Cyber Physical Production Control

Transparency and High Resolution in Production Control

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Abstract. Currently the control of constantly increasing market dynamics and the simultaneously increasing individualization of process chains represent the central challenges for manufacturing companies. These challenges are caused by a lack of transparency in production planning, non-real-time processing of data as well as poor communication between the planning and control level. The research project ProSense addresses this problem and intends to eliminate the current problems in production by developing a high-resolution, adaptive production control based on cybernetic support systems and intelligent sensors. Through the development of a cyber-physical production control as one part of the project, which forms the basis for an innovative self-optimizing advanced planning system, ProSense provides a contribution to accomplish the goals of industry 4.0.

Keywords: Cyber-physical production system · Cybernetic · Production control · Industry 4.0

1 Introduction

The objective of the research project ProSense is the development of a high-resolution, adaptive production control based on cybernetic support systems and intelligent sensors. Focus is on a user-friendly design of control systems, so that human can be optimal supported in the control of production by means of high-resolution data. The cyber physical production system, which provides the framework for a user-friendly production control can be divided into four main tasks. These include the big data acquisition, big data processing, self-optimizing production control system and human-machine interaction (Fig. 1).

The acquisition of big data can be accomplished via simple and inexpensive sensors. In order to ensure a quick and easy interchangeability of these sensor systems, it is necessary to use modular function blocks. These communicate autonomously and act as intelligent units or subsystems. Depending on the level of consideration, it is necessary to adjust the data granularity on demand. This requires uniform interfaces to all IT-Systems to ensure an interoperable capability.

For targeted processing of the collected high-resolution data, these should be kept unchanged in a central database. In this way, high-resolution production data

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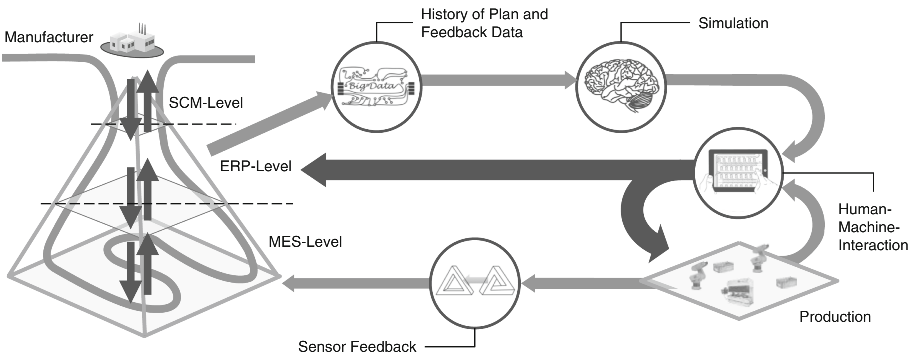

Fig. 1. Target image of the research project ProSense [1]

can be processed appropriate. Based on a standardized data interface, the processed data are then forwarded to a modularly designed production control system.

The third main task is a production control system based on a simulation model. To adapt the simulation model to reality, the real collected data will be used. Subsequently, with the model, different simulation runs are performed which are transferable to the real production. This results in forecasts relating to future meaningful control alternatives, which are then transmitted to the user. The human still retains the task of deciding between the identified control alternatives.

Apart from the validation of meaningful control proposals in particular the interaction between human and control system is very important for the decision support. With the help of an appropriate visualization, relevant decisions can be highlighted and considered simultaneously in an appropriate context. The user will receive an overview of the consequences of his decision and can take on this basis the right decision. With each new proposal, the system relies on the experience from the past. It optimizes itself constantly and gradually improves with the life of the system, the quality of its own control proposals [1].

2 Design of a Cyber Physical Production Control (CPPC)

To develop a cyber physical production control, it is necessary to consider the following points. The control systems must be designed in such a way that they support the human perfectly in control of the production with the help of high-resolution data and their intelligent processing, interpretation and subsequent visualization in order to substantially enhance the efficiency of value-added processes. This leads to increased transparency of the entire manufacturing process control, which will benefit all participating individuals. Due to the provided information the production controller receives a more accurate picture of the status of production and can optimize it in the future. Furthermore, the machine controller better understand why the initiated planning changes are necessary.

The pure assembly of the individual modules such as intelligent sensors, high-resolution data, user-friendly visualization, etc. does not result in a purposeful production support. To ensure the interaction of all components it is necessary to develop a basic structure that can be used as a framework for the cyber physical production system. Its task is to control the system, which consists of centralized and decentralized units according to specific requirements (Quality requirements such as stability and interference compensation and real-time requirements, such as timeliness, predictability and synchronization of the target system). Figure 1 shows the target image of the cyber physical production system and its various subtasks.

2.1 Structure Framework of Production Control

To implement a cyber physical production control, it is necessary to define the basic structure and the regulatory framework of the CPPC. On the premise of controlling complexity, the Viable System Model (VSM) of Beer and the corresponding management model of Versatile Production Systems (VPS) by Brosze is used as a regulatory framework for a cyber physical production control. Structuring principles of the VSM of Beer and the VPS by Brosze are viability, recursiveness and autonomy.

- The principle of viability is the superior of the three design principles. It describes the ability of a system to permanently ensure its institutional continuity over a certain period [2]. Ensuring the viability requires the continued willingness of a company to analyze existing conditions to detect internal or external interferences to react appropriately and if necessary to pursue new goals [3].
- The principle of recursion states, that all viable systems must have the same structure. This means that any viable system consists of several viable systems or is part of a superior viable system [4]. In view of the VSM by Beer this has the consequence that all recursion levels within hierarchical structures are present and that the systems 2, 3, 4 and 5 behave metasystemic in relation to the system 1. At the same time, each system 1 has at the next lower level the same five-stage structure as well as the control mechanisms of the VSM. In combination with the principle of viability the principle of recursivity provides fixed structuring criteria.
- The principle of autonomy addresses the self-design, self-control and self-development of subsystems. In order to enable a correspondingly optimal degree of autonomy, Beer encountered within the VSM the problem with a two-dimensional model. On one hand, the operating units of system 1 can achieve the maximum autonomy and on the other hand, the systems 1 are synchronized with the systems 2–5. Consequently, the systems 1 are not independent, but rather as subsystems of a larger superior system [5].

Figure 2 shows the recursive design of a viable system in relation to the company. The production control system is located on the fourth recursion level and is part of the production system. This in turn is part of a company that integrates itself into the superior supply chain.

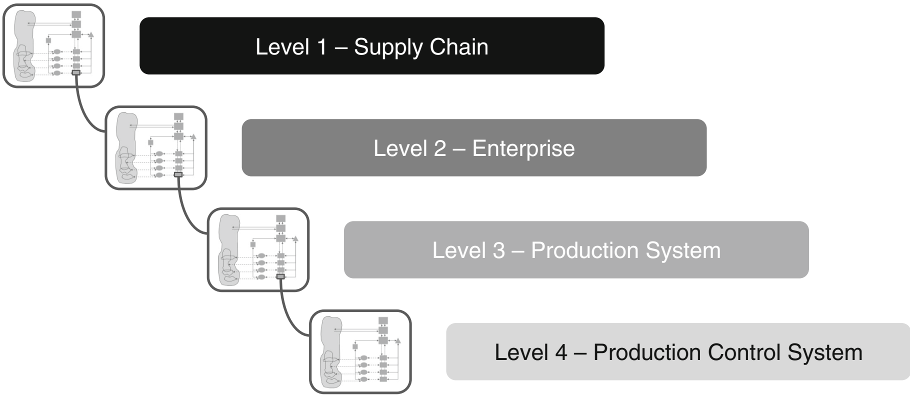

Fig. 2. Recursion levels of an enterprise

2.2 Requirements for the Design of a Cyber Physical Production Control

To the conception of a cyber physical production control, it is necessary to highlight the requirements based on which the new structure will be harmonized. We distinguish between form and content requirements [6].

The content requirements are formulated from the problem and objective of the model structure:

- All entities relevant for production control should be identified and transferred to the VSM structure.
- Any functions of the various production control units and manufacturing entities as well as the significant information flows should be mapped within the Viable System Model.
- Within the model, the instruction and control structures should be designed relating to the VSM mechanisms.
- During the development of the model structure based on the production control system it is necessary to consider, the principles viability, autonomy and recursion of the underlying VSM.

As formal requirements of the established model, the validity, reliability and utility are referred to [6–9]:

- The validity describes the claim of traceability and general applicability.
- The reliability of the results in terms of a similar framework is represented by the reliability.
- In addition, the usefulness of the results must be guaranteed (utility).

With the aim of establishing a cybernetic management model for production control, the functional control structure is transferred to the structure of the Viable System Model and the essential information and referral relationships are designed.

2.3 Structure of a Cyber Physical Production Control

The production control is in the overall model on the fourth recursion level (shown in Fig. 2). This level also has the five-level structure of the Viable System Model. Starting from the main task of the production control 'production of products in the required quantity and at the right time', the metasystem includes all planning and control-related tasks. The entities of production in contrast are defined as operational base units. According to Fig. 3, these are the work areas warehouse, logistics, manufacturing, assembly, maintenance, quality control, and shipment. The definition of the systems 1 requires the compliance of the autonomy principle. In the considered context this requirement is fulfilled by job design and order allocation (system 3) according to the base units which allows autonomous processing of orders for the purpose of superior objectives as well as the self-coordination between the systems 1 (system 2) without regular intervention measures of the metasystem [7]. Relationships between systems 1 and 2 have no hierarchical character. For this reason, the system 2 also belongs to the operational level. With this restriction, the coordination system is defined as a gathering of representatives from all production areas.

The core of the entire system is the operative management (system 3). This role is represented by the production control system, which is used to monitor, to control and to coordinate the production units as well as to guarantee the 'inner stability' of the system. This is supported by the unfiltered information provision of the process monitoring (system 3*). The strategic tasks of the system 4 are executed under consideration of the functional organization in the production planning (work planning and control). The production planning determines planning

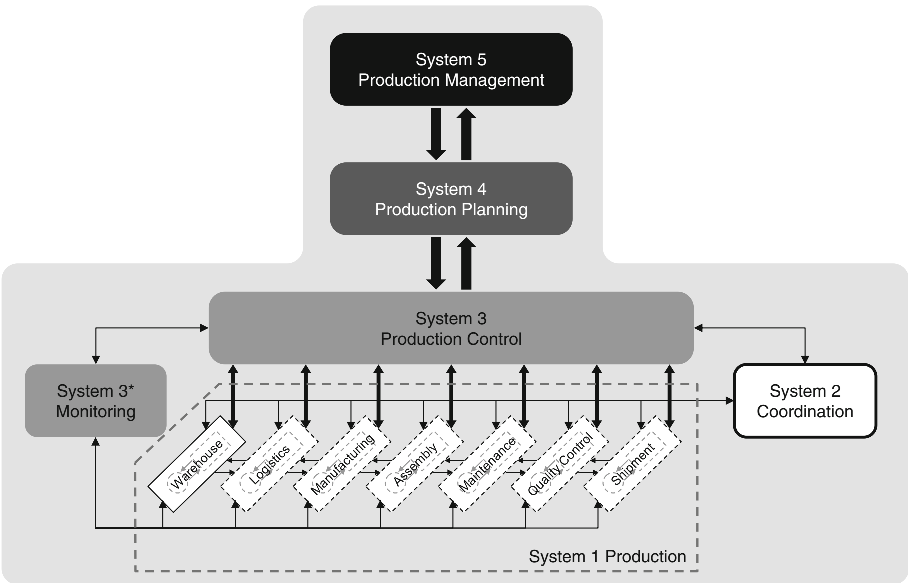

Fig. 3. Structure of a cyber physical production control

specifications and production programs, taking into account the normative action framework and 'external' conditions. The production management is defined as the normative system 5. This performs the tasks of strategic production management.

Figure 3 shows the various structures of communication between the individual entities. For an optimal use of this structure, functions and targets as well as tasks and input and output variables are defined for all control and operating units. The structure and mechanisms of the viable system model form the framework for the production control and support the coordination and instruction procedures, without limiting the system's autonomy and viability.

3 Guideline for Implementation of the Cyber Physical Production Control

To sustain the efficiency in the production control system, an appropriate guideline for implementation of the cyber physical production control system was developed. This is driven by the application guide of the VPS according to Brosze, which was adapted for the production control [7]. The guideline is divided into three major phases: analysis, mapping and design. All major phases are subdivided in more detail. The adapted application guide is shown in Fig. 4.

Phase 1: Analysis The analysis phase deals with assessment of the actual condition and includes the two steps of project setup and process and structure analysis. At this point, the operational processes of the production planning and control should be considered, which are described both in the VPS as well as in the extended process view of the Aachener PPS model of Schmidt [7, 10].

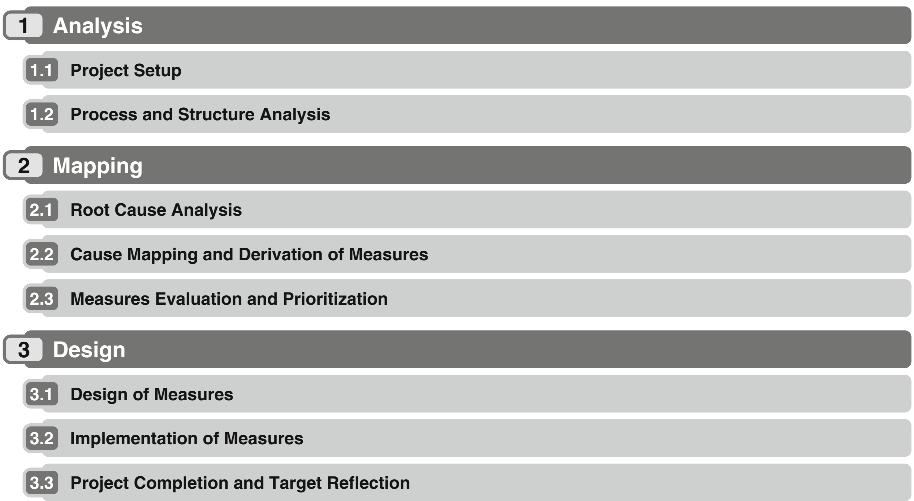

Fig. 4. Guideline for implementation of the cyber physical production control

Phase 2: Mapping Phase 2 focuses the optimization of the production control. Based on the previously identified weaknesses and potential for improvement, the respective causes are identified. The common causes are then clustered and assigned to the problem-solving elements. Finally, the clusters are prioritized with their improvement actions in terms of benefit and cost consideration and placed in an implementation sequence.

Phase 3: Design In the last phase the established measures are designed and operationally implemented. Finally, it is necessary to evaluate the implementation based on pre-defined targets to measure the success of a project and to complete the project.

4 Conclusion and Further Research

In summary it can be stated that the control and execution processes of production are associated with a large amount of information and instruction flow. Each unit of the manufacturing control system has a different kind of skills and responsibilities that must be taken into account in the communication structure and the allocation of tasks concerning the handling of complexity. It is shown that a design of production control according to the approach of viable systems and the consideration of the approach underlying principles of recursion, autonomy and viability supplies the necessary structures and mechanisms to ensure the stability of production and to favor the continuous improvement of processes. Further research is needed in the analysis and integration of appropriate and supportive information and data collection instruments for data transfer. In addition, the planning and control measures for the application of the developed viable production control system together with the communication and referral pathways may be the object of further investigation, so that the requirements are supported by all stakeholders.

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