Journal of Manufacturing Systems 42 (2017) 179–195

Contents lists available at ScienceDirect

Journal of Manufacturing Systems

journal homepage: www.elsevier.com/locate/jmansys

Towards a generic design method for reconfigurable manufacturing systems
Analysis and synthesis of current design methods and evaluation of supportive tools

Ann-Louise Andersen[a,*], Thomas Ditlev Brunoe[a], Kjeld Nielsen[a], Carin Rösiö[b]

[a] Department of Mechanical and Manufacturing Engineering, Aalborg University, Fibigerstraede 16, 9220 Aalborg East, Denmark
[b] Department of Industrial Engineering and Management, Jönköping University, Gjuterigatan 5, 551 11 Jönköping, Sweden,

ARTICLE INFO

Article history:
Received 18 April 2016
Received in revised form
26 September 2016
Accepted 28 November 2016

Keywords:
Reconfigurable manufacturing system
Reconfigurable manufacturing design
Changeability
RMS
Literature review

ABSTRACT

In today's global manufacturing environment, changes are inevitable and something that every manufacturer must respond to and take advantage of, whether it is in regards to technology changes, product changes, or changes in the manufacturing processes. The reconfigurable manufacturing system (RMS) meets this challenge through the ability to rapidly and efficiently change capacity and functionality, which is the reason why it has been widely labelled the manufacturing paradigm of the future. However, design of the RMS represents a significant challenge compared to the design of traditional manufacturing systems, as it should be designed for efficient production of multiple variants, as well as multiple product generations over its lifetime. Thus, critical decisions regarding the degree of scalability and convertibility of the system must be considered in the design phase, which affects the abilities to reconfigure the system in accordance with changes during its operating lifetime. However, in current research it is indicated that conventional manufacturing system design methods do not support the design of an RMS and that a systematic RMS design method is lacking, despite the fact that numerous contributions exist. Moreover, there is currently only limited evidence for the breakthrough of reconfigurability in industry. Therefore, the research presented in this paper aims at synthesizing current contributions into a generic method for RMS design. Initially, currently available design methods for RMS are reviewed, in terms of classifying and comparing their content, structure, and scope, which leads to a synthesis of the reviewed methods into a generic design method. In continuation of this, the paper includes a discussion of practical implications related to carrying out the design, including an identification of potential challenges and an assessment of which tools that can be applied to support the design. Conclusively, further areas for research are indicated, which provides valuable knowledge of how to develop and realize the benefits of reconfigurability in industry.

1. Introduction

It is widely recognized that changes are inevitable in today's global market place. Customer demands are becoming more and more dissimilar, the need for customization of product offerings is increasing, and the pressure for rapid new product introductions is growing [1]. In a recent study, it was indicated that the product variety offered to customers has been more than doubled between 1997 and 2012, while product lifecycles have been shortened by about 25% [2]. The reasons for this are manifold, e.g. the emergence of different regional market segments, competition among companies to attract customers, and the emergence of new materials and technologies to incorporate in product offerings [3]. Thus, manufacturing companies need to find solutions to efficiently handle fluctuating volumes, customization, and frequent introductions of new variants and generations, in order to remain competitive in the global marketplace.

Traditional manufacturing systems, such as dedicated and flexible systems, have major drawbacks in terms of meeting these requirements, as they do not offer adequate responsiveness at a reasonable cost [4]. Dedicated manufacturing lines optimized for one single product and output capacity have in many cases proved inappropriate, as variety, shortening product lifecycles, and demand

* Corresponding author.
E-mail addresses: ala@m-tech.aau.dk (A.-L. Andersen), tdp@m-tech.aau.dk (T.D. Brunoe), kni@m-tech.aau.dk (K. Nielsen), carin.rosio@ju.se (C. Rösiö).

http://dx.doi.org/10.1016/j.jmsy.2016.11.006

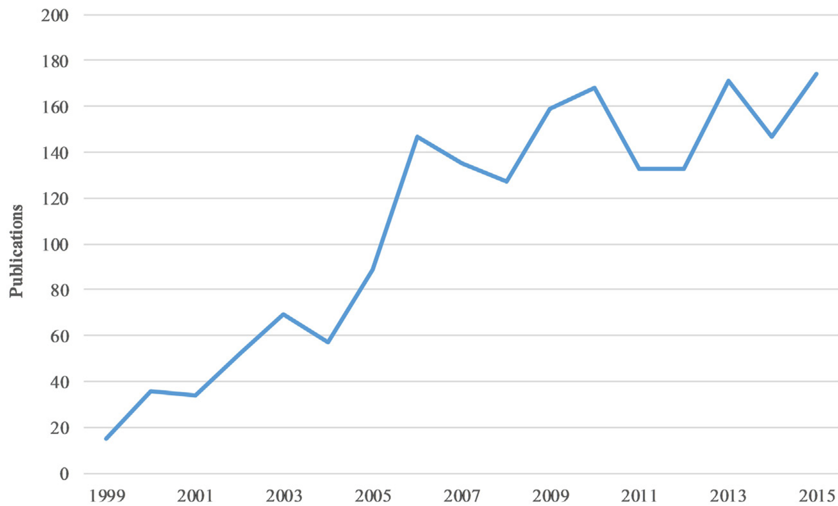

Fig. 1. Publications per year on reconfigurable manufacturing from 1999 to 2015.

changes simply cannot be met with its rigid structure [5]. This is likely to result in the situation where the dedicated lines operate below full capacity and become obsolete rather quickly [6]. On the other end of the continuum, the flexible manufacturing system offers the ability to be converted between the production of different variants, but has in its implementation brought issues of excess flexibility, low production rate, and low return on investments [7,8]. For these reasons, the concept of the reconfigurable manufacturing system (RMS) was introduced in the 90's, combining the high throughput of traditional dedicated manufacturing lines and the flexibility of the flexible manufacturing systems [5].

The RMS is designed for rapid change through the ability to repeatedly change capacity and functionality in a cost-efficient way, in order to meet different demand situations, in terms of variation in volume as well as in product characteristics [9]. This is enabled through six core characteristics: customization, convertibility, scalability, modularity, integrability, and diagnosability. Customization refers to machine and system flexibility being limited and customized to a specific part or product family, which reduces the traditional trade-off between efficiency and flexibility [4,8]. Convertibility and scalability refer to modifying the capacity and functionality of the system and the machines, which is achieved through modularity and integrability. The last characteristic, diagnosability refers to the ability to read the state of the system and obtain information on which corrections that have to be carried out in order to reach the planned performance, which is particularly important in the ramp-up phase after each reconfiguration. With these characteristics, the RMS is adaptable to changing market conditions, and allows for cost-efficient reuse and prolonged lifetime, which is the reason why it has been widely labelled the manufacturing paradigm of the future [10,11].

1.1. Design for reconfigurability

Since the introduction of the RMS concept in the late 90's, research in the area has increased and broadened notably. The development in number of publications in terms of journal papers, conference proceedings, and books is depicted in Fig. 1, where the annual number of publications is depicted from 1999 where Koren et al. [5] initially coined the RMS concept. The figure includes publication results in English from search terms "reconfigurable" and "manufacturing" or "production" in Scopus, covering relevant subject areas, primarily being engineering, mathematics, decision science, computer science, business, and economics.

These publications on RMS cover multiple research issues and structuring levels of the factory, from the highest level, being the network and the factory, to the lowest structuring level being the workstation and tooling [12]. In general, reconfigurations can be divided in physical and logical types, which is also reflected in the different research issues. Physical reconfigurations involve hard changes in equipment and arrangement of machines, which usually requires changes on lower structuring levels, such as the workstation or the cell. Among dominant research issues on this level is the development of reconfigurable machines covering both tools, fixtures, inspection machines, and material handling systems [13]. These reconfigurable machines have modular structures, which enables quick conversion between different parts within a part family as well as in working speed or volumes [14]. On the other hand, logical reconfigurations involve soft changes such as re-routing and re-planning and are mainly related to research issues on system level or higher levels [12]. On the system level, reconfigurability is achieved by adding, removing, or changing the modules of the system, thereby changing the functionality or the capacity [9]. Research issues on system level include optimal reconfiguration selection [15–17], economic justification models [18,19], and system design methods [17,20–22]. Despite the critical importance of all these research issues, one particularly important concern is the design of the RMS, as this issue precedes all of the remaining and directly affects the system's abilities to scale capacity and convert functionality.

Manufacturing system design can be regarded as the task of mapping requirements into the physical system description [23]. Usually, two approaches to this can be taken; creating entirely new systems adhering to the requirements, or considering already existing systems and modifying these to fit the new requirements. In practice, the first approach is rarely taken, as the existing systems are often taken into consideration when designing new systems, but can be relevant for newly started enterprises or existing enterprises going into entirely new products or technologies [24]. When designing reconfigurable manufacturing, both approaches are relevant, as companies may transition towards reconfigurability from either more dedicated or more flexible system types without completely replacing these. In this regards, reconfigurability can be seen as being placed on a continuum between general flexibility and dedication, which is depicted in Fig. 2. In some cases, it may prove most feasible to rebuild existing dedicated systems, and gradually build increasing reconfigurability by changing some parts of the system.