Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 62 (2017) 181 – 186

www.elsevier.com/locate/procedia

10th CIRP Conference on Intelligent Computation in Manufacturing Engineering - CIRP ICME '16

A production planning method to optimally exploit the potential of reconfigurable manufacturing systems

Andreas Hees[a]*, Christina Bayerl[a], Brian Van Vuuren[b], Corné S.L. Schutte[b], Stefan Braunreuther[a], Gunther Reinhart[a]

[a]*Fraunhofer Institute for Machine Tools and Forming Technology (IWU), Project Group Resource-efficient Mechatronic Processing Machines, Beim Glaspalast 5, 86153 Augsburg, Germany*
[b]*Stellenbosch University, Department of Industrial Engineering, Private Bag X1, Stellenbosch 7602, South Africa*

* Corresponding author. Tel.: +49-821-56883-51; fax: +49-821-56883-50. *E-mail address:* andreas.hees@iwu.fraunhofer.de

Abstract

Manufacturing companies must operate in a dynamic environment. Consequently, companies constantly have to adapt their manufacturing systems to stay competitive. One approach to ensure the success of manufacturing companies is to use reconfigurable manufacturing systems (RMS). Current production planning methods cannot quickly realize the production-side adaptions available in RMS and are limited in flexibility. A novel production planning method to optimize the potential of RMS is presented in this paper. First, the key characteristics and planning requirements for an RMS are defined. A feasible configuration is then determined, using a planning method based on mixed integer linear programming (MILP) to realize capacity scalability and functionality changes within planning processes. Finally, an application scenario to validate the method is outlined.

Peer-review under responsibility of the scientific committee of the 10th CIRP Conference on Intelligent Computation in Manufacturing Engineering

Keywords: Production planning; Reconfiguration; Scheduling

1. Introduction

More than ever, manufacturing companies are affected by challenging dynamics [1] caused by shortening product and technology life cycles [2] and increasing numbers of product variants as the demand for individualized products rises [2; 3]. To meet these challenges, manufacturing companies need to provide more individualized instead of standardized products and, in doing so, transform themselves into single- and small-batch producers. In the transformation towards production of small batch sizes, the number of units produced decreases, whereas the number of orders and the coordination effort that is required increase. Consequently, manufacturing companies constantly have to adapt their manufacturing systems to ensure their competitiveness [4]. In particular, to remain sustainable they need to be able to reconfigure their manufacturing resources frequently and increase their efficiency. One approach that makes this possible is the use of reconfigurable manufacturing systems (RMS) [5]. 'Reconfigurability' is defined as the ability to customize the behavior of a system by changing its configuration [13], while 'configuration' is defined as a sequence of workstations in a layout or the set-up of a workstation setting [5].

Although an RMS allows for frequent adjustments and flexibility in manufacturing processes on the one hand, it increases the complexity of the planning and scheduling processes [6] on the other. Existing production planning and control (PPC) systems cannot deal with these dynamic characteristics. Undefined interfaces and incorrect planning parameters are further challenges in production planning and control [7]. In particular, the existing production-planning and control algorithms are fixed in terms of possible objectives and planning parameters and can therefore not meet the market demand [8]. To exploit the inherent flexibility of an RMS, the production planning and control system needs to become more sophisticated [9].

In this article a production planning method, as part of a planning system using reconfigurable manufacturing systems,

Peer-review under responsibility of the scientific committee of the 10th CIRP Conference on Intelligent Computation in Manufacturing Engineering
doi:10.1016/j.procir.2016.06.001

is outlined. The proposed production planning method for RMS is then presented. Finally, an application scenario and the validation of the planning method are discussed.

2. Approaches to production planning with RMS

Since the concept of reconfigurable manufacturing systems was raised by Koren et al. [5], several research publications have analyzed and discussed the characteristics and potential of these systems [e.g. 4; 5; 10; 11; 12]. A key factor of RMS is that they can be adapted quickly in terms of capacity and functionality; hardware and software; technology and structure [5; 10]. The key characteristics of RMS according to [5] are listed in Table 1.

Table 1. Key characteristics of RMS [according to 5].

Characteristic	Description
Modularity	Modular structure of components and controls
Integrability	Standardized interfaces for quick integration of new components and technologies
Customization	Customized flexibility and control
Convertibility	Short conversion times
Diagnoseability	Traceability of product quality during ramp-up

Production planning and control is responsible for planning and controlling production processes in terms of schedule, capacity and output [14]. According to [14] typical objective variables are a high on-time delivery; a constant and high load factor; short lead times; low inventories; and high flexibility.

The main research activities in the field of production planning and control can be divided into *modeling of RMS*, *generation and selection of configurations*, *process planning*, *capacity planning* and *machine scheduling*.

Most of the authors regard the optimal selection of configurations as important elements in the *modeling of RMS* for production-planning and control purposes. Graph theory methods, such as Petri nets, and mathematical approaches have been used to model systems behavior and reconfiguration processes [15; 16; 17].

The main purpose of research activities focusing on the *generation and selection of configurations* is to identify an optimal configuration. To this end, different optimization approaches, mainly based on heuristics, have been developed [18; 19] and different selection strategies used. These strategies include a comparison of the component requirements and the available resource capabilities [20].

The optimization approaches gave rise to different research activities for *process planning* with RMS, such as the specification of part-families [21] and the design of adaptable process plans [22]. Different kinds of process planning tasks for RMS, such as macro process planning and parameter optimization, have also been developed [23].

For *capacity planning* with RMS, it is essential to describe and integrate scalability in terms of the capacity of the systems. In general, capacity scalability is described on a system level by adding and removing manufacturing equipment. By determining the system's capacity and functionality needs based on the market demand, researchers have developed different capacity strategies [6; 24; 25]. The use of reconfigurable machine tools (RMT) for capacity adjustment was also identified [26].

Different mathematical modeling approaches have been used as the basis for *machine scheduling*, with heuristic algorithms mainly being used to solve formulated scheduling problems. Examples include approaches based on fuzzy logic, tabu search, simulated annealing and genetic algorithms [27; 28; 29]. In particular, the minimization of production costs and the reduction of lead times have been formulated as objective variables.

To summarize, the state of the research concerning the use of RMS in the field of production planning suggests that a continuous approach involving different planning phases has not yet been developed. Thus far, the research activities have only focused on specific tasks and aspects of PPC.

The main enabler of reliable planning results with RMS in production planning and control has been the integration of scalability in terms of the capacity and functionality of systems. To ensure scalability, the key characteristics of RMS need to be integrated in the production planning and control process, and production planning parameters must be used to specify the configurations of RMS. In this context, one possible approach could be to use different capacities that are subject to configuration-dependent cycles (systems) or processing times (resources). In addition, feasible configurations need to be selected and assigned within planning procedures. Given the fact that existing approaches only focus on specific areas of production planning and control rather than presenting a continuous approach, new methods for production planning need to be developed.

3. Specification of RMS for production planning

To develop a production planning method for reconfigurable manufacturing systems it is essential to describe the characteristics of RMS in terms of planning capabilities. Thus, in the following sections configuration-dependent processing times and the resultant scalable capacities are outlined as essential basics for the subsequent planning method.

For the production planning method, an RMS is divided into system (SC_k) and resource ($RC_{i,j}$) (i.e. workstation) configurations. Target times are used for production planning, e.g. for capacity planning. Target times consist of set-up and processing times. As the performance of the resource is related to its configuration, a configuration-dependent processing time (t_{ij}^{p}) of a resource i is defined. On the system level, the processing time of the bottleneck resource determines the cycle time (t_k) for the actual system configuration k.

The production capacity that can be provided by the system depends on the cycle time of the system configuration. With the help of reconfigurations, the cycle times can be adjusted. The maximum capacity is described by the fastest system configuration and the available working time. The capacity demand and the available capacity are synchronized