RECONFIGURABILITY OF MANUFACTURING SYSTEMS FOR AGILITY IMPLEMENTATION – *PART I: REQUIREMENTS AND PRINCIPLES*

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Implementation agility in Manufacturing Systems (MS) is one of the most important objectives for nowadays MS considering the complexity of environment. The agility implementation implies new characteristics as well as new implications not considered by the previous MS concept. These are: the dynamic reconfigurability of MS structure (at the first place), the pro-activity, the emergence (as inherent features of agility), and the need for integration of the resources extra-muros of the original MS. These characteristics imply needs for specific organizational tools and frameworks. The issue is presented in two-part paper of which this is the first part that presents the requirements and principles of agility and MS reconfigurability – while the second part presents two architectures for MS reconfigurability in support of MS agility as well as two applications of the proposed architectures.

1. INTRODUCTION

Implementation agility in Manufacturing Systems (MS) is one of the most important objectives for nowadays MS considering the complexity of environment. Although the agility is in the major part equal to flexibility, and by other interpretations to adaptivity, it brings into sight 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 growing importance and complexity of the integration processes, as well as needs for defining specific organizational tools and frameworks capable to manage them.

The issue is presented in two-part paper of which this is the first part that presents the requirements and principles of agility and MS reconfigurability – while the second part presents two architectures for MS reconfigurability in support of MS agility as well as two applications of the proposed architectures.

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

2. AGILTY AND RECONFIGURABILITY AS AGILITY ENABLER

2.1 Agility

Agility is a property of an object or a system. To be *agile* means to be "quick-moving, nimble, active" (Oxford Dictionary). We can talk about agility of a company, about agility of a Manufacturing System (MS) as well as about agility of an individual. The company, MS, or individual, can be agile or not, or better, it can have a certain degree of agility, higher or lower.

In (Goldman, Nagel & Preiss; 1995) we can find the following description: "For a company, to be agile is to be capable of operating profitably in a competitive environment of continually, and unpredictably, changing customer opportunities. For an individual, to be agile is to be capable of contributing to the bottom line of a company that is constantly reorganising its human and technological resources <u>in</u> response to unpredictably, changing customer opportunities". In (Kidd; 1994) the agile manufacturing or enterprise is characterized as follows: "the competitive foundations (of the agile manufacturing or enterprise) are continuous change, rapid response, quality improvement, social responsibility and total customer focus". Many other authors share this perspective.

Considering "rapid response", or "rapid adaptability" which is equal, as the premise of the agility, then agility is equal to flexibility (as the flexibility implies "rapid adaptation" in "response" to the market requirements too). Consequently, if the previous is true, we could say that the "rapid adaptability", flexibility and agility are synonyms.

However, other authors presented other perspectives on agility, i.e. other features of the agility. A good example of a comprehensive definition of agility is given by (Yusuf et al; 1999; p37.).

"Agility is the successful exploration of competitive bases (speed, <u>flexibility</u>, <u>innovation</u>, <u>proactivity</u>[1], quality and profitability) through the integration of reconfigurable resources and best practices in a knowledge-rich environment to provide customer-driven products and services in a fast changing market environment."

The question that emerges is: what are, then, the differences between the adaptivity, flexibility and agility ?

Analyzing the literature sources, the differences between adaptivity, flexibility and agility are interpreted in a different ways, and, we should say, it, there is no a consensus on definitions.

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[1] Underlined by the authors of this paper

A system is said to be adaptable if it can continue to operate in the face of disturbances changing its structure, properties and behavior, accordingly to new situations it encounters, considering as disturbance any event not previously specified.

Some authors make a difference between "agility" and "flexibility" saying that the flexibility implies adaptability (only) and the agility implies "fast adaptability". However, by other authors, flexibility requires some additional feature the "pure" adaptability. Within the concept of Flexible Manufacturing Systems (FMS), the *flexibility* is defined as "a capability of the (manufacturing) system to adapt to the new tasks (i.e. to reconfigure, i.e. to reprogram itself in order to satisfy the demand in an optimal way) <u>without interruption of the production (manufacturing) process</u>". The condition "without interruption" implies "fast", or "rapid". So pure "adaptability", or "reconfigurability", is necessary but not sufficient conditions for flexibility (adaptability $\subset$ flexibility). Any system is possible to adapt but we seek for adaptation of the system so fast that the production process will be not affected. Based on these premises, "fast adaptability" or "fast reconfigurability" is a synonym for "flexibility". Consequently, we also state that the *flexibility* is either equal (synonym) to *agility* or is a part of it.

Almost immediately emerges the comparison with the Flexible Manufacturing Systems (FMS). Considering that the concept of flexibility has emerged historically as the underlying concept of the Flexible Manufacturing Systems (FMS) we could conclude that the flexibility is referring to the processes in the manufacturing workshop environment. On contrary, the agility as a concept has emerged considering the wider environment, i.e. considering the processes within the whole enterprise, i.e. the processes in the enterprise and/or business environment.

From the other side, in the agility definition by (Yusuf et al; 1999; p37.), we should note the designations "*innovation*" and "*pro-activity*". By our interpretation, these two designations, "*innovation*" and "*pro-activity*", are not present in the "usual" definitions of flexibility[2] and, in fact, could make a "stronger" difference between the flexibility and agility.

Therefore, we could assume, mainly based on (Yusuf et al; 1999; p37.), the following: *Flexibility* is a "reactive" concept, i.e. the concept based on reactivity, implying a rapid <u>response to changes</u>, after recognition (detection, identification) of these (changes), the changes whether of the market or of the (workshop, enterprise) internal conditions; while *agility* is a "pro-active" concept, i.e. the concept based on pro-activity, implying anticipating actions, innovation, with the desirable capability of prevision of changes, acting whether on the market or internally in the enterprise (or workshop).

Within the context of this paper, the exact differences between the adaptivity, flexibility and agility are not critical, assuming the positive identification of the need for enterprise or MS *dynamic reconfigurability*, by any of these three requirements designations. However, we will use the agility as the main requirements as it seems

[2] For the sake of truth, the concept of flexibility, as well as the adaptivity, could be applied on the enterprise level too. Also, by some authors the flexibility includes pro-activity too. However, as these approaches are not "typical" we could understand the differences between the adaptivity, flexibility and agility. Otherwise, they are the same – the synonyms.

a more comprehensive and complex requirement then and has a wider connotation concerning an enterprise then when using only adaptivity or flexibility.

2.2 Reconfigurability, and its Dynamics

Adaptability, flexibility or agility, implies the search and selection of new resources (substitute resources) to be allocated to the task to be performed, in order to satisfy the new circumstances (the new tasks, optimization of old tasks, "deadlocks," etc.). When in the system some elements, or resources, are substituted by another elements, or resources, or simply added new elements, or resources, or removed some elements, or resources, we say that the system *reconfigures*. This way, we could say that the adaptation implies *reconfiguration*, and, consequently, that the adaptability implies *reconfigurability*.

Therefore, we will say that the *agility*, is a capability for *fast reconfigurability*, including the pro-activity and the reactivity (fast adaptability), with the objective to explore rapidly the market opportunities and changes or internal innovation potentials (for new products, processes, initiatives).

If any system's, i.e. MS or enterprise, configuration means a system *state*, then the reconfiguration is a process meaning the system's, MS or enterprise, state change. In this way we come to the notion of the (manufacturing or enterprise) *system dynamics*.

"A ***dynamic*** theory considers primarily *a succession of system's states* … (while) a ***static*** theory assumes that the state remains constant" (Rapaport, 1972; p49). Webster dictionary (Merriam Webster) defines it as follows: dynamics consists on "a pattern or process of change, growth, or activity".

In our context, dynamics means precisely the intensity of change the MS, or enterprise, is subject of. MS, or enterprise, organizational dynamics considers a succession of MS's, or enterprise's, states along the time, i.e. the *MS or enterprise reconfiguration dynamics*.

2.3 Manufacturing System Reconfigurability

The set of the resources within which the company searches for alignment improvement represents the resources selection domain. If the enterprise searches for resources "*within the company boundaries*" then we talk about *intra-company reconfiguration*. This is the case of the "traditional" organizational paradigm, which, for the problem of reconfiguration, uses the own resources existing within the organization, i.e. "*intra-company reconfiguration*" or "*intra-enterprise reconfiguration*". On contrary, if the enterprise searches for resources "*across the company boundaries*" then we talk about *inter-company reconfiguration*, i.e. "*inter-enterprise reconfiguration*", Figure 1.

To address the problem of organizational (dynamic) reconfigurability, as one of the competitiveness enablers, there is developed a number of organizational approaches and a number of tools.

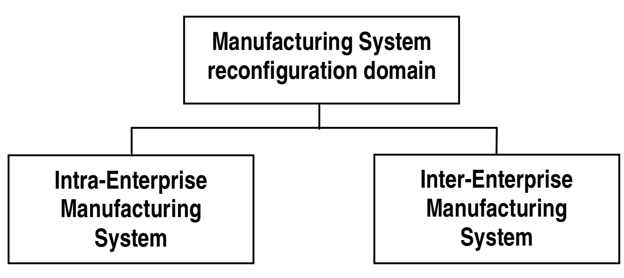


Figure 1 – Manufacturing System reconfiguration domains (adapted from (Putnik *et al.*, 2006))

For the "*intra-enterprise reconfiguration*" well-known approaches, or concepts, are (Putnik at al., 2006):

- Flexible Manufacturing Systems (FMS); which later evolved towards Metamorphic and/or Reconfigurable Manufacturing Systems (or Enterprises) (RMS);
- Computer Integrated Manufacturing (CIM), that integrates the disciplines as CAD, CAM, MRP, MRP II, MIS and similar, and, later, the related Enterprise Resource Planning (ERP); in general: Information Systems (IS); which later evolved towards Fractal Factory (or Manufacturing Systems or Enterprises), Holonic Manufacturing Systems (or Enterprises) (HMS) and Intelligent Manufacturing Systems (IMS), Enterprise Integration (EI);
- Total Quality Management (TQM), Business Process Re-engineering (BPR) and, later, Change Management (CM) approach; which later evolved towards Lean Manufacturing (LM) and Agile Manufacturing (AM) (in relation with these approaches is CM discipline); and
- Learning Organization (LO); which later evolved towards Chaordic Enterprise (CE).

For the "*inter-enterprise reconfiguration*" well-known approaches, or concepts, are(Putnik at al., 2006):

- Supply Chain,
- Agile Enterprise,
- Virtual Enterprise,
- Extended Enterprise,
- Virtual Value Chains,
- Smart Organizations,
- Collaborative Network Organization,
- Agile/Virtual Enterprise,
- BM_Virtual Enterprise (BM_VE),
- OPIM model (One Product Integrated Manufacturing),
- Market of Resources (MR) and other meta-organizational structures and environments as Electronic Institutions and Breeding Environments.

4. TOWARDS ARCHITECTURES FOR MANUFACTURING SYSTEMS AGILITY, OR DYNAMIC RECONFIGURATION ENABLING

Based on the previous discussion, and considering that the MS reconfiguration, or restructuring, process is complex in principle, the MS's agility implementation implies the reconfiguration, or restructuring, process management. Or, by (Putnik; 2001) *resources reconfiguration management*

The resources reconfiguration, or restructuring, process management, as the global task, implies different particular sub-tasks. For example:

1) resource selection
2) resource integration;
3) resource integration scheduling;

4) resource (dynamic) reconfiguration;
5) resource monitoring and reliability analysis;
6) resource control,

and similar.

For the implementation of the resources reconfiguration, or restructuring, management could be applied the basic, classical, “two-layer hierarchy” organization model, Figure 2. Another expressions used for the model are “principal/agent” or “manager/worker” hierarchy, as well as “demand/supply” (Butala, Sluga; 2002). The “principal” is the owner of the vertical structure and the “agent” is responsible for production and affects the principal. The resources reconfiguration, or restructuring, management function is owned by the upper control level i.

But in organizational theory are known higher-order vertical structures as well. The independence of the resource management function corresponds to the “three-layer hierarchy” organization model, Figure 3, or, in other words, “principal/supervisor/agent” or “manager/foreman/ worker” or “demand-mediator-supply” (Butala, Sluga: 2002) hierarchy. The main motivation for application of the “principal/supervisor/agent” model is that “the principal, who is the owner of the vertical structure or the buyer of the good produced by the agent, or, more generally, the person who is affected by the agent’s activity, lacks either the time or the knowledge required to supervise the agent” (Tirole, 1986).

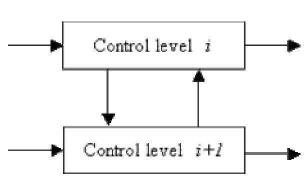
This type of reasoning implies that the MS reconfiguration could be made/managed more efficiently, which is the indispensable requirement (in order to achieve higher levels of reconfiguration dynamics), i.e. the higher levels of agility, if it is performed by a specialized agent as an independent, and in the certain context autonomous, control level as one of the basic elementary MS control element types, or blocks, or level. This agent will be called *resource manager* or *broker* or *mediator*.

Additionally, the corresponding control level will be called the “Resource Management” function or control level.

In this way, three-layer hierarchy architecture will be considered as an elementary agile MS structure architecture pattern.

This reasoning is in the base of the MS architectures proposed, for agility implementation.

In Figure 4 is given an informal presentation of the architecture for MS, or enterprise, reconfigurability for agility implementation.



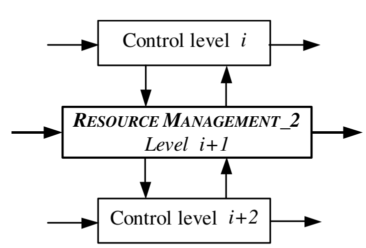


Figure 2 – The basic, classical, “two-layer hierarchy” organizational structural pattern

Figure 3 – “Three-layer hierarchy” organizational structural pattern with resources reconfiguration, or restructuring, management as an independent layer (Putnik; 2001)

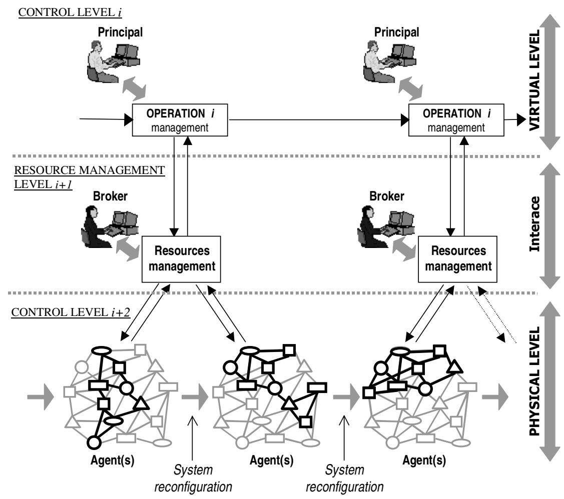


Figure 4 – An informal presentation of the architecture for MS, or enterprise, reconfigurability for agility implementation (mapping from BM_VEARM, (Putnik; 2001))

5. CONCLUSIONS

To achieve higher degrees of the MS, or enterprise reconfiguration dynamics, the of MS have to developed many advanced features. The most expected ones are by (Butala, Sluga; 2003) (1) an open multi-level architecture, (2) advanced communication capabilities, (3) decentralized decision making, (4) self-structuring ability, and (5) redefinition of the work systems in terms of autonomy, evolutionary adaptivity, re-configurability, co-operativeness, interactivity, task orientation within competence, ability of communication, coordination and co-operation and learning capability, or by (Putnik 2001) and (Putnik *et al.*; 2005) the functionalities (1) integrability, (2) distributivity, (3) agility and (4) virtuality as well as the organizational tools (mechanisms) (1) meta-organizational environments (e.g. Market of Resources), (2) brokers and brokerage functions and (3) virtuality (as the structural architecture pattern.

Implementation of these features, the requirement for the agility implementation, should be heavily based on IT tools. Actually, the requirements are so high that the main “battle-field” for agility is within the computer based environments for simulations, decision makings and control of MS and enterprises. In this sense, we would say that the implementation of the highest degrees of agility in MS and enterprises is practically impossible without its “digitalization”.

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