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Dynamic structuring of distributed manufacturing systems

Peter Butala*, Alojzij Sluga

Department of Control and Manufacturing Systems, University of Ljubljana, Askerceva 6, SI-1000 Ljubljana, Slovenia

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Abstract

The paper addresses the problem of dynamic structuring of manufacturing systems. The approach presented in this paper is based on the decomposition of manufacturing objectives and the allocation of tasks to autonomous building blocks, i.e. work systems, in a dynamic environment. The allocation is based on a market mechanism that enables the self-structuring and optimization of a manufacturing system by evaluation and selection among competing work systems. The mechanism presented is based on logic relations and constraints. It enables the building of task-oriented manufacturing structures of work systems acting in series and/or in parallel. The approach is discussed in an example in the part fabrication domain. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Modeling; Work system; Fabrication; Multi-agent structure; Market mechanism; Virtual cluster

1. Introduction

The rising complexity of products, production structures and processing procedures on one side and turbulent market excitations resulting in growing product variety, individualization and shortening time frames on the other are setting new frontiers for the manufacturing business. Despite research efforts and investments in the context of computer integrated manufacturing the existing manufacturing systems are still predominantly based on the obsolete Taylorian philosophy. Therefore they cannot adequately conform to these requirements because of their structural rigidity, deterministic approach to decision making in a stochastic environment, hierarchical allocation of competencies, and insufficient communication and exploitation of expertise.

In order to face these challenges in manufacturing a shift of the existent manufacturing paradigm from deterministic into a new manufacturing prospect considering natural understanding and concern is needed. Several influencing approaches are emerging. Fractal factory [1], bionic manufacturing systems [2], Holonic manufacturing systems [3] and distributed manufacturing systems [4] are some concepts that are making an appearance. Based on these concepts several advances to modeling a manufacturing system in terms of viable structures for more effective mastering of complex and dynamic behavior of the system and its environment are being developed. Various contributions in this direction have been presented and intensively exercised recently [5–9].

In the paper an approach to dynamic structuring of manufacturing systems is presented. It is based on the market mechanism which induces a self-organizing principle and is implemented in the system entitled the adaptive distributed manufacturing system (ADMS).

Section 2 briefly describes the context of distributed manufacturing systems and related works. Section 3 presents the concept of ADMS and the underlying principles. The case study in Section 4 illustrates the abilities of the system in the part fabrication domain. Particularities of ADMS and distinctions to related works are discussed in Section 5.

2. Issues of distributed manufacturing systems

A market is the key segment of the environment which sets primary objectives for manufacturing systems. It demands innovative, customized products and quick responses. The character of the market is dynamic and stochastic.

Traditional manufacturing systems cannot cope with market requirements due to:

- Time response to predominantly random excitations of the markets is unsatisfactory, too slow and in many instances too costly.
- Information is incomplete, inaccurate and unreliable.

* Corresponding author. Tel.: +4774-753; fax: +2518-567.
E-mail address: peter.butala@fs.uni-lj.si (P. Butala).

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Decision-making is based more or less on 'guessing', predominantly using the rule of thumb [10].
- Organizational structures are predetermined and rigid. Traditional structuring of manufacturing systems is based on labor division and the optimization of performance is based on central planing and control [11].

Let us consider an example of a flexible manufacturing system (FMS). It is the most advanced structure of a traditional manufacturing system. It has built-in scenarios to anticipated contingencies. Its scope is fixed and limited. Its structure is predetermined and cannot be modified by adding or removing elements in a short period of time. Therefore it is a closed system.

In order to overcome the earlier mentioned disadvantages of manufacturing systems, new, flexible and adaptable organizational structures capable of performing self-organization of the work process have to be established [10].

Several systems exist which are capable of adapting themselves to changes in the environment. Biological systems are an example of such systems that exhibit characteristics such as self-recognition, self-growth, self-recovery and evolution [2]. Another example of a self-organizing system is the social system called the market economy. It is an economic system controlled, regulated, and directed by markets alone; order in the production and distribution of goods is entrusted to this self-regulating mechanism—the 'invisible hand' as noted by A. Smith two centuries ago.

Both types of systems have inspired researchers to adopt their basic principles in the manufacturing world. Ueda [2] introduced biological manufacturing systems by mapping the analogies from the living world. In his latest work Ueda [7] expanded this concept into interactive manufacturing which recognizes the vital role of a human in manufacturing as proposed by Peklenik [10].

Various authors have adopted the micro-economic model of self-organization on the production planning and control scale. Some promising results have already been obtained [5,6,8,9,12].

The common observations can be summarized as follows: (1) a manufacturing system is a complex system, (2) the architecture is the essential issue, (3) the role of a human subject is dominant, (4) the information and communication technologies are the enabling technologies, and (5) the transition from highly data-driven to particular information, knowledge and learning driven organization is needed.

Therefore new features of future manufacturing systems have to be developed. The most expected ones are: (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.

This research is focused on the problem of how a manufacturing system can be structured for a given objective (e.g. the realization of a product) and how the system can adapt its structure in the case of external and/or internal disturbances (e.g. machine break down).

The key distinction between ADMS and other approaches [5,6,8,9] lies in the level of system decomposition. In other approaches building blocks are entities that model the factory's functions and/or physical entities (e.g. orders, parts, and resources). However, they do not represent a manufacturing structure and thus the reduction of complexity is limited. In ADMS the complexity is managed more efficiently as the building blocks are systems—elementary work systems (EWS).

3. Agent based approach to dynamic structuring in ADMS

ADMS is based on the concept of distributed manufacturing systems. It is structured as a network of building blocks (work systems) acting as agents. Thus it represents an organic structure of interrelated building blocks which are acting in parallel and/or in series and are driven by cooperation and competition on various levels [4,13]. This concept synthesizes the agent structure as a decision network in order to optimize the overall system's behavior according to the current state of the environment.

Structuring is thus an important issue for the achievement of the optimal performance of a manufacturing system. A single optimal structure for different manufacturing tasks cannot be defined. For each particular task the optimal structure has to be built up. A feasible approach to the structuring of the system is to structure the task first. The complex task can be structured by the decomposition of the task into less complex tasks. Thus an incompletely specified problem is transformed into a set of more specified ones. Here it is assumed that complex tasks are decomposed into elementary tasks which can be executed by elementary work systems. The structuring process implies the incorporation of work systems for task execution. It is based on the market mechanism.

The market mechanism is characterized by the operation of the self-adjusting forces of supply and demand. The motivation in the market mechanism is very basic: self-interest with respect to the economic gain. While self-interest may or may not be an universal part of human nature it is certainly a powerful motivating force.

3.1. Basic building block—the work system

In order to realize the concept one has to define the basic building blocks with autonomous behavior and as having the competence and capabilities to perform a particular manufacturing operation.

For the structuring of a manufacturing system a generic building block was introduced by Peklenik [13] in terms of the elementary work system. An EWS is capable of

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