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# Increasing the Regulability of Production Planning and Control Systems

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**Abstract.** In an environment of constantly growing market dynamics and associated increasing complexity of company structures and their production processes, manufacturing companies are forced to adapt to this environment. Information technology is thereby a key for manufacturing companies to regain sovereignty over their own production processes. Digital networking via their own company and as well, the overall supply chain, can only succeed if digital planning reflects reality as accurately as possible and if production control can react to deviations in real time. In essence, this leads to a development of process control towards process regulation. While long-term production and resource planning is usually mapped by Enterprise Resource Planning (ERP) systems, detailed planning, including short-term deviations and real-time data at the production level, is increasingly supported by Manufacturing Execution Systems (MES) at the production control level. However, in order to bring the underlying system concepts into line with Industry 4.0 efforts in a standardized manner, mutual functional integration within the framework of interoperable production planning and control is of crucial importance. For this purpose, studies were carried out in particular into cause-effect relationships. Thus, the overarching research objective is a valid design model to increase the controllability of production planning and control systems (PPC) in the context of Industry 4.0.

**Keywords:** Production Management, Production Planning and Control (PPC), Enterprise Resource Planning, Manufacturing Execution, Management Cybernetics, Industrie 4.0 Maturity Index

## 1 Background

The increasing dynamics and corresponding fluctuations in market demands constantly promote the development of customer requirements and preferences to individualized products, which have to be manufactured in the shortest delivery time and nevertheless in highest quality [1-4]. This inevitably leads to an increasing range of variants with shortened product life cycles and at the same time, an increase in performance, flexibility and speed of the production processes [2-5]. This often results in decreasing order sizes and thus smaller batch sizes, so that the complexity of planning and controlling production processes and their handling is constantly increasing [6].

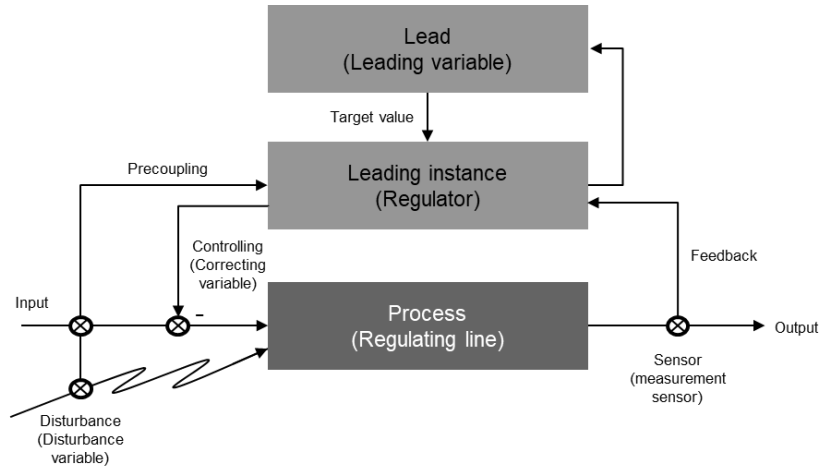
The central challenge in the area of production can be identified as mastery of the resulting complexity and dynamics with parallel rising demands on quality, real-time evaluations and cost pressure. In the future, companies will have to be able to make well-founded, decisions much more quickly based on valid data and information, which can only be done realistically in the production environment because of real-time data - which is processed in the corresponding production planning and control (PPC) systems. [2] Thus companies are in a highly dynamic environment that forces them to continuously increase their own, highly individual productivity and flexibility of their processes and information provision. In particular, this is to be achieved with necessary regard to digital development by supporting suitable operative application systems of PPC in order to secure a long-term existence on the market. [2] For this purpose, a design model is being developed by the authors, which will be described in this paper. Against the background of Industry 4.0 opportunities, this paper addresses the challenges of an increasing controllability of production planning and control systems.

## **2 Introduction**

Today, manufacturing companies are faced with the great challenge of digital networking of their entire production processes. In its implementation, however, the vision of Industry 4.0 turns out to be blurred, not transparent and diverse. The majority of these digitalization challenges arise from the constant demands for increasing process efficiency in the case of unforeseeable events due to non-existent ensuring of valid data quality for real time analysis and evaluation. However, this effort is often countered by poor communication based on insufficient data availability without any system support. A processing of average values with a simultaneous lack of responsiveness to information changes inevitably leads to a wrong decision basis along the planning process. This has a negative impact on production performance, costs and time. [7, 8]

A successful production planning and control process is characterized by its high process efficiency, the real-time availability of information and data in the right place at the right time [9]. Manufacturing companies are already generating and managing an enormous amount of raw data, usually in separate data silos. Thereby the associated data access, data cleansing, data aggregation, data filtering, data contextualization and data synchronization require great manual effort. With regard to cross-domain problems within PPC systems, missing context information, large amounts of data, low information density, limited access as well as the necessary industry knowledge for understanding and using the data are common problems and obstacles within the digital transformation. [7, 9]

Already during the data generation, a refinement must be carried out and an aggregated image (the digital shadow) must be stored, to which different operational application systems of the PPC have access [9]. However, for target-oriented processing of available real-time information by supporting PPC systems, it is imperative not only to control production processes, but rather to regulate them by using an adequate regulation model based on the feedback control loop (see figure 1).



**Fig. 1.** Feedback control loop of systems with cybernetic approach [10]

Therefore, the model approach for developing increased regulability of production planning and control processes by supporting suitable PPC systems in the context of Industry 4.0 levers is subsequently illustrated in this paper. The core objective is to analyse how business application systems can be used properly for digital development.

### 3 Methodological Approach and Preconditions

An essential precondition for the model is the availability of data and information in real time at the right place through the digital image, also called "digital shadow". This has already been improved through the use of various technologies such as barcodes and RFID tags. However, this crucial prerequisite can only be fulfilled by the integration and use of Cyber-Physical Systems (CPS). CPS systems migrate to Cyber-Physical Production Systems (CPPS) through Industry 4.0 and an integrated view of product, production equipment and production system in terms of model technology, architecture, communication technology and interaction, taking into account changing and changed processes. [11]

For this purpose, various scientific models have been analyzed for their applicability. In the scientific past, the Viable System Model (VSM) by Stafford Beer [12] has already established itself for this purpose of dealing with high company complexity and the dynamic environment of production companies. It defines on the one hand the necessary planning and regulation tasks by scientifically founded control mechanisms and on the other hand, the required and sufficient information for the production planning and control processes (see figure 2). Beer defines the viability as continuous conservation of system identity against the backdrop of continuously changing environment. [12] This definition applies to companies in Industry 4.0 transition, so the VSM is used as a conceptual framework.

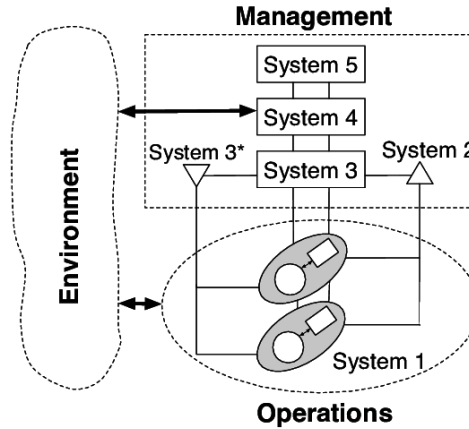


Fig. 2. Structure of the Viable System Model (VSM) [12]

In addition, it represents a promising production control approach for the design and functionality of complex systems. The focus of the VSM model is therefore on the enterprise, which is divided into the following five subsystems of a viable system [12]:

- System 1: Production, the operational units (value-added activities), these units must be viable for themselves.
- System 2: Coordination (of value-adding systems 1), place of self-organization of systems 1 among each other.
- System 3: Optimization (use of resources in the here and now), selective, supplementary procurement of information on the state of the operative systems.
- System 4: Future analysis and planning (resource planning for there and then), the world of options. It focuses on the future and the environment of the entire system.
- System 5: If System 3 and 4 are unable to agree on a common course, System 5 will make the final decision.

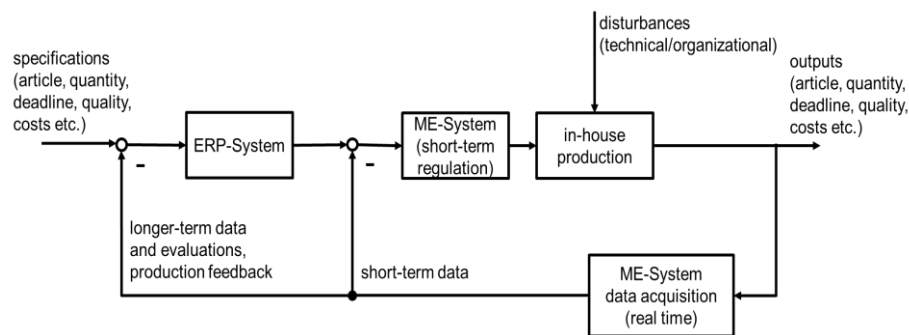
Based on the VSM model, the management model of versatile production systems has been developed [13]. In addition to cybernetic basic principles for control and regulation, this extended model includes the consideration of the essential sub-areas of order processing and production planning and control, based on the “Aachen PPC Model” [5, 13]. This scientific model describes four reference views of tasks, functions, processes and process architecture as the basis of PPC. According to this model, the increase of the regulatability of the operative production planning and control processes can be further explored with an extended research to the tasks and functions of the PPC. This analysis has been carried out with reference to scientific, technical literature as well as norms and standards of PPC systems.

## 4 Components of the Model

The constant development of cybernetic models for the control and regulation of companies, broken down into various business processes along the order processing with

their respective individual tasks and functions, reached its limits with regard to the digital degree of networking for the processing of real-time data. Only Industry 4.0 in direct interaction with the establishment of Cyber-Physical Systems (CPS) and Cyber-Physical Production Systems (CPPS) in production (see also chapter 3) creates a high level of transparency about the production process. This established the basis for the generation and aggregation of real-time data for the use and evaluation of operational application systems of the PPC, on which the model of regulation is based. [14]

This paper build up on existing approaches that broaden feedback control loops of ERP systems by integrating ME systems in order to increase the regulability (see figure 3). However, the remaining open question is how to efficiently align these PPC systems with each other.



**Fig. 3.** Regulation model: Feedback control loop with ERP system and MES [15]

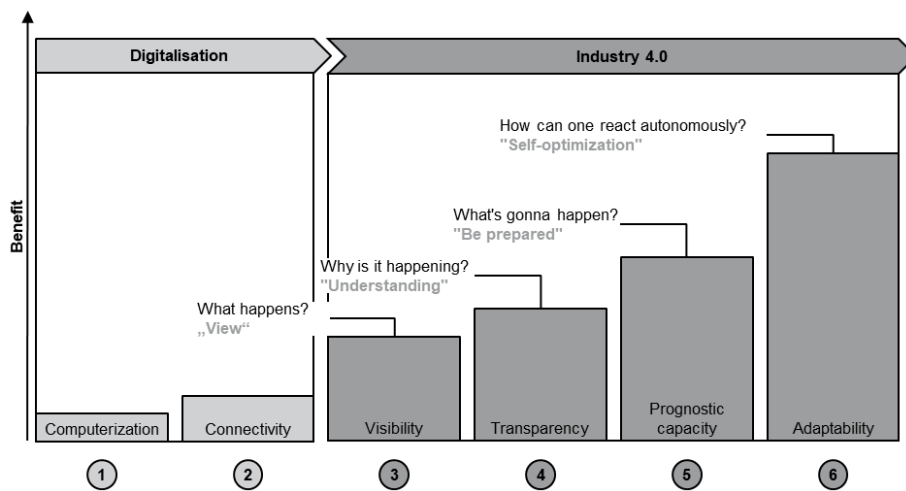
An ERP system is a pure input-output system and does not represent a possibility without further aids to establish a functioning regulation in an enterprise. For example, there are no automated decision proposals for changing inputs, let alone autonomous system interventions in existing master data. Until now, there is no approach to facilitate the integration of these benefits into ERP systems.

By merging the systems and its functional worlds at first, the basis for a functioning control loop can be laid in the PPC. By expanding the functional range of the PPC systems at first, it is possible to interact with real-time data from the production environment in addition to strategic planning and control and to establish a viable feedback loop of the information and data flow. In this regard, Manufacturing Execution Systems are currently established on the software market, which meet these requirements in many aspects. So far there has been no investigation into how companies benefit from the utilisation of MES in regard to a transition to Industry 4.0 via the feedback control loop .[15]

In this context focusing the scientific context, a research gap has been identified. There is still no analysis of which measures must be taken to firmly anchor this basic model of a feedback control loop within the PPC application software with regard to system tasks and functions. The comparison to the requirements of Industry 4.0 and the identification of the benefits is also missing, which would further lead to a comprehensive establishment in the corporate world. The main benefits of digital connectivity are to be illustrated by this study using scientific models. Finally, it must be examined in

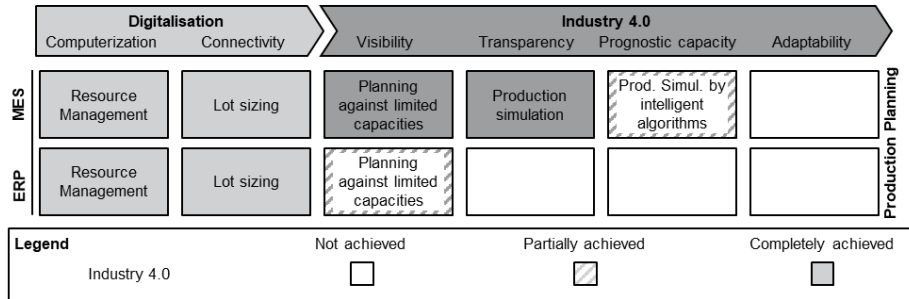
this context how dynamic market influences affect the adaptability of a feedback control loop according to the VSM approach.

To address this deficit, the “Industry 4.0 Maturity Index” has initially been developed by the highly reputable scientific institution “acatech” as German Academy of Science and Engineering to determine the utility of Industry 4.0. The Industrie 4.0 Maturity Index defines a multi-stage development path for the step-by-step further development of companies to Industry 4.0: Digitisation consists of computerisation and connectivity and forms the basis of the fourth industrial revolution. Even then, it includes the development levels of visibility, transparency, predictability and adaptability (see figure 4). [16]



**Fig. 4.** Stages of the Industry 4.0 Development Path [16]

The model corresponds to a directional instruction for the development, but does not indicate how this can be achieved, e.g. with regard to the use of PPC Systems. But along this development, it is now possible to analyse in principle how different the application systems influence the degree of networking of the respective business processes by analysing the different functions they use for mostly the same processes. In order to follow this logic, a differentiated analysis of the ERP and ME system functions is carried out along the standardized business processes of order processing for contract manufacturers. Due to the targeted consideration of the described system interface, the focus of the analysis is especially on in-house production planning and control as a core task of PPC. This study is based on the use of scientific literature, a. o. the VDI guideline 5600, and has been validated through expert discussions. As a representative example of the entire research, the task of detailed production planning, as a fundamental task of PPC systems, is described in more detail (see figure 5).



**Fig. 5.** Maturity comparison of the task "detailed production planning" in ERP and ME systems (own representation)

The difference becomes apparent in how far ERP and ME systems can support this task and how it effects the maturity level of the Industrie 4.0 Maturity Index. ERP systems usually plan against unlimited capacities. Nevertheless, there are already solutions, which are able to plan against limited capacities, thus enabling the visibility of machine utilization and other capacity-limiting variables. ERP systems, however, do not have functions to identify the causes of capacity bottlenecks. ME systems, on the other hand, plan against limited capacities as standard. The additional functional option of production simulation allows companies to identify interrelationships and causes on the one hand and make forecasts about future events on the other. [5, 17] In this way, an ME system achieves the level of transparency and in some cases even the level of forecasting capability in detailed production planning at various points. The extension of the functional spectrum of the PPC by the ME system leads to more precise and real-time information flows within the feedback control loop. Deviations from planning as well as external influences on the feedback control loop can be processed immediately. This also meets the requirements of adaptability and the viability of companies according to the VSM regulatory framework.

## 5 Outlook and further Research

In this paper, existing scientific models in the context of production regulation to derive fields of action for the future initiative Industry 4.0 has been discussed. Therefore the VSM as framework and the Aachen PPC Model has been used to present the scientific foundations for the guidance of organizations and their business divisions. In combination with the Industrie 4.0 Maturity Index and its maturity levels, it has been demonstrated, how business processes are supported by functions from the ERP system in the context of Industry 4.0 maturity. Moreover it has been exemplarily shown, how an extension of the task and function spectrum, e.g. by ME system functions within the in-house production planning and control, has a direct influence on the development of the Industry 4.0 maturity level. As a further research activity, all business processes as well as their tasks and functions must now be examined and a conclusion drawn about the possible extension of the operational application software. This is the only way to realize well-founded and precise recommendations for the design of IT-supported business processes on the development path to Industry 4.0.



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