A NEW METHODOLOGY FOR DESIGNING E-MANUFACTURING PLATFORMS WITHIN VIRTUAL ENTERPRISES

Aurelian Mihai Stanescu[*], Jean-Claude Hennet[**], Carmen-Luisa Diaconescu[*]

**'Politehnica' University Bucharest, Human Resource Training Center,*
132 Calea Grivitei., Sector 5, Cod 78122, Bucharest, Romania
Tel. +4 021 311 16 61, Fax.+4 021 311 17 94,
ams@utis.cpru.pub.ro , carmenluisad@yahoo.fr

***Laboratoire d'Analyse et d'Architecture des Systemes - CNRS,*
7 Av. Colonel Roche, 31077 Toulouse Cedex 04, France
Tel. 33 5 61 33 63 13, Fax 33 5 61 33 69 36,
hennet@laas.fr

Abstract: The new manufacturing paradigms, starting with agile manufacturing and lean production, are leading our society towards a new generation of concurrent enterprises involving virtual enterprise architecture and concurrent engineering methodology for *e*-Enterprise. A continuing adaptation to the global market needs can only be achieved efficiently if also the planning and control processes are optimized both horizontally (Automatic Control Systems) and vertically (Management Control System). Consistent improvement in performance and realization of (fast reactive) highly dynamic enterprise objectives requires a tight integration of the units of the enterprise.
Taking into consideration that the entities of the eEnterprise are cooperating in order to achieve the global goal, a problem appears: how to cooperate not knowing the internal models of the entities who are cooperating? In order to obtain at some moment a real-time solution, a certain form of negotiation appears to be necessary. Contract agents can implement an automated negotiation mechanism. The mathematical background provided by game theory, then provides a decision support for the contract agents. It also allows to model the behavior of the agents in a negotiation.

Key words: Virtual Enterprise, Game Theory, Multicriteria Optimization, Negotiation, Supervisor.

1. INTRODUCTION

The various paradigms for different views of the new manufacturing organization are describing the global research effort focusing on the digital era challenge. The ***NGMS*** (Next Generation Manufacturing Systems), the ***ADMS*** (Advance Manufacturing Systems), the ***DEE***- Dynamic Extended Enterprise, the ***IMS*** -Intelligent Manufacturing Systems, or

the ***CE-*** Concurrent Enterprise are based on the new models: agile, holonic, fractal, bionic, virtual [4]. The future manufacturing systems will be the result of both provoking emerging Information and Communication Technology (ICT) and the new management science approach. They will have in common some characteristic proprieties: autonomy, co-operation, multidisciplinary teamwork, integrated approach for product-process-system design, re-thinking of humans' position and role. They will be agile in terms of organization and virtual for geographic distribution and alliance.

In this paper we try to apply the game theory to multi-agent systems synthesis for *e*-Enterprise design. Game theory provides a mathematical background to model and give solutions in competitive or conflicting situations, between the protagonists called ***players***. The objective of each player is to optimize his gain or to minimize his loss. The main starting idea of game theory is that each player plays to optimally accomplish his goal – maximizing his profit, taking into account that all the others players are playing in the same manner[8]. Multi Agent Systems (MAS) can be used to represent competing players. The goal of each agent is to optimize his value function. From a computer point of view, the agents are able to communicate with each other, to interact with their environment, to adopt a certain strategy depending on the knowledge and on the current context.

2. FROM VIRTUAL ENTERPRISE TOWARDS *e*-ENTERPRISE

One could qualify the new type of distributed networked enterprises as a business integrator, having a specific life cycle of business duration. Each node has to perform a dedicated set of tasks, based on its core competence [7]. This new type of organisation, VE, is faster reactive for facing the business process finite horizon opportunity than well-known traditional organisations (large enterprises or SMEs). The Virtual Enterprise is the most appropriate concept in relation with its basic meta-system features:

- **business integrator**, allowing both the vertical and horizontally integration of SMEs;
- cyber space **friendly user** e- business approach for market place;
- multi-agent based internal **coordinator**, implementing Production Planning and Control (PP&C) within wide-area-network of heterogeneous platforms;
- extended concurrent engineering oriented **designer** for product/ process / production system facilities .

The deployment of the virtual enterprise paradigm (VE) requires the definition of the reference architecture and the development of a supporting platform and appropriate protocols for open system architecture.

Definition: The Virtual Enterprise is an open meta-system in a business universe where acts a set of Fabricators utilizing multi-model representations of products/processes and co-operating in the framework of temporary alliances for achieving a set of goals [5]:
VE = (U, F, Mv, G), where **U** is an universe of discrete business processes and **F** is the set of Fabricators [9]. The Fabricator is an autonomous agent having a set of core competence (*i.e.* a set of functions that it is able to accomplish). A Fabricator could co-operate with other Fabricators with similar/ different core competences by communicating goals and data. By modifying its own performance evaluation measures according to a global goal and optimality criterion, a Fabricator defines itself as a fast-reactive component of a meta-system. As underlined by the definition above, the main features of a VE are: capacity of

innovation; capacity of co-operation; capacity of internal reconfiguration; fast-reactivity; open system architecture compliant with well - known standards (STEP, COBRA, EDI-FACT).

Here is the basic model presented in the paper [11] where was proposed this provoking concept as further research goal: "*e*Enterprise beyond the Concurrent Enterprising / Virtual Enterprise state of the art":

$$\mathcal{E}=f(\mathcal{M}_{\mathcal{P}},\mathcal{M}_{O},\mathcal{M}_{a},\mathcal{M}_{\mathcal{R}},\mathcal{M}_{\mathcal{K}},\mathcal{M}_{\mathcal{A}},\mathcal{G})$$

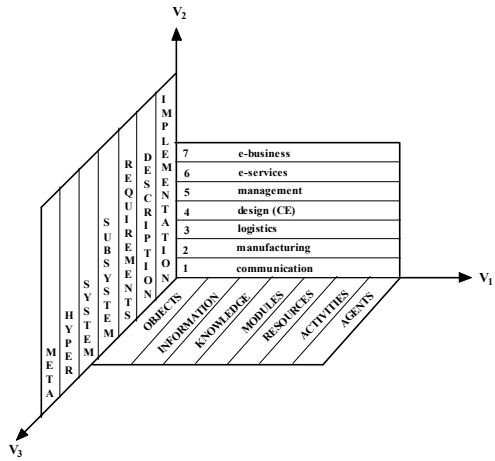

Figure 1 – The extended CIMOSA Cube

In an *e*-Enterprise, all the items of the three dimensional *e*Cube must be considered when negotiating to organize a production activity or a project. Each manufacturing unit has constraints and goals that determine its utility function. As noted by several authors, some degrees of coordination and solidarity between the actors need to be introduced in the problem data at the level of utility functions. This can be done, in particular, through negotiation contracts.

3. COORDINATION USING A NEGOTIATION MECHANISM

In the context of an enterprise or a network of enterprises, the agents are contributing to the execution of several different functions, sometimes sequentially and sometimes concurrently. Several decomposed functions must be allocated in such a way that the resulting workload does not exceed the capacity devoted to each agent. The functional decomposition is followed by the task allocation; an optimization problem with a large number of constraints to be solved.

We intend to propose a negotiation protocol according to which any of the involved agents can participate. The agents involved in the negotiation are associated with the Fabricators. The negotiation mechanism is of the type described in [6]. It can be initiated by any of the existent agents. The agent initiating the negotiation is the one in charge of the job execution and completion [2].

We apply the game theory in the following manner:

- a static game at each step of the negotiation; the stop conditions being the accepting of an offer or the retiring of a candidate agent;
- an offer is submitted by a candidate agent only if it is **acceptable as the best current offer;** an offer is refused only if it has arrived too late;

- n parallel static games: for each of the n candidate agents;
- through multi criterion optimization we obtain a change of the previously submitted offer by a move on the Pareto frontier determined in the bi-criterion optimization of each of the n static games.

The utility functions for both types of agents involved in the negotiation mechanism are the profit functions for each of them. In order to obtain the desired convergence we had to introduce a certain functionality of the candidate agent:

- after a refuse, the agent must restart his evaluation mechanism in order to find a new solution closer to the expectation of the agent in charge of the job;
- the candidate agent optimizes his criterion under constraints based on its available workload capacity, the requirements and the value function of the agent in charge of the job. The current offer must be better than the last accepted offer, in order to make his offer acceptable and the candidate agent must have a certain minimal value for his own utility function.

The necessity of "the minimal value" appears because in conformity with the conceived game, the value, resulting from the evaluation mechanism, is on the Pareto frontier generated by the bi-criterion optimization. And, if the candidate agent wants to obtain a better offer than the last accepted one, he must perform a move of the solution on the Pareto frontier towards a better value of the criterion of the agent in charge of the job, which is, by definition, a better offer than the last one made by this candidate agent. But having in consideration that the two criteria are opposite, a better value for the utility function of the agent in charge of the job means a worse value for the utility function of the candidate agent. However, the benefit of the candidate agent must remain positive, so we need to impose a certain lower limit for his profit. If the candidate agent does not make his desired minimal benefit then it is not worth for him to win the negotiation.

4. A HYBRID CONTROL STRUCTURE

The modeling effort described in this paper, aims at structuring a virtual enterprise in a robust and efficient way. The proposed model involves the *e*Enterprise objects and the enterprise agents who organize the objects in view of achieving particular goals. They are in charge of executing the decisions of the strategic management board of the *e*Enterprise. Producer and provider agents are respectively associated with producer and provider. In the literature, most of the studies on negotiation protocol between the VE agents have considered the non-hierarchical case. The agents on the aggregated-level achieve particular roles of (internal) coordination and (external) negotiation. It appears here the necessity of an automated negotiation mechanism [3] at the lower-level of agents.

Each agent should cover in its negotiation mechanism:

- the capability of initialization of the negotiation mechanism, for the case when he is in charge of the considered job
- the capability of response to another agent's initialization of a negotiation mechanism for the case that he can accomplish the required task.

In order to model this, we consider a model for the negotiation protocol, in which the agents involved are: the agent in charge of the project, who takes the central role in the negotiation as the initiator and decision coordinator of the process and on the other side the agents that are responding to the initial call for the offers. A timed-Petri net of the system is

proposed by composing the model 2.1 with n models 2.2 (according with the number of candidate agents) in the Figure 2.

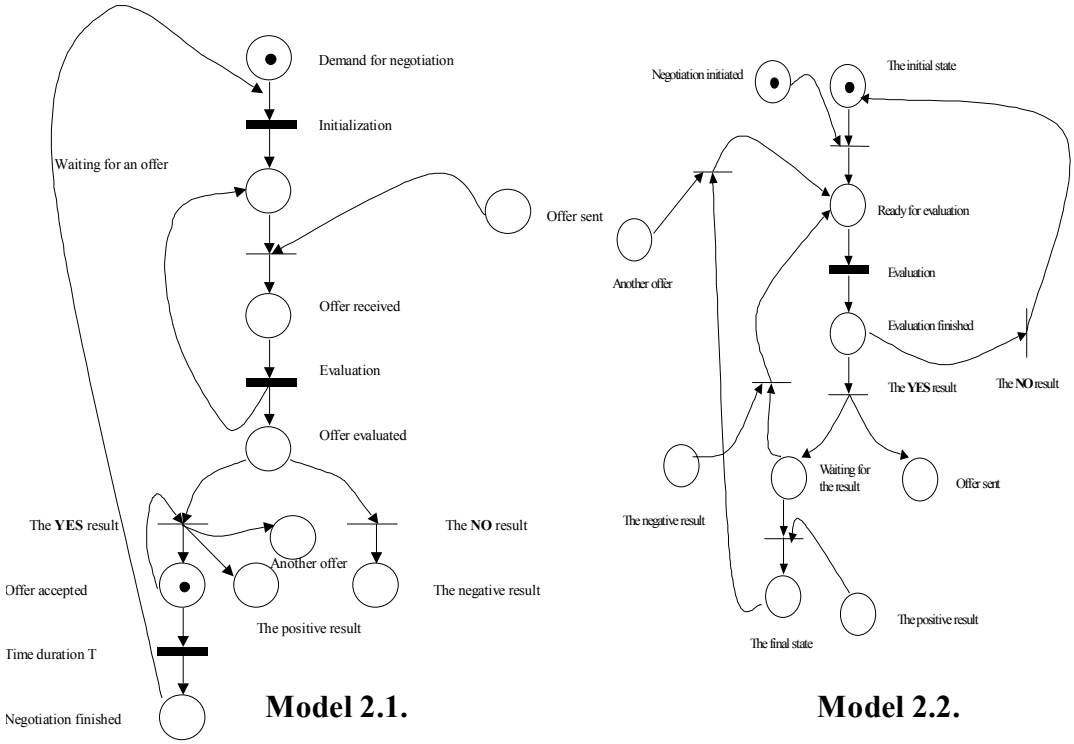

Figure 2 – The model of the agent in charge of a job and of one of the candidate agents

The agent in charge of a job initiates the negotiation process with the contract agents in the system that can accomplish the required task. If a time duration T has passed without an accepted offer then the negotiation has failed.

As shown on Figure 4, a supervisor is needed in the two following cases:

– off-line scheduling imposes the assignment of production units to tasks

– if the negotiation has failed, control is given to the supervisor to adjust the parameters of the negotiation

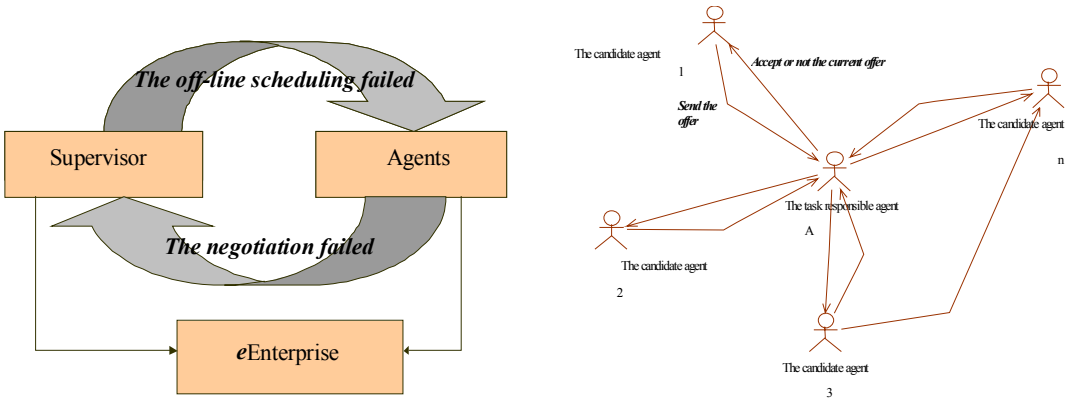

Figure 3 – The proposed structure: agents in the case of negotiation mechanism initiated by the agent A

5. CONCLUSIONS

The paper has proposed a decision and coordination structure based on an automated negotiation mechanism specific for each type of activity. The hierarchical-heterarchical agents approach described in this study has been conceived to address some key problems in the organization of the *e*-Enterprise. The distributed nature of such systems both requires local autonomy and a tight and rigorous coordination between the actors of the VE. The need for a global strategy is crucial for economic and technical reasons. This approach aims at combining the advantages of multi-agents systems in terms of autonomy and reactivity, with the efficiency of hierarchical structures of decision for supervision and coordination.

The feature of this mechanism is that if there is no off-line scheduling made by the supervisor, then the multi-agent system tries to solve the allocation problem by negotiation and only if the negotiation fails, the supervisor comes into the system and reinitiates the negotiation with another parameters or realizes another scheduling.

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