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ScienceDirect

Procedia CIRP 29 (2015) 544 – 549

www.elsevier.com/locate/procedia

The 22nd CIRP conference on Life Cycle Engineering

Sustainability in Manufacturing through Distributed Manufacturing Systems (DMS)

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Abstract

A growing number of manufacturing companies are working on the implementation of sustainable manufacturing and business processes. The objective of sustainable manufacturing initiatives is the creation of products by means of energy-efficient and resource-saving manufacturing systems. Furthermore, customer satisfaction will be achieved in future not only through the creation of products, but also through socially and environmentally responsible as well as economically efficient concepts of manufacturing avoiding negative effects for society. Distributed manufacturing systems (DMS) are currently discussed in science as a possible approach for the realization of sustainable manufacturing. Decentralized networks of adaptable and flexible mini-factories are not only helpful to reduce emissions through reduction of transports, but also serve for the growth and development of regional economic cycles. This paper gives an overview of trends towards DMS as well as reasons and arguments why Distributed Manufacturing Systems are appropriate concepts for more sustainable manufacturing.

Peer-review under responsibility of the scientific committee of The 22nd CIRP conference on Life Cycle Engineering

Keywords: Distributed Manufacturing Systems (DMS); Sustainable Manufacturing; Dispersed manufacturing

1. Introduction

The research on Distributed Manufacturing Systems (DMS) expands over the past two decades. When defining the term DMS the important characteristic is the geographical dispersion of its components that is described in different ways. The first approach was applied in the early era of globalization about 20 years ago, breaking up the value chain and dividing the product into sub-parts or sub-processes with production at different locations [1, 2]. Later the geographical distribution is specified as the distance between a company's divisions and its headquarter [3]. In another approach, that takes into account also the relationships between the production units, DMS is defined as a system of autonomous agents, which are mutually dependent on each other. The former explanations focus on the production plants of a single enterprise. The evolution of manufacturing cooperation between different enterprises leads to an extension of the DMS characteristics. The collaborating companies build up production networks. Consequently, the idea of virtual manufacturing enterprises and networks is linked to DMS with the focus on continuous or temporary collaboration [4]. More recently the scope of DMS evolved to enterprises who deliberately complement each other regarding technology and work force [5]. The practice of building up networks is yet not mandatory for the constitution of a DMS, especially for large companies, but provides multiple opportunities for small and medium sized enterprises [6]. Nowadays, we recognize a shift away from mass production to individual production and micro production [7]. We need modern organizational models for small, flexible and scalable manufacturing units to fulfill actual requirements such as just in time delivery and individual customer needs or a sustainable supply chain [8]. Geographically independent or distributed production facilities composed of reconfigurable and mobile production systems allow quick adjustments of production capacity and functionality with respect to local customer needs and enable a sustainable production and supply chain [9].

Peer-review under responsibility of the scientific committee of The 22nd CIRP conference on Life Cycle Engineering
doi:10.1016/j.procir.2015.01.069

2. Literature Review of Distributed Manufacturing Systems (DMS)

2.1. DMS in the early era of globalization

In the context of the era of globalization parts of the production were shifted in other countries due to cost reasons or for reasons of market expansion. The challenge was to coordinate these geographically distributed production contents together. Due to the geographical distribution of the single production units, it was necessary to adapt the planning of the production process to the changed circumstances [1, 5, 10]. The same necessity occurred for the scheduling of the production process [11, 12]. In various patterns, these two tasks were combined to harmonize them to each another [13, 14, 15]. Furthermore, adjusted resource planning models had to be assessed. This has been done based on multi-agent systems (MAS) that enhances decentralized decision-making [16] and inspired by a biological algorithm with the focus on the controlling of shared resources [17]. The problems of load allocation within the production execution systems have been examined regarding the inner and outer levels of a company [18] and with the restriction to autonomous processing stations [19]. Also the concepts of holonic manufacturing [15, 20], and reconfigurability [21, 22] are specifically addressed.

2.2. Effects of information and communication technology

The ongoing evolution of information and communication technologies offers many new potentials for DMS. The general conception of software integration was discussed modelling different layers of a company's divisions for a company-wide information system [23] and implementing a schedule system in a local and global scope [24]. Early there was a need for the integration of simulation systems [25], [26], also with a practical approach that used commercial software [08]. An attempt was made to develop production execution systems that base on MAS [27], also for the particular case of virtual enterprises [28]. Further work basing on MAS has been done regarding project management [29], reconfigurability [30], and applying the Internet of Things [31]. More recent approaches concerning the companies' ICT-system are facilitated by the web and aim to implement network optimization [32], rapid machining [33], and the customer itself [34] into the production process.

2.3. Virtual DMS networks

The procedure of integrating the single production units into an overall network system has been a fundamental issue for DMS. Research works examined the effect of global distribution, when a company expands by locating plants in new markets [35]. Later, this was readopted for the case of the expansion of small and medium enterprises [36]. Besides, the basic problem of selecting plants that are highly independent from the principal firm has been addressed [37]. Based on MAS, the concept of a self-organized network that uses the biological mechanisms of stigmergy and swarm intelligence was developed [38] for the coordination of production networks.

2.4. Changeable and reconfigurable DMS for mass customized goods and a sustainable supply chain

In contrast to that, there have been made various approaches for general network coordination, that imply the practical implementation of research [39], the idea of lean manufacturing [6], and the goal of a changeable production [40]. A more recent trend is the consideration of mass customization in DMS. It was examined how to design and plan a production network generally [41, 42], and in a scalable and modular way [43]. This trend towards a so-called "glocal" production thus combines the goals of global market development and the fulfillment of local customer requirements [44]. With the rising demand for individual products and product variants the shift from mass production towards a personalized "mass customization" becomes more and more realistic [45, 46]. Innovative production concepts replaces traditional network structures. For this purpose it is necessary in the future, to build decentralized production networks with distributed production units which can offer under the aspects of cost, time, CO2-dioxide-emissions, energy consumption and quality personalized products to local customers [47]. The focus of much of this research is essentially the development of system capabilities for so called "plug and play" manufacturing, where production units can be rapidly interchanged, reconfigured and yet be capable of determining their own role in production [48]. These type of modular solutions are commonly used both in the design of machines and equipment as well as in the construction of manufacturing systems which allow to build reconfigurable manufacturing systems [49].

2.5. Historic evolution of DMS and current trends

The previously mentioned topics of production process, information and communication technology, and production networks are crucial issues of DMS and therefore have been discussed continuously over the past two decades. In addition to that, several more temporary trends of research work can be figured out. In the Nineties, the topic globalization was a fundamental issue and this is reflected also in the studies of DMS [23, 35]. Another trend was production simulation of DMS that, similar to globalization, was of scientific interest for a few years [4, 25, 26]. In contrast to that, the early application of DMS for the business model of franchising [50] was reconsidered recently [43, 51] in combination with the concept of changeability and mass customization. The same accounts for the concept of virtual enterprises [28, 52, 53]. The adaption of DMS concerning the supply chain management has been discussed earlier [54, 55, 56] and is still in the interest of researchers [34, 57, 58, 59]. In the last few years the debate about mass customization arose and is highly discussed [11, 34, 41, 42]. Due to the novel technical possibilities the topic of cloud manufacturing arose lately [53, 60] in combination with Distributed Manufacturing.