15

THE NETMAN AGENT-BASED ARCHITECTURE FOR E-BUSINESS IN NETWORK ORGANIZATIONS

Louis Cloutier[1,2], Jean-Marc Frayret[1],
Sophie D'Amours[1] and Benoît Montreuil[1]
[1]*CENTOR, Université Laval, CANADA*
[2]*APG Solutions & Technologies, CANADA*
{louis.cloutier, jm.frayret, sophie.damours, benoit.montreuil}@centor.ulaval.ca

The NetMan project aims at developing concepts and e-business software support systems for manufacturing networks. The e-business-oriented NetMan Operation System carries out collaboratively the distributed planning and scheduling processes, as well as the manufacturing and logistic operations monitoring in networks organizations. It is based on an extensive use of the new information technologies. This paper presents the agent-based software infrastructure developed in the NetMan project.

1. INTRODUCTION

In order to develop leading competitive advantages, organizations must face the challenging problem of integrating their business processes within and outside their boundaries, into a seamless clients' fulfillment process. Supply chain integration may take several forms (Morash and Clinton, 1998). The one which is particularly addressed in this paper concerns the collaboration closeness between supply chain partners. Thus, collaboration can take place at multiple levels (strategic, tactic and operational). It may involve many concepts (joint product development, joint sales forecasting, information sharing, collaborative contingencies management, collaborative planning, forecasting and replenishment). Collaboration profitability in supply chain has been brought to the fore by some studies (Cudahy and Lee 1999).

The NetMan project aims at proposing concepts to design and to integrate the collaborative operations of networked manufacturing systems. Thus, it proposes an integration plate-form, which uses extensively the new information technologies. Similar work has been conducted in many laboratories, especially in the contexts of supply chain and virtual enterprise integration (e.g., Fox *et al.* 1993; Camarinha-Matos and Lima 1998; Brugali *et al.* 1998; Strader *et al.* 1998; Cloutier *et al.* 1999; Shen *et al.* 1999; Shen and Norrie 1999). This paper presents a multi-agent architecture to support e-business in distributed organizations. It is outlined as following. First, the NetMan integration plate-form fundamental constructs are introduced. Then, the prototyping approach is presented with the industrial case. A conclusion is finally presented.

The original version of this chapter was revised: The copyright line was incorrect. This has been corrected. The Erratum to this chapter is available at DOI: 10.1007/978-0-387-35399-9_52

L. M. Camarinha-Matos et al. (eds.), *E-Business and Virtual Enterprises*

2. OVERVIEW OF THE NETMAN CONCEPTS

The concepts overview presented here are part of an organizational and operational framework introduced in Montreuil *et al.* (2000) and Frayret *et al.* (forthcoming). In order to introduce the NetMan integration plate-form concepts, the NetMan fundamental constructs are first presented.

2.1 The NetMan Centers

The NetMan approach models manufacturing systems as responsibility-based networks (Montreuil and Lefrançois 1996) of semi autonomous and interconnected business units called NetMan centers. Each center receives a set of responsibilities for satisfying specific clients' needs. Frayret *et al.* (2000) delves further into the description of these concepts.

A NetMan center is basically composed as shown in Figure 1. First, the center is composed of a physical system (PS), which includes human operators, processors, tools, etc. These elements carry out the NetMan center physical operations. At this level, the physical flow allows the circulation of physical elements among the centers. Then, the information and decision system (IDS) includes human decision makers, decision support tools, advanced planning and scheduling systems (APS), e-business agents, etc. These systems plan production, make decision, measure performance and monitor operations done at the physical system level. Thus, the IDS is closely interacting with the physical system. At the IDS level, the information flow allows the circulation of information among the NetMan centers.

Both the PS and the IDS constitute the NetMan operating system. In other words, the NetMan operation system is responsible for planning and performing the NetMan center operations. This also includes collaborative interactions with other NetMan centers at both the physical and information flow levels.

2.2 The NetMan unit

The NetMan unit (the NetMan center's information and decision system), is responsible for (a) planning the operations of the center (according to the NetMan approach), (b) monitoring operations and detecting eventual problems and contingency situations, (c) collaboratively interacting with other units, and finally (d) measure internal and inter-center performances.

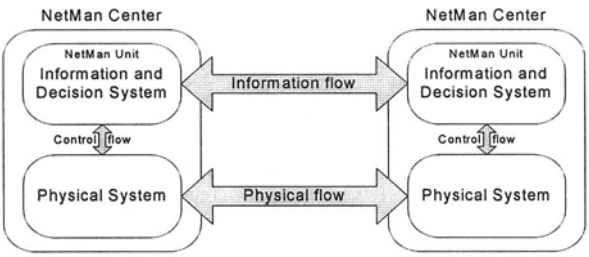

Figure 1 : NetMan center components

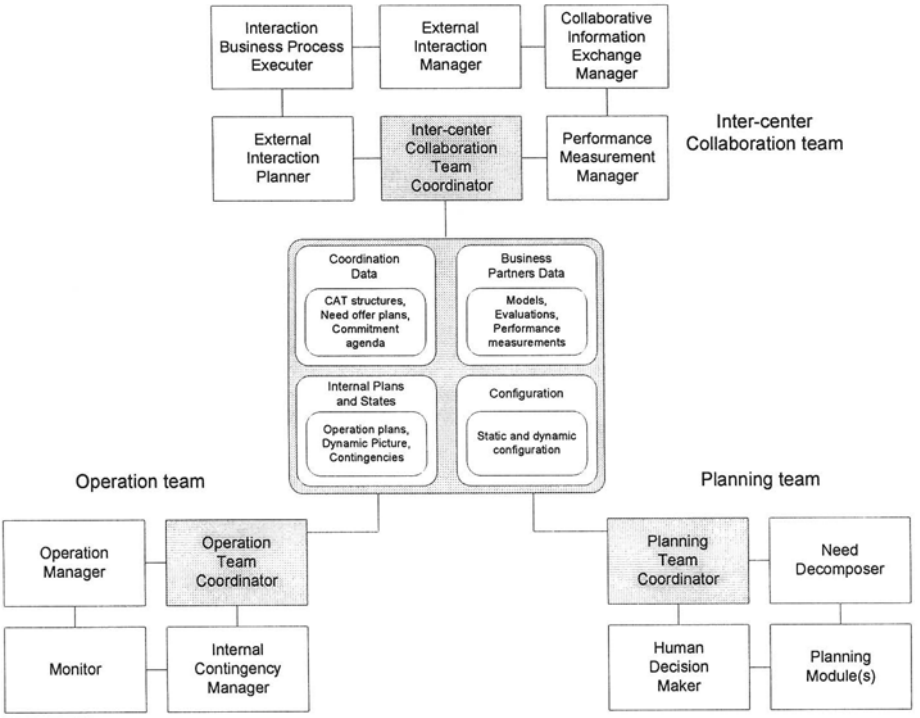

Figure 2 : NetMan Unit Internal Architecture

These processes require many functional responsibilities. In order to present these responsibilities in details, the agent-based NetMan unit software architecture is introduced (Figure 2). This software architecture is composed of three teams of agents that share a common data structure. Technically, every team includes a team coordinator, which can be viewed as the single point-of-contact of the team. This is necessary in extensible teams such as the planning team. However, direct communication among the agents remains possible. The three teams are presented with their underlying concepts, but first, the data structure is presented.

2.3 The data structure

A common object-oriented data structure constitutes the knowledge/data base of each NetMan unit. The unit's agents share information through this data structure that can be viewed as a blackboard (Fenell and Lesser 1977, Velthuijsen 1992). It can be decomposed in four main parts :

1. **Coordination Data**. It contains data relevant to the interactions with collaborating NetMan centers. It describes coordination structures and transactions based on the CAT coordination framework. More details on this coordination framework are presented in the next section. It also includes needs and offers plans, which are decomposed in four plans: the center's clients need, the center's offers expressed to its clients, the center's needs expressed to its

providers, and the offer received from them. Furthermore, the Coordination Data contains the commitments made on actions to performed (in general confirmed offers) to or from collaborating NetMan centers.

2. **Business Partners Data**. It deals with collaboration information, including clients and suppliers models shared with the center, and performance measurements data of the collaborating client and supplier centers.
3. **Internal Plans and States**. It contains data related to the use of the center's physical system: operations plans (stipulate the planned use of the physical resources), the monitor dynamic picture (describes in real-time the state of the physical world), and a contingencies list (containing detected or anticipated physical system problems such as failures, absenteeism and back-orders).
4. **Configuration**. This part of the data structure deals with the center's static and dynamic configuration. It is called the PPP configuration (for Product–Process–Processor). It describes, the products provided by the center, the processes it can carry out (with their physical and precedence constraints), the processors it owns (human operators, machines, tools) and their capabilities and capacities. The dynamic configuration deals with the evolution of the physical system in time (known future absenteeism of human operators, acquisition of new processors, new technology acquisition, etc.).

2.4 The Inter-center Collaboration team

The Inter-center Collaboration team is responsible for managing the interactions with external centers, that is collaborating NetMan centers, and for coordinating these interactions with internal actions. This team is composed of six agents and is mainly based on the CAT coordination framework (Cloutier *et al.*, 1999).

2.4.1 The CAT coordination framework

CAT (Convention, Agreement and Transaction) has been proposed for the specification of interactions among NetMan centers. The main purpose of this framework is to (a) provide coordination structures that allow coordinated and flexible information exchange among the centers, (b) provide a framework for specifying the coordination structures in the context of specific business relationships such as a pair of partners or a group of partners and (c) facilitate the coordination of manufacturing operations at the physical flow level. This last purpose is based on the commitment-oriented manufacturing paradigm that is not presented in details here (Cloutier *et al.* submitted). Briefly, centers commit on punctual operations to perform such as delivering product, providing a resource or executing a process. The coordination structures provided by CAT allow the specification of commitments resulting for particular interactions such as conversations. Consequently, the centers can plan their interactions according to the goal they want to achieve.

CAT provides two main coordination mechanisms : the *conversation protocol* and the *contingency rule*. Conversation protocols are formal finite sequences of messages that may be exchanged during an particular interaction named a *conversation*. These *conversation protocols* are graphically represented as finite

state machines and are formally specified in a language named CAT-L. Figure 3 presents an example of such a conversation protocol which is used for task delegation in our industrial case. This mechanism is flexible and allow the representation of complex interactions such as negotiation protocols. A conversation protocol has final states (graphically represented as double-circles) that may be associated with generic commitments. Thus, commitments are made by the centers when a conversation reach such final states. CAT-L is based on XML (Extensible Markup Language) and FIPA/ACL has been adopted has the agent communication language (FIPA 1997).

The *contingency rule* is proposed for specifying actions to perform or commitments to make when contingency situations arise. A rule may specify for example to trigger a conversation protocol when a specific event occurs. Both the conversation protocols and contingency rules are organized into formal structures : conventions and agreements. A convention is shared among a large group of individuals or among all the community of NetMan centers and specify conversation protocols and contingency rules. An agreement is elaborated for few business partners, usually two, and specify both conversation protocols and contingency rules elaborated in the context of one business relationship. Also, many other elements are included in an agreement such as the involved partners in the agreement, the competencies of the partners (the actions on which they can commit in the context of this agreement), the authority that may be informed in case of misunderstanding, etc.

Transactions, finally, are the instantiation of either conversation protocols or contingency rules and their resulting commitments.

2.4.2 Team members

The Inter-center Collaboration team is responsible for acting according to the conventions and agreements in which the center is involved. Six agents compose the team : the Coordinator of the team, the External Interaction Manager, the Interaction Business Process Executor, the External Interaction Planner, the Collaborative Information Exchange Manager and the Performance Measurement Manager.

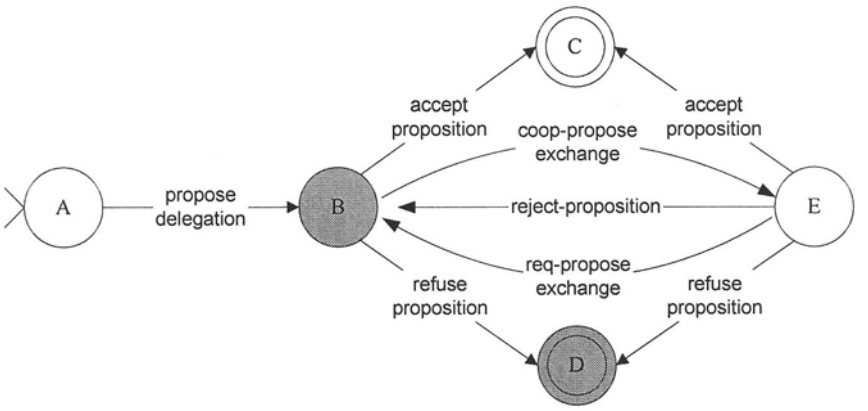

Figure 3 : Conversation protocol example

The External Interaction Manager manages conversation instances and validates incoming messages according to known protocols, active conversations and also current states of active conversations. It also triggers conventional or agreed contingency rules when specified situations arises. This may lead to conversation triggering, message passing or commitment making. The Interaction Business Process Executor constitutes the bridge between external interactions (conversation protocols) and internal business processes. In fact, since the conversation protocols only specify interactions and that the deliberation of the center remains private, each center as to develop private realization plans that specify how the center participates in a particular conversation protocol.

The Collaborative Information Exchange Manager is responsible for producing models for its clients and suppliers according to the models of its own capacity to satisfy its client's needs, as well as its suppliers' and providers' capacity to satisfy its own needs. This task involves model aggregation that make sure that the center's models that are communicated to collaborating NetMan centers also take in to account the models of their own collaborating NetMan centers. For example, a center's lead-time for a product it provides will be affected by the lead-times of the components of this product provided by other centers. Also, the need forecasts that a center communicates to his suppliers must reflect its own client's forecasted needs.

The Performance Measurement Manager is responsible for acquiring relevant data in order to measure its own performance, as well as its partners' performance, according to a collaboratively agreed upon set of criteria. The External Interaction Planner is involved in decision making when supplier selection is necessary. This may be useful when multiple suppliers provide the same product. A selection is made according to relevant data on the suppliers such as performance measures.

2.5 The planning team

The Planning Team is a flexible team that may be composed of multiple planners. NetMan promotes the decentralization of planning responsibilities onto autonomous NetMan centers. Thus, it allows the development of powerful and highly adapted planners according to each NetMan center's responsibilities and needs.

The team is composed of multiple agents: (a) a Coordinator, needed when multiple planners have to be coordinated, (b) a Need Decomposer, responsible for decomposing needs in order to plan their satisfaction processes (involving internal and/or external operations), (c) multiple Planning Modules, responsible for planning internal operations according to the decomposed needs, and (d) Human Decision Makers, who may fine tune operation plans or make final decisions when necessary.

2.6 The operation team

The Operation Team is responsible for interacting with the center's physical system. The team is composed of four agents : the Operation Manager, the Monitor and the Internal Contingency Manager. The Operation Manager interacts with the physical system. It is responsible for launching operations in order to fulfill the internal plan produced by the planners and to fulfill the commitments made to other centers (deliver a product, provide a resource, etc.). The Monitor agent is responsible for

keeping an accurate real-time picture of the physical system. It includes the processors states, the work-in-process, the local stocks level, etc. This real-time picture enables the contingency situations detection, and eventually executing contingency plans. The Internal Contingency Manager is responsible for applying contingency plans when internal contingencies occur. These contingencies may be different from the ones specified in conventions and agreements. Actually, internal contingencies may be solved locally without any interaction with other centers. In some other cases, the situation may require cooperative problem solving that involves interactions with collaborating NetMan centers.

3. PROTOTYPING

The software architecture presented above has been developed and has evolved during the four years of the NetMan project. The third generation of prototypes has been developed and been experimented and tested with a real industrial case. The industrial case itself is quite complex and is explained with details in Frayret *et al.* (forthcoming). It is briefly introduced here.

3.1 The industrial case

Prévost Car, from the Volvo group, is a leading motor coach manufacturer in North America. It is a partner of the NetMan project. The manufacturing case based on Prévost Car includes multiple NetMan centers. Figure 4 presents the NetMan centers involved in the prototype. These centers can be classified into five categories :

- **Customer front-end**. The Sales Department (SD) is the only NetMan center in this category. It is responsible for interacting with the end customers. It schedules buses assembling to be delivered according to a slot calendar and with respect to a model of the assembly line capacity (which is aggregated and expressed by HALC), and customers' satisfaction functions (expressed in terms of earliest, preferred and latest delivery dates).
- **Manufacturing line coordination**. The H Assembly Line Coordinator (HALC) is an autonomous center that is responsible for balancing assembly processes across the line, according to the assembly time slot assigned by the Sales Department, and the workstations' models that represent their actual assembly capacities. Thus, it is responsible for assigning all the processes involved in carrying out specific buses assembling to the workstations according to their supply, material and precedence constraints. HSLC is also a line coordinator (structure assembly) that is responsible for coordinating the line that provides bus structures to the H assembly line. This line is not actually detailed in the current prototype.
- **Assembly workstations**. Fourteen assembly workstations are involved in the prototype (tagged like WS-xx). They are responsible for finely scheduling and carrying out processes on buses, and also for dealing with their suppliers for getting the involved products on time. Workstations have their own human resources and tools.

- **Components suppliers**. Five components suppliers have been implemented in the prototype (SAC, Prelco, BC, Fabri-Metal and Multifoam). These NetMan centers are responsible for providing components to their different client centers. Some are internal centers (SAC), and the others are actual suppliers of Prévost Car.
- **Supply coordinator**. SCD (sub-component department) is responsible for coordinating the common supplies of the workstations. It aggregates the workstation expressed needs for bulk supplies. It interacts with two suppliers : Fabri-Metal and Multifoam.
- **Human resource supplier**. The Mobile Worker Department (MWD) is the only NetMan center in this category. It is responsible for providing the assembly workstations with specialized mobile workers when requested. These workers may be necessary to cope with absenteeism or different kinds of problems that may occur during operations.

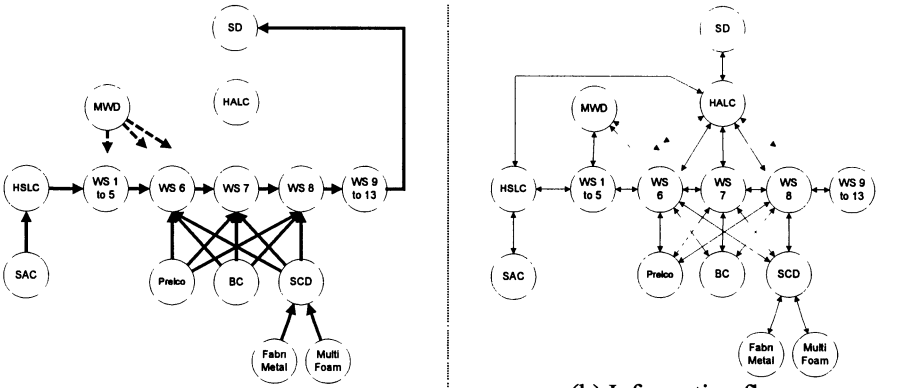

Figure 4 : NetMan prototype structure

This industrial case has been modeled to support four types of buses with multiple options. Almost 2000 processes are involved in the realization of the buses. Each of these processes has input products, which are supplied by different NetMan centers according to different constraints such as lead-times and capacity.

A distributed simulation approach has been adopted for testing and evaluating the prototypes (Lyonnais *et al.* 1999). Thus, in this approach the physical system is substituted by a distributed simulation system. This system is responsible for communicating physical events to the monitor agent, member of the operations team. These events include product flow, process realization, bus ordering, etc.

As stated above, the responsibility-based definition of NetMan centers allow the development of specialized planning agents that are highly adapted to the specific centers' needs. In the prototype, multiple planning agents have been developed. The SD includes an agent that assigns buses needs to slot lines based on a mathematical model and linear programming. The Cplex commercial package is used to solve the mathematical model. The HALC decomposes a bus into a sequence of processes and apply an heuristic-based line balancing algorithm to assign those processes to

workstations. The workstations perform fine scheduling of their assigned processes according to multiple material and human resources constraints. The MWD manage its mobile workers according to workstations needs and schedules its resources based on a genetic search algorithm. The SCD planning agent aggregates workstations' needs and apply an economical production lot method to deal with its suppliers. Finally, each supplier applies its own planning strategy.

Collaborative contingency management is a key aspect of the NetMan concepts. NetMan centers are geared up with contingency plans that allow them to collaboratively solve problems such as late deliveries, back-orders, machine breakdowns, delayed processes, etc. As stated before, contingency rules are specified in agreements and conventions. They specify actions or conversations protocols such as negotiation protocols to trigger when such situations occurs. Thus, a negotiation protocol has been developed to enable assembly workstations to exchange processes when necessary.

Another important concept in NetMan is collaborative information exchange. For this purpose, specific agents (collaborative information exchange managers) have been developed in each NetMan unit. Each unit uses its suppliers models and its own internal model to calculate and thus provide updated particular models to its clients. Planning is conducted in the units according to these models. These models provide each NetMan center with a partial view of its interactor centers, in order to let it plan its internal resources with respect to its multiple dependencies with them.

4. CONCLUSION

This paper has introduced the NetMan agent-based software architecture. First, some NetMan concepts have been introduced with the main constructs: the NetMan center and the NetMan unit. NetMan centers are the autonomous or semi-autonomous centers of the networked organization. They are composed of a physical system and a NetMan unit which implements an information and decision system. The agent-based architecture of the NetMan unit has then been introduced. This extensible architecture has been developed and tested on a large scale industrial case. This experimentation has shown that the adopted architecture and coordination framework are flexible and open.

The agent paradigm, that has been adopted, offers an interesting abstraction for the modularization and concurrent execution of autonomous modules. This approach also facilitates the introduction of human agents in the teams. Many agents are very generic and have been reused for most of the NetMan centers: the External Interaction Manager, the Monitor and the External Interaction Planner. The other agents such as the Interaction Business Process Executor, the Operation Manager, the Collaborative Information Exchange Manager, the Performance Measurement Manager and the members of the planning team are customized for each unit or class of unit (such as the workstations which are similar).

This architecture deals within a specific context and thus may be incomplete in others. New agents or teams may be necessary to introduce in order to extend this architecture. The NetMan project focuses on the benefits brought by the proposed

concepts dealing with planning and operation management. Thus, it makes abstraction of financial transactions aspects and so the architecture does not propose any components that would support it.

5. REFERENCES

1. Barbuceanu, M., Fox, M.S.. The Information Agent: An Infrastructure for Collaboration in the Integrated Enterprise. Cooperating Knowledge Based Systems. 1994; 257-295.
2. Brugali D, Menga G, Galarraga G, 1998, Inter-Company Supply Chain Integration via Mobile Agent, in: G. Jacucci, G.J. Olling, K. Preiss, M.J. Wozny, eds., The Globalization of Manufacturing in the Digital Communications Era of the 21st Century: Innovation, Agility, and the Virtual Enterprise, Kluwer Academic Publishers
3. Camarinha-Matos L.M., Lima C.P., 1998. A framework for coopration in virtual enterprises.in Proceedings of the international conference on Distributed Information Infrastructures for Manufacturing, Information Infrastructure Systems for Manufacturing, Fort Worth, USA
4. Cudahy G.C., Lee H.L., 1999, Logistics Collaboration: What Types of Collaboration Create Value?, presented at the Council of Logistics Management Annual Conference, October 17-20, Toronto, Ontario, Canada
5. Cloutier L., Espinasse B., Lefrançois P., 1999. Networked Enterprise Integration: an Agent-Based Coordination Framework, In Proceedings of The 14th World Congress of International Federation of Automatic Control (IFAC'99), Special session on Enterprise Integration. July 5-9 1999, Beijing (China).
6. Cloutier L., Frayret J.M., D'Amours S., Espinasse B., Montreuil B.. A Commitment-Oriented Approach to Networked Manufacturing, submitted to International Journal of Computer Integrated Manufacturing (IJCIM), Taylor & Francis.
7. Fennell, Richard D. and Lesser, Victor. Parallelism in Artificial Intelligence Problem Solving: A Case Study of Hearsay II. IEEE Transactions on Computers. 1977; C-26(2):98-111.
8. Frayret, J.M., Cloutier, L., D'Amours, S., and Montreuil, B., A Distributed Framework for Collaborative Supply network Integration, 2nd IFIP / MASSYVE Working Conference on Infrastructures for Virtual Enterprises - Managing Cooperation in Virtual Organizations and Electronic Business Towards Smart Organizations
9. Frayret, J.M., D'Amours, S., Montreuil, B., and Cloutier, L., A Network Approach to Operate Agile Manufacturing Systems, *to appear in* International Journal of Production Economics.
10. Foundation For Intelligent Physical Agents (FIPA), 1997. FIPA 07 Specification Part 2 - Agent Communication Language.
11. Lyonnais P., Montreuil B., Lefrançois P., 1999. Agent-Oriented Distributed Architecture for Simulation of Networked Manufacturing Systems: A Case Study, in: A. Langevin, D. Riopel and P. Ladet, eds., Proceedings of the Conférence Internationale en Génie Industriel, Montréal, Canada, May 1999, 1, 75-84
12. Montreuil B., Frayret J.-M., D'Amours, S., 2000. A Strategic Framework for Networked Manufacturing". Computers in industry, 42(2-3), 299-317
13. Montreuil B., Lefrançois P., 1996. Organizing Factories as Responsibility Networks, in : R.J. Graves, L.F. McGinnis, D.J. Medeiros, R.E. Ward and M.R. Wilhelm, eds., Progress in Material Handling, (M.H.I, Braum-Brumfield, United States) 375-411
14. Morash E.A., Clinton S.R., 1998. Supply chain integration: Customer value through collaboraive closeness versus opertional excellence, Journal of Marketing Theory and Practice, 6(4), 104-120.
15. Shen, W., Norrie D. H., 1999. Implementing Internet Enabled Virtual Enterprises using Collaborative Agents, in Proceedings of Pro-VE 1999, Porto, Portugal.
16. Shen, W., Ulieru, M., Norrie D.H., Kremer R., 1999. Implementing the Internet Enabled Supply Chain through a Collaborative Agent System, in Proceeding of Agents'99 Workshop on Agent Based Decision-Support for Managing the Internet-Enabled Supply-Chain, Seattle, USA
17. Strader T.J., Lin F.R., Shaw M.J., 1998. Information infrastructure for electronic virtual organization management, Decision Support Systems 23, 75-94
18. Velthuijsen, Hugo, 1992. The Nature and Applicability of the Blackboard Architecture. PTT Research.