RECONFIGURABILITY OF MANUFACTURING SYSTEMS FOR AGILITY IMPLEMENTATION – *PART II: TWO ARCHITECTURES*

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For the agility implementation in Manufacturing Systems (MS) the implementation of the mechanisms for dynamic reconfigurability of MS structure, the pro-activity, the emergence (as inherent features of agility), and the need for integration of the resources extra-muros of the original MS are required. This paper presents two architectures for MS reconfigurability in support of MS agility as well as two applications of the proposed architectures. This paper is the second part of the two-part paper that addresses the issue of imagility implementation in MS (the first part presents the requirements and principles of agility and MS reconfigurability).

1. INTRODUCTION

Implementation og agility in Manufacturing Systems (MS) requires implementation of new characteristics as well as new implications not considered by the previous concept of FMS and other MS architectures. These characteristics are the need for dynamic reconfigurability of MS structure – at the first place, the pro-activity – as an inherent feature of agility, emergence – or self-organization, and the need for integration of the resources extra-muros of the original MS. These characteristics, i.e. requirements, imply the needs for defining specific organizational tools and frameworks capable to manage them.

This paper is the second part of the two-part paper that addresses the issue of imagility implementation in MS (the first part presents the requirements and principles of agility and MS reconfigurability).

The sources on which the paper is conceived are (Putnik *at al.*; 2006), (Putnik; 2001), (Putnik *et al.*; 2005) and (Butala & Sluga; 2002).

2. TWO ARCHITECTURES FOR MANUFACTURING SYSTEMS RECONFIGURABLITY

Two architectures for implementing agility in MS are presented, namely the *Adaptive Distributed Manufacturing System* (ADMS), (Butala, Sluga; 2002) and *BM_Virtual Enterprise or Manufacturing Systems* (BM VE/MS), (Putnik; 2001), (Putnik *et al.*; 2005). Both approaches, although developed independently, are based on the market mechanism for developing an adequate structure that would be the most competitive for the order considered, and employs the "three-level" hierarchy architecture pattern, see (Putnik, Sluga; 2006 – this volume). The "three-level" hierarchy architecture pattern implies a specialized independent, and in the certain context autonomous, agent as an independent intermediate control level as one of the basic elementary MS control component types, or blocks, or level, for the resources reconfiguration, or restructuring, management. This agent is called *resource manager* or *broker* or *mediator*.

Both approaches to the reconfigurability of the MS, consider the MS structure reconfiguration domain.

3. ADAPTIVE DISTRIBUTED MANUFACTURING SYSTEM - ADMS

ADMS, (Butala, Sluga; 2002), is conceived as a distributed MS structured as a network of elementary work systems (EWS), representing the MS building blocks, that act as agents. They (building blocks or agents) can be related in a series or and/or in parallel, and are driven by cooperation and competition on various levels. The agent structure is synthesized through the market mechanism in order to provide self-organization and adaptivity. In order to align with the environment the structure, through the market mechanism, can reconfigure optimizing the overall system's behavior, or performance, in accordance, or aligned, with the environment. A EWS is capable of performing single manufacruing task, e.g. process planning, machining. It consists of hardware elements necessary to implement a work process, work process identification for process control and optimization and a human operator as an autonomous subject for making decisions and synthesis. In ADMS a virtual work system (VWS) is introduced in order to delegate the EWS in a distributed environment. The VWS is an agent and it represents the EWS in a distributed environment. The EWS are interconnected via corresponding VWS agents into a network and thus constitute the ADMS. The agents operate and communicate over the network and coordinate their actions to accomplish complex tasks by exploiting their competences, taking into account their own objectives (inherent to the market mechanism).

The MS structuring is a critical process. For each particular task, the optimal structure has to be built up. It is assumed that the complex task are decomposed into less complex tasks, in the limit to the elementary (primitive) tasks. The coordination process implies task decomposition as a recursive task structuring process. The structuring process implies the incorporation of the (elementary) work systems for task execution through the market mechanism.

The market mechanism is characterized by the operation of the self-adjusting forces of supply and demand. The market based dynamic structuring process consists of bidding – negotiation – contracting phases.

Thus contacts between demand and supply are established on the network, resulting in a task-oriented dynamic cluster of cooperating and competing agents, Figure 1.

Timing of the dynamic structuring process, i.e. of the task coordination process, Figure 2, is a critical factor. The efficiency of dynamic structuring mostly depends on a time lag between the task assignment "milestone" and the time of task execution. The shorter the time gap the more the assumption of a quasi-stable environment is realistic.

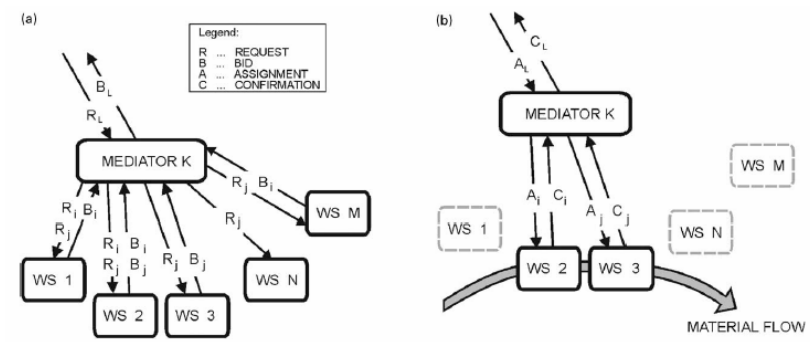


Figure 1 – Dynamic structure of work systems: a) dynamic structure, b) executive structure (Butala, Sluga, 2002)

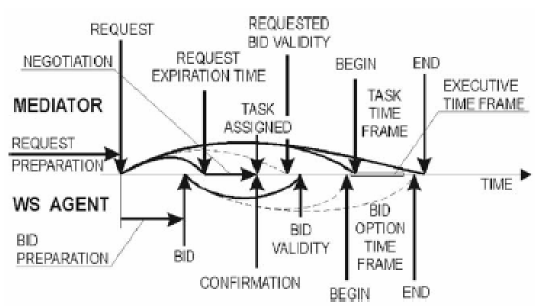


Figure 2 – Timing of a task coordination process (Butala, Sluga, 2002)

Case study

The ADMS approach is demonstrated in an experiment in sheet metal manufacturing on industrial data.

The requested set of tasks was composed of various sheet metal components with different shapes, dimensions and batch sizes. The selected material as well as sheet thikness was the same in order to provide an opportunity for the nesting of

Table 1. Requested tasks

Requested tasks

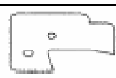
Task	Sketch	PCS	S (m^2/pc)	L (m/pc)	Time frame	
					Begin	End
K9		50	0,003	0,32	8:30	10:30
K15		40	0,107	4,39	10:00	13:00
K10		28	0,071	3,31	9:30	14:30
⋮						

Table 2. Bidden tasks

Bidden tasks

Task	Bidder	Price	Time frame		Assigned
			BEGIN	END	
K9	WS1	13.029	9:30	10:45	√
	WS2	13.920	10:30	11:30	
	WS3	12.314	12:00	13:00	
K15	WS1	12.343	10.45	11.45	√
	WS3	11.728	13:00	14:00	
K10	WS1	10.018	11:45	13:00	√
	WS2	10.315	10:30	12:30	
	WS3	9.695	14:00	15:00	
:					

different components on the same sheet and, thus, for an optimization of material and time utilization.

Examples of requested tasks (components to be cut) and corresponding basic data are shown in Table 1.

Examples of the bids are shown in the Table 2. Bids were evaluated by the mediator in terms o: (1) fulfillment of task objectives in terms (in this case it was assumed that the biding work system was capable of performing the task), (2) minimization of costs and (3) fulfillment of constraints (time frame limits). The best bids were selected and corresponding work system assigned as shown in table 2.

4. BM_VIRTUAL ENTERPRISE OR MANUFACTURING SYSTEM

The second architecture for dynamic reconfigurability of MS, for agility implementation, we present is an application of the BM_Virtual Enterprise (BM_VE) model for the Manufacturing Systems. BM_VE is a virtual enterprise (VE) in a total or partial conformance with the BM_Virtual Enterprise Architecture Reference Model (BM_VEARM), (Putnik, 2001) and (Putnik *et al.*, 2005).

BM_VE is the VE as a dynamically reconfigurable inter-enterprise network integrated over the global domain, satisfying the requirements for integrability, distributivity, agility, and virtuality as the competitiveness factors.

Therefore, by BM_VE, i.e. BM_VEARM, the reconfigurability domain for MS, concerning the enterprise organizational environment, is primarily *inter-enterprise*.

BM_VE uses three main mechanisms, or tools: market of resources, broker, and virtuality. Virtuality as a tool is a specific organizational structure pattern that contributes to further improvement of agility/reconfiguration dynamics.

Market of resources (MR), that BM_VE uses, is an institution, or enterprise, that serves as a meta-enterprise of the operating VE. It (MR) is an environment to support the VE dynamic reconfiguration, providing a way to overcome (i.e., to minimize) two fundamental networking disablers: "transaction," i.e., reconfiguration cost, and the VE partners' knowledge and rights protection – which are critical reconfigurability dynamics enabling factors for the *inter-enterprise* MS domain, and providing an environment for the market mechanisms.

The broker, as the second mechanism, is described in (Putnik, Sluga; 2006 – this volume). His main role is to be the agent of agility and organization reconfiguration dynamics, acting as an "*MS structure reconfiguration manager*," or *resource manager* or *mediator*. The second fundamental role of the broker is to be the agent of virtuality. In this role, the broker provides the intermediation services "online" with the operations in a way that the operating agents, the client and the server, are not aware of each other – the client and server are hidden from each other and they communicate through the broker. By this structure, the BM_VE or MS, could be (software) system architecture (e.g., CORBA[1]).

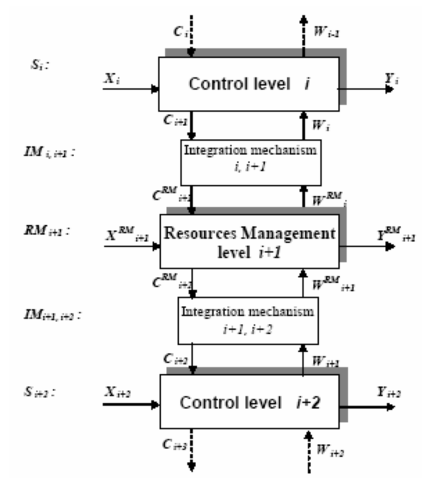


Figure 3 – BM_VEARM elementary structure, or structural pattern (Putnik, 2001)

BM_VE Architecture Reference Model (BM_VEARM) – Elementary Structure

The BM_VEARM (Putnik, 2001) is a reference model to design and control virtual enterprises/manufacturing systems ensuring four fundamental functionalities/ characteristics: integration, distribution, agility, and virtuality.

The BM_VEARM elementary structure, or elementary structural pattern, which is a hierarchical structure, satisfying the above-mentioned fundamental functionalities or characteristics, is represented in Figure 3.

BM_VE Formal Specification and Theory

At the present, BM_VE is rigorously formalized for the structural aspect. For the formalization of the BM_VE structural aspects, an attributed context-free formal grammar, denoted as G_{BM} was developed in (Sousa; 2003), (see also (Putnik et al., 2005)). As integration mechanisms can be omitted from the representation of the

[1] CORBA is "the object bus" architecture that "lets objects transparently make requests to, and receive responses from, other objects located locally or remotely. The client is not aware of the mechanisms used to communicate with, activate, or store the server object. … (it) lets objects discover each other at run time and invoke each other's services" (Orfali et al., 1997, p. 7).

BM_VE structure (because the integration mechanism acts as an interface between adjacent levels but in implementations it is usually included within those levels), G_{BM} deals with only two types of building blocks: control level block (the terminal symbol c_i) and resource management block, or *broker*, (the terminal symbol r_j).

Some examples of BM_VE structures synthesized by G_{BM} are represented in Figure 4. The components of a BM_VE may obviously have their own internal compositions. The structural, or reconfigurability, dynamics, of the BM_VE or MS could be presented as in the Figure 5.

reconfigurability dynamics

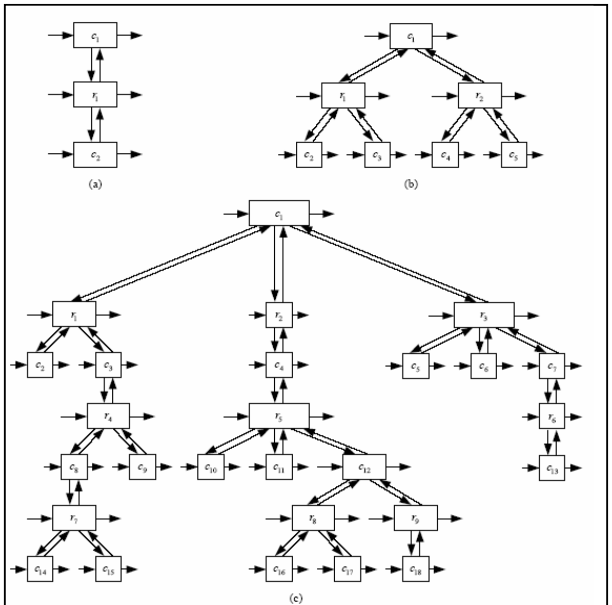


Figure 4 – BM_VE system canonical instances generated by GBM grammar

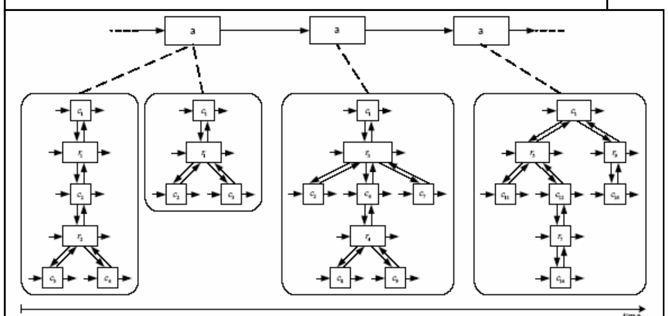


Figure 4 – BM_VE system canonical instances generated by GBM grammar

Development of the BM_VE or MS Demonstrator

In order to fulfill the requirements of the project(s) validation, including the VE reference model, it is implemented a laboratory installation which will serve as a demonstrator for the VE and MS reconfigurability design and control. The laboratory installation is conceived as a Distributed/Virtual Manufacturing System (D/V MS) Cell, named *AURORA 98* (Putnik et al., 1998). In the first period the laboratory was used for research of distributed manufacturing system. In the second (present) period the laboratory is extended with the components which are expected to provide the full demonstration of the VE concept based on the BM_VEARM.

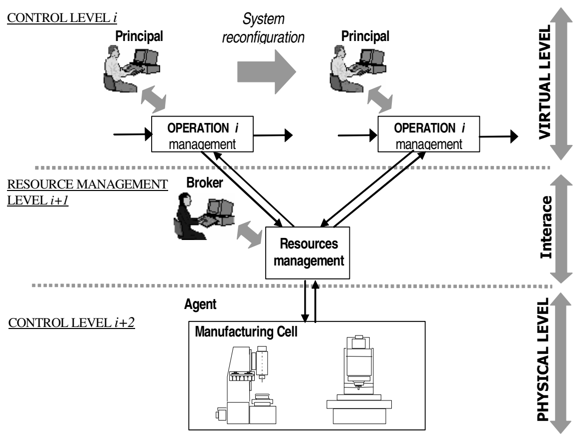


Figure 7 – An informal scheme of the virtual enterprise demonstrator based on the *BM_Virtual Enterprise Architecture Reference Model*

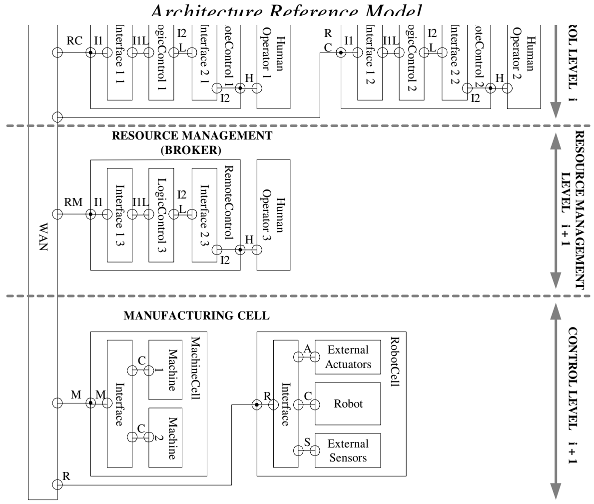


Figure 8 – A formal scheme (ESTELLE based) of the virtual enterprise demonstrator based on the *BM_VEARM*

The components of the D/V MS Cell structure which will be used in the first phase for the VE model validation, based on the *BM_Virtual Enterprise Architecture Reference Model* and therefore for its validation as well, is composed of, Figure 7: 1) *Machine cell*: Two machine simulators, Robot SCORBOT ER-VII, vision system, conveyor system; 2) *Broker*: Computer based remote resource manager; 3)*Control center_1*: Computer based remote machine cell controller; 4) *Control center_2*: Computer based remote machine cell controller.

The cell formal specification (ESTELLE based) is given in the Figure 8.

The reconfiguration of the system consists of switching, through negotiation, between two manufacturing cell controllers in accordance with their availability, service cost and quality. The broker performs the function of the system configuration manager. Manufacturing cell controllers, as well as broker, could be located at any point in the world as the system is Internet based.

5. CONCLUSIONS

The architectures proposed combines some good properties of hierarchical and heterarchical systems. Actually, the hierarchical and heterarchical structures interchange dynamically through different phases of reconfiguration and execution providing capabilities for the highest degrees of agility (or flexibility, or adaptivity).

The heterarchy of the system is especially important during the reconfiguration process, that occurs when new task appears or because of other disturbances or circumstances. The main idea is to build the most adequate MS structure for each task, instead to relay on the previously defined rigid, or with low flexibility, hierarchical structures. For the tasks and time frames defined, the potential resources (not known in advance) for task execution are searched and the MS structure is build through the market mechanism (negotiation). In this way it is provided the emergence, or self-organization, of the MS structure from the actual state of the system and its environment expressed in constraints.

However, there are a number of problems to be positively responded. Some of them are related with a) the complexity that emerges from the dichotomy of the autonomy of an individual work system and the potential synergy rising from cooperation, b) how to control the structuring process if the entire manufacturing system domain is taken into account under the dynamic reconfiguration f the parts of the structure, c) the optimal, or required minimal, reconfigurability domain size, and others. Some aspects of these problems have been already investigated and validated in the real industrial environments, in laboratory environments as well as through the theoretical models, indicated that the approach presented is viable.

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