Human Machine Cooperation in Smart Production: Evaluation of the Organizational Readiness

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***Abstract*—Cost pressure, competitiveness and the increasing turbulence of globalized saturated markets have been the driver for a variety of research activities in the field of production planning and control (PPC) during the past decades. For some time past an increasing awareness for introducing Information and Communication Technologies (ICT) and the Internet to industrial production can be noticed. This trend is synonymously called 'Smart Production', 'Industry 4.0' or 'Internet of Things' (IoT). The key aspect aims to improve the basis for planning by optimising the data quality to ensure a mastery of the turbulent planning environment. So-called cyber physical systems (CPS) form the basis of this approach and allow an intelligent networking and interaction of products, machines, storage systems, production resources and human employees. Although there are many promising approaches, a solely implementation of innovative smart IT-solutions will not be sufficient to prepare a company´s production for future changes. For a successful and effective realization of the IoT concept, important adaptions of existing organizational structures and processes are necessary. To accelerate the digital transformation, the requirements for a successful cooperation between human employees and technology within production planning and control need to be further analyzed and evaluated. This paper presents the key results of an extensive study that was conducted by the Laboratory for Machine Tools and Production Engineering (WZL) of the RWTH Aachen University to evaluate the current situation and examine the organizational readiness for the upcoming digital transformation. The study aims to show the need for action within different industries as a first step towards the digitized and networked production of the future.**

***Index Terms*—cyber-physical production system, digital transformation, industry 4.0, internet of things, IoT, production planning and control, human-machine cooperation**

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I. Introduction

Fluctuating market requirements as well as product individualization with accompanying individualization of process chains increasingly pressurize companies to implement highly efficient production processes [1]. Besides, today's globalized markets and the massive competitive pressure cause an increased importance of logistic performance regarding supplier evaluation. Thus, the compliance with delivery dates and delivery times are perceived as decisive differentiation features in a saturated buyers' market and occur as a basis for decision-making more and more [2]. The associated and necessary reduction of delivery times and the simultaneously increasing variance and complexity of manufacturing and assembly processes, combined with rising market dynamics, lead to an indispensable position of production planning and control (PPC) [1]. However, the fact that a high delivery punctuality is often not achieved, especially in customized individual and small series production, shows that current planning systems cannot perform the needed production flexibilisation, which is composed of complex production conditions, short-term changes to customer orders and other unpredictable planning deviations [3].

So far, various IT-Systems like Enterprise Resource Planning (ERP), Manufacturing Execution System (MES) or Advanced Planning and Scheduling (APS) have been established in production control [2]. These systems offer a different functional scope and level of detail, but often they cannot guarantee a high logistic performance contrasting manufacturers' promises [4]. On the one hand, that is due to an inadequate data quality and granularity on the basis of which the above-mentioned IT-Systems operate. Because of inconsistent or even wrong records, just as insufficient level of detail, it can lead to a failure of the overall system. On the other hand, the required time such as the total effort between data collection and its

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processing and data analysis is too high for an adequate reaction rate to be ensured. The resulting lack of process transparency causes that the production planner has no sufficient and particularly no assured planning and decision-making basis available. Nevertheless, planning decisions are nowadays mostly based on assessments and experience of the responsible employee of the production control, although there is already an existing extensive use of IT-Systems [5].

The concept of Smart Production, also known as 'Smart Factory', 'Internet of Production' or 'Industry 4.0' mainly in Germany, aims to integrate so-called cyber-physical systems (CPS) into the actual production process and the associated construction of an intelligent network based on 'Internet of Things' [6, 7].

Hence, the main goal of Industry 4.0 is to improve the above described planning basis by optimizing the data quality and granularity and thus to ensure mastery of the turbulent planning environment [8, 9]. In this case, the cyber-physical systems form the basis and link products, machines, storage systems and resources with each other. By networking the listed production units, they are able to collect and exchange information self-sufficiently, to simulate action scenarios and thereby to support the responsible decision-maker through generated suggestions. CPS are even able to act independently within a limited framework, so that a semi-autonomous control of all production processes is made possible. Further, the real-time process transparency gained through the accumulation of information ensures that decisions must be made at shorter intervals in order to react appropriately to process and environment instabilities [6].

Considering the described possibilities, the production control is facing a radical change, since the central challenges as mentioned above require a breakup of existing organizational structures. The innovative production control systems, which go with Industry 4.0, ensure an increased product transparency by multiplication of data as well as real-time capability, so that the resulting strongly rising data volume will lead to an intensification of decentral handled decisions. In the future, decentralized decision-making instances will more focus on the employees as the leading decision-makers [9].

Consequently, there are many challenges to remain competitive in Germany and Europe as production location regarding the established production control. This market pull view describes the need for new, innovative technologies that increase the performance of the production control system and is individual adaption to the needs of the company. On the other hand, there is the technology push view with ever-faster developments, especially in the field of CPS [10]. Particularly in mechanical engineering and plant engineering, which show a highly individualized and highly flexible production, it is most likely that so-called 'dark factories', otherwise known as 'automatic factories' or 'lights-out factories' [11], will not establish. Rather, future production systems must be understood as highly interactive socio-technical concepts. It can be assumed that, especially in a high-wage country like Germany, the demographic change as well as the lack of experts and the rising need for a fair work-life-balance cause that knowledge-based activities will play an increasingly central role for production. As a result, the employee as the leading decision-maker needs to be integrated in the operation method of a cyber-physical system [12].

Consequently, the challenge for companies, especially in medium-sized mechanical engineering and plant engineering companies, is to find the right balance between their individual needs (market pull) and the available technological possibilities (technology push). A solely implementation of innovative technology solutions is generally not sufficient to make the most of the potential. Production management is often limited by historically evolved organizational structures and processes, which are not suitable to use cyber-physical systems to the full extend. In order to ensure success in the long term, a systematically coordinated cooperation between employees and technology is required. The present study investigates the path to an ideal form of cooperation and design options for the configuration of a cyber-physical production control of the future.

II. Purpose of the Study

The target of the study, conducted by the WZL of the RWTH Aachen University, was to investigate the need for systematically developed cooperation models to exploit the potential of cyber-physical production control. For further research, the current state of production planning and control in German manufacturing companies has to be evaluated and the need for action has to be clarified. Therefore, the conducted study was structured in three parts. Firstly, the impact of new technological possibilities in context of Industry 4.0 on production control was to be evaluated. Furthermore, the need of necessary adjustments for the established cooperation processes between human operators and technological applications was identified. Finally, the influencing factors on designing these cooperation processes were specified.

III. Design and Concudtion of the Study

The conception and implementation of the study is based on a five-step methodology according to Sproull [13]. In addition to the operationalization of the interrelationships and the selection of the analysis units just as of the totality of the analysis, the procedure for the creation of the questionnaire and the pretest as well as the actual data collection are the central elements for carrying out a statistical hypothesis test.

Four central hypotheses were developed to examine the problems described above. These were formed based on an extensive literature research and observations in the industry and were confirmed by various expert talks. In detail, the following hypotheses were tested by the study:

Hypothesis 1: "The relevance of an intelligent network of decentralized control mechanisms will increase in the future."

This first hypothesis displays the conjecture on the one hand, that decision-making in production will increasingly occur at the shopfloor, but will be resolved decentral there at the same time. This especially concerns short-term decisions, but above all the behavior in case of a failure or deviation from the plan. On the other hand, this first hypothesis states that an increased use of intelligent networking of people and objects (machines, products, IT-Systems) leads to a shorter reaction time of production control in any case of failure.

Hypothesis 2: "The established forms of cooperation in production control are not suitable for optimally utilizing the CPS potential."

The second hypothesis already examines the immediate situation in the production control of the surveyed companies. There is the presumption that existing forms of cooperation between human operators and technology within production control cannot optimally exploit the potential of cyber-physical systems for a fast and flexible reaction. This means that the solely use of new technologies does not automatically lead to an improvement in the capacity of production control, but rather that there is a need for a systematic construction of cooperation forms and their core processes.

Hypothesis 3: "Companies to not know how a cooperative model for cyber-physical production control can be designed systematically."

The third hypothesis reaffirms and clarifies the need for action, which has already been demonstrated. It is assumed that many companies know that an adaption of their forms of cooperation within cyber-physical production control is necessary, but they do not know how to develop such a model systematically. Thus, this hypothesis confirms the relevance of the scientific project and shows the benefit for a subsequent implementation of the research results in practice.

Hypothesis 4: "The development of a cooperation model depends on the level of digitalization in production control."

Finally, the last hypothesis already examines a first influential factor on the solution of the cooperation model. Therefore, it is assumed that especially the individual level of digitalization of companies, particularly in their production control, must be taken into account in the actual development. In addition to this, further influential factors on the creation of several models are investigated explorative in the course of the study.

The said hypotheses were transferred to a questionnaire according to the methodology after Sproull mentioned above. Before the questionnaires were sent out, the study was carefully examined in a pretest by several scientific employees of the Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University and with an industrial company. The study was sent to a total of 6,700 contacts in industry from Germany, Austria and Switzerland, and was performed from December 2015 to February 2016. A total of 371 questionnaires were returned from the contacted people, which corresponds to a return rate of 5.5%. Since some were returned insufficiently completed, a final sample size of 282 questionnaires could be evaluated.

IV. Results of the Study

A first evaluation of the results shows that the majority of the returned questionnaires comes from companies in the mechanical and plant engineering sector with 39% (Fig. 1). Therefore, this sample reflects the study area of the investigation very well, since the research questions to be examined are to be referred mainly from small and medium-sized companies from this industrial sector.

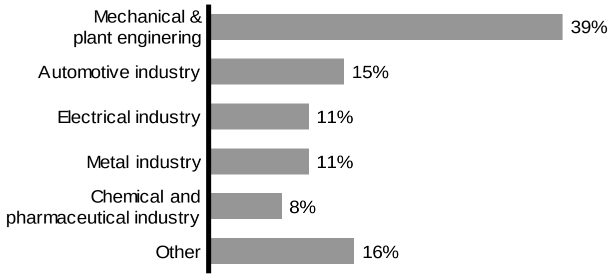

Figure 1. Industry sectors of the surveyed companies

A similar result was obtained by the product structure of the examined companies. Two thirds of the surveyed companies indicate to produce mainly or even only customized products (Fig. 2). Therefore, this also shows the importance of the study for companies with single and small batch production. It is assumed that deviations from plan or unscheduled disturbances will occur permanently, especially in the very customer-specific production of medium-sized companies, which require a fast and flexible response of the decentralized production control. For that reason, the chosen sample provides a good representation of the current situation in production control of German enterprises.

The first hypothesis can be examined with two questions. The participants were asked separately about the potential of decentralized control mechanisms as well as of an increase of the degree of networking in production control. Thus, 66% of the respondents said that they see an increase of decentralized decision-making for the future (Fig. 3). Mechanical engineering and plant engineering companies agree to that point with 67% in total, which is only slightly above the average.

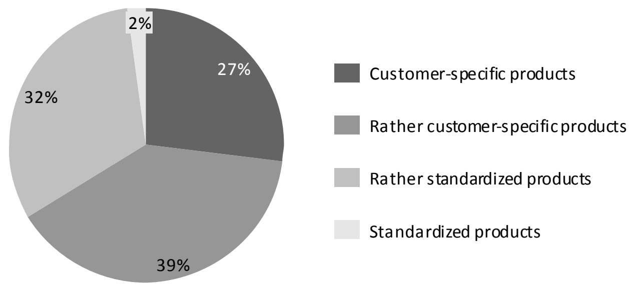

Figure 2. Product structure of the surveyed companies

The second part of the hypothesis can be examined by questioning the potential of networking. In total, 92% of the surveyed companies stated that intelligent networking would increase the speed as well as the flexibility of production control, so that only slight differences occur between the various branches of industry again. If now both questions are merged, it makes sense that German companies see a big potential in intelligent networking of decentralized control mechanisms regardless of their industry sector. Consequently, the first hypothesis was confirmed and forms the basis of further investigations.

The second and third hypotheses were used to examine the surveyed companies' need for action to develop new cooperative ways of working between human operators and technology in production control. 61% state that their established cooperation processes within production control are not suitable for using the potential of innovative cyber-physical systems optimally (Fig. 4).

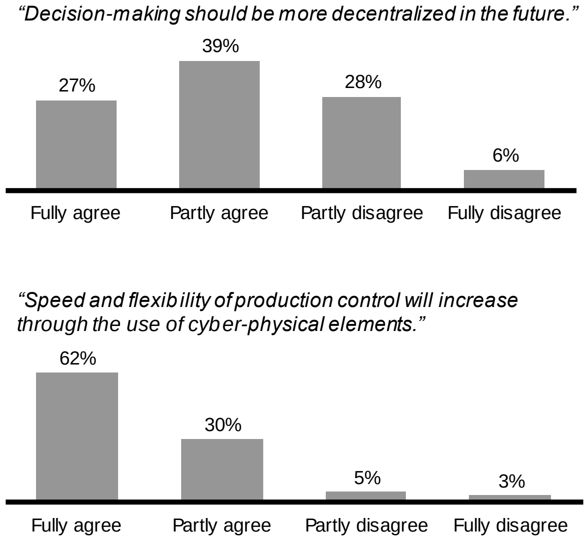

Figure 3. Relevance of cyber-physical systems in production control

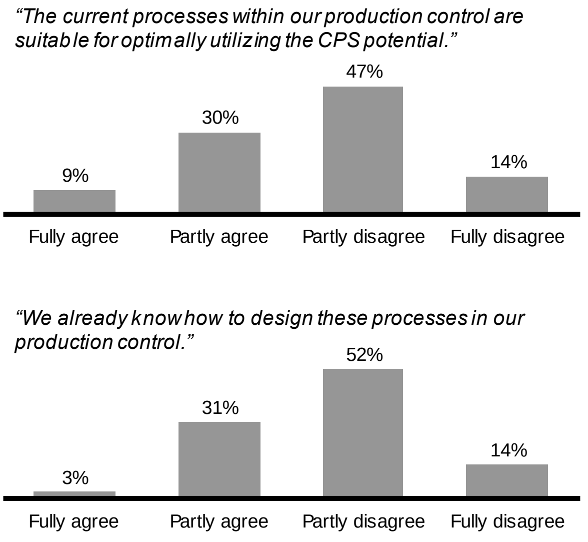

Figure 4: Lacking concepts to design cooperation in production control

Thereby, the second hypothesis can be confirmed, which shows that there is a higher research need to develop new cooperation models, especially to offer added value for the industry in order to extend the competitiveness and the ability to produce flexibly and cost-effectively in the future. This finding is also confirmed by the evaluation of the next question, in which two-thirds (66%) of the previously identified companies with an inadequate cooperation process state that they do not know how to design these processes so that the potential of cyber-physical systems can be used. Thus, the third hypothesis can be confirmed as well.

Although a majority of the surveyed companies is uncertain about establishing new cooperation processes in the future, a clear tendency towards the orientation of the processes to be developed can be observed. Because 87% of the companies state that cooperation within production control should be oriented on the individual level of digitalization of each company (Fig. 5), which can be determined by the extent to which digital technologies are used in production control. Also, in this point companies from different sizes or industrial branches are in agreement, so that the validation of the fourth hypothesis can already be seen as a core element of a possible further research approach. Thus, the adaption to the individual level of detail will play a leading role while developing requirements for human machine cooperation in production control. However, to make this possible at all, the level of digitalization must be made measurable beforehand, which might be a second preceded component of the later approach.

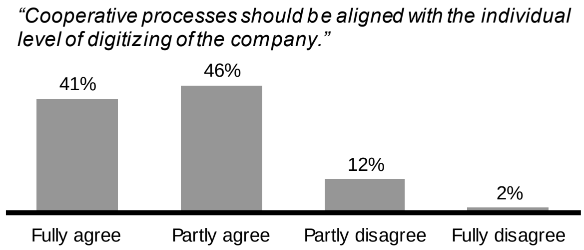

Figure 5. Correlation of the level of digitalization

In addition to the level of digitalization, the study also investigated other possible influencing factors for the conception of a cooperation model (Fig. 6). When evaluating the results, it is noticeable that three factors have a comparatively high influence on the cooperation models: production structure, corporate culture, and the decentralization of production control. About 90% of the participants state that the production structure has a strong or even very strong influence on the conception of the cooperation model in production control. This may be because production control is very different depending on the production structure, especially since the detailed objectives and tasks of the employees can be highly variable. For example, in the control of serial production, the focus is on the utilization of the lead times compared to the workshop production, which is rather confronted with short-term changes in the production process. This is closely linked to the decentralization of production control, since 81% of the surveyed companies expect a strong or even very strong influence on the cooperation model. Again, the different objectives and tasks of production control are linked to the decentralization of the control system.

The corporate culture is perceived as a soft (or less measureable) influencing factor by 86% and will have to be particularly taken into account in the further research for developing a suitable cooperation approach. A much smaller

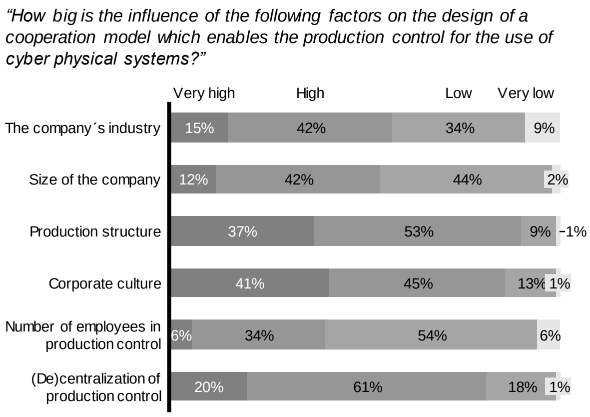

Figure 6. Factors influencing the conception of a cooperation model

impact is expected from the industry sector or size of the companies as well as from the number of employees in production control. The achieved results show only a first indicator for the research approach, but not a complete listing of influencing factors on the conception of a cooperation model, which are to be examined in detail in subsequent research projects. However, the focus should be on the factors of the production structure and the decentralization of the control, as well as on the level of digitalization of production control.

V. Conclusion

The study has confirmed that a majority of companies in the German industry expect a huge impact of new technologies of the internet of production or Industry 4.0. Those cyber-physical systems will change the established cooperation between human operators and machines especially in production control in a dramatically way. Most companies don´t see their current organizational processes to be suitable to already use the enormous potential of cyber-physical systems. It seems to be alarming that two-thirds of these companies don´t even know how to adapt their production control to make use of this potential. For this reason, further research has to be carried out to provide methods for adapting cooperation processes within production control and to perform a target oriented digital transformation. The Laboratory of Machine Tools and Production Engineering (WZL) of the RWTH Aachen University has already started to further examine this need for action and to develop a first approach for designing the cognitive cooperation between human operators and technology in production control.

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