Journal of Manufacturing Systems 42 (2017) 11–28

Contents lists available at ScienceDirect

Journal of Manufacturing Systems

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

Full length article

A new method for autonomous control of complex job shops – Integrating order release, sequencing and capacity control to meet due dates

Sebastian Grundstein [a,b,*,1], Michael Freitag [a,b], Bernd Scholz-Reiter [a]

[a] University of Bremen, Bibliothekstr. 1, 28359 Bremen, Germany
[b] BIBA – Bremer Institut für Produktion und Logistik GmbH at the University of Bremen, Hochschulring 20, 28359 Bremen, Germany

ARTICLE INFO

Article history:
Received 14 May 2015
Received in revised form 26 October 2016
Accepted 27 October 2016

Keywords:
Autonomous control
Manufacturing control
Production planning and control
Cyber-Physical Production Systems
Industry 4.0

ABSTRACT

Due to the development of Cyber-Physical Production Systems, autonomous control of manufacturing processes is of increasing significance. Particularly, these manufacturing control approaches have considerable potential in job shop manufacturing. However, research in this field tends to focus on subtasks of manufacturing control without considering the interdependencies. This article presents the autonomous production control method (APC), which integrates all control tasks – order release, sequencing and capacity control – to meet due dates. The APC is benchmarked with established method combinations using event-discrete simulation. The results demonstrate the potential of our method to meet due dates and emphasise the method's relevance for practical applications.

1. Introduction

Situation-dependent control of production and logistics processes is of increasing relevance [1]. Decentralised and autonomous approaches are considered to be especially promising in this context [2–4]. These approaches have inherent rapid reactivity towards disturbances, which depends on current data from the production process [5]. However, these data are often not available [6]. Latest developments toward Cyber-Physical Production Systems (CPPS) with advanced Information and Communication Technologies (ICT) offer avenues for providing and using these data by improving the networking between shop floor and IT [7]. CPPS are production systems with such properties as ad-hoc networking, self-configuration and decentralised intelligence [8]. This intelligence is often achieved by the implementation of sensor technologies, such as Radio Frequency Identification (RFID) [1]. Manufacturing companies with CPPS benefit from enhanced transparency, efficient production data organisation and the capability for real-time shop floor control [9].

The development towards CPPS also changes the traditional task sharing between production planning and control. Production planning (scheduling) typically determines a schedule, which comprises the exact dates for the start or end of operations and thus also determines the sequence of production orders considering available resources [10]. The typical task of production control is to execute the schedule, despite possible disturbances [11]. In contrast, CPPS envision an autonomously controlled factory, in which autonomous objects cooperate within the limits of a central master schedule [12]. In autonomously controlled factories, production control will control the production decentralised/autonomously on the basis of due dates and capacity restrictions of the master schedule [13]. Therefore, production control has the functions of sequencing (comprising dispatching and sequence of queue processing), order release and capacity control [14]. In the last decades, research in the field of Production Planning and Control (PPC) focussed on (re-)scheduling strategies and methods while disregarding production control [10].

CPPS and decentralised autonomous control approaches have considerable potential for job shop manufacturing [15]. Stations in job shop manufacturing are arranged according to their function principle, i.e., similar types of workstations are pooled into a single job shop [16]. This manufacturing type is generally characterised by high flexibility concerning product variants, as well as high throughput times and low productivity [17]. The particular potential of decentralised and autonomous approaches in job shop

* Corresponding author at: University of Bremen, Bibliothekstr. 1, 28359 Bremen, Germany.

E-mail addresses: gru@biba.uni-bremen.de, sebastian.grundstein@googlemail.com (S. Grundstein).

[1] Web: www.ips.biba.uni-bremen.de.

http://dx.doi.org/10.1016/j.jmsy.2016.10.006

manufacturing originates from the enormous number of decision alternatives which complicate scheduling and rescheduling of job shops. For example, rescheduling, i.e., updating the schedule in case of disturbances, has been in need of better algorithmic solutions for decades [18] and remains a focus of research [19]. The higher the complexity and dynamics (e.g., the frequency of disturbances) of a production system, the sooner the (re-)scheduling algorithms are pushed to their limits [20], especially as the basic assumptions in scheduling research are often far from the complexity of real production systems [21]. In contrast, autonomous control approaches focus on the use of existing flexibility potentials in the production logistics system [5]. For example, decision-making for machine scheduling is performed in a decentralised manner in heterarchical structures, rather than via central scheduling [20].

Research in the field of autonomous control tends to focus on issues, such as technical infrastructure [22], general framework and modelling systems [23], procedure models [24] and particularly on negotiation mechanisms between machines and/or orders [25–30]. These approaches focus primarily on sequencing (i.e., dispatching and queue processing) while widely disregarding order release methods other than immediate order release and capacity control [31]. This finding is attributable to the neglect of production control in academic research, as well as in practice, despite its increasing significance [14]. There has been an increasing interest in integrating these tasks in the last years, for instance focusing on integrating order release and sequencing/dispatching rules [32,33] or scheduling and capacity control [34]. However, to the best knowledge of the authors, there is no method in the state of the art that integrates all control tasks and is applicable for job shop manufacturing (cf. literature review in Section 2.3).

The basic hypothesis is that an integrated method achieves a higher logistic performance than combinations of methods, which fulfil single manufacturing control tasks isolated from each other. The developed method needs to be applicable for job shop manufacturing and take into account the implications of the development towards autonomous control in CPPS.

Basic requirements of the presented approach are systematically derived from a discussion of the state of the art and a literature review in Section 2. Section 3 presents the concept of the APC method, which comprises the three tasks of production control in CPPS – sequencing, order release and capacity control – for application in job shop manufacturing, considering the possibilities and requirements of the advances in ICT and development towards CPPS. The industrial case study is presented in Section 4. Section 5 discusses the results. The paper ends with a conclusion and outlook in Section 6.

2. Background

2.1. Basic problem

Basic problem addressed by this paper is the customer-oriented complex job shop manufacturing. Customer-orientation in this context means that the production work is "made-to-order" such that the due dates are agreed upon and must be kept. For most of these companies, due date adherence is the most important logistic objective. For instance, Brosze et al. [35] found that due date adherence is the most important logistic objective for two thirds of the participating companies. Job shop manufacturing is a particularly promising field of application for autonomous control, as scheduling problems in this case are NP-hard or even NP-complete [10]. Complex job shops are characterised by:

- a large number of products with a changing product mix over time,
- sequence-dependent set-up times,
- unrelated parallel machines,
- a mix of different process types, including batch processes (a batch is defined as a temporary collection of lots with the aim to process them at the same time on the same machine),
- different types of internal and external disturbances,
- re-entrant process flows due to very expensive machinery [21].

The subsequent literature review focuses only on methods that are applicable for this basic problem. Our literature review (see Section 2.3) was conducted focusing on the requirements for integration, which are defined in the next section.

2.2. Requirements for integration

Considering the basic problem of this paper, the technological aspects and overall tasks of production control, several requirements for an integrated method are defined:

- As setup times are sequence-dependent, they must be considered to keep due dates.
- The decision logic of the method must be kept simple to reduce the computational effort and to enable quick decisions.
- The production control method must be capable of deciding autonomously and react to dynamic influences. Order release and capacity control must leave room for decision making on the shop floor. As a consequence, capacity control and order release must work independent of the route that an order takes through the production system.
- Past data should be considered in decision making due to their positive effect on the methodís performance.
- It is important to take measures before a due date is not kept or a backlog occurs.
- Bottlenecks should be explicitly considered.
- The control method should be able to cope with deviations in demand, e.g., by accelerating or delaying certain orders.
- Work in progress (WIP) should be controlled on a defined level to improve the performance of the manufacturing system.
- Due to the costs of capacity increase measures, these should be taken as the last measure if other measures of order release and sequencing have already been exceeded.
- Sequencing interchanges and blocked WIP should be generally avoided. Blocked WIP in this context means that orders are not passed on to the next station, for example because the subsequent buffer is full or a defined WIP limit would be exceeded. It is generally advantageous to avoid sequencing interchanges and blocked WIP because procurement and supply decisions are triggered and resources are allocated according to a predefined schedule.

This paper presents the APC method, which is designed to explicitly address these requirements. It is required, because no existing method fulfils all these requirements, as the following literature review will show.

2.3. Literature review

This section provides a review of existing approaches. Tables 1 and 2 evaluate these existing methods regarding the defined requirements to explain the necessity for the APC method. Table 1 contains methods of order release and queue processing. Table 2 comprises methods of dispatching, capacity control and autonomous control. The evaluation in the tables indicates whether a method explicitly fulfils a certain requirement, as marked with an "x". The "(x)" indicates that the requirement is implicitly fulfilled. For instance, the due date-based order release implicitly considers due dates and sequence-dependent setup times if the schedule was