Collaborative System Model for Dynamic Planning of Supply Chain

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***Abstract*— The business need to be structured as an integrated supply chain pushes companies to make use of a greater level of co-operation and coordination. As a means of coordination, negotiation has been chosen in this work. The object of this paper is to present formalism for negotiation in dynamic planning of a supply chain with the objective of maximizing the overall profit of each partner. To model the SC, we use the multi agent approach. Each enterprise is represented by its negotiator agent. The negotiations are formalized using UML language. The proposed negotiation process allows agents to develop a feasible production schedule.**

Keywords- supply chain; negotiation; collaboration; dynamic planning; UML

I. INTRODUCTION

In the collaborative planning supply chain context, there is a need firstly to develop sophisticated optimization and decision support tools to help explore and analyze alternatives and secondly to develop tools for coordination and collaboration.

How can supply chain partners form temporary alignments to quickly respond to market requirements as well as effectively utilize their competencies? The ability of partners to plan quickly and effectively, utilize their resources throughout the chain is a key to successful supply chain planning. To achieve this, it is crucial to rapidly and effectively coordinate them through the planning process, where various constraints must be taken into account such as capacity, quality, cost, timeliness, and inter-dependencies between partners. The constraint may be limited to a partner (e.g., the capacity of production, panes machines…), or related to more than one, (e.g., the quantity of the components to be purchased, a manufacturing service should be scheduled to start after the procurement service is completed). A solution to one partner (called a node of supply chain) does not have a global view and would not satisfy both intra-node and inter-nodes constraints.

A solution of a node is usually unable to take into account the constraints embedded in interdependencies among the partners, very often resulting in incoherent and contradictory hypotheses and actions. Existing studies on this problem have focused on facilitating bilateral exchange between customers and suppliers, and have relied on complete information about resources and tasks without adequately capturing the dynamics and uncertainties of the operating environments [1]. It is a complex problem to schedule, and coordinates a set of partners from a large number of resources under various constraints and even uncertainties. The complexity is mainly due to the ambiguity in determining the requirements of components node's; the uncertainty of solutions to component services (e.g., availability, capacity, and cost); and interdependencies among component services. The uncertainties and constraints may result in dynamisms and difficulties in searching and coordinating the services. Given this observation, the main problem is to find a way to achieve coordination and coherence among the decisions of partners in a supply chain network.

Agent technology helps understand and model complex real-world problems and systems by concentrating on high-level abstractions of autonomous entities [1,2]. The benefits of adopting agent technology in supply chains have been recognized in an increasingly wide variety of applications involving inter-enterprise collaboration, extending the boundaries of strategic partnership to wherever the network technologies can reach.

The application of multi-agent systems (MAS) in manufacturing and supply-chain management is not new. In intelligent manufacturing, agents have been used in the following functional areas: manufacturing control [3], collaborative design [4] and coordination in MAS for agile manufacturing [5]. Montreuil et al. [6] have developed a strategic network for supply chain. Lin and Solberg [7] have developed a market mechanism to coordinate agents in real time in an integrated shop floor control model. Sikora and Shaw [8] have provided a multi-agent framework for the coordination and integration of information systems.

Cauvin et al. [9] proposed an approach to minimize the impact of disruptive events on the whole intra-organizational information system. It is based on an analysis of disruptive events. The aim of this work is to assist human decision makers in the design of the recovery process, proposing them solutions for the final decision. These functionalities are characteristics of a decision corrective system. The system is unable to perform autonomous corrective actions.

Lorena et al [10] complete [9]'s study. Their system performs autonomous corrective control actions but not propose how agents make decisions.

Compared to previous approaches, we will model supply chain as a multi agent system and each partner as a multi agent system able to communicate and negotiate and plan in uncertain environment.

In our study, we suppose that each partner of the supply chain has established the planning for the future horizon. Our aim is to propose a framework for information sharing and negotiation for a collaborative planning when there were unexpected orders or impervious change.

II. Framework'S Supply Chain Using Multi Agents System

A. Conceptual model of the SC

As a solution to the problem of collaboration for planning supply chain, partners use agent negotiation. Due to dynamic changes in the internal and external environments, it is not easy to coordinate the conflicts of interests among supply chain members. What's more, quick response to those dynamic changes is required. Coordination of activities across a network of suppliers is essential for reacting quickly to uncertain environments [11]. For this reason, the use of an agent system has come to the fore. An agent system uses a coordination mechanism to approach a global optimization, along with the local objective of each agent. In addition, negotiations are widely being used as a coordination mechanism [12].

We model a supply chain as a number of nodes. A node can be supplier or\and customer of other nodes. Each node is a multi-agent system composed of a planner agent and a negotiator one. The communication and negotiation is established between negotiator agents via messages. We distinguish message of orders, agreements, proposition and negotiation.

We present on figure 1, the conceptual model of the proposed architecture using UML language.

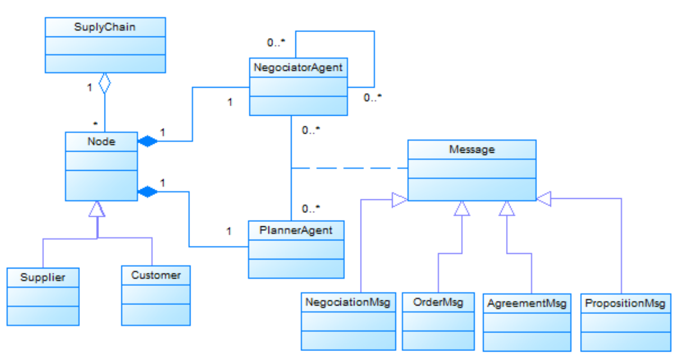

Figure 1. Conceptual model of a supply chain

B. Architecture of the node of the supply chain

As showed in figure1, a node of supply chain is composed of a planner agent (PA) and a negotiator agent (NA). The planner agent has tools for planning and make decision while the negotiator agent have to first, communicate and negotiate with customers and suppliers; second to communicate with its planner agent.

As shown in Figure 2, this approach allows separating planning tasks and communication protocol. The NA negotiates with suppliers and customers and communicates with the PA. The description of negotiation process will be presented in section III.

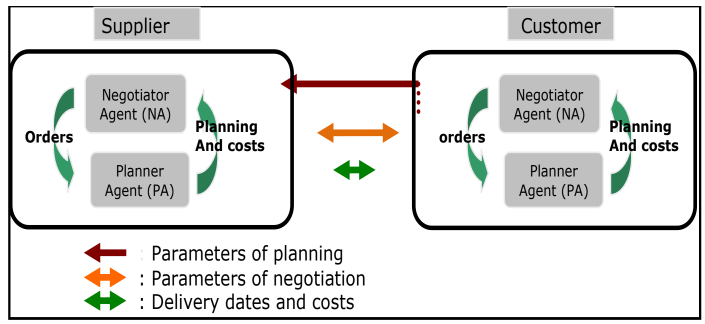

Figure 2. Architecture of a node of supply chain (NSC) in relation with customer or supplier

We assume that the planning of each partner of the SC is established. In case of an unexpected order, internal event or changing the supply plans, The planner agent has to calculate new planning and gives new solutions of planning. The PA can work in two modes:

- Backward mode: when there is an unexpected order from customers or an internal change of production system. In this case, the PA calculates the components it needs to ask from its suppliers, negotiates with them and gives new scheduling. Each schedule gives the production quantities produced by periods and the overall cost of the solution in terms of over hours and the quantities contracted.
- Direct mode: when one or more suppliers give new supply plan different from what it is provided. In this case, the PA must calculate the amount of product that can realize from these components and negotiate with customers.

We describe in next sections tools that assist the PA for planning and decision.

C. Tools for planning and decision of the planner agent

1) Linear programming model of the planner agent

A planner agent encapsulates the knowledge needed to perform every time planning and costs study. When it receives a modification of constraints curves from customers or suppliers, it uses a specific planning technique depending on the problem at hand. An example of a linear model used by the planner agent is presented.

The planning model consists in minimizing the various production costs (in terms of normal working hours, or over-time hours), the unemployed hours and costs of subcontracting and penalties of delay.

In addition, it is assumed that:

- Procurements made for period t-1 will be useful for the production of the period t
- Products take exactly one unit of time to be moved between two nodes (i.e. what is produced, stored or moved by a node for period t can be used by the following node for the period t+1, without worrying about the exact moment when transformations are carried out for the period t)
- Times of change of manufacture (set-up times) are negligible
- The production is carried out in a complex workshop in which the production lines are in series (in the event of parallel production lines, the capacity of the resources are multiplied)
- The process plans are known as well as the occupancy rate of each product on each machine. In our case, our interest is on purchased items at the entry, times spent on each machine and finally products at the exit, without worrying about intermediate products

First, let us denote the notations used. Then, the planning model will be presented.

2) Notations used

a) Definition of sets:

P: Set of products indexed by p (1<=p<=Np)

Npi: Number of products that are supplied (raw materials) indexed by i (1<=i<=Npi)

Npo: Number of products that are delivered indexed by j (Npi+1 <= j <= Np)

R: Set of resources indexed by r

T: The planning horizon

T': The planning horizon plus one period

Various costs taken into account:

$cpn_{j,r}$: Production cost in normal hour of one unit of product j on the resource r

$cot_{r,t}$: Cost of one overtime hour on the machine r during the period t

$csc_{j,t}$: Cost to subcontract one unit of product j during the period t

$chu_{r,t}$: the cost of one unemployed hour on the machine r during the period t

Information concerning the production system:

$g_{i,j}$: Quantity of product i required to manufacture one unit of product j

$C_{r,t}$: Normal capacity of production, in hours, of the resource r for the period t

$b_{j,r}$: Time to produce one unit of the product j on the resource r

MaxSCj,t: Maximum sub-contracted quantity of product j during the period t

MaxOHr,t: Maximum of overtime hours on the resource r during the period t

t0: First period of the plan

b) Information concerning customers and suppliers:

$CGDS_{i,t}$: quantity of product i proposed by suppliers at the beginning of period t (This quantity is a known parameter that corresponds to a strict constraint when computing a direct planning or a soft constraint when computing a backward planning.

$CGUS_{j,t}$: quantity of product j asked by customers at the end of period t (This quantity is a known parameter that corresponds to a strict constraint when computing a backward planning or a soft constraint when computing a direct planning.)

$ct_{j,c,t}$: The unit penalty (in €/day) of the product j not delivered in time (differed delivery) to the customer c at the period t

Secondary variables:

$CDS_{i,t}$: quantity of item i supplied at period t (is equal to $CGDS_{i,t}$ for direct planning)

$CUS_{j,t}$: quantity of product j delivered to customers at period t (is equal to CGUSj,t for backward planning)

c) Decision variables:

$X_{j,t}$: Quantity of products j produced during the period t in normal hours.

$SC_{j,t}$: Quantity of products j subcontracted for the period t.

$XHS_{j,t}$: Quantity of products j produced in overtime at the period t.

$U_{r,t}$: Unemployed hours on the resource r at the period t.

$Late_{j,t}$: Delay of delivery of the product j at the period t.

D. Objective function

To take into account the effect of time, i.e. the reliability of the data that the node has, an up-dating rate (1/(1+α)t-t0) is introduced, where α is an actualization factor. The function is:

$$Min \left[\sum_{t=t0}^{T} \left(\frac{1}{(1+\alpha)^{t-t0}} \left[\sum_{j \in Npo} \sum_{r \in R} X_{j,t} * cpn_{j,r} + (csc_{j,t} * SC_{j,t}) + ct_{j,c,t} * late_{j,t} + \sum_{r \in R} (cot_{r,t} * b_{j,r} * XHS_{j,t} + chu_{r,t} * U_{r,t}) \right] \right) \right] \quad (1)$$

E. Constraints

The planning model constraints are for each i $\in$Npi, j $\in$Npo, t $\in$ T and r $\in$R.

$$CDS_{i,t} \leq CGDS_{i,t} \quad (2)$$

$$(X_{j,t} + XHS_{j,t} + SC_{j,t}) = CUS_{j,t} \quad (3)$$

$$\sum_{j \in Npo} (X_{j,t} + XHS_{j,t}) * g_{i,j} = CDS_{i,t} \quad (4)$$

$$late_{j,t} \geq (CGUS_{j,t} - CUS_{j,t}) \quad (5)$$

$$late_{j,t} \geq 0 \quad (6)$$

$$\sum_{j \in Npo} b_{j,r} * XHS_{j,t} \leq MaxO_{r,t} \quad (7)$$

$$SC_{j,t} \leq MaxSC_{j,t} \quad (8)$$

$$\sum_{j \in Npo} b_{j,r} * (X_{j,t} - XHSj,t) + U_{r,t} = C_{r,t} \quad (9)$$

$$CDS_{i,t}, CUS_{j,t}, XHS_{j,t}, X_{j,t}, U_{r,t}, SC_{j,t} \geq 0 \quad (10)$$

Explanations of constraints are:

2: The provisioning necessary for the production at period t should not exceed what is proposed by the suppliers.

3: At each period t and for each product j, the quantity delivered is equal to the sum of what is produced in normal hours, overtime or subcontracting.

4: At each period t, the quantity of component i used in production is equal to the sum of the requirement in components at period t.

5 and 6: The delay of the delivery of product j at the period t is equal to the maximum of 0 and the difference between what is required and what is produced.

7: Limits overtime available to a maximum value.

8: Limit subcontracted quantities for each product with a maximum value.

9: Ensures that the capacity of the resources available is equal to the sum of the operational durations and the unemployed hours minus overtime.

10: Indicates that all the variables of decision are positive or null.

III. THE MODEL OF NEGOTIATION PROCESS IN THE SC

A. Negotiation in supply chain

The negotiation is the communication process of a group of agents to reach a mutual agreement accepted by all parties [13]. For example, in the field of production, the agreement could focus on quality, costs and deadlines. Therefore, the basic idea behind the negotiation is to reach a consensus. Negotiation can be competitive or co-operative behavior by different agents involved in it [14].

The strategy of negotiation that we propose is based on a co-operative negotiation. The flow of information shared between the different agents of the supply chain includes initial orders, agreements and propositions.

We distinguish the nodes of the SC in relation with customers and the internal nodes of the chain. We will not study the case of nodes in relation with external suppliers because it is assumed that there are no problems with raw material suppliers because in general they work on stock.

B. The process of planning and negotiation in the supply chain

In the case of a change due to unexpected orders, the negotiator agent (NA) seeks urgent solutions. Firstly, it checks the inventory, if the order can be fulfilled, it responds with an agreement else it asks the planner agent to restart schedule. In the first case, the AP uses backward plan, calculate components needs, which the NA asks to suppliers (figure 4) and gives solutions that can satisfy the customer with additional costs ie additional costs of raw materials, costs of over times, quantities that can be outsourced and possible delays. It transmits the message to the (NA) which in turn transmits it to the customer. If there is agreement, the negotiation ends else the customer can change requests. The message can be represented by a 6-upla (product, quantity, time, price, penalties, possible delays on certain products). The NA keeps the database of different scenarios proposed by the PA for a final decision.

In the case of changes in supply plan from a supplier, the NA sends the change to the PA and asks it to restart the direct plan trying to optimize resource utilization and satisfy as many customers. The PA transmits the result of the optimization model to the NA. The process is shown in figure 4

The solution proposed by the PA initiates the negotiation between the node and its customer. The negotiation is done in a round-trip message.

The negotiation process with customer is shown in figure 3

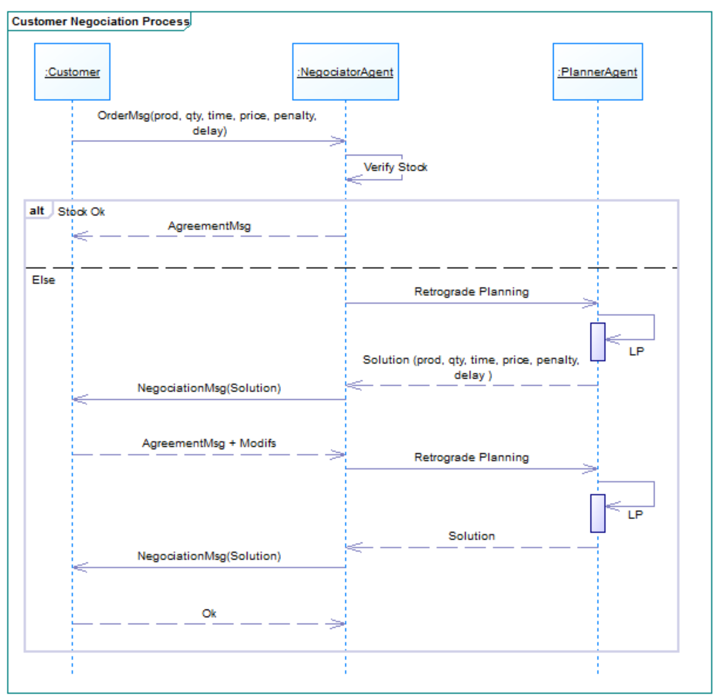

Figure 3. The process of negotiation between a node and custumer.

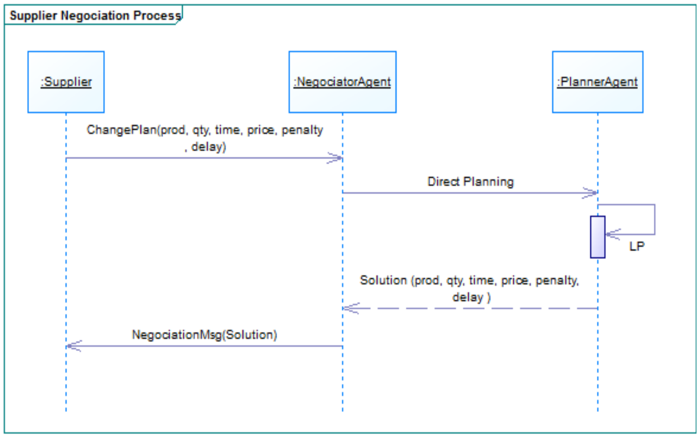

Figure 4. The process of negotiation between a node and supplier.

IV. CONCLUSION

Dynamic planning of the supply chain remains a difficult task because of the changes in production capacity and lead times. Thus, the success of each supply chain lies in the ability of partners to share information, synchronize their activities and try to work with a win-win principle to overcome contingencies. In this paper, we have opted for negotiation as a means of coordination that we have formalized using multi-agent systems.

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