Autonomous Work Systems in Manufacturing Networks

P. Butala[1], A. Sluga[1] (2)
[1]Department of Control and Manufacturing Systems
University of Ljubljana, Ljubljana, Slovenia

Abstract
Manufacturing networks open new possibilities and potentials in design, development and production of complex high-tech products while they combine good characteristics of large companies with advantages of SMEs. In order to manage the structural complexity of a manufacturing network, the paper proposes the business-to-manufacturing network B2MN approach based on the market mechanism. Next, the network nodes in terms of the autonomous work system (AWS) are conceptualized. AWS encapsulates functionalities and competencies related to its management and manufacturing operations, as well as its autonomous information system, which supports autonomous decision-making and cooperation in the network. The case study illustrates the implementation of the AWS concept in industry.

Keywords:
Distributed manufacturing, Work system, Structure

1 BACKGROUND AND MOTIVATION

Networking of manufacturing enterprises, especially SMEs, is becoming a key issue. It introduces new challenges to the manufacturing business. In order to exploit the potential of networking in manufacturing, research in new working structures and principles is essential.

New organizational forms, such as manufacturing networks, clusters and virtual enterprises, which are based on cooperation, are being developed [1]. A manufacturing network provides a basis for competitiveness, innovativeness, agility and adaptiveness by enabling interconnected partners to (1) form long-term business coalitions, (2) develop mutual understanding and trust, (3) jointly react to business opportunities, (4) gain synergetic effects by cooperation and (5) share information, knowledge, resources, competencies and risks.

The main question here is how nodes of a network are defined. Most approaches in the literature consider entire manufacturing enterprises as being the nodes (e.g. [1, 2]). The shortcoming of this approach lies in the fact that such a node is an autonomous, but complex hierarchical structure, which, as a rule, withstands effective communication and decision making and is reluctant to be subjected to control. Thus, the complexity of a network increases with the number of involved partners.

In order to manage the structural complexity of a manufacturing network, the paper proposes the concept of an autonomous manufacturing work system (AWS), which represents a network node. Hence, the building blocks that constitute the network are rather simple structures with autonomous behavior instead of complex structures, i.e. enterprises. The AWS encapsulates functionalities and competencies related to management and operations of its core manufacturing process and communication with the network.

The paper first discusses the manufacturing network issues and related works. Next, it introduces the business-to-manufacturing network (B2MN) approach and the concept of the AWS. Further on, the information and control system of AWS is presented. Finally, the results and experiences of an industrial implementation are examined in a case study.

2 MANUFACTURING NETWORKS

2.1 Related work

The application of communication networks in production is recognized as perhaps the most important solution in manufacturing in the last decade [3]. The employment of modern communication technologies will become a major factor of success [1].

Based on communication networks, the manufacturing networks, (in some literature referred also as production [1] or collaborative [2] or supply [4] networks) are being widely recognized as important emerging organizational forms in manufacturing. They represent a real challenge for planning and management of production systems [5].

Networks are acknowledged as complex adaptive systems which emerge rather than result from purposeful design of a single entity [4]. Therefore, new approaches to structuring of network manufacturing systems are being developed, e.g. [3]. In this context, also the importance of autonomy of manufacturing systems for future development in manufacturing is recognized [6].

Networks offer new potentials for improving value-adding processes [1]. The importance of networks is emphasized by the following notion: "In ten years, in response to fast changing market conditions, most enterprises and specially the SMEs will be part of some sustainable collaborative networks that will act as breeding environments for the formation of dynamic virtual organizations" [2].

Why is research and development in manufacturing networks so actual and intensive? The manufacturing networks combine some good characteristics of large companies, such as critical mass, competencies, development potential, economy of scale, vast capital, etc. with advantages of SMEs, such as entrepreneurship, niche products and markets, flexibility, responsiveness, adaptiveness, etc.

This work arises from the previous research in agent based systems [7] and distributed manufacturing systems [7] and is based on the concept of complex adaptive manufacturing systems (CAMS) [8]. Within CAMS the elementary work systems (EWS) are defined as building blocks [8]. EWS are adopted in this work.

2.2 B2MN approach to manufacturing networks

Manufacturing of complex high-tech products, such as industrial and power equipment requires a project-based, engineer-to-order approach to design, development and production. With respect to high volume products, which are nowadays produced in supply chains in optimized dedicated manufacturing and logistic systems, the project-based products are fabricated in one-of-a-kind or small batch fashion in general-purpose manufacturing systems.

The networks promise new possibilities and challenges for this kind of products, where a manufacturing structure is not known in advance and have to be structured and optimized for each project from scratch.

Considering the above statement, two levels can be identified. The first one is the business level, where projects and project tasks are defined. The second level is the manufacturing systems level. In classical organizational forms the levels are bridged by centralized production planning and control with well known problems.

As decisions in networks are taken in a distributed way a new solution has to be developed. A partner that would orchestrate operations in the network does not exist. Functionalities, e.g. broking, coordination and contracting, which did not previously exist to such an extent, have to be implemented [1].

In the B2MN approach the two levels represent demand and supply which, by nature, are effectively connected by the market mechanism. A similar approach is proposed in [9] but limited to allocation and scheduling of resources.

Figure 1 reveals the structure of the B2MN environment. The link between the business and manufacturing levels is provided over the marketplace, where the market mechanism governs the distribution of project tasks to candidate AWSs. AWSs are cooperative and competitive. Cooperativeness provides the basis for planning and coordination and induces controllable behavior while competitiveness provides the basis for negotiation and induces emergent behavior.

For the network it is essential to keep the balance between control and emergence. Too much control limits adaptiveness and innovation, while too much emergence weakens predictability and manageability. In the B2MN approach, the balance is assured with proper design of a network and AWSs. The design of the network is based on the adaptive distributed manufacturing system (ADMS) concept [7] where an ADMS is structured as a network of building blocks, i.e. AWSs.

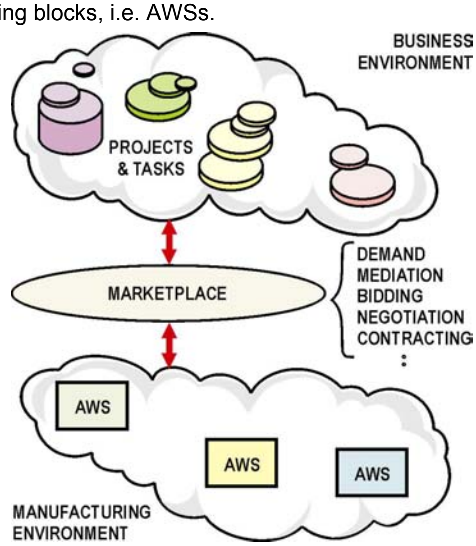

Figure 1: B2MN environment.

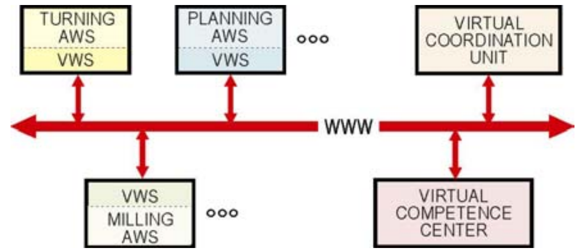

Figure 2: ADMS agent communication structure.

AWSs cooperate in structuring and control of network operations. Each AWS is represented by an agent, i.e. virtual work system (VWS) which is realized as a communication interface to the network.

Figure 2 shows the ADMS agent communication structure as a multi-agent system, which represents one of the most promising technological paradigms for the development of open, distributed, cooperative and intelligent software systems [10]. According to [11] two special entities are introduced in the network beside AWSs in order to enable cooperation and coordination on the network These are (1) the virtual coordination unit, which provides the marketplace where the cooperative relationships based on the market mechanism are established, and (2) the virtual competence center, which provides information and communication support for network operations.

3 AUTONOMOUS WORK SYSTEM

3.1 AWS conceptual model

As already stated, manufacturing networks are complex structures. It is evident that decomposition of a complex structure into a set of less complex structures decreases the overall complexity. The question is at which level should the decomposition stop? In the context of networks, the decomposition is feasible till the level of self-sufficient functional entities, i.e. systems, which are capable of performing certain functionality and at the same time capable of acting in the network autonomously. Further decomposition into smaller elements would not lead to further reduction of complexity. In contrary, the overall complexity would increase while (1) the number of elements in a network would increase significantly, and (2) the elements are not self-sufficient.

Let us now define an autonomous manufacturing work system (AWS) based on the above observation. AWS is a system with rounded technological functionality and corresponding management functionality. The technological functionality is built upon its core element EWS, which, according to [8], consists of a process, process implementation device, and a human subject. Thus, the EWS possesses the competence and capabilities to perform a particular manufacturing process.

Figure 3 shows the base level diagram of the AWS. The basic AWS functionality is transformation of inputs into outputs. Elements of the AWS are resources (process knowledge, machine-tools, tools, etc.) and a human subject (individual or team). These elements round the functional competence of AWS, which is needed to perform the transformation process. For example, turning competence requires turning process knowledge (about the material removal mechanism, cutting parameters determination, tool selection, etc.), a lathe with tools and a competent turner. Besides, AWS is supported by services providing additional expertise for effective operations of AWS (e.g. maintenance, logistics, process consultancy, and tooling expertise) which support AWS operability.