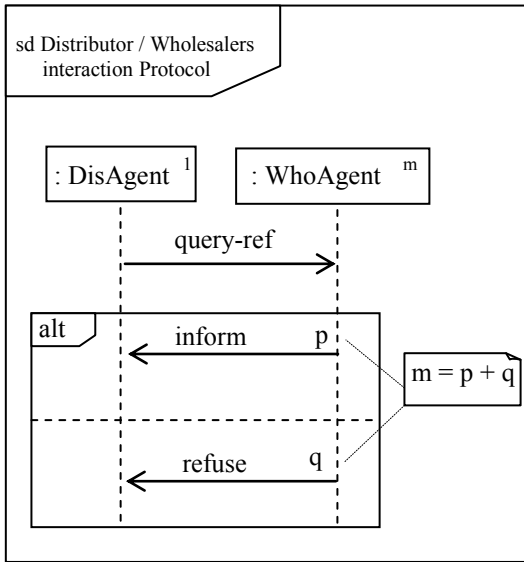


Figure 3. Distributor / Wholesalers interaction Protocol

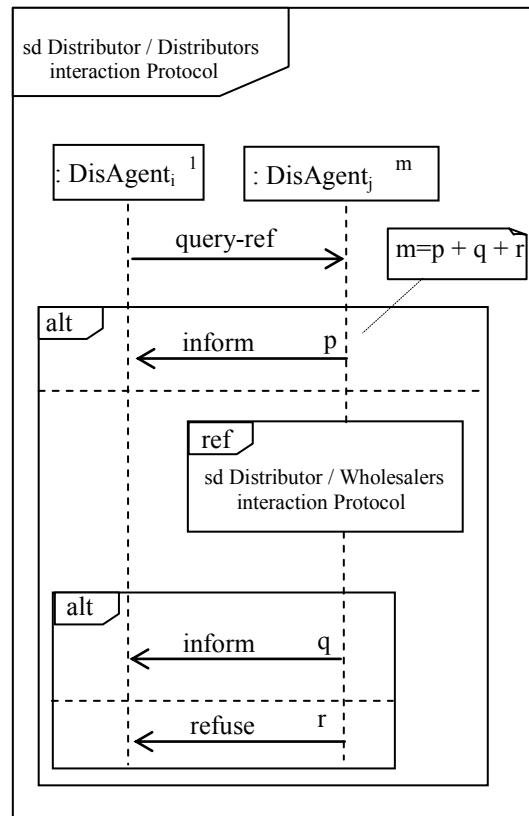


Figure 4. Distributor/Distributors interaction Protocol

5 NEGOTIATION PROTOCOLS

In our distributed architecture, the agents use several negotiation protocols. The negotiation is the mechanism by which the agents can establish a common agreement. In the case of intelligent agents and of the MAS (Multi-Agent Systems), the negotiation is a basic component of the interaction because the agents are autonomous (Jenning et al., 2001); there is no solution imposed in advance and the agents must find solutions dynamically, while solving the problems.

In the SCM process, the agents are co-operative, having the same goal (aggregation of the local objectives). They share and solve problems together. For this reason, the agents must provide useful reactions to the proposals that they receive. These reactions can take the form of a counterproposal (modified proposal). A counterproposal of an agent for a proposal is defined as the solution which is constructed by modifying the communicated proposal (Yoshida, 2007). From such reactions, the agent must be able to generate a proposal which is probably ready to lead

to an agreement. Consequently, the agents of our system must use protocols respecting the criteria which have been stated above and that mainly depend on three parameters:

- The branch of supply chain sector (textile and clothing sector, consuming goods sector, etc.);
- SCM strategies and practices used for the companies' co-operation and coordination;
- Objects to be negotiated: rush order, ordinary order, sales forecasts, orders forecasts; modification of delivery plans in case of trouble, etc.

5.1 Heuristic Negotiation

The heuristic negotiation is shown in figure 5 (Florea, 2002). In this protocol several proposals and counterproposals can be exchanged in various steps. Agent "A", with proposal "pA", is the initiator of the negotiation, whereas the agent "B" (participant) can reply with the answers "p1B", "p2B" and "p3B" (to modify the request). The number of the counterproposals is limited. Once this limit is reached, the agents arrive to a rejection. We propose to recapitulate the heuristic negotiation protocol using an UML sequence diagram (Figure 6).

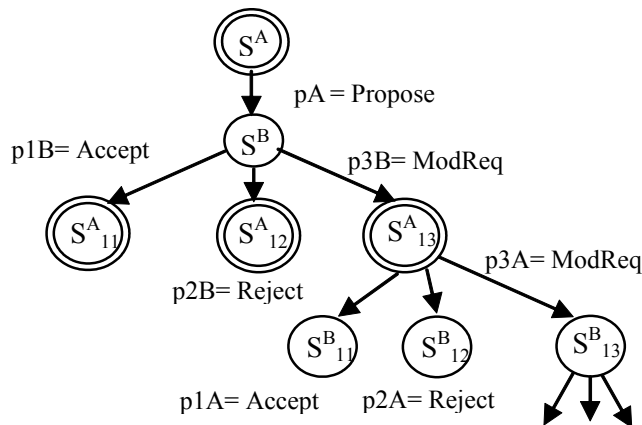


Figure 5. Heuristic negotiation

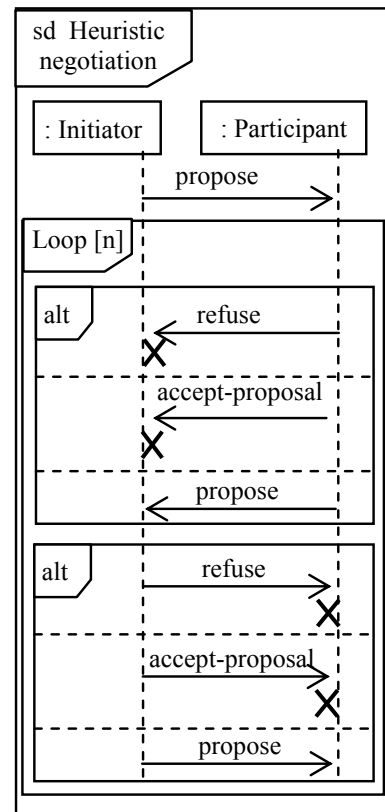


Figure 6. Heuristic negotiation

5.2 Proposal for a Firm Heuristic Negotiation

In some situations of negotiation, the collaborative agents must find an agreement. For this reason, the heuristic negotiation (cf. Figure 6) should include only ACCEPT-PROPOSAL or PROPOSE performatives (without the REFUSE performative). Thus, we propose the “firm heuristic negotiation protocol” which is a particular case of the heuristic negotiation. The word “firm” stands for this protocol since it always leads to an agreement. Figure 7 shows the sequence diagram that describes this protocol.

5.3 Proposal for a Recursive Heuristic Negotiation

The recursive negotiation protocol that we propose takes place at least between three agents, the initiator of the negotiation (sender), and the receiver who could become the initiator of a new heuristic negotiation with the third agent; hence the word “recursive” qualifying this heuristic protocol. Figure 8 shows the corresponding sequence diagram.

In our system, the recursive heuristic negotiation either belongs to a protocol corresponding to a SCM practice and strategy or corresponds to the negotiation of a rush order or scenario to be adopted in the case of disturbance (such as a disturbance of transport). In the general case, the negotiation takes place in the following way:

- The initiator of the negotiation sends messages (not necessarily identical) of type PROPOSE to all the direct agents (upstream and/or downstream) whom he thinks could be candidates in a negotiation. So, the initiator launches several independent negotiations. It does not wait for all the answers to make a decision. Moreover, according to the situation and the time interval, it can come up with the best solution by creating new proposals deduced from the received answers;
- Since the agents of our architecture are co-operative, each one of them - receiver of a message - can start a negotiation if necessary between other agents in order to find the best solution.

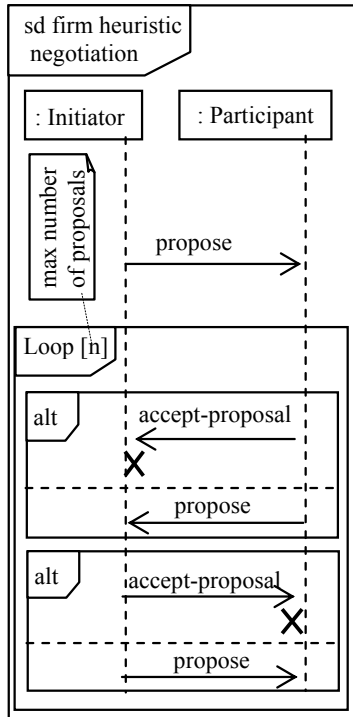


Figure 7. Firm Heuristic negotiation

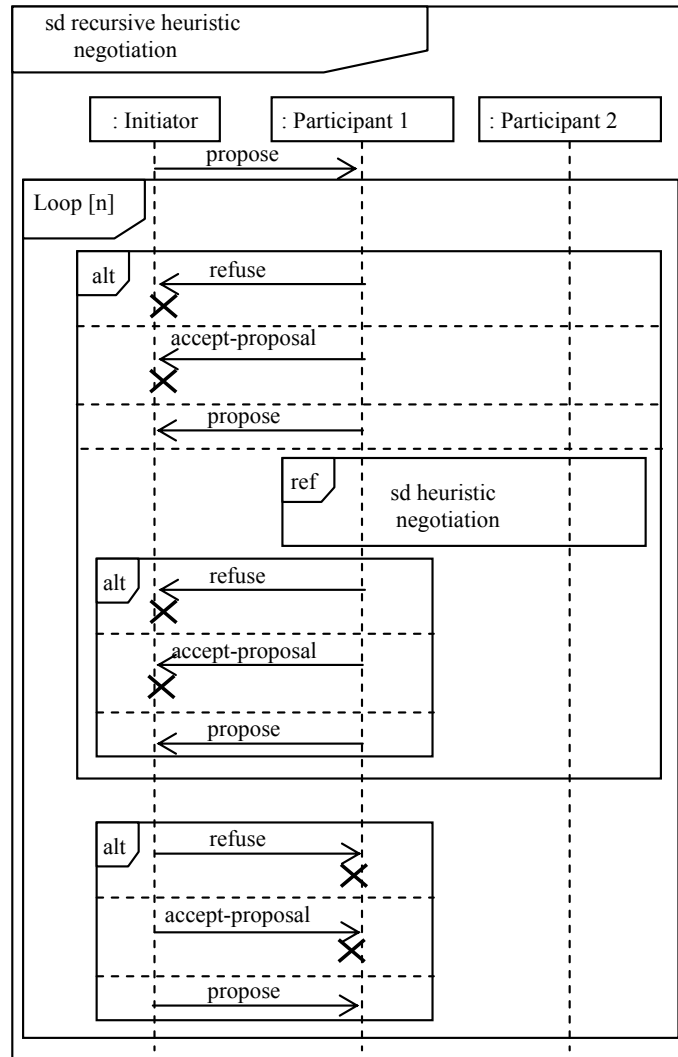


Figure 8. Recursive heuristic negotiation

6 CASE STUDY: VALIDATION OF SOLUTION APPROACH

6.1 Description

A case study of the proposed agent-based distributed architecture is conducted at a leading distribution company in North Africa. The aforementioned company operates in the sectors of toilets and showers (washbasin, baths, etc.), taps, tiling, plumbing and pieces of furniture. It offers about 800 economical and high-end items at both its wholesale and retail market locations which are geographically distributed throughout the region. The products are sourced from two national suppliers (Morocco) and two main foreign suppliers (Spain and Turkey). The distributor mainly manages three types of independent-demand inventory systems: Periodic Review system

(sometimes called a fixed interval reorder system or periodic reorder system) (Baglin et al., 2001) which is used to manage the inventory of the high-end products sourced from the foreign suppliers; a new order is always placed at the end of each review; the Time Between Orders (TBO) is fixed at 6 months for high-end items of plumbing, and 1 month for high-end items of tiling. The reorder point system (or fixed ordering quantity system), which tracks the remaining inventory of an item (sourced from national suppliers) each time a withdrawal, is made to determine whether it is time to reorder. Demands are estimated from forecasts and/or customer orders. A sourcing-to-order is used for some items depending closely on taste and last fashion (like products of tiling, etc).

The distributor has noticed that, in the whole, there are 6 to 10 rush unexpected orders that could take place each month. Actually, it is a big challenge because the aforementioned orders do not concern the same product. At the average level, 60% of such orders are cancelled, 20% are made at other distributors, and the delivery time of the other 20% can be modified after a tough negotiation with the customer.

6.2 Example of an emergency situation

At the beginning of the month of January 2007 (the beginning of the low sales season), a real-estate operator (who already promised the delivery of the apartments to the customers at a precise time) must have closed the building site (located in Fez city) during one week in order to have the housing license agreement as soon as a high-end item required in the construction had been in shortage. This latter is due to the inventory shortage of this item at the distributor. Because of a problem in the supplying process mainly due to one of the foreign suppliers, the next planned delivery of this item has been backlogged. In addition, the required high-end item cannot be supplied from other distributor because the aforementioned distributor is the only exclusive actor of such product. This order placed during the first week of the month was regarded as an unexpected firm rush order (delivery time: 9 hours; and it can neither delayed nor cancelled).

6.2.1 *Adopted solution*

In this emergency case, the distributor was compelled to place an order of an equivalent item (brand, color...) at another competitor distributor located in Casablanca city (289Km from Fez city). Even if the costs were high, the distributor was interested to attract and retain the real-estate operator.

6.2.2 Solutions provided by the proposed system

In order to show the effectiveness and usefulness of the suggested architecture, we have made use (as a tangible demonstration) of the aforementioned item inventory level history of 37 wholesalers distributed throughout the country (Table 1). They are identified by scm1, scm2... scm37.

Table 1: Cities of the wholesalers

| scmName | City |
|---------|-------------|
| scm1 | Agadir |
| scm2 | Al Hoceima |
| scm3 | Azilal |
| scm4 | Beni Mellal |
| scm5 | Boulemane |
| scm6 | Casa Blanca |
| scm7 | Casa Blanca |
| scm8 | Casa Blanca |
| scm9 | Casa Blanca |
| scm10 | Casa Blanca |
| scm11 | Chefchaouen |
| scm12 | El Jadida |
| scm17 | El Kelaa |
| scm13 | Errachidia |
| scm14 | Essaouira |
| scm15 | Fez |
| scm16 | Figui |
| scm18 | Kenitra |
| scm19 | Khemisset |
| scm20 | Khenifra |
| scm21 | Khouribga |
| scm22 | Laayoun |
| scm23 | Marrakech |
| scm24 | Meknes |
| scm25 | Nador |
| scm27 | Oujda |
| scm26 | Ourzazate |
| scm28 | Rabat |
| scm29 | Safi |
| scm30 | Settat |
| scm31 | Smara |
| scm32 | Tanger |
| scm33 | Tan-Tan |
| scm34 | Tarfaya |
| scm35 | Taza |
| scm36 | Tetouan |
| scm37 | Tiznit |

Figure 9 shows three of 13 existing solutions (paths and quantities) proposed by the unexpected order facilitator agent, according to the value of the number of wholesalers involved in each path. This number is chosen by the manager (Figure 10). Figure 11 shows only the first three paths. In the Figure 9, Q_{min} is the minimal quantity of product which can be transported in a segment connecting a wholesaler and the next wholesaler in the same path.

Results and discussions:

- We notice that even if the required quantity cannot be delivered completely by only one wholesaler, it can be gathered from both wholesalers scm26 (Ourzazate) and scm23 (Marrakech). This solution is not appropriate since the distance of the path is 687km. Indeed, the costs of transportation will be high.
- The distributor has 12 choices concerning the paths including 3 wholesalers. The time of the first three paths are almost equal to half of the required delivery time. The distances (323km, 343km) of the first two paths (Tetouan→Chefchaouen→Meknes→Fez; Tanger→Tetouan→Chefchaouen→Fez) are about 289km (distance

between the competitor distributor and the customer). Certainly, these two solutions are better than the adopted solution, at least for two reasons:

1. The costs of transportation will be almost the same;
2. The purchase prices offered by the collaborative wholesalers (involved in the same supply chain) are lower than the offered prices from the competitor distributor.

We deduce that the distributor had three solutions better than the adopted solution. We can conclude that more the number of actors constituting a path and the required quantity are large, more the number of choices is important.

In practice, several emergency situations exist and depend closely on the branch of supply chain sector.

Figure 9: Proposed solution

```

*****
**** Paths including only one wholesaler ****
*****
Sorry: No solution including only one wholesaler

*****
**** Paths including two wholesalers ****
*****

---Path 0: Total distance(Km): 687 ; Total time(Hours) : 8.587499999999999
Actor :scm26 ; City :Ourzazate ; Type :Wholesaler ; Qmax :8000 ; Dista :204km ; Time(hours):2.55 ; Qmin :4000
Actor :scm23 ; City :Marrakech ; Type :Wholesaler ; Qmax :4000 ; Dista :483km ; Time(hours):6.0375 ; Qmin :9700
Customer City: Fez

*****
**** Paths including three wholesalers ****
*****

---Path 0: Total distance(Km): 323 ; Total time(Hours) : 4.0375
Actor :scm36 ; City :Tetouan ; Type :Wholesaler ; Qmax :3000 ; Dista :61km ; Time(hours):0.7625 ; Qmin :1200
Actor :scm11 ; City :Chefchaouen ; Type :Wholesaler ; Qmax :5000 ; Dista :202km ; Time(hours):2.525 ; Qmin :4000
Actor :scm24 ; City :Meknes ; Type :Wholesaler ; Qmax :4000 ; Dista :60km ; Time(hours):0.75 ; Qmin :600
Customer City: Fez

---Path 1: Total distance(Km): 343 ; Total time(Hours) : 4.2875
Actor :scm32 ; City :Tanger ; Type :Wholesaler ; Qmax :4000 ; Dista :57km ; Time(hours):0.7125 ; Qmin :1200
Actor :scm36 ; City :Tetouan ; Type :Wholesaler ; Qmax :3000 ; Dista :61km ; Time(hours):0.7625 ; Qmin :1200
Actor :scm11 ; City :Chefchaouen ; Type :Wholesaler ; Qmax :5000 ; Dista :225km ; Time(hours):2.8125 ; Qmin :4500
Customer City: Fez

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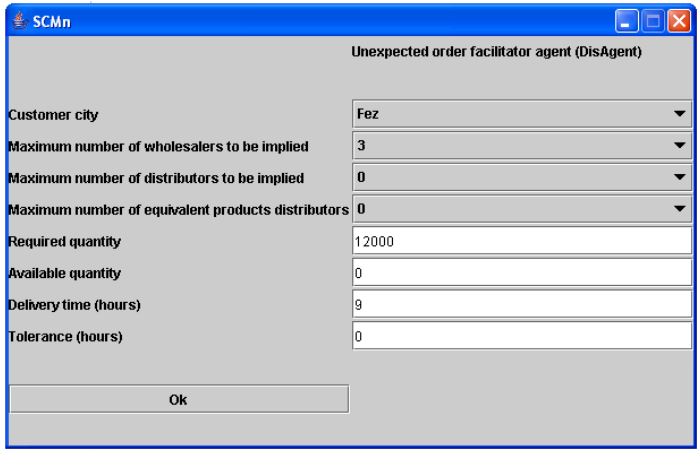


Figure 10. Unexpected order facilitator agent

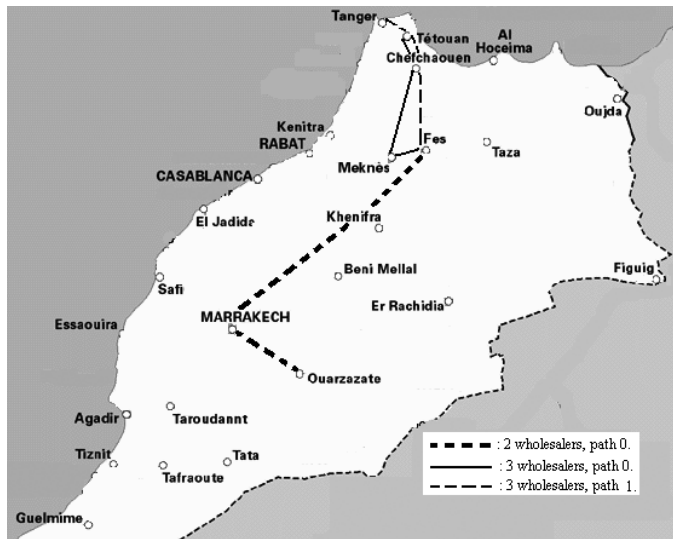


Figure 11. The first three paths

6.3 Implementation

The prototype has been implemented using JADE (Java Agent Development Framework) from CSELT, Turin, Italy. JADE is a middle-ware that could be used to develop agent-based applications in compliance with the FIPA specifications for inter-operable intelligent multi-agent systems (Bellifemine, Poggi, & Rimassa, 1999). JADE is

java-based and provides the infrastructure for agent communication in distributed environments, based on FIPA standards. Table 2 shows our implementation environments for the prototype.

Table 3: Implementation environments for the prototype

| | |
|------------------------------|--------------------|
| Implementation environment | JADE 3.4 |
| Implementing language | Java |
| DBMS | SQL Server 2000 |
| Agent communication language | FIPA ACL Standards |
| Operating system | Windows XP |

7 CONCLUSION AND FUTURE WORK

In this paper, we presented an agent-based distributed architecture for collaborative decision-making processes within the global distribution supply chain. We proposed a process (thanks to the multi-agent properties) for a best management of the rush unexpected order. At this stage, the architecture is validated and tested on a leading distribution company. The results are very promising and show that our proposed system could be connected to the existing SC tools. In this case, enterprise application integration assumes a great importance. Enterprise Application Integration (EAI) enables an enterprise to integrate its existing applications and systems and to add new technologies and applications to the mix.

In the next stage of this work, we will take into account the size of the transported batches, i.e. to represent the price of transportation per unit of product as being lower when the transported quantity is large. In this case, it will be necessary to seek the quantities which optimize the costs of transportation (we intend to use a genetic algorithm). Then, we will extend our architecture in order to use it in the global manufacturing supply chain (including manufacturers, suppliers...).

Acknowledgement

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