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Mastering Complexity with Autonomous Production Processes

Hanna Theuer*, Sander Lass

Chair of Business Information, University of Potsdam, August-Bebel-Str. 89, Potsdam, 14482, Germany

* Corresponding author. Tel.: +49-331-977-3355; fax: +49-331-977-3406. *E-mail address:* theuer@lswi.de

Abstract

For the consolidation and improvement of a companies market position it is necessary to master the increased complexity of production processes with suitable methods. This paper will examine whether and how far autonomous production processes are suitable to master the complexity of production processes. The paper starts with an introduction of the problem definition followed by an explanation of theoretical foundations of complexity in production, autonomy and cyber-physical production systems. In addition, selected already existing methods to master complexity are presented. The second part of the paper starts with an introduction into measuring the degree of autonomy in production processes which is the basis for the following simulation-based analysis. Afterwards, the simulation environment is presented. The third chapter is about the experimental analysis of the presented research question. Therefor, the experimental set up and the implementation are presented. The paper ends with an outlook on further evaluation activities.

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1. Problem definition

Changing market conditions, variable customer demands and growing customer requirements lead to an increasing complexity in production processes. Additionally, they are some reasons for manufacturing companies to create flexible and adaptable processes to fulfil the customer demands in a high quality. Companies have to determine the best grade of complexity for their specific processes. On the one hand side they have to fulfil the customer demands, on the other hand side they must be able to handle the complexity in an adequate manner. There are several methods for dealing with the named challenges: lean production, advanced software systems and decentralization of decision making with the help of intelligent autonomous technologies for instance. While lean production focus on the elimination on non-value adding processes, software systems may assist the process by the automatisation of decision making due to algorithms. With the help of technological or human based autonomy it is possible for production objects to proceed the information making and decision execution on their own. This decentralisation of production control seems to be an adequate method to deal with the current requirements on production processes. This paper will examine whether and how far autonomous production processes are suitable to master the complexity of production processes. Section 2 provides an introduction into the underlaying theoretical foundation, section 3 describes the process evaluation for the analysis of the benefit of autonomy to handle complex production systems. The paper ends with an outlook on further research activities.

2. Theoretical Foundation

This first section provides a theoretical foundation. Firstly, fundamentals of complexity in production systems are presented, followed by a brief introduction into cyber-physical systems. The section ends with a presentation of autonomous production systems.

2.1. Complexity in Production Systems

As there are several different disciplines using the term of complexity, there is no consistent definition of the term. Exemplarily, the definitions of complexity in systems theory, cybernetics, and computational science are presented in this paper. Systems theory defines complexity as a ratio of elements of the systems and their connecting relations [1]. Cybernetics uses the variety for measurement. Variety describes the amount of possible and distinguishable states a system can hold [2]. Computational Sciences use complexity for the analysis of time and space requirement of algorithms.Used methods are Big O and turing machines for example [3].

Also, various classes of complexity can be distinguished. For production systems, the most relevant are product, pro-

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cess, coordination, and environmental complexity. As there are impacts between the different classes of complexity, they may not be considered separately but in a correlated way. For instance, the product complexity has a direct influence on the processes produced in and thereby the belonging process complexity [4,5].

Complexity in production processes has increased during the last years. Reasons for this are among others an increasing diversity of variants caused by individual and heterogenous customer demands, changed requests of piece items down to one piece production, technological innovation, decreasing cycle of innovation, short-time lifecycle, increasing international sales and procurement market, differences of planning and decision systems of cooperating companies as well as a increasing connectivity caused by the reduction of vertical range of manufacture [6–8]

The named facts clarify that complexity as itself is not bad and has to has to be avoided. Instead, complexity may be a basis for the successful fulfilment of customer demands and the directly linked business activity. Nevertheless, complexity has risks e. g. The incapability of acting or increasing costs. It is necessary to determine the right dimension of complexity. In a next step, adequate methods have to be selected and applied to these dimensions. Basic categories of those methods are the avoidance, the reduction and the mastering of complexity[7].

The underlying research work for this paper focuses on the mastering of complexity. The applicability of an autonomous production control for mastering complexity is determined. It is mandatory to make quantifiable complexity as well as autonomy. Section 3 presents appropriate approaches.

2.2. Cyber-Physical Production Systems

LEE provides a definition of cyber-physical systems that has a general characterisation [9]:

> ”Cyber-Physical Systems (CPS) are integrations of computation and physical processes. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa.”

Therefore, CPS combine software based information processing and interaction with the surrounding physical environment. Due to this interaction, embedded systems and their linkage realises tasks of control and monitoring as intelligent control loops [9].

Additionally, ACATEC describes CPS as software intensive and embedded systems and integrated application that realise the usage of data and service anywhere in the world. This is realised with the help of sensors, actors and local information processing in combination with a comprehensive networking [10]. Dedicated utilisation interfaces and various integration in digital networks allow a wide spreading integration of functions [10,11].

The term of cyber-physical production systems (CPPS) often finds application in the context of CPS-based automation [12]. Existing plant components, as well as whole production facilities, are combined to CPPS. This implies that a CPPS is the combination of several, initially independent CPS to a larger production system. A high degree of networking of elements characterises this production system. It represents an autonomous and intelligent production unit [13].

2.3. Autonomous Production Systems

Various fields of live and science e. g. politics, automobile industry and psychology use the term autonomy to describe the independence of field specific objects and instances. Autonomous production systems are characterised by the existence of several decentral actors that control the systems by their own. These actors can be part of a cyber-physical system. They need to fulfil at least three characteristics: information processing, decision making and decision execution [14].

When regarding autonomy in production processes in literature, there is a clear focus on technology [15,16]. But in due consideration the three named characteristics, it turns out that there is more needed than technology to enable autonomy in production. According to the etymology of the term autonomy (it is defined as the capacity of a rational individual to make an informed, un-coerced decision [17]) an other possibility to create an autonomous controlled production is autonomy by human action and organisation. Both (hardware (machines, workpieces, carriers or conveyors) and human) are able to proceed intelligently, either independently or due to a combination of them. The degree of combination may vary from a high interaction to a nonexistent one [18].

Information processing includes data input, data storage and data aggregation. Relevant data has to be tagged to the production object. Therefore special technology is necessary [14]. An common examples for such an technology is Radio Frequently Identification (RFID) [19]. Decision making combines the aiming system with predefined rules as well as the communication with further production objects. For the decision execution the communication of different production objects as well as the capability of a production objects to performance alternative processes is necessary [14]. Even though humans have the names characteristics ”integrated”, they might require the availability of information for an adequate decision making. These information might be provided by software terminals that are placed directly at the shop floor for example. Autonomy in production systems gained in importance during the last years. Autonomous production objects are one core capability for Industrie 4.0 (a term mainly used in Germany) or Smart Production [20].

3. Process Evaluation

This section firstly describes methods for measuring autonomy and complexity in production systems as well as the determination of key figures followed by a short conception of the used simulation environment.

3.1. Measuring Autonomy in Production Systems

To analyse autonomous production systems, the authors of this contribution developed a method that enables a measurement of autonomy of production systems and thereby gives a basis for the evaluation and comparison of various systems or their set ups [21,22]. The core element of this method is the