Industry 4.0 - Potentials for Creating Smart Products: Empirical Research Results

Rainer Schmidt[2(✉)], Michael Möhring[1], Ralf-Christian Härting[1], Christopher Reichstein[1], Pascal Neumaier[1], and Philip Jozinović[1]

[1] Business Information Systems, Aalen University, Beethovenstr. 1, Aalen 73430, Germany
{Michael.Moehring, Ralf.Haertingh, Christopher.Reichstein}@htw-aalen.de
[2] Business Information Systems, Munich University of Applied Sciences, Lothstr. 64, Munich 80335, Germany
Rainer.Schmidt@hm.edu

Abstract. Industry 4.0 combines the strengths of traditional industries with cutting edge internet technologies. It embraces a set of technologies enabling smart products integrated into intertwined digital and physical processes. Therefore, many companies face the challenge to assess the diversity of developments and concepts summarized under the term industry 4.0. The paper presents the result of a study on the potential of industry 4.0. The use of current technologies like Big Data or cloud-computing are drivers for the individual potential of use of Industry 4.0. Furthermore mass customization as well as the use of idle data and production time improvement are strong influence factors to the potential of Industry 4.0. On the other hand business process complexity has a negative influence.

Keywords: Industry 4.0 · Cyber physical systems · Empirical research · Business information systems · Study

1 Introduction

Combining the strengths of optimized industrial manufacturing with cutting-edge internet technologies is the core of Industry 4.0 [1]. Therefore it does not surprise that Industry 4.0 is experiencing an increasingly growing attention especially in Europe [1], but also in the United States, coined as Industrial Internet [2]. Industry 4.0 is often compared with proceeding disruptive increases in production [3] such as the industrial revolution(s) initiated by steam, electricity etc. Similar to Industry 4.0 these "revolutions" were initiated not by a single technology, but by the interaction of numbers of technological advances whose quantitative effects created new ways of production [4]. Three disruptive changes of industrial production happened until now [5].

1. At first industrial revolution and the ubiquity of mechanical energy combined with control systems such as the centrifugal force controller enabled huge productivity increase in the textile industry [6].

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2. The second large bouleversement was the replacement of steam by electricity [7]. Again, the coincidence of a set of technological advances such as transformation of alternating current [8] and advanced means for isolation [9] was necessary.
3. The use of electronics to the automation of production is considered as the third disruptive development. The intelligent control of robots and automated production and their integration provided the breakthrough.

In the same way as these proceeding disruptions, Industry 4.0 will change supply chains, business models and business processes significantly [1]. Therefore, many companies face the challenge to assess the diversity of developments and concepts summarized under the term industry 4.0 and to develop their own corporate strategies [6]. However, as many disruptive developments before, industry 4.0 is also accompanied by hype and overenthusiasm [10, 11]. Therefore, many companies and organizations are exposed to a dilemma: Neither to wait too long with their industry 4.0 implementation nor to start too early and commit fatal errors. There is a lack of research of the potential use of Industry 4.0. Nowadays, it is unclear what important factors influence the potential use of Industry 4.0.

Therefore, this paper aims to provide empirical information on the potentials of use Industry 4.0. In this way it will help academics and practitioners to identify and prioritize their steps towards an Industry 4.0 implementation. This is achieved by identifying those factors with a positive impact on the use of Industry 4.0.

It proceeds as follows. In the next chapter, the concepts of industry 4.0 are defined in detail. The research design and methods are defined, such as the design of the study and the data collection. The results are presented in the following section. Finally a conclusion and an outlook are given.

2 Smart Products, Processes and Technologies

Industry 4.0 is the superposition of several technological developments that embraces both products and processes. Industry 4.0 is related to the so-called Cyber physical systems [12] that describe the merger of digital with physical workflows [13]. In production, this means that the physical production steps are accompanied by computer-based processes. Cyber-physical systems include compute and storage capacity, mechanics and electronics, and are based on the Internet as a communication medium. Another related technology is the so-called Internet of things [14], defined as the ubiquitous access to entities in the internet. The so-called Internet of services [15] pursuits a similar approach with services instead of physical entities. The economic effects of smart products and industry 4.0 are manifold. As same as new products and services will be created [16], also traditional settings will profit from industry 4.0. E.g. the ability to provide more individual or even products that are malleable at the customer site may reduce the number of product returns [17]. In this paper industry 4.0 shall be defined as the embedding of smart products into digital and physical processes. Digital and physical processes interact with each other and cross geographical and organizational borders.

Smart Products. Smart products are products that are capable to do computations, store data, communicate and interact with their environment [18, 19]. Starting from early approaches enabling products to identify themselves via RFID [14] the capabilities of products to provide information on them evolved. Today smart products not only provide their identity but also describe their properties, status and history. Smart products are able to communicate information on their lifecycle. They know not only about the process steps already passed through, but are also able to define future steps. These steps include not only productions steps still to be performed on the unfinished product, but also upcoming maintenance operations. The capability to individually specify its properties can be used for an individual production with varying size. Smart products interact with their physical environment. They are capable to perceive and interact with their environment [6]. E.g. sensors allow to capture physical measures, cameras to get visual information on the product and its environment in real-time. Actors [6] enable products to impact physical entities in their environment without human intervention.

Industry 4.0 implies a huge increase of variety, volume and velocity of data creation [16]. The type and the amount of collected data has grown significantly due to advances in sensor technology and the products contained computer capacities. In the past, selectively measured values were captured. Today, data is collected continuously, creating a continuous stream of data. Also the type of data has evolved. Before, only simple types, such as temperature measurement were collected, now larger data types such as images or even real time videos are used. Due to the significantly higher processing capacity images, sounds and video files can be collected and used for triggering maintenance operations.

Intertwined Digital and Physical Processes Across the Whole Product Lifecycle. The following graphic shows the concepts associated with industry 4.0. They describe an extensive digitization of the value chain and how optimization and flexibility shall be achieved. The steps involved in the creation of value are fully integrated. Through social software [20], customers and suppliers are included in the innovation of the product. In the use phase of the product, the product is networked and connected with cloud services. The product stays connected during its entire life cycle and collected data. Using Big Data [21] a feedback loop into the production phase can be established. Big Data is the interplay of a number of technological advances with changed algorithms and model that are able to process data in an unprecedented volume, velocity and variety [21]. Technologies from the Big Data context such as [22] are able to process the enormous amounts of data and analyze them in near-real-time.

Base Technologies. Industry 4.0 is based on a number of technologies. The most important ones are mobile computing [23], cloud-computing [24] and Big Data [25]. The importance of cloud computing and mobile computing for Industry 4.0 lies not so much in providing scalable compute capacity, but rather in the provision of services, which can be accessed globally via the Internet. So, support services can be easily integrated and used (Fig. 1).

The easy integration of services also promotes the cooperation between the partners along the entire value chain. This has resulted in that relationship and not transactions stand increasingly in the foreground. Cloud computing is also the basis for the creation

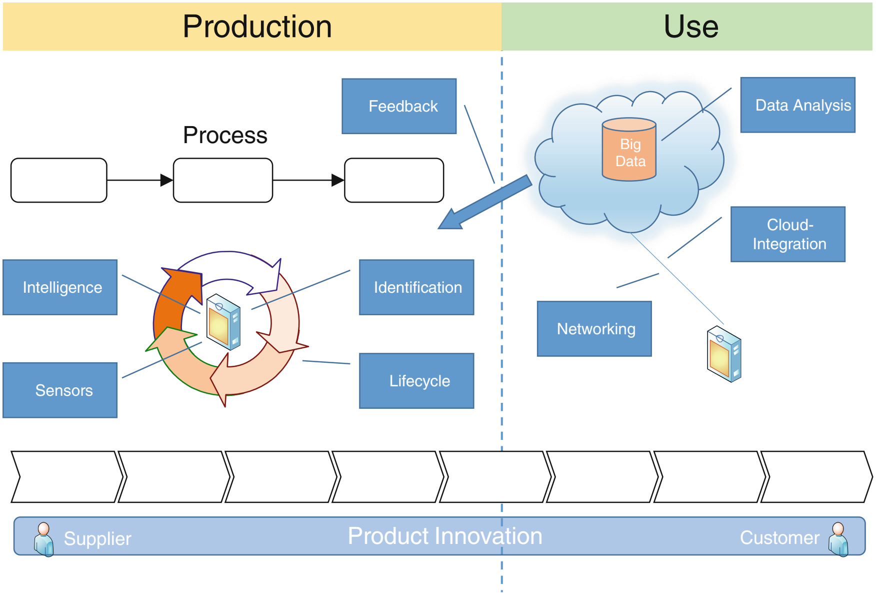

Fig. 1. Industry 4.0 based on [26]

of new business processes and models. Products integrated with cloud computing in the field can provide data that enable a predictive maintenance, and to give information about optimization possibilities in the production.

Already before the rise of cloud-computing and the internet, data was collected during production [27]. However this data remained in the production systems and had to be deleted after some time due to lack of storage capacity. Today the use of integrated networking and integration of products into the Internet data will give far reaching possibilities to collect data [28]. Instead of single data points or short intervals, a continuous stream of data is now available. The huge amounts of data available can now be used to continuously analyze and optimize production. This enables to foster predictive analytics [29].

3 Research Design and Methods

3.1 Design of the Study

To explore the potential use of industry 4.0, we design a quantitative research study. In this section as well as in Fig. 2 we developed our research model. The potential use of Industry 4.0 can be defined as the individual perceived capability of the implementation of Industry 4.0. The design of our study contains six hypotheses shown in Fig. 2.

The importance of production time for supply chain performance is identified in [30]. Its reduction is identified as a potential benefit from Industry 4.0 in [31]. Therefore we created hypothesis 1:

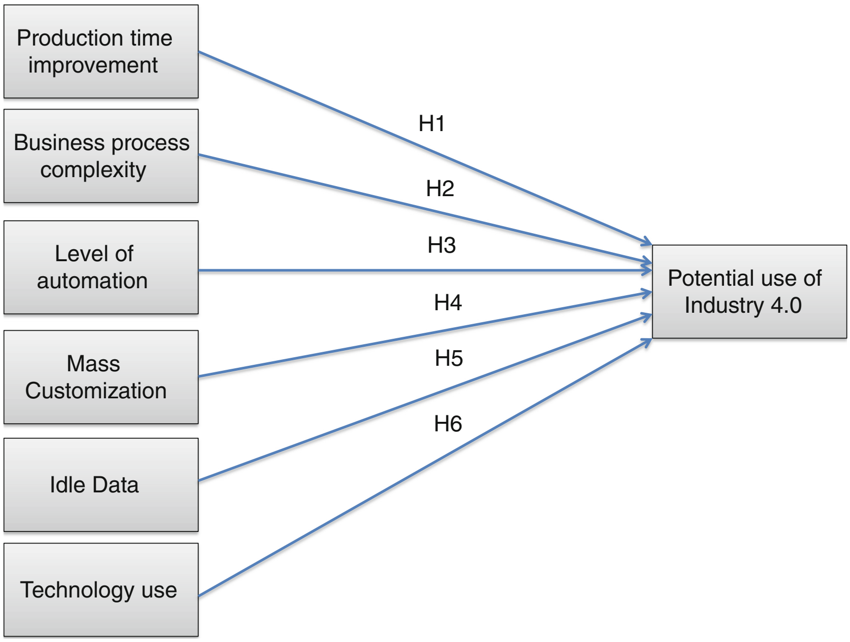

Fig. 2. Research model

H1: An Improvement of the Production Time Positively Influences the Potential Use of Industry 4.0. The complexity of business processes may [32] hamper overall supply-chain performance. However increasing integration and data exchange may overcome these negative effects. As industry 4.0 also fosters integration and data exchange [6], we introduce hypothesis 2:

H2: Complex Business Processes Positively Influences the Potential Use of Industry 4.0. The positive effects of automation in production systems in supply chain performance have already been identified in [33]. Especially the combination with computer integrated manufacturing [34] yields substantial benefits. Therefore, also industry 4.0 should provide these benefits as postulated in [1]. This lead to the creation of hypothesis 3:

H3: A High Level of Automation Positively Influences the Potential Use of Industry 4.0. Mass customization is an important means for competing in consumer-driven markets [35]. Industry 4.0 provides an excellent support for mass customization [1]. Therefore we create hypothesis 4:

H4: Mass Customization Positively Influences the Potential Use of Industry 4.0. The next hypothesis discovers the influence of idle (unused) data as a driver of Industry 4.0. According to Schmidt et al. [36] the amount of idle data has a negative influence on the use of Big Data. Big Data is also one technology driver of Industry 4.0. Therefore, we designed the following hypothesis:

H5: The Amount of Idle Data Negatively Influences the Potential Use of Industry 4.0. The influence of Big Data [16], Cloud-Computing [10], Mobile Computing [37], Internet of Things [14] and Cyber-Physical Systems [13] on industry 4.0 has already been discussed on a theoretical level. However there is still a lack of empirical evidence. Therefore we create hypothesis 6.

H6: Current Technologies Like Big Data, Cloud-Computing, Mobile Computing, Internet of the Things and Cyber-Physical Systems Positively Influences the Potential Use of Industry 4.0. For discovering the special attributes, we use a Likert [38] scale of one to six (1: low to 6: high) for all items (see Table 2). Only the questions about the use of the technology's (e.g. Big Data, Cloud, etc.) are ranged on a scale of one to two (1: use, 0: not in use).

3.2 Research Methods and Data Collection

Our quantitative research study based on a web survey in German speaking countries (Germany, Austria and Switzerland). The study were implemented via the open source tool Limesurvey **[**39**]**. To ensure a high quality, we tested our model and study with a pre-test and improve our study on the basis of our results. The main study started in July 2014 and ended in October 2014. We invited several leading experts in the field of information technology as well as manufacturing. These experts were contacted via email, telephone, letter and professional practical journals in Germany, Austria and Switzerland. We collected 592 answers. Because of this very special topic we implemented check-questions (e.g. industry background) to get only experts in the field of Industry 4.0. Only n = 133 answers were collected after data cleaning to ensure a high quality of our study.

More than 42 % of the experts work for enterprises with more than 500 employees. The majority of the asked experts came from the manufacturing sector (54.14 %), followed by the information and communication sector (13.35 %). Further industry sectors are e.g. the energy and facility management sector as well as health care and governmental sector. The experts came from Germany (87.22 %), Austria (5.26 %) and Switzerland (7.52 %). The classification of industry sectors was based on the European Classification of Economic Activities (NACE Rev.2). More than 60 % of the asked enterprises will implement Industry 4.0 or have done an implementation of Industry 4.0.

We used a structural equation modeling (SEM) [40–43] approach to analyze our causal model. Therefore, it is possible to use tools like IBM SPSS AMOS or Smart PLS. Because of our limited data set, we used a Partial Least Squares (PLS) [40] SEM approach. SEM [42] is a method to test the fit of a causal model with empirical data [40, 43]. The smart PLS approach is focusing on a partial least squares regression based on sumscores and significances are calculated via bootstraping.

4 Results

Finally, we analyze our data via the SEM approach by using SmartPLS 3.1 [41] and got the following results:

According to Hypothesis 1 (**An improvement of the production time positively influences the potential use of Industry 4.0)** the results of the SEM shows a positive effect (+0.236) of the production time to the potential use of Industry 4.0. Therefore the hypothesis can be confirmed. One argument for a positive influence of an improvement of the production time might be the fact that the complexity of business processes [32] hinder an overall supply-chain performance. An increasing integration and data exchange may outbalance possible delays created by using Industry 4.0 concepts (Fig. 3).

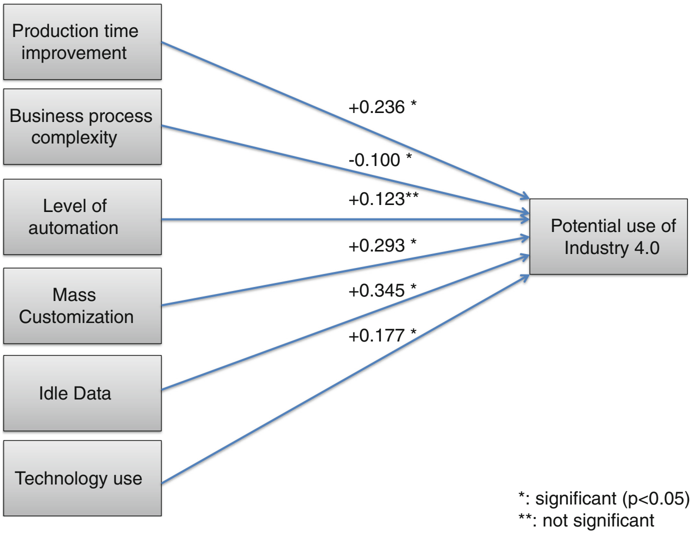

Fig. 3. Structural equation model with coefficients

The influence of the complexity of business processes on the potential use of Industry 4.0 were discussed in Hypothesis 2 (**Complex business processes positively influence the potential use of Industry 4.0**). Based on our model results, we must reject the hypothesis because of a negative value (−0.100). A higher complexity indicates a lower potential use of Industry 4.0. The negative impact of the complexity of business processes can be explained by the theory of transaction costs [44]. Studies based on this approach indicate that new information technologies are able to raise business processes to a higher level of efficiency and to generate economies of scale [45]. But in a situation of high uncertainty respectively high complexity an opposite effect arises. People, who are involved in complex business processes, become uncertain concerning using new technologies like Big Data, Cloud-Computing or Mobile-Computing. That increases the transaction costs, leads to a lack in digital trust and a reduced use of Industry 4.0 technologies.

The level of automation has a positive effect (+0.123) on the potential use of Industry 4.0. But this influence is not significant ($p = 0.135 > 0.05$). According to this results, hypothesis 3 (**A high level of automation positively influences the potential use of Industry 4.0**) must be rejected.

Furthermore Mass Customization is a very strong driver of Industry 4.0 according to the literature [37]. Our data can confirm this statement following Hypothesis 4 (**Mass Customization positively influences the potential use of Industry 4.0**). The influence of Mass Customization to the potential use of Industry 4.0 is +0.293. Therefore Hypothesis 4 can be confirmed. Industry 4.0 allows an individualized reacting on customer requests with a high degree of self-organization. For example some concepts of Mass Customization are working with intelligent work pieces (e.g. RFID). These pieces contain information regarding relevant process steps and raw materials. Furthermore, consumers who buy products in online shops often return it (especially in the European Union), because they do not fit to their individual preferences [17, 46]. Therefore, mass customization via Industry 4.0 can may reduce product returns by producing more consumer individual products.

The literature shows very interesting results of the impact of idle data to technologies like Big Data [36]. In contrast to [36] we get a positive influence of the amount of idle data (+0.345) to the potential use of Industry 4.0. Following this results, Hypothesis 5 (**The amount of idle data negatively influences the potential use of Industry 4.0**) must be rejected. Therefore, unused data are very important for the implementation of Industry 4.0.

Hypothesis 6 investigates the technology influence on the potential use of Industry 4.0 (**Current technologies like Big Data, Cloud-Computing, Mobile Computing, Internet of the Things and Cyber-Physical Systems positively influences the potential use of Industry 4.0**). Based on our data, Hypothesis 6 can be confirmed (+0.177). Therefore, new technologies are the base and driver of Industry 4.0. Current technologies of Industry 4.0 are also the fundament of new business models. In that context, Industry 4.0 is a disruptive innovation [47]. That means Industry 4.0 and its disruptive technologies have an above-average growth rate and are able to replace conventional technologies shortly.

Tables 1 and 2 contain important quality values of the SEM. Furthermore, the coefficient of determination (R2) is good (0.604 > 0.19) [41] as well as the quality criteria Cronbach Alpha for scales (>0.70) [48].

Table 1. SEM coefficient

SEM-Path	Path coefficient	Significance (P Values)
Automation level – > potential use of Industry 4.0	0.123	0.135
Business process complexity – > potential use of Industry 4.0	-0.100	0.049
Mass-customization – > potential use of Industry 4.0	0.293	0.001
Production time improvement – > potential use of Industry 4.0	0.236	0.001
Technology use – > potential use of Industry 4.0	0.177	0.003
Idle data – > potential use of Industry 4.0	0.345	0.000

Table 2. Cronbach-Alpha and items

Factor and items	Cronbach Alpha
Technology use (Current use of Big Data, Mobile Computing, Internet of the Things, Cyber Physical Systems, Cloud Computing)	**0.834** (5 item)
Production time improvement (use potentials of Industry 4.0 to the reduction of Pre-production time, production time, production wait time, time to market)	**0.831** (4 items)
Business process complexity (Business process complexity of the asked enterprise)	**1** (1 item)
Level of automation (Industry 4.0 impact on the automation level)	**1** (1 item)
Mass customization (Desire for individual products of the customers of the asked enterprise)	**1** (1 item)
Idle data (Amount of idle data in the production sector of the enterprise)	**1** (1 item)

5 Conclusion

Industry 4.0 introduces smart products which capture major data holdings due to significantly increased compute and memory performance, and can evaluate and can identify itself to higher-level systems. Industry 4.0 also intertwines physical and digital processes.

Our empirical research generates some interesting findings of the potential use of Industry 4.0. The use of current technologies like Big Data or Cloud are drivers for the individual potential of use of Industry 4.0. Furthermore Mass Customization as well as the use of idle data and production time improvement are strong influence factors to the potential of Industry 4.0. Business Process Complexity has a negative influence.

Academic research can benefit from our results to get a better understanding of the potential use of Industry 4.0 and can so adopt current approaches in the field of e.g. business intelligence and knowledge management. Managers can use these results for better decision making for e.g. implementing Industry 4.0 and can so save costs.

Our research is limited to the asked Industry 4.0 experts. We only asked experts from German speaking countries and mainly in Germany. One aspect (automation level) is not significant. Furthermore, there may be some further aspects to discover and a qualitative research approach can get some more detailed insights. Therefore, future research can enlarge the number of countries as well as the research approaches (e.g. qualitative interviews) to get a broader view of Industry 4.0. Furthermore some special aspects (e.g. pre-production time and costs) can be a great opportunity for a detailed research in the future.

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