Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 57 (2016) 345 – 350

www.elsevier.com/locate/procedia

49th CIRP Conference on Manufacturing Systems (CIRP-CMS 2016)

Employing order allocation flexibility in cyber-physical production systems

Dennis Horstkemper[a]*, Bernd Hellingrath[a]

[a]*University of Münster, Leonardo Campus 3, 48145 Münster, Germany*

* Corresponding author. Tel.: +49-251-83-38021; fax: +49-251-83-38009. *E-mail address:* dennis.horstkemper@wi.uni-muenster.de

Abstract

One of the main goals of Industrie 4.0 research is to enable the usage of so far unutilized flexibility potentials in production and logistics. While Industrie 4.0 research generally considers most flexibility types, such as material handling flexibility, machine flexibility and operation flexibility, order allocation flexibility in particular is so far rarely investigated. Order allocation flexibility describes the flexibility potential that occurs when half-finished goods are not assigned to a specific customer order in a production system employing the make-to-order strategy, but instead can be freely assigned to any order that might require this half-finished good with its current specifications. Furthermore, this allocation from half-finished goods to orders might even change during the production process. Employing order allocation flexibility directly increases the degree of freedom for the other aforementioned flexibility types and has therefore already found application in the production of customer specific goods, e.g. in the form of a multi-phased order release in the automotive industry. In this context, cyber physical production systems with their capability of self-optimization and control theoretically offer the possibility to determine the allocation of half-finished goods to orders in near real time during any production step, leading to a further increase of flexibility in the overall production system. This work contributes to the state of the art in Industrie 4.0 research by first analyzing the potentials of a stronger consideration of order allocation flexibility into Industrie 4.0 enabled production systems and discussing the compatibility of existing research approaches with this flexibility type. Second, a conceptual model for production planning and control employing order allocation flexibility in a cyber-physical production system will be derived.

Peer-review under responsibility of the scientific committee of the 49th CIRP Conference on Manufacturing Systems

Keywords: flexibility; Industrie 4.0; production planning; production control

1. Cyber-physical systems as flexibility enablers

For several years the business environments of supply chains are growing ever more complex, dynamic and uncertain. Manufacturers in high-wage countries furthermore try to differentiate themselves from their competition by offering a high number of product variants and features. This leads to shorter product life cycles and a reduction of beneficial risk pooling effects, causing an increase in customer demand variance and a lack of predictability of these. [2]. At the same time, delivery reliability remains the most important key performance indicator for 67% of enterprises across a multitude of industry sectors [3]. Creating efficient ways for the manufacturing of customer specific goods considering such unstable demand profiles is one of the main goals within the research field “Industrie 4.0” (I 4.0).

The main technological mean to achieve these goals is the introduction of Cyber-physical systems (CPS) into production processes. “CPS are integrations of computation with physical processes. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa” [4]. Thus, CPS potentially enable close to real time reactions on unforeseen interruptions and other events occurring in physical production processes, e.g. a customers’ wish to change the specifications of a product he has already ordered.

A network consisting of multiple CPS, which are able to communicate with each other and thus collaboratively plan and control themselves, are known as a Cyber-physical production System (CPPS) [5]. Employing the computational capabilities of each single CPS within a CPPS enables decentralized planning and control approaches, envisioned to emerge in a robust production system which can achieve a cost efficient

Peer-review under responsibility of the scientific committee of the 49th CIRP Conference on Manufacturing Systems
doi:10.1016/j.procir.2016.11.060

production of customer specific goods under todays' uncertain business environments [6].

While decentralized planning approaches are not capable of optimizing the whole system performance as cost efficient as a centralized planning approach theoretically could, they greatly diminish the complexity of the performed planning tasks by dividing the overall planning tasks into several subtasks [5]. This allows for the introduction of further planning parameters and variables into the planning process, which would have considerably decreased the solvability of centralized planning models. Thus, it becomes possible to include several manufacturing flexibility types into these planning models and consequently make use of so far unconsidered flexibility potentials. Additionally, changes made in a part of the production system, e.g. through rescheduling the production processes to be performed on a machine, can be communicated throughout the CPPS and the following production processes can be adapted accordingly. Employing flexibility potentials to decrease the effect of unforeseen events at their point of occurrence as well as the ability of the overall CPPS to quickly adapt in accordance to these changes within the production processes are meant to create a positive emergence [7] and thus enable the creation of the aforementioned robust production systems within I 4.0.

However, current I 4.0 research does not consider all types of manufacturing flexibility that could possibly be employed. To explain how particularly the notion of "order allocation flexibility" can be included in an I 4.0 capable CPPS, the remainder of the paper is structured as follows: Section 2 gives an overview about manufacturing flexibility in general and order allocation flexibility in particular. Section 3 describes the current state of employment of manufacturing flexibility in I 4.0 research. In section 4, a conceptual model is proposed to explain, how order allocation flexibility could be included in current I 4.0 production planning and control approaches. Finally, section 5 gives a shirt summary of the findings and discusses open issues.

2. Manufacturing Flexibility

Manufacturing flexibility is a research area with a long tradition. Early definitions focus on the adaptability of a production system to uncertain conditions [8]. Generally, flexibility describes the pre-defined capability of a given system to adapt its states to react on changing circumstances with the lowest possible penalty in time, effort, cost or performance [9]. Manufacturing flexibility can be subdivided into several flexibility types and multiple classifications have been developed. However, neither a single definition of manufacturing flexibility nor a certain set of flexibility types have asserted themselves in literature [10]. Based on a Framework by Sethi and Sethi, Windt and Jeken created a classification for manufacturing flexibility focusing on potentials that can be leveraged during operational planning and execution in autonomous systems [10][11]. They derived four types of manufacturing flexibility based on established literature:

(1) Machine flexibility denotes the potential of a resource to be able to switch between a multitude of operations without incurring high costs or long setup times.
(2) Material handling flexibility describes the capability of a system to route different part types efficiently through system towards the position in which required production steps are to be performed.
(3) Volume flexibility defines the ability of a production system to be operated in a profitable manner even when varying output volumes are produced.
(4) Operation flexibility determines the possibility to manufacture a product using alternative processing plans, selecting the best matching towards given requirements and customer specifications.

While several more flexibility types have been discussed in literature, they are either not relevant in the aforementioned scope or can be seen as a further differentiation of these four abstract types. Therefore, this classification avoids the existence of overlapping flexibility types. However, all of these flexibility types are directly meant to adapt the physical capacity of a production system.

In addition to these physical types of manufacturing capacity, Windt and Jeken also introduced the notion of order allocation flexibility [11]. This term describes the flexibility potential which can be achieved, when half-finished goods or even singular workpieces in a make-to-order production are not directly coupled towards a final customer order. Instead, the allocation of a half-finished good to a customer order is supposed to be performed situationally as well as repeatedly. As a change of allocations between the physical half-finished good and the final customer order requires no physical changes, this flexibility type can be classified as purely logical.

Order allocation flexibility directly increases the degree of freedom for other flexibility types, as the situational allocation towards specific customer orders might e.g. create more alternative routing options throughout a production system. Thus, an increased number of decision alternatives is created, which generally positively influences the capability of an autonomously controlled system like a CPPS [7]. Further information as well as examples for the advantageous nature of the employment of order allocation flexibility can be found in [11,12].

Fig. 1 shows the manufacturing flexibility classification by Windt and Jeken [11]. They are first categorized between the purely logical and physical types of flexibility. The element of the production system which is influenced by the mentioned flexibility type is used for a further classification. Lastly, the classification names the to-be-influenced decision for each flexibility type to describe its degree of freedom.

An example for the potentials of order allocation flexibility can be observed during the manufacturing process of a car: During assembly, two cars exist, that so far have been assembled with identical specifications. They will however diverge in the next step of assembly, as the customer of the first car in the released assembly order has requested the installation of specific electrical appliances.