MODELLING AND SIMULATION OF SUPPLY CHAINS WITH A MULTI AGENT SYSTEM

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ABSTRACT
Nowadays, in the economic context, Supply Chains and their management present a major interest for industrial enterprises. We propose in this paper a modelling approach for supply chain management, based on the MultiAgent paradigm. This modelling allows the study of the behaviour of the different actors of the chain and of the whole chain, through the simulation of the model. We propose a MultiAgent modelling framework as well as behavioural protocols, allowing complex decision making, in the aim to optimise Supply Chain Management (SCM). The aim of our work is to propose, in fine, a modelling framework and a simulation-emulation platform to aid decision-makers in SCM, with simulation results on various scenarios. We present as a first step of our research the MultiAgent platform MASC that we have developed to model and simulate Supply Chain, through its general architecture and the structure of its agents. Then we show how this platform can be used to model and simulate a specific supply chain.

INTRODUCTION AND PROBLEMATIC
The globalisation leads to an increasingly competitive economic context for industrial enterprises. The development of world-wide economic areas and the reduction of commercial regulations generate new realities of global competitiveness. The transformation of the economic environment and the evolution of customer requirements are new economical dynamics. To face up to these new dynamics, industrial enterprises try to maximise their profits and to reduce their stocks (Blackwell et al 1999). The solution requires the enterprise integration in a collaborative network: the Supply Chain (SC).

The problematic of Supply Chain Management
The problematic of the Supply Chain concerns the optimisation of the Supply Chain working at local and global levels. This optimisation makes the customer demand satisfaction possible in terms of price, quality and delays. This management must take into account disturbances related to hazard such as: provider failures, modification of customer wishes, and machine breakdown. Consequently, management and control of the whole Supply Chain have a major importance for the industrial enterprises.

A way to improve the performances of the Supply Chain Management sets in the improvement of coordination and synchronisation of the actors of the chain (Estempe et al 1999). However, this requires a well fitted modelling.

Our research is based on this fact to study the problematic of the Supply Chain Management (SCM). In a first time, we show how much the MultiAgent approach (coming from DAI) is appropriate for SC modelling and simulation.

The modelling approaches
We can note three main modelling approaches (Parunak et al 1998): (i) the “Control Theory” approach, based on differential equations, (ii) the “Operations Research” approach with relies on optimisation theories, and (iii) the “Simulation-Emulation” approach, which relies on experimentation through executable models (Swaminathan et al 1996).

This last approach offers several advantages and allows more realistic observation of the Supply Chain behaviour (Parunak et al 99). It allows an analysis of the Supply Chain dynamics. In fact, it leads to an observation of the chain behaviour along time, allowing at the same time an understanding of the organisational decision-making, an analysis of the interdependencies between the actors of the Supply Chain, and a analysis of the consistency between the coordination modes and the decisional policy.

In the “Simulation-Emulation” approach we can note two main type of model: (i) the “equation-based modelling” expresses the relations between the observable (quantifiable characteristics of one or more individual); the execution of the model is the evaluation of these equations that make evolve the observable; (ii) the “agent-based modelling” in which the agents are “individuals” encapsulating the behaviour of each actor of the Supply Chain; the execution of the model is a simulation of the behaviour in terms of observable accessible to the agents. This type of model is now recommended in several research approaches (Teigen and Barbuceanu 1997; Chen et al 1999; Sadeh et al 1999; Sauter and Parunak 1999; Strader et al 1999).

Agent-based models offer several advantages for the Supply Chain modelling: (i) the representation of Supply Chain is greatly facilitated by the fact that one agent can directly represent one actor of the chain; (ii) the agents are autonomous, therefore MultiAgent Systems (MAS) are well fitted to the strong evolutivity of the Supply Chain by
allowing to add or remove agents without the need of an entire reconstruction of the system; (iii) MAS can easily be set up on previous information systems without any disturbance on their functioning, and consequently can use pre-existing capabilities dedicated for example to scheduling or stock management, without reprogramming; (iv) the MAS “natural” ability to solve problem by cooperation implies that they can faithfully reproduce the behaviours of the Supply Chain actors.

In fact, most of the developed platforms present some lack in agent representation, or in communication protocol representation.

In the aim to offer an aid to the optimisation of the SCM through a simulation platform, we propose in this paper a SC modelling approach based on the MultiAgent paradigm, and taking into account complex decision-making, action synchronisation decision coordination, problem solving cooperation and negotiation between the actors.

This modelling allows the study of the behaviours of the different actors of the chain as well as the entire chain as a whole, through the simulation-emulation of the system. It leads to a way for the optimisation of SCM. Our aim is to provide a help to the different decision-makers that intervene in the management of the chains through the results of the running of various scenarios.

A SCM MULTIAGENT MODELLING

We propose a MultiAgent modelling framework as well as behavioural protocols, allowing complex decision making, in the aim to optimise Supply Chain Management. These complex decisions can include action synchronisation, decision coordination, cooperation for problem resolution and negotiation between partners. We propose a modelling method that relies on:

(i) a specific formalism for the specification of the behaviour and the interactions of the agents;
(ii) knowledge representation language and formalisms;
(iii) a MAS coordination framework consistent with the Supply Chain specificity.

The specification formalism

The specifications of the behaviour and interactions of the agents are based on a formalism that allows describing the agents’ behaviour, formalism named RCA (Représentation de Comportements d’Agents – representation of agents behaviour), introduced by previous DIAM research works. This formalism appears as a state-transition chart strongly typed, allowing to define Behavioural Plans representing the set of activities of an agent. This formalism constitutes a MAS design aid tool, thanks to the display of the interaction and connection between agents (Tranvouez and Espinasse 1999). It is composed of states (representing the activity that the agent realises when it has reached this state) connected between themselves with arcs (corresponding to the transitions that condition the passage from a state to an other.

Figure 1 : RCA formalism convention

This specification gives to the designers and users a view of the interactions existing in the system, as much at the local level (agent behaviour) as at the social level (system behaviour). The identification of an actor of the Supply Chain with an agent allows the study of the behaviour of the global chain as well as the actors that composed it, thanks to the modularity of the formalism. This behaviour description tool makes it possible to visualise coordination scenarios and synchronisation points.

MAS Architecture and knowledge representation

The MultiAgent modelling framework that we propose associates the standardised communication language ACL-FIPA and two specialized agents. Indeed, the MAS model proposed is compound of two types of agents: the principal agents, each one representing one physical entity of the modelled SC, and the auxiliary agents (ANS and R-agent) which participate to the general management of the MAS. The ANS is in charge of making a list of the agents that intervene in the MultiAgent System, keeping in its memory their name and address (constituted by an IP address and a number of listening port), thus providing the follow-up of the exchanged messages. The R-agent is a repertory agent, to which each agent of the MAS must register and define its name and its skills. Thus, any agent can appeal it to send a message to all the other agents, or to a restricted group of agents, or even to know the list of agents owning one or several special skills. The auxiliary agents are set to help to define the structure of the MAS and the general running of the system; they are not representative parts of the Supply Chain modelling. They can be seen as “White Pages” and “Yellow Pages” mail repertoires that each modelled physical entity could have in its own to communicate.

The MAS coordination framework

We propose a MAS coordination framework consistent with the Supply Chain specificity. We distinguish two coordination levels, the first one defines the interactions related to the agent societies, and the second one describes the organisational structure of the Supply Chain actors. For the first level, we base our work on three structural approaches and four coordination modes which have been identified, and that specify the role of the coordinator agents. For the second level corresponding to the coordination in the Supply Chain, the proposed framework identifies and define the various management policies that are applicable to the different coordination modes.

MAS coordination framework

In Supply Chain domain, an efficient coordination needs an explicit exchange of information. The coordination approaches proposed in the following section call for message exchange between the different actors.

In MAS, coordination depends on interaction modes that are communication, cooperation and negotiation. In order to organise these interaction modes, it is necessary to define the coordination and cooperation models according to a cooperative distributed problem solving approach. An approach based on coordination (at a global point of view) will rely on synchronisation and planning mechanisms. An approach based on cooperation (local point of view) is based on four different models: i) cooperation by task sharing; ii) cooperation by hierarchy (control); iii)
cooperation by call for proposal; and iv) cooperation by competition.

The choices made in terms of interaction modes do not influence the organisational structure of the MultiAgent System. There is two type of architecture for MAS : “horizontal” or “vertical” (Labidi and Lejoual 1993).

In Distributed Artificial Intelligence three factors allows differentiating the organisational structures : i) the communication type (act language theory), ii) the type of agents (cognitive – reactive), and iii) the interaction mode (cooperation and coordination).

Consequently, a number of conceptual choices are needed for the realisation of a MAS platform. For our framework, we have firstly adopted ACL-FIPA language to ensure communications (i.e. the message exchange) between the cognitive agents of the model. Then, the management of Supply Chains needs interactions that emphasize coordination and cooperation modes. The association of three modes (hierarchy, task sharing and call for proposal) allows covering the majority of the possibilities of management at local and global level.

The coordination and cooperation modes are methods used by the agents for distributed problem solving, coordination being based on agents communications.

To reach the individual goals (local level) and the common goals (global level), agents must coordinate theirs activities to manage the possible constraints. To support a coordination mode three possibilities of architecture are available for MAS designers (Liu et al 1994) : i) one coordination agent (fixed), ii) one coordination agent (revolving), and iii) several coordination agents (an agent society). The function of a coordination agent consists of distributing problems or parts of a problem to the agents owning appropriate solving competences. These coordination agents come within the scope of two architectures of agent society organisation (Bond 1990) : i) horizontal structure, i.e. there is no hierarchy levels, all the agents being at the same level; ii) vertical structure, the agents being structured by hierarchy levels, each level corresponding to an horizontal structure.

Beyond the structural framework, four coordination modes have been identified (Liu et al 1994), precising the role of the coordination agent : i) hierarchy mode, ii) process flow mode, iii) mediator mode, iv) constraint satisfactory mode.

Supply Chains coordination framework

From the four main management policies identified by (Kjenstad 98) (Just-In-Time (JIT), Safety Delays (Buf.), Order Refusal (Ref.), and Due Date Negotiation (Neg.)) we identify and characterise the parameters that have to be taken into account for the simulation-emulation of the behaviour of Supply Chain actors in terms of performances (Labarte 2000). These policies do not influence directly the organisational construction of the Supply Chain.

To design such a network, it is necessary to identify the pre-existing physical coordination modes. The implementation of such systems, based on coordination and activity cooperation, focuses on the organisational architecture adopted by the whole set of enterprises to optimally collaborate. The architectures that induce specific coordination modes are : in Line, Multiple Customers, Multiple Providers, or a hybrid of the previous ones.

We have proposed here a MAS modelling framework with behaviour specification tools (RCA) associated to fitted languages and formalisms of representation (JavaACL), as well as a consistent coordination framework for the MultiAgent modelling of Supply Chain.

The next section presents the proposed modelling and simulation platform.

MASC : A SCM MODELLING AND SIMULATION MULTIAGENT PLATFORM

We present here, as a first step of our work, the MultiAgent platform MASC, that we have developed to model and simulate Supply Chain, through its general architecture and the structure of its agents. At last, we show how this platform can be used to model and simulate a particular SC.

MASC Modelling framework

MASC offers a fitted coordination framework and allows to create Supply Chain models and to observe theirs behaviours. This platform integrates a representation with behavioural classes instanciable according to agents needs. It describes the models in a hierarchical way, breaking down, in this way, the complexity level of the Supply Chain Management. MASC is developed in Java and integrates the JESS rule-based system, which is a partial implementation in Java language of CLIPS expert system generator. With the integration of JESS, MASC has a knowledge representation language available, to which is added a complete communication protocol.

We have adopted the standardised inter-agent communication language ACL-FIPA. It is well suited to our problematic with its rich and flexible syntax and with its ability to support complex conversation protocols allowing to provide negotiation and collaboration activities. Thus the principal agents follow the ACL-FIPA standard to communicate, achieving complex conversational protocols. This language is used by the mean of a library of JAVA communication functions using TCP-IP protocol, named JavACL developed in the DIAM (Cloutier 1998).

The functions provided by the JAVA-ACL library are grouped inside an extension of JESS (an expert system generator in JAVA). This facilitates the implementation steps during the design of the MAS that models the SC.

The agents are mainly constituted of an instance of the inference engine of JESS. This allows them to have a total independency towards the others agents. The emulation of the Supply Chain model is realised by running the MAS.

Figure 2 shows the structure of an agent.

Conclusion of the modelling framework
The internal architecture of the principal agents is based on three modules (“mental state”, “action” and “conversation”), grouping on the whole eight parts (mental state, management of the mental states, action (or conversation) protocols and primitives, management of action (or conversation) protocols).

In figure 3 we show the relations existing between principals and auxiliary agents, according to a network configuration (three computer stations accommodating four principal agents, the ANS and the R_agent).

**Simulation-emulation of a Supply Chain with MASC**

The inter-enterprise supply chain we have modelled is made up of six actors corresponding to six principal agents (each principal agent represents one actor of the chain). The agents are the following ones:
- the customer agent, which originates the customer proposal;
- the logistic agent, which is in charge to supervise the supply chain;
- two production agents, the painting facility agent and the assembly line agent;
- two transporting agents, which execute the transportation tasks between all the actors, and to the customer.

The two auxiliary agents participate to the general management of the system but not to the representation of the Supply Chain.

The logistic agent is one important actor of the Supply Chain; its role in the MAS is defined at the time of the simulation initialisation. However, in the proposed model each agent can in turn possess the same functionalities as the logistic agent, and so being the interface between the customer and the other SC actors.

For this specific Supply Chain, we have chosen Just-In-Time policy as the management policy, based on the calculation of the production capacities. This policy strongly relies on the MultiAgent coordination mode Process-Flow. The structural organisation comes within the scope of a Supply Chain In Line. Indeed, at the level of the structural coordination, the contractor agents comes within the scope of a Multiple Provider configuration when they are put in competition for one proposal. Once selected, they belong to an In Line SC, in which they position themselves according to theirs competences. In that case, it is then possible for them to communicate with the other agents of the SC whatever be their position in the chain.

The simulation of the material flow processing is modelled inside the agents with a delay corresponding to the physical processing time.

**SIMULATION RESULTS ANALYSIS**

We present here the running of the emulation of the SCM model that validate the model, the modelling framework and the platform. The aim was to validate the message exchange process, the role protocols and the individual and social behaviour plans, of the agents modelling the actors of a Supply Chain, and at last establish several coordination protocols.

The platform has been tested by emulation of the previous example of Supply Chain, taking into account a same customer order according several scenarios. This order contains a painting task on rough pieces, an assembly task of semi-finite products and a transportation task of the final product. It specifies the final delivery of 20 finite products of same type at day d+30 (d being the day of the order); no margin is allowed because the agents are in a J.I.T delivery policy.

The production capacities of the contractors are assumed infinite, with production cycles of four days. Each production agent determines itself if it can realise the required products quantity or not, according to the personal goal of : maximise its own production load. Afterwards, the customer agent decides of the production launching or of the order cancelling, and of the rejection or the acceptance of a counter-proposal. When the logistic agent receives the order for the customer agent, it breaks it down into production task, and plans the work to do. According to our hypothesis, this planning is done at the earliest, and is materialised by the creation of the production tasks that are send to the contractors agents. The scenarios taken into account are: order feasible without concurrence, order feasible with concurrence, contractor breakdown, order feasible under counter proposal, and order non-feasible.

The simulation of these five scenarios allows validating the SC model and the MASC platform. It also highlights the advantage of having a simulation tool when negotiating deals. The emulation of a MAS distributed on a logistic network allows to improve contractors reactivity and reliability, by simple information sharing.

In our study case, the modelled Supply Chain is an inter-enterprise chain concerning the networking of several well distinct actors; note that the proposed model can be used in the case of an intra-enterprise Supply Chain. In such a case, the logistic agent can represent, for instance, the department that stays in touch with the customer, or the production department (more particularly the planning department) of the enterprise.

The observation of the model behaviour during simulation allows highlighting coordination modes both at organisational level and at agents society level. From these observations, we can note the significance of a coordinator agent for modelling Supply Chains. Indeed, this agent has various coordination modes available according to the type of the exchanged messages and to the applied management policies. The main ability of this coordinator agent is to be dedicated to the orders management; acting so it can be seen as a mediator between customers and contractors.

In our example, the logistic agent plays a central role in the design of the Supply Chain and in the agent society; it is the coordination agent. With its multiple coordination modes, the logistic agent can develop numerous competencies such as contractor actions synchronisation, task planning, contractors selection, constraints issue, and real time production follow up.
The simulation/emulation according a given management policy highlights that the agent who has available several coordination modes, as much as the agent society level as at the physical level, allows to improve the relations between the actors of the chain.

CONCLUSION

The interest of the results of this approach is to validate the modelling framework and the platform, and to evaluate the information exchange phases accounting dynamically for the processes and the cooperation modes, based on a decentralised decision-making of the actors of a Supply Chain. The construction of such a modelling framework, based on various research works, allows emphasising the management problematic through the difficulty to coordinate the SC actors activities.

Therefore, we can consider, as the next step of our researches, the introduction of complex coordination protocols such as planning or cooperative re-scheduling. To obtain a larger validation of MASC, we are going to test various management policies on real industrial SC, in the aim to observe the behaviour of the coordinator agent and of the other agents according to local and global goals and constraints. This will allow forecasting some results at the time of complex decision-making.

REFERENCES


Kjenstad D., “ Coordinated Supply Chain Scheduling.”, PhD Thesis, Department of Production and Quality Engineering, Norwegian University of Science and Technology.

Labarthe O. 2000, “Modélisation MultiAgent de chaînes logistiques”, mémoire de DEA, Université Aix-Marseille III.


