Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 9 (2011) 680–687

Engineering Procedia

TRIZ Future Conference 2006

TRIZ based tool management in supply networks

R. Teti[a] *, D. D'Addona[b] *

University of Naples Federico II, Department of Materials and Production Engineering, Piazzale Tecchio 80, 80125 Naples, Italy

Abstract

The Multi-Agent Tool Management System (MATMS), based on intelligent agent technology for automatic tool procurement in supply networks and provided with a Flexible Tool Management Strategy (FTMS) for optimum tool inventory control, is presented in this paper. The MATMS operates in the framework of a negotiation-based, multiple-supplier network where a turbine blade producer (client) requires dressing jobs on worn-out CBN grinding wheels from external tool manufacturers (suppliers). Tool supply cost minimization involves inventory level minimization, whereas stock-out risk prevention entails inventory constrained maximization. The MATMS integrates the inventive problem solving method, known as the TRIZ method, that can suggest invention directions based on heuristics or principles to resolve the contradictions between production needs and cost minimization.

Keywords: Tool management; Supply network; Inventive problem; Multi-agents; TRIZ agent;

1. Introduction

The Multi-Agent Tool Management System (MATMS) [Teti, 2003a], based on intelligent agent technology for automatic tool procurement in supply networks and provided with a Flexible Tool Management Strategy (FTMS) for optimum tool inventory control, is presented. The MATMS operates in the framework of a negotiation-based, multiple-supplier network where a turbine blade producer (client) requires dressing jobs on worn-out CBN grinding wheels for Ni base alloy turbine blade fabrication from external tool manufacturers (suppliers) [Teti, 2003b, c; Fox, 2000]. Its intelligent Resource Agent is responsible for inventory management and its problem solving function is the FTMS.

Such environment is affected by significant non-random uncertainty involving fluctuations in tool delivery time and unpredictable tool demand. Moreover, a trade-off between tool supply cost and stock-out risk prevention characterizes the inventory sizing dilemma with reference to reusable tools such as grinding wheels.

[a] * Corresponding author.
E-mail address: roberto.teti@unina.it .
[b] * Corresponding author.
E-mail address: daddona@unina.it .

1877–7058 © 2011 Published by Elsevier Ltd. Open access under CC BY-NC-ND license.
doi:10.1016/j.proeng.2011.03.155

The formulation of the control task is intrinsically ambiguous, as conflicting control objectives need to be concurrently pursued. Tool supply cost minimization involves inventory level minimization, whereas stock-out risk prevention entails inventory constrained maximization.

The MATMS integrates the inventive problem solving method, known as the TRIZ method, that can suggest invention directions based on heuristics or principles to resolve the contradictions between production needs and cost minimization. The MATMS includes the Invention Agent (TRIZ Agent), the Coordination Agent (Enterprise Level Agent), and Domain Specific Problem Solving Agents (Resource Agent, Dressing Time Prediction Agent, Order Distribution Agent).

2. Traditional and innovative CBN grinding wheel tool management

Turbine blade fabrication is carried out in parallel along several production line, each for an engine model requiring a specific set of CBN grinding wheel types (part-numbers), planned to work a maximum number of pieces. Each time a CBN grinding wheel reaches its end-of-life, a dressing operation is required from an external tool manufacturer in a supply network and the worn-out tool is unavailable for a time defined as dressing cycle time. For each part-number, a sufficient number of CBN grinding wheels (serial-numbers) must be available at all times to prevent production interruptions due to tool run-out. The current strategic plan for CBN grinding wheel part-number (P/N) inventory sizing is based on the selection of an appropriate number of serial-numbers (S/N), for each P/N, sufficient to cover production needs during the number of months required without new or dressed tool supply. This traditional tool management procedure does not always prove satisfactorily reliable in assuring a correct CBN grinding wheel management [Teti, 2003a, b, c]. The turbine blade producer is aware of the drawbacks of the traditional tool management practice and proactively modifies the inventory size trend by modifying the P/N inventory level on the basis of past experience. The results of this policy, founded on skilled staff knowledge, are the historical inventory size trends. In some cases, the expected trend matches the historical one. In other cases, it is underestimated, with risk of stock-out, or overestimated, with excessive capital investment.

A Flexible Tool Management Strategy was proposed in [Teti, 2003b, 2005; D'Addona, 2005a, b] as an alternative to the traditional tool management procedure for tool inventory control. The FTMS paradigm is configured as a domain specific problem solving function operating within the intelligent agent of the MATMS, the Resource Agent, holding the responsibility for optimum tool inventory sizing and control, tool supply cost and stock-out risk minimization. The FTMS purpose was to make sure that the P/N on-hand inventory size, I, remains within an interval defined by two real-time control limits (Fig. 1): the P/N demand during the purchase order lead time (lower limit, I_{min}) and the P/N demand calculated using the dressing cycle time prediction (upper limit, I_{max}). The inventory level, I, is left free to oscillate within the limits [I_{min} , I_{max}], provided neither of them is crossed. Whenever I decreases due to a tool wear-out event, the CBN grinding wheels are sent out for dressing. If the lower control limit is crossed ($I < I_{min}$), the turbine blade producer must either provide additional S/N or, if the upper control limit is crossed (I > Imax), reduce the P/N on-hand inventory by suspending the dressing job order allocation to bring the stock level within the control range.

The FTMS optimization in terms of the two diverging minimization requirements of stock-out risk and tool supply cost is based on a dynamic management purpose assignment paradigm aiming at preventing panic buying as a result of stock-out risk aversion [D'Addona, 2006]. The attraction band, i.e. the range delimited by both control limits in Fig. 1, plays the role of attractor for the inventory level trend. The system global behaviour is described by an oscillating pattern affecting the inventory level trend in the nearby of the attraction band. The oscillation amplitude mainly depends on the attractor bandwidth as well as on the peaks attained by tool demand rate during the tool management period.

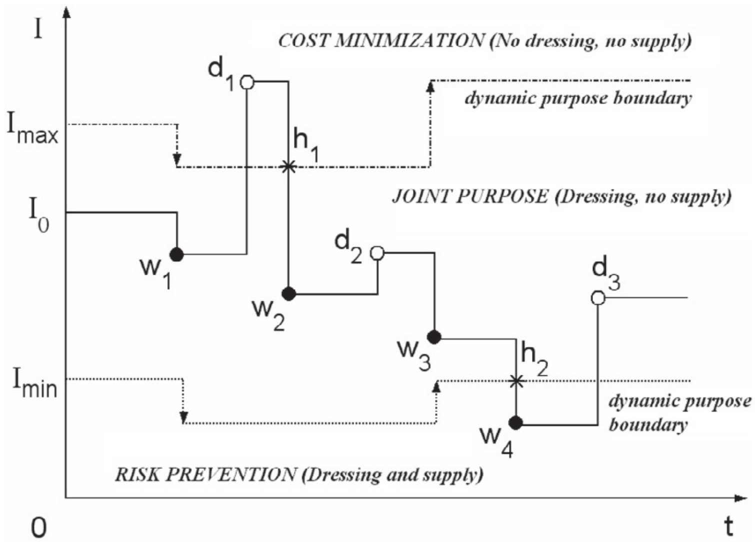

Figure 1: Generic part-number on-hand inventory level, I, vs. time, t.
w = tool wear-out event (•); d = tool delivery event (o);
h = control limit crossing due to a w-event (*).

3. Architecture of the multi-agent tool management system

The adoption of multi-agent technology is based on the three most important system domain characteristics: data, control, expertise or resources are inherently distributed; the system is naturally regarded as a society of autonomous cooperating components; or the system contains legacy components that must interact with other, possibly new software components [Bond, 1998]. Supply network management by its very nature has all the above domain characteristics [Yuan, 2001]. A supply network consists of suppliers, factories, warehouses, etc., working together to fabricate products and deliver them to customers. Parties involved in the supply network have their own resources, capabilities, tasks, and objectives. They cooperate with each other autonomously to serve common goals but also have their own interests. A supply network is dynamic and involves the constant flows of information and materials across multiple functional areas both within and between network members. Multi-agent technology therefore appears to be particularly suitable to support collaboration in supply network management.

The MATMS was developed by making use of agent development tools integrated in a Generic Agent Shell that provides off-the-shelf but customisable services for communication, coordination, reasoning and problem-solving [Fox, 2000]. The Generic Agent Shell provides several layers of reusable services and languages. They are concerned with agent communication services to exchange messages with other agents, specification of coordination mechanisms (shared conventions about exchanged messages during cooperative action with other agents), services for conflict management and information distribution (voluntary or at request information of interest to other agents), reasoning and integration of purpose built or legacy application programs. The glue that keeps all layers together is a common knowledge and data management system on top of which these layers are built. The approach allows for a clear distinction between an agent's social know-how (communication services, coordination mechanisms, information distribution services and other) and its domain level problem solving capability. Purpose built application programs can make use of this agent architecture to enhance their problem solving and to improve their robustness through coordination with other agent based applications. Pre-existing (legacy) application programs can also be incorporated with little adaptation and can experience similar benefits. This latter point is important because in many cases developing the entire application afresh *would be considered too expensive or too large a change away from proven technology.*

The MATMS activities are carried out according to the multi-agent interaction and cooperation protocols described below. In Figure 2, the block scheme of the developed MATMS, subdivided into three functional levels is reported [Teti, 2003a]: (a) the Supplier Network Level, comprising the external tool manufacturers in the supply network, is responsible for carrying out the dressing jobs on worn-out grinding wheels; (b) the Enterprise Level, comprising the logistics of the turbine blade producer, is responsible for coordinating the MATMS activities to achieve the best possible results in terms of its goals, including on-time delivery, cost minimization, and so forth; (c) the Plant Level, comprising the production lines of the turbine blade producer.

The agents of the Enterprise Level and their functions are: (a) the Resource Agent (RA) combines the functions of inventory management, resource demand estimation and determination of resource order quantities; (b) the Order Distribution Agent (ODA) selects the external supplier to which the CBN grinding wheel dressing job orders should be allocated on the basis of negotiations and constraints through its domain specific problem solving function for order allocation implemented in ILOG OPL Studio 3.5 [Van Hentenryck, 1999]; (c) the Dressing Time Prediction Agent (DTPA) carries out the predictions of CBN grinding wheel dressing cycle times, founded on historical data [Teti 2003b, c]; the DTPA employs as domain specific problem solving function a neuro-fuzzy paradigm known as Adaptive Neuro-Fuzzy Inference System (ANFIS) [Jang, 1993, 1995]; (d) the Knowledge & Data Base Agent (K&DBA) collects all the information relevant for tool management activities, including the updating of historical data on grinding wheel dressing cycles; (e) the Warehouse Timer Agent (WTA) takes care of the incoming and outgoing CBN grinding wheels, including the evaluation of actual dressing cycle times; (f) the Invention Agent or TRIZ Agent (TA) uses the TRIZ theory in the invention process in order to suggest principles to improve or solve the contradictions between production needs and cost minimization [Soo, 2005]; (g) the Coordination Agent (CA) coordinates each individual agent's goal searching activity by balancing different objectives, finds the "all-agreed" solution in a short time period and cooperates with the User and such Domain Agents (DA) as the DTPA, RA, ODA and K&DBA to obtain a feasible solution [Soo, 2005].

4. Theoretical development

4.1. TRIZ agent and coordination agent

The inventive problem solving method, known as the TRIZ method, is configured as a domain specific problem solving function operating within the intelligent agent of the MATMS, the TRIZ Agent, holding the responsability for suggesting invention directions based on heuristics or principles to resolve the contradictions between production needs and cost minimisation. These contradictions allow, through the contradictions matrix (Mc_{m*n}, where m = 31 and n = 31 for Management Systems and m = 39 and n= 39 for Technical Systems), to identify among the 40 inventive principles established by Altshuller the most adequate for each contradiction [Farias, 2005]. The contradiction matrices are constantly updated, reviewed, and extended to application to many fields (management, food, social) beyond the original applications in engineering and technology [Altshuller, 1994, 1995]. After positioning the contradictions indicated by Althshuler's contradictions matrix, adapted to the logistics problems, the inventive principles which are most adequate to the logistic scenario are identified.

The first step of an invention process is to identify the problem. The TRIZ Agent allows the User to express the problem to be solved in terms of physical contradictions. The User must identify the technical characteristics to be improved and those that will be worsened when the problem is solved. The related attributes and possible conflicts are communicated to the CA through Agent Communication Language (ACL) messages [FIPA97].

In the present tool management case, the engineering parameters to be improved are the tool run-out risk and the tool demand forecast. These parameters are inputted by the User into the TRIZ Agent (first step) that returns the results in terms of 2 principles (second step): (a) Principle #25: Self-service. This principle consists of enabling a system to perform its own functions or to self-organise. In the MATMS, the agents give feed back to the K&DBA allowing updating in real time. (b) Principle #36: Phase transition. This principle proposes that transition phases might be capitalised in order to clarify the real necessities of the MATMS system: the optimal availability CBN grinding wheels. The domain specific problem solving function (TRIZ) of the TRIZ Agent identifies the principles on the basis of contradictions matrix for Management Systems [Farais, 2005]. In the MATMS this phase is carried out through the FTMS paradigm that is configured as a domain specific problem solving function operating within the MATMS intelligent Resource Agent holding the responsibility for optimum tool inventory sizing and control of CBN grinding wheels.

In the third step, the User considers principle #25 less relevant to the problem and thus chooses principle #36 to solve the problem. In the fourth step, the TRIZ Agent maps the Domain Ontology to the Patent Claim Ontology instances. The TRIZ Agent suggests to the CA, according to principle #36, that the engineering parameter "Inventory level" is to be modified. The role of the CA is to coordinate and cooperate with the User and such Domain Agents (DA) as the DTPA, RA, ODA and K&DBA to obtain a feasible solution [Soo, 2005]. The DAs contain domain knowledge to find the best solution. They can conduct the engineering analysis to verify if the solutions proposed by other agents violate the domain constraints or the production plans. For example: the CA receives the suggestion to modify the CBN grinding wheel inventory level according to principle #36 from the TRIZ Agent. The CA sends a request ACL message to the RA to verify the inventory level size. After several iterations of communication protocols, by collecting solutions from DAs the CA makes a decision on the CBN grinding wheel inventory level size.

4.2. MATMS functioning

In Figure 2, the block scheme of the MATMS functioning is reported. Initially, the CA receives from the TRIZ Agent the suggestion to modify the CBN grinding wheel inventory level according to principle #36. The RA in the Enterprise Level receives information on grinding wheel end-of-life events from the PA_i in the Plant Level through P_j-R inform communicative acts, containing the P/N and S/N of the worn-out CBN grinding wheels, and a request act from the CA. For each worn-out grinding wheel, the RA is informed on current monthly production, P/N tool life, and P/N inventory level, I, by regularly interrogating the K&DBA through a R-K subscribe act, followed by a K-R inform reply. Simultaneously, the RA obtains the information about the supplier-independent dressing cycle time predictions from the DTPA through a R-D request act, followed by a D-R inform reply. To issue a dressing cycle time prediction, the DTPA asks for the updated historical dressing cycle times from the K&DBA through a D-K subscribe act, followed by a K-D inform reply. On the basis of supplier-independent dressing cycle time predictions, current monthly production data and part-number tool life values for the relevant part-number, the RA evaluates the demand for CBN grinding wheel dressing to carry out the part-number inventory sizing and control through its domain problem solving function: the FTMS. If the RA does not consider necessary the dressing operation for a certain part-number, it informs the K&DBA through a R-K inform act that the worn-out CBN grinding wheel serial-number is kept on-hold in the enterprise warehouse. If the RA deems necessary to issue a dressing job order, the RA sends a R-O request act to the ODA asking to start a procedure for dressing job order allocation; this request is followed by an O-R agree reply. The task of the ODA consists in allocating the required dressing job order to one of the external tool manufacturers in the supply network on the basis of negotiations and constraints. To this purpose, the ODA needs to gather information necessary for supplier selection from the relevant agents: DTPA, K&DBA, $SOAA_i$. The ODA starts negotiating with the SOAAi in the Supply Network Level to obtain from each of them the dressing price and time (offers) for the required worn-out CBN grinding wheel part-number. The negotiation is initiated by an O-S_i call for proposals act to which the $SOAA_i$ respond with their offers through S_i-O propose acts. Simultaneously, the ODA obtains from the DTPA the supplier-dependent dressing cycle time prediction (one for each supplier in the network) and from the K&DBA the dressing job reference price, due-time, etc., through O-D and O-K request acts followed by D-O and K-O inform replies. On this basis, the ODA ranks the responding suppliers and allocates the dressing job order to the first supplier in the rank through an O-S_i accept proposal. The selected $SOAA_i$ accepts (refuses) the dressing job order through a S_i-O agree (refuse) act. In case of order refusal, the ODA contacts the second supplier in the rank list, and so on and so forth. At the end of this procedure, the ODA informs the K&DBA about the order allocation results through an O-K inform act and requests the WTA to send the worn out CBN grinding wheel for dressing to the selected supplier using an O-W request act, followed by an W-O agree reply. The WTA records the delivery and reception dates of each CBN grinding wheel for actual dressing cycle time evaluation. These data are regularly fed to the K&DBA that makes them available for further requests and interrogations by the relevant agents; this is obtained through a K-W subscribe act, followed by W-K inform replies.

5. Conclusions

The Multi-Agent Tool Management System (MATMS), based on intelligent agent technology for automatic tool procurement in the framework of a negotiation-based, multiple-supplier network where a turbine blade producer requires dressing operations on worn-out CBN grinding wheels from external tool manufacturers, was presented.

In the MATMS, tool supply cost minimization involves inventory level minimization, whereas stock-out risk prevention entails inventory constrained maximization. The inventive problem solving method, known as the TRIZ method, was integrated into the existing MATMS architecture to suggest invention directions, based on Altshuller's principles, to resolve the contradictions of the above inventory dilemma. Initial experimental results on he functioning of the TRIZ agent integrated MATMS have been obtained only recently and will be presented in soon to appear publications.

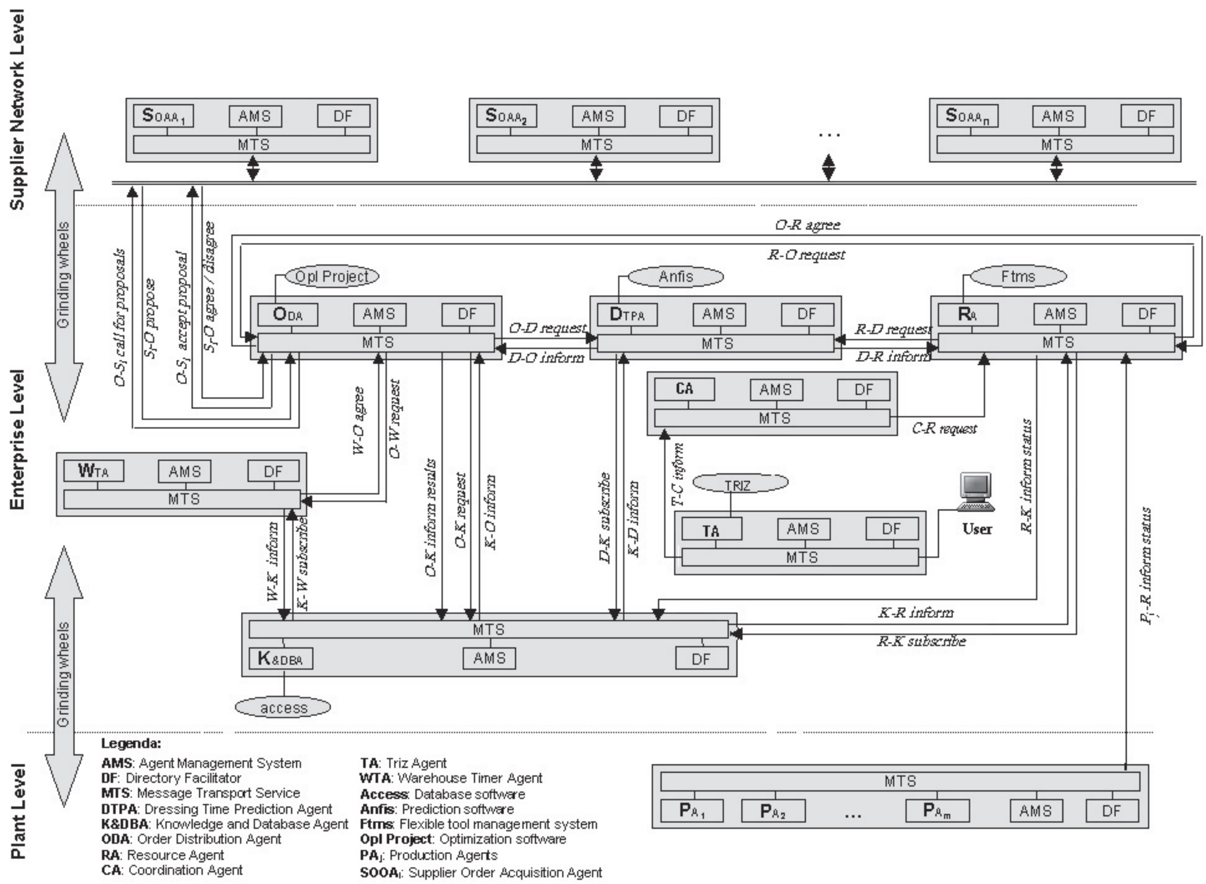

Figure 2. Block scheme of the Multi-Agent Tool Management System (MATMS) integrated with the TRIZ Agent (TA) and the Coordination Agent (TA).

References

- Altshuller, G., 1994, "The Art of Inventing (And Suddenly the Inventor Appeared)", translated by Lev Shulyak. Worcester, MA: Technical Innovation Center. ISBN 0-9640740-1-X.
- Altshuller, G., Fedoseev, Y., 1995, "40 Principles: TRIZ Keys to Technical Innovation", Technical Innovation Center, Inc.; Vol. 1, ISBN: 0964074036
- *Bond, A.H., Gasser, L., 1988, Readings in Distributed Artificial Intelligence, Morgan Kaufmann*
- D'Addona, D. Teti, R., 2005a, "Flexible Tool Management Strategies for Optimum Tool Inventory Control", 1st Int. Virtual Conf. on Intell. Prod. Mach. & Syst. – IPROMS 2005, 4-15 July: 639-644.
- D'Addona, D., Teti, R., 2005b, "Intelligent Tool Management in a Multiple Supplier Network", Annals of the CIRP, Vol. 54/1: 459-462.
- D'Addona, D., Bontempi, A., Teti, R., 2006, Emergent Synthetic Approach to the Inventory Dilemma in a Complex Manufacturing Environment, The 6th International Workshop on Emergent Synthesis in cooperation with CIRP Workshop on Engineering as Collaborative Negotiation, August 18-19, 2006, Kashiwa, Japan, pp. 1-8.
- Farias, O., 2005, The Logistic Innovation Approach and the Theory of Inventive Problem Solving, CLADEA, Asamblea Anual 2005, 20 – 22 October, Santiago de Chile
- "FIPA97 Specification" part 2, ACL. Foundation for intelligent physical agents, October 1997
- Fox, M.S., Barbuceanu, M., Teigen, R, 2000, "Agent-Oriented Supply-Chain Management", Int. J. of Flexible Manufacturing Systems 12, pp. 165-188.
- Jang, J.-S. R., 1993, "ANFIS: Adaptive-Network-Based Fuzzy Inference System", IEEE Trans. on Systems, Man, and Cybernetics, Vol. 23/3: 665-685.
- Jang, J.-S. R., 1995, "Neuro-Fuzzy Modelling and Control", IEEE, 83: 378-405.
- Soo, V., Lin, S., Yang, S., Lin, S., Cheng, S., 2005, "A Cooperative MA Platform for Invention based on Ontology and Patent Document Analysis", 9th Int Conf on CSCW Design, Coventry, UK.
- Teti, R., D'Addona, D, 2003a, "Agent-Based Mulptiple Supplier Tool Management System", 36th CIRP Int. Sem. on Manufacturing Systems - ISMS 2003, Saarbrücken, 3-5 June, pp 39-45.
- Teti, R., D'Addona, D, 2003b, "Grinding Wheel Management through Neuro-Fuzzy Forecasting of Dressing Cycle Time", Annals of CIRP, Vol. 52/1, pp 407-410.
- Teti, R., D'Addona, D, 2003c, "Multiple Supplier Neuro-Fuzzy Reliable Delivery Forecasting for Tool Management in a Supply Network", 6th AITEM Conf., Gaeta, 8-10 Sept., pp. 127-128.
- Teti, R., D'Addona, D., Segreto, T., 2005, "Flexible Tool Management in a Multi-Agent Modelled Supply Network", CIRP Journal of Manufacturing Systems, Vol. 34/3: 203-218.
- Van Hentenryck, 1999, "The OPL Optimisation Programming Language", Massachusetts Institute of Technology, Boston, USA.
- Yuan, Y., Liang, T.P., Zhang, J.J., 2001, Using Agent Technology to Support Supply Chain Management: Potentials and Challenges, M. G. De Groote School of Business, Working Paper N. 453.