A Conceptual Framework for Collaborative Design and Operations of Manufacturing Work Systems

A. Sluga[1], P. Butala[1], J. Peklenik[1] (1)

[1] Department of Control and Manufacturing Systems

University of Ljubljana, Ljubljana, Slovenia

Abstract

The paper addresses a conceptual framework for collaborative product design and related manufacturing system development, operations and maintenance. The framework consists of (1) a conceptual model for collaboration among autonomous manufacturing work systems and (2) an ICT platform which supports collaborative operations over the web. The framework improves visibility, understanding and control of the processes involved and on a practical level provides a platform on which geographically distributed operations can be conducted effectively. The system is developed as an integrated prototype web application. The case study presents the implementation of the concept in the development, operations and maintenance of manufacturing cells for die-casting of aluminum and magnesium components for automotive industry.

Keywords:

Manufacturing system, Distributed manufacturing, Virtual coordination

1 BACKGROUND AND MOTIVATION

There is a steady growing pressure on companies, urged by the world wide competition, to streamline operations involving product and product related manufacturing system design, product manufacturing and system maintenance.

The picture of a stand-alone company that is linked to its customers and suppliers only by delivery and procurement of products is no longer valid [1]. The customer-supplier relationship has undergone a substantial transformation from the traditional, simple buy-sell relationship toward the current one, which is focused on partnership.

To realize these trends and to improve the efficiency and effectiveness in business and manufacturing activities the collaboration has been recognized as one of the most critical factors [2]. E-collaboration and collaborative systems have opened the possibility for geographically dispersed teams to work together by supporting communication, coordination and cooperation [3].

In order to reach the competitive level of performances in terms of reactivity, productivity, product quality and system availability, companies, especially SMEs, are motivated to join collaborative networks. On the one hand companies focus on their own competencies. On the other hand, they acquire complementary expertise and resources over collaborative networks. Thus, companies cooperate vertically along supply chains and horizontally among peers [4].

The research is focused on collaborative product design, and related manufacturing system development and its operations. These processes and their interrelations are complex due to incomplete data and knowledge, combinatorial explosion of states, and dynamic changes in the environment [5]. They are performed by several partners in timely and geographically distributed manner.

Let us consider the relationship between a customer and a manufacturing equipment supplier. The customer is primary focused on a product which he delivers just-in-time to his customer. Therefore, he requires not just a manufacturing equipment supplier but a partner who would develop, manufacture, install, put the equipment into operations and, later on, who would offer support in operations in terms of process optimization, maintenance, system improvement, upgrading, reconfiguration, etc.

In the paper a conceptual framework for collaboration in a network is proposed. It is implemented in an industrial network interconnecting a die-casting producer, a manufacturing system manufacturer and various service providers.

2 ADAPTIVE DISTRIBUTED MANUFACTURING SYSTEM (ADMS) CONCEPT

New organizational forms and structures such as production networks, virtual enterprises and production clusters are being developed. These forms enable companies to form business coalitions in order to react jointly to emerging business opportunities, to gain the synergetic effects and a competitive advantage by sharing of competencies and risks, and to form flexible and goal-oriented temporary cluster structures.

In order to develop a conceptual framework for collaboration within the networks, the Adaptive Distributed Manufacturing System (ADMS) approach was introduced [6]. ADMS is based on the concept of Complex adaptive manufacturing systems (CAMS) [7] and on the concept of dynamic production clusters [8].

Within CAMS the basic building blocks are defined in terms of elementary work systems (EWS) [9]. The EWS consists of a process, process implementation device, and a human subject [9]. EWS possesses the competence and capabilities to perform a particular manufacturing process.

ADMS is structured as a network of building blocks – autonomous work systems (AWS), as defined later on, and represented by agents. Thus it represents an organic structure of interrelated agents which are acting in parallel and/or in series, or in both ways, and are driven by cooperation and competition on various levels [7]. This approach synthesizes the agent structure as a decision network. The AWSs are interconnected via corresponding agents into the network and thus constitute the ADMS. Within the system the market mechanism stimulates the building of dynamic manufacturing structures for particular manufacturing objectives.

The ADMS approach promotes autonomy and self-interest of AWSs, and system adaptability by self-organization and distributed decision-making [10]. The latter is performed collaboratively. Here, collaboration implies the communicative, cooperative, coordinative and collective characteristics which enable transparent, flexible, simultaneous, synchronized, jointly shared, and continuously integrative system operations. The autonomy of an AWS is characterized by its particular competence in terms of knowledge, experiences and resources, as well as the responsibility for decisions about its own actions.

Figure 1 reveals a conceptual framework for collaborative ADMS system operations. On the baseline, i.e. operational level there are heterogeneous and redundant AWSs which are capable to perform various manufacturing processes, such as design, process planning, machining.

The key elements of an AWS are: manufacturing operations, management and control, and measurement systems for inputs and outputs. Measurements support monitoring of real-time performance for important changes, threats and opportunities, for management of operations and prediction of appropriate actions for best operating results, for local decision making, as well as for providing visibility on the coordination level.

The coordination level coordinates a product specification process with the market/customer and suppliers on one side and AWSs operations on the other side with the objective to optimize an overall system performance. The coordination process is governed by strategic goals defined by stakeholders of the network on the strategic level.

Let us examine the example of an AWS. Figure 2 reveals the functional model of AWS. The management function is responsible for coordination, organization and optimization of work. It sets objectives and priorities for operations and resources within AWS autonomously. It also communicates and coordinates AWS activities with other AWSs over the coordination level.

The scheduling function provides schedules of operations according to objectives, optimization criteria and constraints set by the management function, and current states of the AWS.

The operation planning function prepares instructions and additional information for operations based on product-related information. Here specialized knowledge is needed for a localization of process-related information according to the AWS particularities.

The AWS operation includes all necessary activities to perform a process and performing of the process itself on EWS. There is at least one EWS in AWS.

An information flow rate is particularly high in manufacturing operations. Therefore, the role of the monitoring function is of decisive importance for proper decision making.

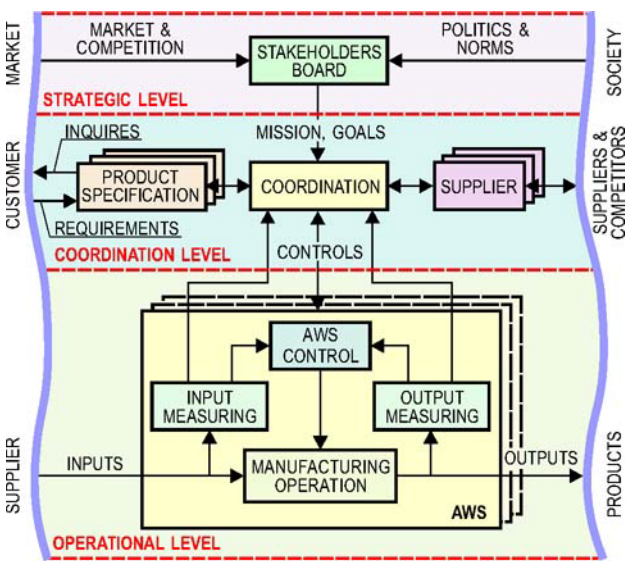

Figure 1: ADMS conceptual framework.

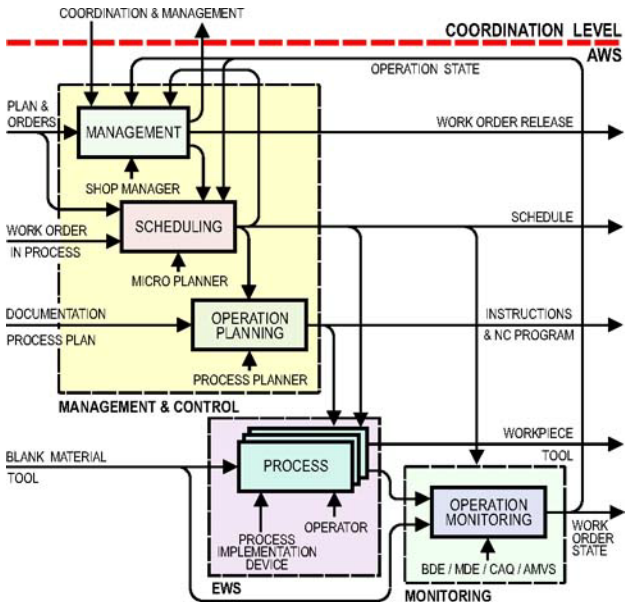

Figure 2: Autonomous work-system model.

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The monitoring process measures and collects data about events and states in operations related to products, processes, resources and quality. It provides progress reports and diagnostics of malfunctions.

This information is available for decision making in AWS locally and over the web for the coordination and other decision making entities, e.g. project management and plant management.

The key issue for the implementation of the AWS concept is the development of an autonomous and integrative information system supporting the mentioned functionalities. The development of such web-based information system is given in [11].

The described structure of AWS is generic and can be applied to any AWS performing manufacturing operations.

3 COLLABORATIVE DESIGN AND OPERATIONS

The ADMS framework represents a generic solution for collaborative product design and related manufacturing system development and its operations.

Figure 3 reveals the model for collaborative product development and manufacturing in a distributed environment. Two distinct phases are characteristic, namely (1) product design and related manufacturing system design and (2) operations.

In the first phase product development activities from product specification, conceptual, detailed and process design to prototyping are performed [12]. Next, a corresponding manufacturing work system based on the product definition is developed. It can be either a reconfiguration of an existing manufacturing system or a completely new development.

The second phase, i.e. operations, starts once the first phase is accomplished. The production is driven by the market demand. To maintain a high level of operation performances, such as constant product quality, high productivity, reliability and system availability, an adequate operations support is provided by various services.

These include process support, tooling support, system