

The 22nd CIRP conference on Life Cycle Engineering

Increasing collaboration productivity for sustainable production systems

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Abstract

Due to the potentials of Industrie 4.0 such as cyber-physical systems, manufacturing companies will connect their intelligent products and machines. The resulting smart factory enables integrated engineering across the entire value chain. Furthermore, intelligent assistance systems will support employees so that they can focus on value adding activities. Within the Cluster of Excellence “Integrative Production Technology for High-Wage Countries” of the RWTH Aachen University, which is funded by the German Research Foundation DFG, four mechanisms were developed regarding these current developments to increase collaboration productivity and therefore facilitate a sustainable production system. The mechanisms “radically short product development processes”, “virtual engineering of complete value chains”, “better performing than engineered” and “revolutionary short value chains” do not only improve manufacturing processes but also product development processes and thus meet current challenges as resource and energy efficiency.

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Peer-review under responsibility of the scientific committee of The 22nd CIRP conference on Life Cycle Engineering

Keywords: Productivity; Sustainability; Manufacturing; Collaboration

1. Introduction

Industrie 4.0 is part of the high-tech strategy of the German government, which promotes the computerization of the manufacturing industry [1]. The target of this project is to realize the so-called Smart Factory, describing an intelligent and adaptable factory, which increases collaboration productivity as well as energy- and resource-efficiency. To implement this strategy the characteristics of cyber-physical systems and the Internet of Things are used [2]. These approaches are also applied in other projects, e.g. the Smart Manufacturing Leadership Coalition in the United States [3].

The Cluster of Excellence “Integrative Production Technology for High-Wage Countries” of the RWTH Aachen University, which is funded by the German Research Foundation DFG, concentrates on the one hand on how to increase collaboration productivity and on the other hand how to achieve a growing energy- and resource-efficiency in the context of Industrie 4.0. Two papers have been published, focusing on the increase of collaboration productivity. Therefore, four mechanisms were developed on the basis of Industrie 4.0-enablers [4,5]. Thus, the present paper gives a

short introduction regarding Industrie 4.0-enablers. Afterwards the four mechanisms are derived from those enablers. Then it is shown, how these mechanisms can also improve resource- and energy-efficiency besides increasing collaboration productivity to facilitate a sustainable production within an Industrie 4.0-environment.

2. Resource and energy efficiency due to Industrie 4.0

Industrie 4.0 as the fourth industrial revolution is seen from different angles [6–8]. Nevertheless most researchers agree to the fact that Industrie 4.0 applications contribute to an increase in productivity. As a related contribution resource efficiency and sustainability are improved as well by Industrie 4.0 applications [9]. In 2011 the Smart Manufacturing Leadership Coalition (SMLC), consisting of 6 universities as well as 25 companies, released a report in which they formulated their expectations on changes due to smart manufacturing for a 10 year period. They assume that smart manufacturing will improve the overall operating efficiency by 10%, reduce safety incidents by 25% and improve energy efficiency by 25% [9].

Preconditions and tools to enable Industrie 4.0 applications were defined within the Cluster of Excellence [4]. To benefit from the current transformation process a company needs to adopt measures and integrate Industrie 4.0 enablers into the structure and organization of the company, since Industrie 4.0 activities are not initiated on the shop-floor level but mostly within the overarching structure [10].

The required preconditions to enable Industrie 4.0 applications are categorized within a two-dimensional framework [4]. The first dimension defines whether the cyber or the physical parts of the company or the production system are affected. The second dimension describes the character of the precondition, which can be either software or hardware. Within this matrix four main enablers were identified and categorized as shown in Fig. 1. The enablers are IT-Globalisation, single source of truth, automation and cooperation.

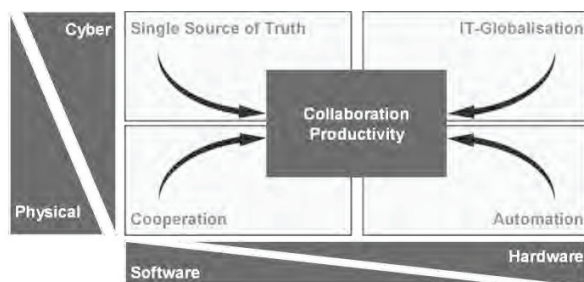


Fig. 1. Enablers of collaboration productivity [4]

In the following section the four enablers will be explained with a focus on their contribution to higher resource efficiency and by association a higher sustainability.

1) IT-Globalisation:

Out of the combination of the cyber world with new hardware innovations results a development which is named IT-Globalisation. New generations of computers provide opportunities and advantages, since a higher performance is available and the investment costs relative to performance are decreasing [11,4]. Due to a higher computing speed, greater storage capacities and lower relative prices [12], companies are enabled to store massive amounts of data in a central cloud, which can be accessed from all over [4]. The availability of data in addition with the higher computing speed allows a more efficient production planning as well as a wider use of simulation tools. With the use of simulation tools the planning and scheduling of production processes can be improved, such that a higher utilization is reached [13,14]. Through the combined simulation of production processes and energy consumption higher resource efficiency is possible [15]. Within manufacturing processes advanced simulations can be used to lower scrap and failures [16]. Since relying highly on IT-Infrastructure creates also risks, continuous availability of the IT infrastructure needs to be maintained and especially data security becomes increasingly important [17].

2) Single Source of Truth: For a successful use of simulations, the availability of complete and consistent data is inevitable. This is reached by the storage of all product lifecycle data within one single database [18]. To keep the

data in this “single source of truth” consistent and up to date a continuous maintenance in terms of product lifecycle management (PLM) is necessary [19–21,4]. This task is supported by new technological innovations such as the mentioned improvement in computer hardware as well as by new software solutions. A non-negligible share of collected data in manufacturing has missing values or inconsistencies [22], but with the application of data mining techniques from different industries, many of these inconsistencies can be covered, such that a higher share of the collected data can be used effectively [22,23]. With this principle and with the new software solutions a single and trusted source of truth [24] can help to reduce mistakes and bad planning and thereby finally help to improve resource efficiency.

3) Cooperation: The single source of truth is also one important aspect of the third enabler, the cooperation which aims at the connection of industries and activities. As production happens more and more within networks [25], the cooperation between all players is increasingly important. One important task thereof is that targets and information are communicated to enable decision makers [10,4]. The cooperation is important to maintain the competitiveness of a company as well as to improve the resource efficiency. As an example of the first aspect, a US company was able to reduce the lead time in development projects by 50% due to an increased cooperation [26]. In addition to that, a better cooperation along the supply chain allows better forecasts, which enable a more advanced and efficient planning process within each company, such that for example bullwhip-effects, as a reason for over-production, can be reduced [16]. With the combined use of IT-Globalization and Cooperation, activities such as monitoring, diagnostics, and the change of machine settings can be done without physical access to the actual machine and therefore faster with a lower downtime and therefore higher utilization and efficiency [27].

3) Automation: The intersection of the physical world and new innovative hardware opportunities is captioned with the term automation. It means the use of cyber physical systems (CPS) which are a combination of computers, sensors and actuators. Through the computers the physical environment is linked to the cyber world [28]. As mentioned already under the cooperation aspect, through CPS, processes can be decentralized and automation supports the collaboration in networks [29,4]. In addition CPS are capable of adapting to dynamic processes and therefore reach a higher level of quality as well as performance [30]. By the use of sensor data and advanced analytics not only machine communication is improved, but also skilled workers are provided with relevant information about the production process to improve their actions. In addition sensors and smart systems help to protect workers from serious accidents [9].

The four enablers which were presented are no stand-alone solutions, but need to be implemented as an integrated concept for a successful Industrie 4.0 transformation [31,4]. For example the success of cooperation as well as automation is depending on the availability of correct real-time data from the single source of truth and big data transfers and computing can only be done with sufficient IT hardware.

3. Mechanisms and target states due to increased resource and energy efficiency

The proposed enablers for an Industrie 4.0 environment are able to help increase the collaboration productivity (described in [4,5]) and sustainability significantly. This significant increase is represented by the four mechanisms “Revolutionary product lifecycles”, “Virtual engineering of complete value chains”, “Revolutionary short value chains” and “Better performing than engineered” [4]. This paper focuses on sustainability. Therefore, in the following the mechanisms are presented regarding sustainability and it is described how Industrie 4.0-enablers help to achieve them. Examples developed within the Cluster of Excellence are presented to demonstrate how these mechanisms are implemented in reality so that they can be used in every manufacturing system.

3.1. Revolutionary product lifecycles

Today, producing companies face the challenges of shorter lifecycles and the demand for individualised products has increased [32]. Therefore on the one hand it is important for such companies to further improve their innovation productivity [33]. One performance indicator for a company’s innovation productivity is the time to market. The faster a company is able to introduce new products to the market the shorter the development process has to be. On the other hand the mass production process must be adapted for smaller lot sizes. This compression of the development process is made possible within an Industrie 4.0 environment [4].

Concurrently, the sustainability must be regarded in this context, too. In mass production processes the development and manufacturing of dies is combined with high efforts and costs. Starting from a first draft, the die designer changes the geometry iteratively based on empirical knowledge. This happens via deposition or removal of material until the produced profile satisfies the previously defined quality criteria. Depending on the complexity of the geometries up to 15 iteration loops are necessary [16]. This type of production is very time-consuming and costly and additional material is needed for these experiments.

To reduce consumption of material it is necessary to transfer the iteration loops from the physical in the virtual world. Within the virtual world the iteration loops are run automatically. Thus, physical iteration loops are avoided and better products are brought more quickly to market without material consumption. The improved quality of the die extends its product life cycle.

This adjustment of the product development process in terms of time and quality is regarded within the Cluster of Excellence. Two common industrial mass production processes are presented in the following: the high-pressure die casting (HPDC) and profile extrusion. To find an optimal die design with minimal effort and high quality an automated optimisation approach for the design of HPDC and profile extrusion dies is developed. In this approach the die is designed in a virtual world and the real process is imitated through simulation. To find the best die in the virtual world,

optimisation algorithms are applied. If the optimal die is found it is produced in reality. The challenge of this approach is the representation of the real process. However, the automated optimisation approach has already been tested successfully for the plastics profile extrusion process [34,16].

These examples show how the lead time of a product from its idea to its start of production can be reduced even in common industrial mass production processes. Therefore, the adapting process during the die developing must be transferred in the virtual world. On the one hand companies will strengthen their competitiveness by concentrating on the time of development and shortening its length. On the other hand companies will increase sustainability by reducing material consumption and improving the quality of dies.

3.2. Virtual engineering of complete value chains

Manufacturing companies must create their order processing process in an efficient and transparent way. Today, they face challenges like insufficient data availability, low information transparency and an inadequate integration of information systems. Therefore, actors in the supply chain can only work with their local information and are not able to see the processes of the whole value chain and their status. Thus, sustainable decisions concerning the whole value chain are not possible [16]. These problems can be avoided by the application of the Industrie 4.0-enablers described before to facilitate sustainable decisions.

The vertical integration (within the company) is defined as the harmonisation and integration of the company’s internal information technology from the automated acquisition of high-resolution movement data (e.g. RFID) till the use of this data in higher-mounted planning and control systems (e.g. Manufacturing Execution System), see Fig. 2.

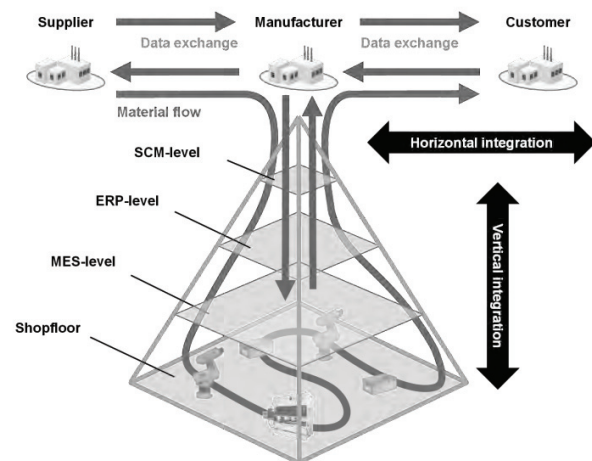


Fig 2: Horizontal and vertical integration [16]

A cross-company exchange of relevant information along the supply chain is defined as horizontal integration. It enables companies to share electronic messages such as orders, order confirmations, delivery notes etc. paperless and without large time delays. The interplay of vertical and horizontal integration provides a stable base for flexible

supply chains. The ability to react opens up the possibility of targeted cost savings through transparent process design. Cost-intensive sectors, such as stocks, can be identified and sustainably improved.

The networking of different companies along the supply chain is analysed within the Cluster of Excellence to show the potentials of horizontal and vertical integration. The developed logistic demonstrator connects different ERP systems along the supply chain. By exchanging the high-resolution data between the participating companies transparency is given. Various scenarios can be tested and the effects of any change can be disclosed. Therefore, the members of the supply chain can see the impacts of their decisions on the entire supply chain and the ways to optimise it. [16]

This demonstrator proves that by connecting ERP systems from different companies along the supply chain transparency of the complete value chain is given. On the one hand the inventory of the whole value chain can be reduced and thus the resource efficiency is increased. On the other hand the effects of decisions are comprehensible and thus every decision is much more sustainable. An optimisation potential in the form of an 8% reduction in stock level with the same service level and/or a 46% increase in the service level with a stock level of just 12% more is measured [35]. This demonstrates the logistical performance capability.

3.3. Revolutionary Short Value Chains

Companies have to offer more and more individualised products in order to meet the customer requirements, as described before. Hence, there is a demand for productivity and the ability to produce any complex component. By the aid of Industrie 4.0 it is possible to shorten the value chain. Integrating and substituting process steps along the value chain allow eliminating interfaces that would otherwise lead to disruptions. The development of multi-technology production systems is challenging since more interdependencies have to be considered [16]. This is enabled by Industrie 4.0.

One example is developed within the Cluster of Excellence, where various manufacturing technologies of traditional individual machines are integrated into so-called Multi-Technology Platforms (MTP). The benefit of such Platforms is that a MTP can perform several manufacturing processes in a single setup, which reduces the length of the value chain. Thereby interfaces are minimized, which reduces the clamping and unclamping as well as the transport of products. This leads automatically to a higher quality of the product. In addition, more complex products can be produced. The operator of a MTP can achieve higher accuracies and prevent waiting and setup times. However, the number of technologies integrated in one MTP is limited and depends on the lot size of the manufactured products [36].

This example demonstrates how the quality of a product, manufactured by a MTP, is increased and therefore reject is reduced. This shows that a reducing of interfaces within the manufacturing process enables higher resource efficiency. Moreover, it is proven that a MTP with two workspaces is

almost twice as productive as a MTP with a single workspace [37].

3.4. Better Performing Than Engineered

The mechanism “Better performing than engineered” refers to the self-optimising capabilities of production systems, which are already possible [38]. Self-optimizing systems are able to analyse the current situation continuously, determine targets depending on the current situation, and adapt their behaviour independently to achieve these targets [39], see Fig. 3. With this definition of self-optimization, it has a huge impact on the flexibility and reactivity of a production system and therefore contributes significantly to its productivity and the quality of its processes.

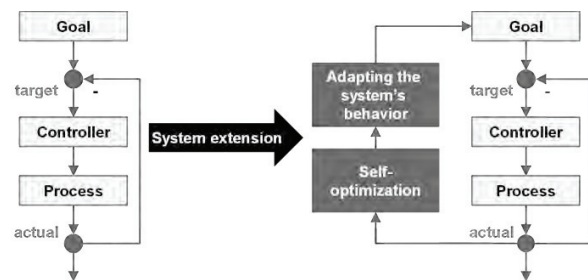


Fig. 3: From traditional controlling to self-optimization [35]

The core element of self-optimization is the creation and use of feedback data from the manufacturing processes. Manufacturing processes of all kind are designed in advance to reach the required process quality and economic targets. However, manufacturing processes have to deal with many different disturbances, which cannot be considered completely during the design phase. If the process is implemented in reality, the process stability is sometimes not sufficient and the quality of the manufactured products is not as defined during the design phase. In this case, products are reworked or even rejected. To reduce or even avoid this lack of quality, Industrie 4.0 provides an opportunity. By the increasing automation of manufacturing processes and the intensified implementation of sensors, more information can be collected from the real manufacturing process. The challenge is to use this feedback data to improve manufacturing processes.

Within the Cluster of Excellence there are many examples of the application of feedback data to improve manufacturing processes. One example is described in the following. Cutting processes like five axis milling are one of the key technologies in manufacturing. To increase the controllability of the 5-axis milling process, the idea of self-optimization is applied to these metal cutting processes. Monitoring and control strategies are implemented to ensure the required process quality. New sensors have been developed to get the needed data from the process. To ensure self-optimization within the 5-axis milling process, a virtual model of the whole process is developed, which is updated by the information of the real world. Thus, a model-based control is applied. [16]

This example shows how the process quality can be increased by using feedback data so that the quality of the manufactured product is sufficient and rework and reject is

avoided. Thus, resource efficiency is increased and sustainable manufacturing processes are established.

4. Conclusion

This paper describes how Industrie 4.0 increases sustainability. Accordingly, four main enablers as preconditions for Industrie 4.0 are introduced. Afterwards, mechanisms to increase sustainability are suggested. The first mechanism states that resource efficiency in development processes can be reached by transferring the development process in the virtual world. Only when the process is virtually completely developed, the process is implemented in reality. The second mechanism states that vertical and horizontal integration enable sustainable decisions. Therefore, ERP systems of different producing companies are connected, which enables transparency for decisions along the whole value chain. The third mechanism describes that a reduction of value chains achieve higher accuracy and thus less reject. The last described mechanism proves that it is important to use the data generated within manufacturing processes. By adapting the processes depending on the feedback information the process quality is increased and thus reject and rework is reduced. With that resource efficiency and sustainability are ensured.

These four mechanisms give manufacturing companies an orientation, how they should adapt their manufacturing processes in the future. The paper proves how Industrie 4.0 and the resulting increased collaboration productivity can increase the sustainability of production systems. In the future, the described mechanisms must be applied in manufacturing companies.

Acknowledgments

The authors would like to thank the German Research Foundation DFG for the kind support within the Cluster of Excellence "Integrative Production Technology for High-Wage Countries".

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