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New perspectives in manufacturing: an assessment for an advanced reconfigurable machining system

A.A.G. Bruzzone[a], D.M. D'Addona[b,]*

[a]DIME, University of Genova, Genova, Italy
[b]Department of Chemical, Materials and Industrial Production Engineering, University of Naples Federico II, Naples, Italy

* Corresponding author. Tel.: +39-081-7682367; fax: +39-081-7682362. *E-mail address:* dorianamarilena.daddona@unina.it

Abstract

Traditionally manufacturing cycle involves several production processes that are carried out according to the required technologies tacking into account the constraint due to the production capacity provided by machine tools and the customers' orders time schedule
In this paper, a new modular, reconfigurable and scalable machining centre is presented. The resulting system is characterized by the possibility of modifying the machining capacity as well as exchanging the role between workpieces and machining/operating resources. This augmented flexibility creates new opportunities for efficient manufacturing; however, the increased system complexity demands a new approach for the jobs scheduling and machining control. An architecture based on agents modelling is proposed and discussed.

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Keywords: Reconfigurable Machining System, Multi Agents Systems, Complex Systems

1. Introduction

Complexity characterizes the manufacturing industry; in fact, globalization, competitiveness, and the economic crisis made products manufacturing a difficult task that requires the coordination of designers, processing technologies, suppliers, in order to satisfy customers requirements.

Historically, the efficiency of manufacturing has been improved by organizational and technological innovations starting from the introduction of the chain driven assembly line, Dedicated Manufacturing Line (DML), to CNC machining centers, FMS, CIM. Although some proposals have been widely adopted, other machining tools and manufacturing systems innovations resulted of difficult and limited application in the manufacturing industry.

In the last decades, the Reconfigurable Machining Tools concept has been suggested and several examples are reported in literature [1-3]. One of the last proposal on reconfigurable machining systems [4] expands reconfigurability by introducing scalability through a Lego-like architecture; the augmented capabilities and flexibility however require new control strategies able to face the associated complexity.

This paper presents the novel Lego-like reconfigurable machine tool architecture and proposes an emergence approach based on Multi Agents System (MAS) to manage the machining system complexity that results from the novel reconfigurability approach.

2. Manufacturing System Complexity

Nowadays manufacturing systems (MS) are complex systems difficult to reduce to a linear paradigm by avoiding the external environment which is considered able to accommodate all the MS production, including fallout and side effects, due to the hypothesis of independence between the MS and the external environment. Moreover, the resources are considered under full control, e.g. employees can be fired, the environment can be polluted, etc. Systems composed of interconnected entities that show properties and behaviours not manifest from the sum of its single parts are defined complex systems [5].

Complex systems can be composed of agents, hardware and software, that are connected, interdependent, diverse, adaptive, and path dependent, and their interactions result in emergent phenomena [6].

Complex systems modelling by traditional analytical methods reaches a limit when trying to understand non-linear emergent phenomena with an intermediate degree of interdependence. Computer simulations provide numerical results that provide an important understanding of emergent dynamics in many kinds of systems.

Ueda explained the synthesis problem and the emergence concept as well as their connection with problem-solving difficulties in complex manufacturing systems [7].

The term synthesis, used with reference to the human activities for creating artificial items, is defined as the "*engineering design … of an artifact*", where the latter is an "*artifactual system having a certain purpose and a certain environment in which the system works*". In this framework, synthesis is a necessary component of the problem-solving processes in almost all phases of an artifact's life cycle. The life cycle of an artifact starts with design, continues through the phases of planning, production, and consumption, and ends with removal of the product. The main question is how the problem of synthesis can be solved: how to determine the system's structure, which shows its function, to reach a goal under the constraints of dynamic environments and incomplete information.

Solving the problem of synthesis is "*to determine the system structure in order to realize its purpose under the constraints of the environment*".

Instead of traditional approaches, which are analytic and deterministic, emergence based approaches are being developed with both bottom-up and top-down features. They include evolutionary computation, self-organisation, behaviour-based methods, reinforcement learning, multi-agent systems, game theory, etc. As to the characteristics of emergent systems, key words such as evolution, adaptation, learning, multi-agents, coordination and interactivity are appropriate: they indicate promising approaches for offering efficient, robust and adaptive solutions to the problem of synthesis [8].

3. Lego-like reconfigurable machining system

In order to improve efficiency and provide high production capacity, industry uses Dedicated Manufacturing Line (DML), characterized by high automation level and high throughput. This approach however does not provide the desired flexibility to achieve product variability and proliferation. Other approaches, such as FMS and CIM, although providing the required flexibility, demand very costly investments that could not be acceptable whenever the market demand is variable, in particular during phases characterized by economic crisis.

Starting in 1996 at the Engineering Research Center for Reconfigurable Manufacturing Systems (ERC/RMS) of the University of Michigan College of Engineering, the concept of a Reconfigurable Manufacturing System was developed, which is defined as a system "*designed at the outset for rapid change in its structure, both for its hardware and software components, in order to quickly adjust its production capacity and functionality within a family of parts in response to sudden changes in the market or in the requirements imposed by regulations*" [9,10].

Reconfigurable Machine Tools (RMTs) are essential to implementing such a system, as they extend the reconfigurability concept from the system (RMS) to the machine tool. In particular, reconfigurable machine tools have lower costs than numerically controlled machines (CNC machine tools), because with respect to the latter they employ a customizable flexibility that is the minimum necessary in order to manufacture products that belong to a given family.

Since 1996, three typologies of RMT have been proposed: (i) Modular machine tools RMT, (ii) Multi-tool RMT, (iii) Arch-type RMT. By grouping several RMTs with a material handling system, such as conveyors, gantries modules, reconfigurable inspection modules, it is possible to configure a Reconfigurable Manufacturing System, RMS.

Lego-like reconfigurability extends the paradigm characterizing RMT and RMS by considering the elements that are present in every machine tool [11]:

- a device that supplies energy, by virtue of which a relative coupled motion is obtained between the tool used to provide the process and the workpiece;
- a device for fixing and orientating the workpiece;
- a device for conveniently fixing and orientating a tool;
- a device for controlling the three above mentioned elements;
- a device for operating the tool according to the used transformation process.

A new kinematic architecture combines these elements and defines a new class of dynamically reconfigurable machine tools whose modular and scalable structure permits to dynamically host and integrate different processing technologies.

Actually, the new kinematic architecture is conceived by rethinking the leadscrew-sleeve linear motion axis, specifically by topologically exchanging the role between the sleeve and the screw in order to eliminate the requirement concerning the holding structure necessary to support the screw and, consequently, any limit to the axis excursion: instead of giving the sleeve the function of converting the screw rotation into a linear movement, this function is assigned to the screw.

Fig. 1-a shows the bed structure of the machine tool with the integral leadscrew racks (Fig. 1-b) that extend on the machine tool bed along the full length of the linear axis. The rotating screws are hosted on the movable cross-table (Fig. 1-c); this solution permits to simultaneously accommodate on the same bed structure one or more cross-tables, where each cross-table can move independently from the others. On board of the single cross-table, the components for a specific processing or measuring task, such as milling, additive FDM, etc., can be hosted.

a)

b)

c)

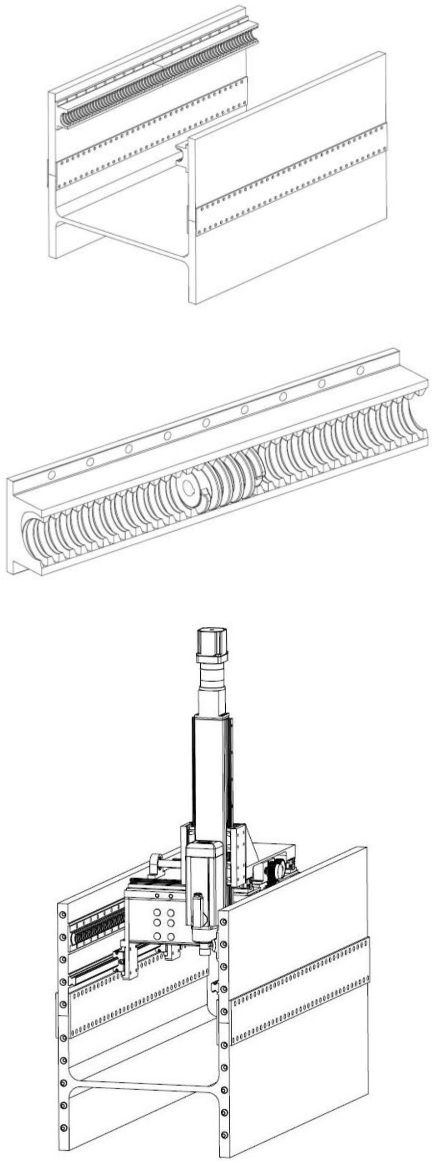

Fig. 1. a) Modular bed structure with racks; b) screw-rack geometry; c) bed structure hosting one moving milling cross-table

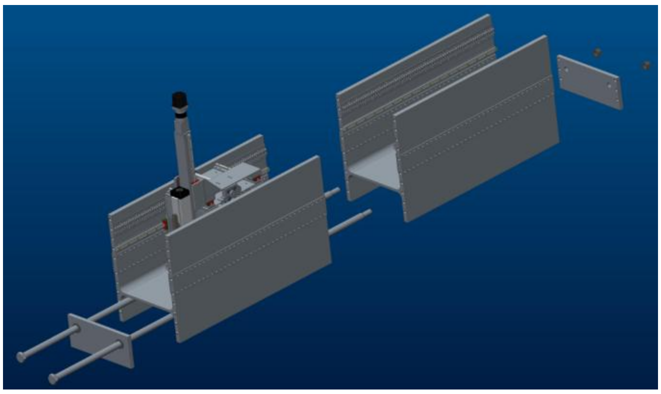

Fig. 2. Two Lego-like joined bed hosting one movable cross-table

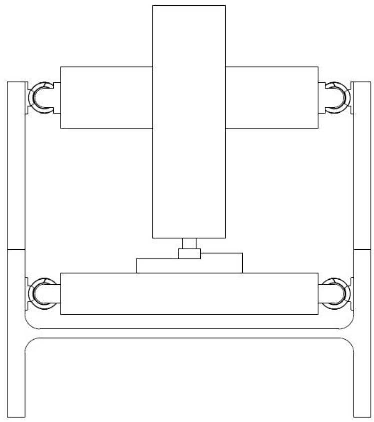

Fig. 3. Bed structure with two movable cross-tables: top milling spindle; bottom workpiece holder

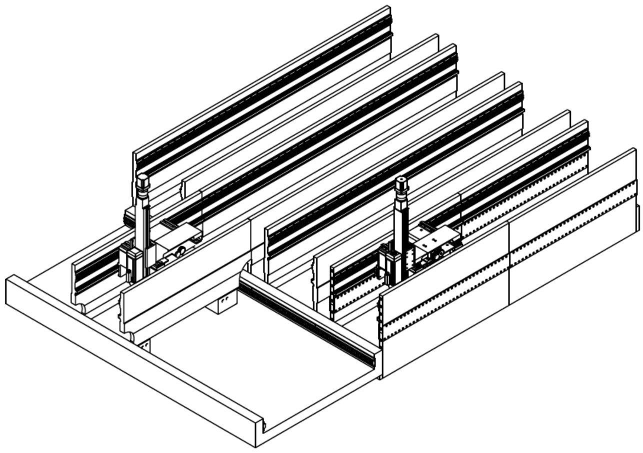

Fig. 4. Bed distribution structure serving four linear structures

By dimensioning the longitudinal extension of the bed structure along the linear axis direction as an integer multiple of the teeth pitch of the leadscrew racks, two or more bed structures can be joined by means of coupling elements; this design permits to extend the axis length of the machine tool in a Lego-like fashion according to a modular scheme (Fig. 2). The duplication of the rack-screw solution on the bed structure consents to host on the modular bed other cross-tables that can move independently on parallel racks lines (Fig. 3). On these movable cross-tables, various devices to fix, move or rotate the workpieces as well as the tools can be hosted. Essentially two parallels rack lines can accommodate two cross table sets: up movable cross tables and bottom movable cross table. Each cross-table contains the actuating device (motor) to rotate the screws engaged with the leadscrew racks providing in this way the motion along the bed structures.

In order to extend the flexibility and the reconfigurability of the machining system a distribution bed structure can be used (Fig. 4). In this way, any layout with linear as well as parallel lines can be set.

The resulting system is characterized by the possibility of modifying the machining capacity as well as the processing technologies. Furthermore, available capacity and processing technologies may dynamically change. This characteristic provides another dimension to the manufacturing system complexity; actually, the number and the typologies of the machine tools available in the shop floor are no more statically predetermined.

In order to face the reconfigurable system complexity an emergence based approach based on multi-agent systems technology could be a solution for controlling the Lego-like reconfigurable machining system.

4. Multi-agent technology

A new software architecture for managing production systems at the tactical and operational levels has emerged. It can view a manufacturing system as composed of a set of intelligent agents, each responsible for one or more activities and interacting with other agents in planning and executing their responsibilities [12].

An agent is an autonomous, goal-oriented software paradigm that operates asynchronously, communicating and coordinating with other agents as needed [13].

A multi-agent system consists of a group of different types of agents that can take on specific roles within an organizational structure [14]. It can be defined as a loosely coupled network of problem solvers that interact to solve problems that are beyond the individual capabilities or knowledge of each problem solver [15].

Important characteristics of a multi-agent system are [16]:

- each agent has incomplete information or capabilities for solving the problem (limited viewpoint)
- there is no system global control;
- data are decentralised;
- computation is asynchronous.

Most research on multi-agent systems focuses on the coordinative intelligent behaviour among a collection of autonomous intelligent agents considering that the group of agents provides more than the sum of the capabilities of its members [17].

4.1. Generic agent shell

The FIPA Agent Management Reference Model that provides for the creation, registration, location, communication, migration and retirement of agents [18] is used in this paper. The entities contained in the reference model (Figure 4) are logical capability sets (i.e. services) and do not imply any physical configuration. These can be combined in the physical implementation of Agent Platforms (AP) defined by FIPA as the environment where agents can physically exist and operate [19].

FIPA agents located on an AP utilise the facilities offered by the AP for achieving their functionalities. In this context, an agent, as a physical software process, has a physical life that has to be managed by the AP. The implementation details of individual AP and agents are the design choices of the individual agent system developers.

The Generic Agent Shell (Figure 4) provides several layers of reusable services and languages. The services concerned with agents 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 providing the problem solving capability.

Purpose built application programs can make use of this agent architecture to enhance their problem solving capabilities 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 complex from existing technology.

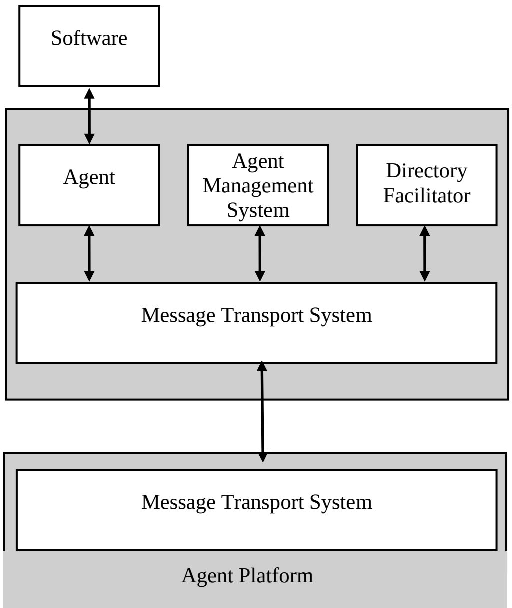

Fig. 4. Generic agent shell.

5. Multi-agent Lego-like reconfigurable machining system

The multi-agent Lego-like reconfigurable machining system (MALReMS) activities are carried out according to the multi-agent interaction and cooperation protocols described below.

Figure 5 shows the block scheme of the developed MALReMS, subdivided into three functional levels:

- Enterprise Level,
- Bed Unit Level,
- Machine Level.

In Figure 6, the detailed block scheme of MALReMS is shown. The Enterprise Level is responsible for coordinating the MALReMS activities to achieve the best possible results in terms of its goals, including on-time delivery, cost minimization, and so forth.

The Enterprise Level comprises the Cooperation Agent (CA) and a Knowledge & Data Base Agent (K&DBA) that handles all the information relevant for production, including the updating of historical data.

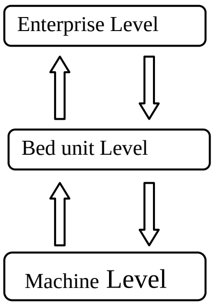

Fig. 5. MALReMS block scheme.

The Bed Unit level comprises one type of agent, the Bed Unit Agent, BUA, that is responsible for modifying the dimension of the travel length and the modular beds system layout.

The Machine tool level comprises three types of agents:

- the leadscrew axes agent (LAA);
- the up movable cross-tables agent (UPA);
- the bottom movable cross-tables agent (BA).

The leadscrew axes agent is a passive agent and its main task is to communicate its actual state in terms of the position of the up and bottom movable tables coordinates.

The up movable cross-tables agent is responsible for varying the number of tools/devices that machine the workpiece without requiring a modification of the elements (spindles, extrusion heads etc.) that already operate on the machining center, in particular a machine tool.

The bottom movable cross-tables agent is responsible for moving the workpiece holder table taking into consideration the presence of other bottom tables

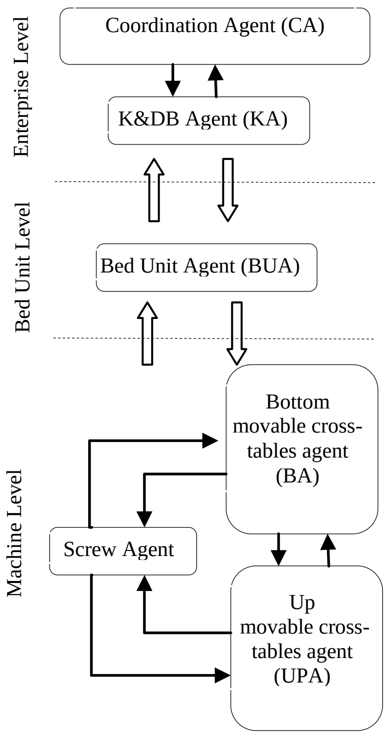

Fig. 6. Detailed MALReMS block scheme.

5.1. MALReMS agent communication

Communication is a fundamental aspect of a multi-agent system activity and takes place through exchange of messages between agents. The latter use a common language, the Agent Communication Language (ACL), to transfer information, share knowledge and negotiate with each other.

The most widely used ACL is the one developed by the Foundation for Intelligent Physical Agents (FIPA), FIPA ACL [20], based on the "Speech Act Theory" by J.R. Searle [21]; this language originated from the linguistic analysis of human communication and is based on the idea that speech does not constitute only communications but also provides real actions.

The unit for communication analysis is the message, called communicative act or performative. In FIPA ACL, the types of communicative acts that constitute the language basis are identified through the analysis of communication processes of interest for the world of artificial agents.

FIPA ACL offers a set of standard communication acts or performatives to describe agent actions: e.g. to inform and confirm, request and query, agree and accept, propose, etc. It also allows users to extend them if the new defined actions conform to the rules of the ACL syntax and semantics.

In Table 1, the communication acts or performatives utilized in the MALReMS are summarized.

Table 1
FIPA ACL performatives utilised in the MATMS

PERFORMATIVE	DESCRIPTION
Inform	the sender informs the receiver that a given proposition is true
Subscribe	the action of requesting a persistent intention to notify the sender of the value of the reference, and to notify again whenever the object identified by the reference changes
Request	the sender requests the receiver to perform some action
Agree	the action of agreeing to perform some action, possibly in the future
Refuse	the action of refusing to perform a given action and explaining the reason for the refusal
Propose	the action of submitting a proposal to perform a certain action, given certain preconditions
Call for proposals	the action of calling for proposals to perform a given action
Accept proposal	the action of accepting a previously submitted proposal to perform an action

5.2. MALReMS functioning

A simplified configuration of the Lego-like reconfigurable machining system (Fig. 6) has been considered to describe the functioning of the MALReMS in terms of agent communications and activities in the three system levels.

The reconfigurable machining system has two parallels rack lines accommodating two cross table sets: up movable cross tables and bottom movable cross table. The following configurations can be considered:

1) the bottom movable cross table hosts various devices to fix, move or rotate the workpieces, while each up

movable cross table hosts different tools. In this type of configuration, the bottom cross table moves under each up cross table to permit the related machining operation;

2) the workpiece inertia is very high, the bottom cross table is secured in a fixed position while each up cross table moves on it.

For the sake of simplicity, the functioning of the MALReMS, is described by considering the configuration 1).

Initially, the CA in the Enterprise Level receives information from other CA on the sequence of processing operations to be carried out on the workpiece and inform the K&DBA through a C-K inform communicative acts. The CA requests to all UPA to perform the first operation through a C-U_i request act.

Each UPA_i starts collecting the necessary information (e.g. type of tool mounted on it) deciding whether or not the required operation can be carried out. The UPA_i accepts (refuses) the request to perform the operation through an U_i-C agree (refuse) act.

In case of order refusal, the CA contacts external CAs requesting an UPA able to perform the required operation. At the end of this procedure, the CA informs the K&DBA about the operation allocation results through a C-K inform act and requests the BA, to move under the UPAi, ready for the first machining operation, through a C-B propose act followed by a B-C agree (refuse) act.

Simultaneously, the BA obtains from the BUA the availability of unit for moving in the requested position, through B-BU subscribe act followed by BU-B inform replies. The BA informs the K&DBA about the its status and position, through a B-K inform act. If the chosen UPAi and BA are in the right position, the CA asks to the UPAi to start with the machining operation on the workpiece mounted on the BA through a C-UP request act. At the end of the machining operation, the UPAi informs the K&DBA. 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-UPi subscribe act, followed by UPi - K inform replies.

The CA asks regularly to the KA about the UPAi in order to start a new procedure for the second operation on the just machined workpiece.

The previous steps are repeated for each machining operation describes by the process planning until the completion of the required output workpiece.

6. Conclusion

In this paper, a new modular, reconfigurable and scalable Lego-like machine tool is presented. The resulting system is characterized by the opportunity to increase or reduce the machining capacity. This augmented flexibility creates new possibilities for efficient manufacturing and enables cooperation strategies; however, the increased system complexity demands a new approach for the jobs scheduling and machining control. An emergence approach based on Multi Agents System (MAS) to manage the machining system complexity, that results from the novel reconfigurability approach, has been presented.

References

[1] Landers RG, Min BK, Koren Y. Reconfigurable machine tools. CIRP Annals - Manufacturing Technology 2001; 50(1):269-274.

[2] Gadalla M, Xue D. Recent advances in research on reconfigurable machine tools: A literature review. International Journal of Production Research 2016.

[3] Koren Y, Kota S. Reconfigurable machine tool. 1999; U.S. Patent 5,943,750

[4] Bruzzone, A.A.G., D’Addona, D.M., Lego-like reconfigurable machining system; new perspecives to optimize production capacity, The 15th IEEE International Conference on Industrial Informatics, INDIN 2017, Jul 24-26, 2017, Emden, Germany

[5] Monostori, L., Csáji, B.Cs, 2008, Complex Adaptive Systems (CAS) approach to production systems and organisations, in: Manufacturing systems and Technologies for the New Frontier, The 41th CIRP International Seminar on Manufacturing Systems, May 26 - 28, 2008, Tokyo, Japan, Springer, 19-24

[6] J.H. Holland, Emergence : from chaos to order, Helix Books, New York (1998)

[7] Vaario, J. & Ueda, K. Journal of Intelligent Manufacturing (1998) 9: 129

[8] Ueda, K., Markus, A., Monostori, L., Kals, H.J.J., Arai, T., 2001, Emergent Synthesis Methodologies for Manufacturing, Annals of the CIRP, 50/2: 535-551

[9] Koren, Y., Jovane, F., Heisel, U., Moriwaki, T., Pritschow, G., Ulsoy, A.G., VanBrus- sel, H., 1999, Reconfigurable Manufacturing Systems, Annals of the CIRP, Vol. 48/ 2, 6-12

[10] Koren, Y., 2006, General RMS Characteristics. Comparison with Dedicated and Flexible Systems. In: Dashchenko A.I. (eds) Reconfigurable Manufacturing Systems and Transformable Factories. Springer, Berlin, Heidelberg

[11] Bruzzone, A.A., Monti, M., Godani, A., Reconfigurable Machining Center, Patent Application PCT/IB2017/050737

[12] Teich,T., Zschorn, L., 2002, Automatic Procurement in Production Networks: Introducing the Probabilities of Delivery to Quantify the Uncertainties in Supply and Production Processes, 3rd CIRP Int. Sem. on Intelligent Computation in Mftg. Eng. (ICME 2002), Ischia, 3-5 July: 37-42

[13] Fox, M.S., Barbuceanu, M., Teigen, R., 2000, Agent-Oriented Supply-Chain Management, Int. J. of Flexible Manufacturing Systems, 12: 165-188

[14] Chen, Y., Peng, Y., Finin, T., Labrou, Y., Cost, R., Chu, B., Sun, R., Willhelm, R., 1999, A Negotiation-Based Multi-Agent System for Supply Chain Management, Working Notes of the ACM Autonomous Agents Workshop on Agent-Based Decision-Support for Managing the Internet-Enabled Supply-Chain, May 1999

[15] 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

[16] Durfee, E.H., Lesser, V., 1989, Negotiating, Task Decomposition and Allocation Using Partial Global Planning. In Distributed Artificial Intelligence, Eds. Gasser, L., and Huhns, M., San Francisco, CA, Morgan Kaufmann, 2: 229-244

[17] Sycara, K.P., 1998, Multi-Agent Systems, AI Magazine, Summer 1998: 79-92

[18] FIPA Agent Management Specification, SC00023K, 2002/12/03, Foundation for Intelligent Physical Agents, Geneva, Switzerland, 2002, http://www.fipa.org

[19] FIPA Agent Management Specification, SC00023J, 2002/12/03, Foundation for Intelligent Physical Agents, Geneva, Switzerland, 2002, http://www.fipa.org

[20] FIPA97 Specification part 2, Agent communication language. Foundation for intelligent physical agents, October 1997.

[21] Searle, J.R. Speech acts. Cambridge University Press, Cambridge, England, 1969