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Collaboration Mechanisms to increase Productivity in the Context of Industrie 4.0

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Abstract

In retrospective industrial revolutions always lead to a significant increase in productivity. Thus, the question arises what mechanisms contribute to raise productivity in the current revolution "Industrie 4.0". Whereas the initial point of all past industrial revolutions can be located in the industry, they resulted in a tremendous change in society. In the present industrial revolution it is the other way around: Reviewing the beginning of the current transformation process, it is not driven by the production industry itself. Instead one of its main drivers is the invention of social networks and smart devices in combination with the employees' appealing to it. This development of interconnectivity pushes into the industrial sector today. For instance, there exists a desire of employees to bring their own device to work. According to a survey by Accenture 82 percent of the Chinese respondents would be "more resourceful" if they chose their own hardware and software for work. The first three revolutions had a strong focus on the shop-floor. This is also true for the present industrial revolution: The public view is merely on its impact on production processes. Therefore, this paper expands this view and additionally analyses the effects of the relating transformation processes to the indirect departments. The paper first analyses the enablers which mainly contribute to Industrie 4.0. Subsequently a reference systems is deduced which consists of basic collaboration mechanisms to increase productivity in the direct and indirect departments. A wide transparency and understanding of those collaboration mechanisms empower producing companies to profit from Industrie 4.0 by deriving individual activities which lead to a growth in productivity and therefore competitiveness. The specified approaches were conducted within the framework of the Cluster of Excellence "Integrative Production Technology for High-Wage Countries" of the RWTH Aachen University.

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Keywords: Collaboration, Mechanisms, Productivity, Industrie 4.0

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1. Introduction

The core of every industrial revolution is an increase in productivity [1]. Previous industrial revolutions had a strong impact on the "shop-floor"-level and production processes itself. Companies gained a higher productivity through the utilization of the steam engine, electricity as well as the shift from analogue to digital technology for example [1]. The impact of the fourth industrial revolution, however, is more extensive and it affects apart from production also the indirect departments, especially engineering processes. That means that the potential of productivity growth particularly lies in the improvement of brainwork and decision making processes. Collaboration at all levels can help to accelerate this process.

Therefore, this paper proposes that one core characteristic of Industrie 4.0 is raising collaboration productivity across departments which can lead to a better competitiveness of companies. Accordingly, this paper examines the essential enablers of Industrie 4.0 as well as the underlying mechanisms to increase collaboration productivity.

2. Industrie 4.0 enables Collaboration Productivity

Literature corresponding to the current industrial change differs widely and often addresses highly diverse aspects of Industrie 4.0 [2][3][4]. In most cases their common ground is that they are motivated by the high potential of productivity growth that bears this transformation process. However, the producing industry itself is responsible to initiate measures to

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profit from the social and technological change [5]. In order to do so, this paper proposes to create necessary preconditions in the production system. The required preconditions in a production system can be classified on two levels: The first level is the allocation to the cyber or the physical world and the second is the distinction between hard or soft component. This categorisation leads to four main preconditions, which are portrayed in Fig. 1 as enablers: IT-Globalisation, single source of truth, automation and cooperation.

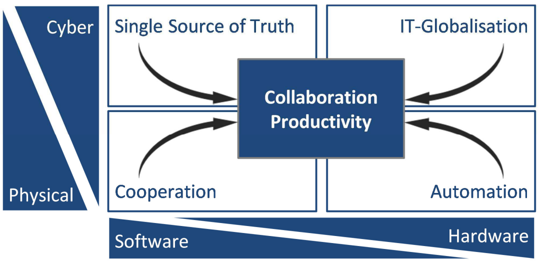

Fig. 1. Enabler of collaboration productivity

The realisation of these enablers is the technological and organisational foundation to eventually realise collaboration productivity as the major source of productivity growth in Industrie 4.0. The understanding of collaboration within this paper involves the jointly work on human-human, machine-human and machine-machine level and goes beyond the regular definition in dictionaries [1][6].

The four enablers are analysed in detail in the following in order to create a better understanding for the preconditions of collaboration productivity in the context of Industrie 4.0.

1) *IT-Globalisation:* One key enabler relates to the potential and advantages of computers whose impact on economic growth in the past was very large in comparison to their share of capital stock or investment and is likely to increase further in the following years [7]. Therefore computing power and global information technology (IT) need to be considered and promoted by producing companies. The advancement of both storage capacity and high speed computing is immense and is continuously raising [8]. In future it will be possible to store data in such a global cloud system where it can be recalled fast and independently from any local place.

2) *Single Source of Truth:* In order to be able to use simulations as decision tool, they need to be embedded in the right software environment. That is why the simultaneous development of software systems plays a significant role for preparing Industrie 4.0. On the basis of the improving hardware, the chance to ensure a complete product lifecycle management (PLM) software emerges, in which all product information along the value chain is available [9]. Thereby, “single source of truth” needs to be realised across the complete lifecycle which avoids ambiguity and assures that any change of product and production relevant information is visible [10] [11]. It is needed to allow a reporting and decision support that is valid and consistent across the organisation [12].

3) *Automation:* Another enabler for Industrie 4.0 is the advancement of the performance of decentralised and autonomous processes collaborating in networks [13]. This becomes possible by linking the virtual world with the physical environment by cyber-physical systems (CPS) which embed computers, sensors and actuators into an application platform [14]. The integration of information and communication technology into the industrial environment is also referred to as Internet of Things [15]. On the one hand, automation of production systems requires intelligent and self-optimising components by adapting the systems behaviour to dynamic objectives in technological and organisational area as already appearing in smart factories [16]. On the other hand, it is important to properly integrate the employee into such an autonomous system where especially highly qualified and skilled workers best fit into. If necessary the gap between technological and organisational progress needs to be closed by investing in advanced training and knowledge which usually is a time consuming approach [17].

4) *Cooperation*: The fourth main enabler in the physical world is the soft component of cooperation across all borders, technologies and activities. For instance, at Thiokol, a major supplier for NASA’s Space Shuttle Program, collaborative practices between different workstations lead to a reduction of product development lead-time of 50% [18]. A stronger cooperation can be established firstly by cultivating a network in order to communicate the overall target and secondly by empowerment of decision-makers in a decentralised system [5]. Such an open network can be supported by stimulating the exchange of the employees or by approving the use of private smart devices. According to a survey by Accenture, 82 percent of Chinese respondents would be “more resourceful” if they chose their own hardware and software for work [19].

The four enablers influence and depend on each other. For example the use of simulations based on big data is not possible without ensuring big storage capacities. And automation is not working properly if the cooperation between machines, workers and between human and machines is not assured. That is why in preparation of Industrie 4.0 the simultaneous development of all four fields is necessary.

3. The Reference System of Collaboration Productivity

After having established necessary preconditions on a cyber or physical level for soft as well as hard components, a reference system is needed to describe mechanisms which may lead to collaboration productivity. Accordingly, such a construct is deduced in this chapter. First the core elements are defined and secondly the symmetries are discussed which these elements are following.

3.1. Core Elements to Increase Collaboration Productivity

The superior target of a raise in collaboration productivity in the context of Industrie 4.0 is lower costs per piece. In order to measure this target and understand the correlations it is necessary to measure the effects in both core areas of a producing company – the production and the engineering. The two superior ratios are:

1) Return on production and
2) return on engineering.

This ensures that a wide spectrum of activities of producing companies is covered: direct and indirect departments.

The core of both productivity improvements is an enhancement of the decision-making ability. Return on engineering lowers straight from the beginning costs per piece: Through a qualitatively better and significantly faster development process the development costs are lower, so that every manufactured piece costs less in the end. Return on production on the contrary enables lower costs per piece at a posterior stage in the lifetime cycle of a product: Through continuously improving production processes in combination with shorter process chains, costs per piece decrease with every manufactured unit. Return on production and return on engineering are made possible through four core mechanisms which are object of research within the Cluster of Excellence "Integrative Production Technology for High-Wage Countries" [20]. These four mechanisms were confirmed as main fields of action through interviews with leading decisions makers from the industry.

On the production side, the two major mechanisms are integration and self-optimisation. Integration means a revolutionary short value chain. Through an improved information basis and decision-making ability more functions can be integrated and combined in one process step or person [6]. Moreover collaboration enables more employees to work together in order to address challenges in different areas [18]. Self-optimisation means that one can improve beyond the theoretical boundaries and therefore become better as expected. Cybernetic effects and structural changes of the system at the right time can change the parameters and framework conditions to constantly improve the production system [16].

On the engineering side, the two major mechanisms are a radically shortened product engineering process as well as a complete virtual value chain. The shortened product engineering process addresses an improvement in time and flexibility regarding the product development. Approaches such as Scrum in combination with a decent staff qualification enable small, interdisciplinary teams to become faster and to handle complexity better [21]. The virtual copying of a complete value chain allows the use of simulations as decision support. As the solution space is frequently too large, complex and variable for a single person to oversee and fully understand [22], simulations clarify the decision space and offer the possibility to considerably improve the decision-making quality by a fast and easy creating of scenarios.

3.2. Symmetries of the Reference System of Collaboration Productivity

The described mechanisms are based on different approaches which exist of certain dichotomies. Therefore the reference system shows a particular symmetry which links each mechanism with the other mechanisms. This will be explained in the following.

1) The first dichotomy consists of the two core elements of the reference system, as described in section 3.1: Return on engineering and return on production are complements and therefore both need to be considered and aimed for in a production system. Whereas the former aims at an increase of overhead productivity in the indirect departments by shortening the product development process and by virtual decision support, the latter refers to the efficiency in the production processes by accelerating the production process and self-optimising production systems.

2) Secondly, there are the two dichotomies scale and scope, and plan and value, which are also called the polylemma of production [20]. Scale and scope deal with the quantity which is optimal to develop and produce. When shortening both the product development process as well as the production process, a balance needs to be found between scale effects and flexible customisation. Plan and value consider the effort of planning in contrast to the added value. The producing industry has always to find its position in the field of tension between production and planning profitability by investing the right amount of effort in either virtual planning or the creation of value by means of self-learning effects [20].

3) The last dichotomy includes deterministic and cybernetic models. They refer to the handling of production control. Cybernetic models are rule-based and can adapt to boundary conditions dynamically, as desired when the focus lies on the shortening of the product development process or on the improvement of the performance. However, this approach prioritises the overall target and neglect specific due times such as delivery dates [23]. In contrast, deterministic production control as the name suggests determines certain parameters from the beginning, for instance an exact starting time for a manufacturing order. This approach needs high processing power and corresponds to the virtual engineering of the complete value chain and the increase of productivity in the production processes. However, in order to be able to plan the whole production system on the one hand, and to control its dynamic on the other hand, it can be necessary to follow both strategies.

The previously depicted coherences of the core elements to increase collaboration productivity as well as their symmetries are summarised in the following Fig. 2.

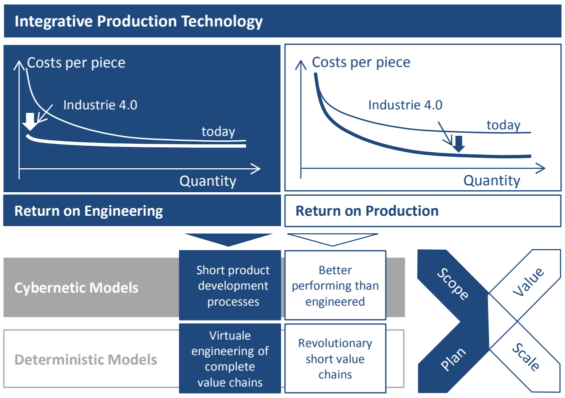

Fig. 2. Symmetries of the reference system of collaboration productivity

4. Mechanisms of Increasing Productivity

Regarding the described reference system of collaboration productivity in section 3, there exist four major mechanisms in the context of Industrie 4.0 which contribute to a raise in (collaboration) productivity. Those mechanisms will be outlined in the following and directly associated with their benefits. In order to further clarify the effects and enable an evaluation of progress key performance indicators (KPI) are derived.

4.1. Radically Short Product Development Processes

Today, disruptive innovations increasingly occur in the business environment [10]. Thus, the lifecycle of many products is often shortened abruptly because they are suddenly forced from the market place. In order to keep up with the competitor's speed of innovations it is essential for a company to radically compress its product development process. With Industrie 4.0 new technologies, for example new tool machining concepts, merge which can help to minimise the length of time to develop products [24]. Industrie 4.0 includes a higher priority on individualised products which means higher customised products, more variants and smaller quantities of the same product [25] [24].The potential lies firstly in prototypes. By focusing more on prototypes when producing tools, products can be manufactured at an earlier stage of the value chain. Even if the prototypes of tools and machine tools need to be adjusted and optimised within the process which means a disruptive invest there still can be expected a higher profit due to the earlier time-to-market. Furthermore, it means a raise in flexibility as the tool can be changed during the process in order to conduct necessary changes on the product. Secondly, it is important to generate inventions and potential innovations faster. Building small, interdisciplinary teams like in the Scrum Theory helps to systematically realise new innovations [21].

In Fig. 3 the curve of the well-known product lifecycle is displayed against the radically shortened one which bears a high potential in a higher profit [26]. The former begins with a high invest in the introduction phase, then grows steeply and finally approaches to a maximum in the stage of maturity. The latter which refers to Industrie 4.0 starts with the alternation of smaller invests and profiting, then starts to grow to an earlier point of time and closes with an even higher maximum of profit.

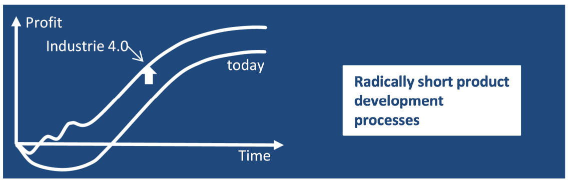

Fig. 3. Radically short development processes

Thus, the lead time of a product from its idea to its start of production (SOP) needs to be considered as 'Return on Engineering 1' (ROE_1), see Fig. 4. It is the direct indicator for the performance of the product development process. By concentrating on the time of development and shortening its length companies will strengthen their competitiveness.

$$ROE_1 = Lead\ Time(Idea\ until\ SOP)$$

Fig. 4. Return on Engineering (ROE_1)

4.2. Virtual Engineering of Complete Value Chains

Nowadays the chance to reproduce the complexity of the whole value chain exists for the first time. For example, the software tool OptiWo can depict global production networks in a holistic way and helps to optimise their complete design and setup [27]. Concerning periods of days and weeks those reproductions are real-time capable. A complete virtual value chain offers several advantages of which one is transparency. Problems and bottlenecks in the workflow can directly be detected. Furthermore, the whole process chain with its output and performance is presented in detail. This allows drawing conclusions about the key elements which influence the overall target. The virtual reproduction of the complete value chain offers advantages especially for the development department. In the fields of quality management it is known that this is where 75 percent of the faults originate [28]. With the combination of simulations products can iteratively be developed. That means while developing a product, its production can simultaneously be simulated, so that barriers can be exposed and eliminated from the beginning. This is also called Virtual Tryout [29].

However, decision makers need to trust simulations in order to be able to use their results as decision support. Until now, difficult and complex decisions require to think through all possibilities. According to Bernoulli, the quadrupling of scenarios doubles the quality of the result [30]. Hence, this correlation can be transferred to simulations and means that the multiplying of a smaller number of simulations does have a stronger effect to the decision capability as the multiplying of large numbers of simulations. This is portrayed in Fig. 5. Overall, the decision maker can trust the result of simulations better when he conducts a larger number of simulations.

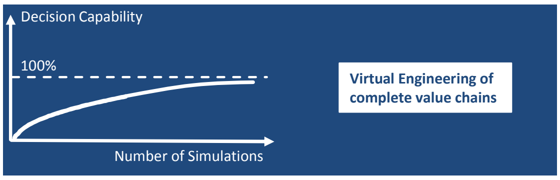

Fig. 5. Virtual Engineering of complete value chains

In order to profit from the possibility and availability of simulations it is important to focus on the time which is needed to create a simulation result, as displayed by the second key performance indicator 'Return on Engineering 2' (ROE_2) in Fig. 6. The faster a high number of simulations can be conducted the faster a result of high quality is generated.

$$ROE_2 = Time\ to\ create\ a\ Simulation\ result$$

Fig. 6. Return on Engineering$_2$ (ROE_2)

4.3. Revolutionary Short Value Chains

Due to the trend of more customisation the variants in several branches increase. In the automobile industry, for instance, it is offered an immense number of over 15 billion variants of the Ford Fusion [31]. That means the operation of production and assembly lines becomes increasingly difficult. Machines are usually able to execute only one distinct task and lack the integration of multiple functions. The production of different variants in one production line raises the complexity of the production system significantly. That is why machines in the near future are supposed to integrate different functionalities and processing steps. For example, the combination of a milling machine with a robot that simultaneously trims a component can economise non-productive time [32]. Also multi-technology products can save processing steps. For instance, conducting paths that are insert-moulded into the final form of a product save the processing step of joining [32]. Thus, shortening the production processes in the context of Industrie 4.0 means a reversion of Taylorism, as described in the following as Taylor^{-1}. Whereas the return on production during the second industrial revolution was generated by an assembly line [33], this industrial revolution decreases the amount of deployed production and assembly lines and establishes production cells. Autonomous production and assembly cells structurally require a decentralisation and concerning the responsibility of employees an empowerment of decision-making, as described in section 2. Moreover, it is necessary that all contributors of one process cell collaborate with each other.

However, as shown in Fig. 7, there exists an optimum in the number of contributors or process steps in one cell which keeps the process efficient. All levels outside this interval result in an increase in costs per piece. In contrast to Taylorism, Taylor^{-1} decreases the costs per piece the less contributors take part in the process or the less process steps are needed, however with a lower limit. Thus, Taylorism loses its significance, as a demand for customisation arises.

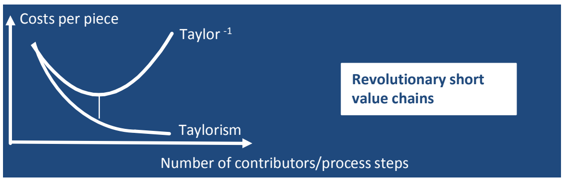

Fig. 7. Revolutionary short value chains

Therefore, the first KPI of Return on Production (ROP_1) is the number of process steps or contributors see Fig. 8. As a result, customising products and simultaneously decreasing the costs per piece can be reached by focussing on the number of process steps.

$$ROP_1 = \text{Number of process steps/process chains}$$

Fig. 8. Return on Production$_1$ (ROP_1)

4.4. Better Performing Than Engineered

Complete self-optimising production systems are theoretically already possible [23]. Until now only their implementation fails as the enablers from section 2 are not yet established. Once selfoptimising production systems are working accurately they reduce the workload and efficiently work at the optimal operating point. With their high flexibility and reactivity they can adapt to sudden impacts or changes in the production process. Already existing self-learning machines can only reach the theoretically expected maximum. The advantage of self-optimising systems of the future is their aim for an even higher goal. In fact they are supposed to be constructed in such a way that they surpass the previously expected efficiency. In order to enable such an efficient system, it is necessary to consider cybernetic effects. That means, the structural change of the system as a result of considering different boundary conditions enables new opening possibilities. This implies to approach sudden changes from a different perspective. They can be used to improve the system by adjusting its structures and rules. An assembly line with a natively planned output of 20.000 units and an improved output of 25.000 units after one year using the same resources can serve as a theoretical example.

Fig. 9 shows the previously expected productivity by self-learning systems. It is oriented to the self-learning curve. In contrast, the curve of potential productivity of selfoptimising systems of the future is shown. It portrays the possibility of surpassing the previously planned productivity.

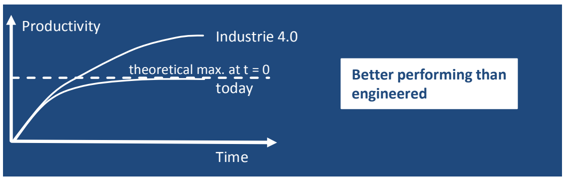

Fig. 9. Better performing than engineered

The key performance indicator for a self-optimising production system is therefore the relation of the realisable productivity to the predicted maximal productivity before SOP. This Return on Production 2 (ROP_2) is displayed in the following Fig. 10.

$$ROP_2 = \frac{\mathit{Productivity\ (Number\ of\ pieces\ n)}}{\mathit{max.\ predictable\ Productivity\ (at\ point\ of\ time = 0)}} > 1$$

Fig. 10. Return on Production$_2$ (ROP_2)

All introduced KPIs and graphs have to be considered as an abstraction of the set of problems in reality. However, they contribute to gain a better understanding of Industrie 4.0 and the underlying mechanisms that empower the (collaboration) productivity growth. This does not only help for future research but also provides a first guideline for the industry.

5. Conclusion

This paper pursues the vision that one core characteristic of Industrie 4.0 is a raise in collaboration productivity. Accordingly, four main enablers as preconditions for Industrie 4.0 and collaboration are introduced. In the following this paper derives a reference system with underlying mechanisms for enabling collaboration productivity. This reference system consists of the two indicators "return on engineering" and "return on production". Within both indicators concrete mechanisms to increase productivity are suggested and the symmetrical structure of the reference system is described. The engineering-oriented mechanisms as well as the production-oriented mechanisms are depicted in detail and corresponding key performance indicators are derived.

Future research will focus on the empirical validation of the depicted key performance indicators in order to strengthen the pursued vision.

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