

# Ecosystem Effects of the Industrial Internet of Things on Manufacturing Companies

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## ABSTRACT

*The Industrial Internet of Things (IIoT) represents a novel, future-oriented paradigm of industrial value creation, which facilitates the creation of networks across and within manufacturing companies. Consequently, the IIoT is associated with an adjusted characterization of respective business ecosystems. As current research has primarily focused on the IIoT's technical fundamentals, economic research is still in its infancy. This article aims at examining the effects of IIoT on manufacturing companies' business ecosystems by applying a mixed-method approach. Thus, we carried out a quantitative survey among 198 German manufacturers from several industries based on insights of 15 expert interviews. This study contributes to the sparse body of scientific IIoT literature from an economic perspective by revealing that IIoT adoption is associated with greater openness of manufacturers toward participants of all analyzed ecosystem dimensions, i.e., customers, suppliers, organizations external to the own industry, and research institutions. Moreover, an intensified ecosystem integration is expected over time..*

**Keywords:** Industry 4.0, Industrial Internet of Things, Business ecosystem, Manufacturing companies, Mixed method.

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## 1. INTRODUCTION

The Industrial Internet of Things (IIoT) represents a novel, future-oriented paradigm of industrial value creation. At its core, it represents the proceeding digitized connection of industrial manufacturing based on the application of cyber-physical systems (CPS). They enable the connection of the physical and the virtual world and therefore facilitate the creation of networks across and within manufacturing companies (Frazzon et al., 2013). In addition, machines, products, and entire buildings are equipped with embedded systems like actuators, sensors, and microcomputers providing them with intelligence. This results in the “real-time capable, intelligent, horizontal, and vertical connection of people, machines, objects, and ICT systems to dynamically manage complex systems” (Bauer et al., 2014, p. 18). In the final vision, smart factories allow the autonomous and flexible guidance of products through entire value chains. Furthermore, machines are able to automatically set-up and to reschedule the production on their own in the case of an error. Consequently, this visionary production approach enables a flexible and efficient execution of production and offers the potential for resolving recent challenges for manufacturers like shortened technology and innovation cycles, batch-size-one production at the cost of a large-scale production, and intensified competition originating particularly in Asia (Bauer et al., 2014; Dais, 2014). In parallel, IIoT business ecosystems emerge due to the IIoT-inherent networking possibilities. They involve companies in different roles, e.g., module providers, machine-to-machine service providers, network operators, and users that interact and share connected hardware, software, and platforms among each other (Iansiti & Levien, 2004; Mazhelis et al., 2012).

To date, scholars have primarily focused on technological prerequisites, fundamentals, and challenges (Brettel et al., 2014; Kiel et al., 2016). Equally important, but still in its infancy, is economic research with regard to the IIoT. Although there are some works that deal with economic topics such as human resource management (e.g., Bonekamp & Sure, 2015; Nagar & Raj, 2013) and business models (e.g., Arnold et al., 2016; Kiel et al., 2016), scientific studies examining the effect of the IIoT on companies’ business ecosystems and relations to partners are still very scarce. The term “ecosystem” has its origin in biology and refers to a “community of organisms, interacting with one another, plus the environment in which they live and with which they also interact” (Moore, 1997, p. 26). In the business context, an ecosystem comprises actors within a company, the value chain, and the entire market, and describes the interrelationships among these actors (Mazhelis et al., 2012). Correspondent to the biological analogy, a business ecosystem is composed of a multitude of actors, which act separately but depend on each other through common interests (Iansiti & Levien, 2004). Business ecosystems are furthermore characterized by dynamic connections, which can be established and cut according to recent developments (Peltoniemi & Vuori, 2004).

The absence of scientific work on this perspective in the context of IIoT effects is somewhat surprising, as the IIoT aims at connecting all supply chain participants, which necessitates a linkage of various organizations in new ways (Obermaier, 2016). Moreover, triggered by CPS, business ecosystems will supersede traditional linear value chains (Geisberger & Broy, 2012). Consequently, we address this research gap by dedicating ourselves to the following research question: How does the IIoT affect the business ecosystems of manufacturing companies?

A review of relevant contributions related to our research question identified only a few studies that contain IIoT-driven business ecosystem effects. In their work, Weill and Woerner (2015) identified so-called ecosystem drivers, which establish a joint platform with other companies in order to serve their own customers with complementary products and services. Eloranta and Turunen (2016) examined how companies leverage network-related complexity in their operations. It has been found that in particular, platforms that enable increasing ties with suppliers lead to an enhanced value added. Furthermore, the authors argue that platforms facilitate the collection of information within the ecosystem and blur company boundaries, resulting in a greater importance of the ecosystem as a whole in relation to the single ecosystem participants. Berman and Korsten (2014) also reveal that increasing digitization and associated interconnectedness blur company boundaries. Consequently, ecosystem actors jointly employ assets like data and resources.

## **2. METHODS**

Based on the sparse body of extant literature and the absence of academic studies that address the effects of the IIoT on the ecosystems of manufacturing companies, in particular, we decided to apply a mixed-method approach. This is a combination of qualitative and quantitative research techniques and methods, which are applied in one single study (Johnson & Onwuegbuzie, 2004). Such an approach is particularly suitable for gaining a comprehensive understanding of complex technological, organizational, and social phenomena, like with the IIoT (Venkatesh et al., 2013). Following the most prevalent mixed-method approach, we applied a sequential study (Creswell & Plano Clark, 2011).

In a first step, we conducted qualitative expert interviews with 15 German companies operating in the electronic engineering and machine and plant engineering sectors. By doing so, we aimed at confirming IIoT-triggered effects on business ecosystems addressed in the sparse existing literature and identifying additional effects experienced by the interviewed companies (Engelken et al., 2016). Secondly, we carried out a quantitative survey among 198 German manufacturing companies in order to test the propositions based on literature and the expert interviews' results (Engelken et al., 2016).

## **3. EXPERT INTERVIEWS**

We conducted 15 semi-structured expert interviews with knowledgeable and experienced managers of German electrical engineering and machine and plant engineering companies. We chose manufacturers from these two industries because the former represents crucial suppliers of necessary technological foundations for the IIoT (Atzori et al., 2010) and the latter are supposed to be among the major beneficiaries of this new production paradigm, as the machine and plant engineering sector represents the largest among all German industrial sectors (Federal Bureau of Statistics, 2016). Hence, we argue that companies operating in these two industries are among the first to experience IIoT-specific business ecosystem changes. Moreover, statements made by experts from electrical engineering companies serve to verify and supplement machine and plant engineering companies' statements with regard to suppliers. The interviewed informants had to be reliable and knowledgeable experts. Therefore, they had to possess a middle or top management position, relevant technical and business knowledge, and know the companies' ecosystems and other environmental influences well. We contacted 99 companies, of which we interviewed 15 companies of different sizes that had already gained experience with the IIoT in their own production; seven originating in the machine and plant engineering sector and eight originating in the electrical engineering sector. All interviews were conducted between March and May 2016.

The interviews were audio-recorded, transcribed, and analyzed according to the qualitative content analysis (Miles & Huberman, 1994). The developed categories were informed by extant literature but defined inductively (Kelley et al., 2009) in order to allow concepts to emerge from this process (Graebner & Eisenhardt, 2004). For the coding and analysis process, we followed the scientifically recognized and recommended work of Gioia et al. (2013). According to them, the first step is to perform an initial data coding, which maintains the integrity of first-order (informant-centric) concepts. The first author of the paper at hand provided the initial data coding, which was discussed afterwards in team, resulting in consistently checked and revised categories. In a second step, we organized the first-order concepts into second-order themes. Against the background of our research goals, these second-order themes were inspired by our previous knowledge based on having consulted literature. The findings of the expert interviews enabled us to develop propositions with reference to business ecosystem changes due to the IIoT, which were subsequently tested by applying a quantitative survey.

## **4. QUANTITATIVE STUDY**

For our quantitative data analysis, we conducted a cross-sectional field survey to collect data about IIoT effects on business ecosystems of German manufacturing companies. The German market was chosen since the term 'IIoT', in its German equivalent 'Industrie 4.0', originally appeared in Germany and the German manufacturing industry is a global leader and has always been a pioneer in terms of implementing innovative technologies (Breznitz, 2014). Additionally, the manufacturing sector is the most important one for the German economy in terms of

employees and contribution to the GDP (Federal Bureau of Statistics, 2016), which justifies our examining of manufacturers in particular.

German manufacturers were identified by consulting the bisnode database, which lists German companies from all industries and sizes. We contacted appropriate companies via e-mail and telephone and gave them access to an online questionnaire between January and March 2017. Referring to the procedure described by Kurniawan (2008), this questionnaire is based on the expert interviews' results and consists of closed-ended questions. Section A contains questions about company demographics, followed by a dichotomous question about whether the company has already adopted the IIoT or not. If not, they were asked if an adoption is planned in the medium term. Section B comprises questions regarding the items measuring the proposed ecosystem changes. They all consist of a Likert-Scale from 1 (strongly disagree) to 5 (strongly agree). Section C deals with respondent's personal data.

To assure comprehensibility and content validity, ten companies participated in a pilot test of the survey (Cooper & Schindler, 1998). Feedback resulted in minor adjustments of the questionnaire and the final survey link was sent to 2,750 German manufacturing companies. As a result, we received 362 questionnaires, representing a response rate of 13.2%. After a data-cleaning procedure, which eliminated incomplete values, a total of 198 usable questionnaires was left, constituting a final 7.2% response rate. In order to account for a potential non-response bias (Fowler, 1993), we compared data between early and late respondents. Therefore, we employed size in terms of revenues and four randomly selected items. The results of the Mann-Whitney test shows no significant difference between early and late respondents, indicating the absence of non-response bias (Ramsey et al., 2008).

## **5. FINDINGS**

### **5.1. Expert Interview Results**

Most of the interviewed machine and plant engineering companies reported on various IIoT-driven changes regarding their customers. They increasingly face customers who are unsure about potential benefits of IIoT-ready facilities. Therefore, they increasingly engage in consultation activities. If the customers were already aware of the IIoT, the interviewed companies extended exchange of information and knowledge and intensified joint technology and product development. By doing so, they aim at ensuring that new products meet changing customer requirements. In addition to pure development activities, some interviewees reported on joint production activities with customers. Therefore, the end customer is directly integrated into the production process. Consequently, we deduce the following proposition regarding IIoT-driven ecosystem changes in terms of customers:

Proposition 1. Manufacturing companies that have already implemented the IIoT into their production perform more customer consultation activities, exchange more information with customers, conduct more intensely joint developments with customers, and integrate customers more into their own production processes than do manufacturers without any IIoT experience.

Taking a look on the other side of the supply chain, a similar picture emerges regarding manufacturer's suppliers. Machine and plant engineering companies do not only advise customers with reference to the IIoT, but also draw on consultations themselves. Additionally, they increasingly exchange knowledge with their suppliers. This is confirmed by the experts who originate in electrical engineering companies reporting on a rising need for expert advice by machine and plant engineering companies, particularly in terms of potential benefits of the IIoT or how to connect machines to the internet. Machine and plant engineering companies further conduct joint development activities with suppliers, especially with sensor suppliers. The aim of such development cooperation is a target-oriented advancement of sensors required for specific IIoT applications as well as to ensure compatibility of components obtained by several suppliers that have to work in combination. Although stated by only one expert originating in the machine and plant engineering industry, those companies seem to be increasingly integrated with the production of electrical equipment suppliers, as this is also stated by some electrical engineering companies. Due to the above-outlined expert statements, we deduce the following proposition regarding supplier-related ecosystem changes:

Proposition 2. Manufacturing companies that have already implemented the IIoT into their production demand more supplier consultations, exchange more information with suppliers, conduct more intensive joint developments with suppliers, and are integrated more into their suppliers' production processes than are manufacturers without any IIoT experience.

The expert statements indicate that not only are suppliers and customers, i.e., direct value chain partners, important entities in future production, but also organizations external to the traditional value chain. They increasingly utilize knowledge from outside their own industry. In this context, they state, for example, IT enterprises being consulted regarding data analyses or consultancy agencies in terms of future IIoT application fields and required hardware. Further, machine and plant engineering companies start to cooperate with competitors in order to offer a joint product portfolio that is more powerful than the solution of one company alone. The interview results also show the particular importance of research institutions like universities since nearly all experts made statements about a respective knowledge transfer. To be more precise, they draw on know-how developed by such institutions. Additionally, most of them conduct joint development activities with universities and similar institutions. Therefore, we consider the emphasis of research institutions and deduce the following two propositions:

Proposition 3. Manufacturing companies that have already implemented the IIoT into their production more strongly draw on knowledge from outside their industry sector and offer a larger joint portfolio in cooperation with competitors than do manufacturers without any IIoT experience.

Proposition 4. Manufacturing companies that have already implemented the IIoT into their production exchange more knowledge with research institutions and conduct more intensive joint developments with research institutions than manufacturers without any IIoT experience.

In addition to the aforementioned four propositions, we expect that IIoT-related business ecosystem changes will be further intensified in the future, as we are just on the threshold of the IIoT. Thus, manufacturers just started to implement this new production approach into their value creation and modify their business ecosystems. Furthermore, it is arguable that companies that have already implemented the IIoT are more poised to further open toward their business ecosystem than those companies that have not yet dealt with the IIoT. Therefore, we add the following proposition:

Proposition 5. Manufacturing companies that have already implemented the IIoT into their production will experience stronger business ecosystem changes in future than manufacturers without any IIoT experience.

## 5.2. Quantitative Survey Results

Survey results show that the majority of the respondents are at least senior managers (64.8%) and are well-educated (84.4% hold at least a university degree). Referring to company data, most respondents operate in the machine and plant engineering sector (33.5%), followed by metal processing (14.4%) and electrical equipment (11.9%). Table 1 summarizes the demographics of the sample.

Regarding IIoT implementation, data show that 23.2% have already adopted it. Among non-adopters, 55.3% have plans to implement the IIoT in the medium term. As we are still at the threshold of this new production paradigm, it is reasonable to consider intent to adopt in addition to actual adoption (Vowles et al., 2011). Consequently, 65.7% of the sample at least intend to adopt the IIoT in the mid-term future.

Based on the expert interviews and referring to proposition 1, the companies were asked to assess the IIoT's effects in terms of comprehensively consulting customers, excessively exchanging information with customers, integrating customers into their own production processes, and conducting comprehensive, joint development activities. A Mann-Whitney test resulted in highly significant differences between companies intending to adopt or already adopted the IIoT (hereinafter referred to as adopters) and those companies without an intention to implement the IIoT in the medium term (hereinafter referred to as non-adopters).

**Table 1.** Demographics of respondents (n = 198)

Variables	Frequency	Variables	Frequency
Revenues (in million EUR)		IIoT adoption	
0-10	33.0%	IIoT adopted	23.2%
10-50	29.8%	IIoT not adopted	76.8%
50-100	10.5%	Educational level	
100-250	6.8%	Apprenticeship	14.5%
250-500	4.2%	University degree	74.7%
500-1,000	1.6%	PhD degree	9.7%
1,000-5,000	4.2%	Other	1.1%
5,000-10,000	0.5%	Job position	
10,000-50,000	4.7%	Executive board	15.1%
>50,000	4.7%	Top management	23.2%
Industry sector		Senior management	26.5%
Machine and plant engineering	33.5%	Middle management	15.7%
Metal products	14.4%	Employees with managerial responsibility	8.1%
Electrical equipment	11.9%	Employees without managerial responsibility	11.4%
Electronics	10.8%		
Automotive	9.3%		
Chemical products	5.2%		
Rubbber & plastics	4.6%		
Other	10.3%		

As Table 2 shows, today’s mean value of all four items is at least 2.15 among adopters, while non-adopters show an average manifestation of 1.88 at most. This indicates that manufacturers already dealing with the IIoT are more open toward customers than non-adopters, although they still do not experience strong IIoT-driven ecosystem effects regarding their customers. This picture is confirmed when comparing the median of each item between adopters and non-adopters, which is more robust against single outliers (Müller, 2000). Regarding all customer aspects except information exchange, the median of the responses referring to today’s evaluation is 2 among adopters. Information exchange is the only item with a medium assessment, expressed by a median of 3. In comparison, the median for all four customer aspects is 1 among non-adopters. Hence, the majority of those companies strongly disagrees with having any customer contact beyond pure product selling. This indicates that the implementation of the IIoT comes along with a more open and intensified relation toward the customer perspective of a company’s business ecosystem, albeit at a rather low level. Hence, proposition 1 is supported.

**Table 2.** Results with regard to a business ecosystem’s customer dimension

		today		medium term	
		mean	median	mean	median
customer consultations	adopters	2.47	2	2.98	3
	non-adopters	1.81	1	2.28	2
information exchange	adopters	2.72	3	3.36	3
	non-adopters	1.82	1	2.29	2
integration into own production process	adopters	2.15	2	2.92	3
	non-adopters	1.54	1	1.82	1
joint development activities	adopters	2.45	2	2.98	3
	non-adopters	1.88	1	2.25	2

With regard to our second proposition dealing with suppliers, the companies were requested to evaluate to what extent IIoT adoption leads to the utilization of comprehensive consultations by suppliers, excessive information exchange with suppliers, an integration into suppliers’ production processes, and comprehensive, joint development activities with suppliers. A Mann-Whitney test again resulted in highly significant differences between adopters and non-adopters. Taking a look at the mean value of each item reveals a similar picture as for the customer side. Again, this is supported by the median values since all items have a median of 2 for today’s assessment among adopters, while all non-adopters show a median of 1, as illustrated in Table 3. This is a

difference at a rather low level, but adopters seem to maintain at least some connection to their suppliers. In contrast, more than half of all non-adopters strongly disagree to have a connection to their suppliers beyond obtaining products. This indicates that, at a very low level, IIoT implementation is associated with a more open and intensified relation toward suppliers as part of the business ecosystem. Thus, proposition 2 is supported.

**Table 3.** Results with regard to a business ecosystem’s supplier dimension

		today		medium term	
		mean	median	mean	median
consultations by suppliers	adopters	2.10	2	2.82	3
	non-adopters	1.68	1	2.01	2
information exchange	adopters	2.33	2	3.21	3
	non-adopters	1.76	1	2.18	2
integration into suppliers’ production processes	adopters	1.99	2	2.82	3
	non-adopters	1.66	1	1.94	2
joint development activities	adopters	2.16	2	2.91	3
	non-adopters	1.75	1	2.07	2

To test proposition 3 and 4, the respondents were asked if IIoT adoption would result in the utilization of knowledge and resources of companies external to the own industry, the offering of joint, complementary product portfolios with competitors, extensive information exchanges with research institutions, and comprehensive, joint development activities with research institutions. A Mann-Whitney test resulted in significant differences between adopters and non-adopters regarding all items except for joint portfolio with competitors. This indicates that manufacturers only minimally operate as joint suppliers of a broader solution package together with direct competitors, as in both cases, the majority of respondents state a rather low manifestation. As Table 4 shows, adopters have a medium manifestation of external knowledge utilization with reference to today, i.e. a mean value of 2.85 and a median of 3, while non-adopters rated it rather low. This partly supports proposition 3.

With reference to research institutions, a similar picture emerges. While adopters show a manifestation of both items of at least 2.16 in average for today’s evaluation, non-adopters reach 1.85 at most. Taking a look at the medians reveals that more than half of non-adopters do not draw on knowledge of research facilities or conduct joint developments activities. In contrast, the median of adopters’ responses is 2, thus, proposition 4 is supported.

**Table 4.** Results with regard to a business ecosystem in terms of organizations external to a company’s own industry

		today		medium term	
		mean	median	mean	median
utilization of knowledge of companies external to industry	adopters	2.85	3	3.38	3
	non-adopters	2.03	2	2.49	3
information exchange with research institutions	adopters	2.41	2	2.97	3
	non-adopters	1.85	1	2.22	2
joint development activities with research institutions	adopters	2.16	2	2.82	3
	non-adopters	1.76	1	2.19	2

When it comes to the future assessment of the ecosystem configuration, i.e., proposition 5, both adopters and non-adopters expect an increasing development with regard to all requested items. Furthermore, it is conspicuous that the difference between today’s and future assessment is higher for adopters in all cases. Thus, proposition 5 is supported. Taking a closer look at the customer dimension shows that future information exchange with customers has the highest mean value for both adopters and non-adopters. A difference can be observed regarding the absolute increase of mean values. Non-adopters expect the highest rise for both information exchange and customer consultations. By way of contrast, adopters expect the highest increase in terms of customer integration into the own production processes, i.e., the item that necessitates the most intense customer integration and collaboration.

The ecosystems’ supplier perspective shows a quite similar picture. Among both adopters and non-adopters, future information exchange with suppliers experiences the highest estimation in terms of mean values. In contrast to the customer dimension, it is the same item experiencing the highest growth for both adopters and non-adopters, i.e.,

information exchange with suppliers. Nevertheless, for IIoT adopters, information exchange is closely followed by integration into suppliers' production processes, which again required the most intense collaboration with suppliers.

With respect to ecosystem participants, in addition to traditional value chain partners, our findings reveal an interesting aspect with reference to research institutions. Here, adopters indicate the highest future assessment for information exchange. Non-adopters, on the contrary, expect the highest manifestation for joint development activities with research institutions. Thus, it is the non-adopters, which expect the highest future manifestation for the item that requires the most intense collaboration.

## **6. DISCUSSION AND CONCLUSIONS**

This study enhances existing IIoT research from a business perspective in several ways. Our findings show that the IIoT has an effect on manufacturers' business ecosystems. The empirical results reveal that in particular, relationships to traditional value chain members, i.e., customers and suppliers, are concerned since all examined aspects of these ecosystem dimensions show significant intensifications when comparing IIoT adopters and non-adopters, albeit at a rather low level. Furthermore, IIoT adoption is associated with increasing cooperation with research institutions in terms of utilization of external knowledge, as well as joint developments. This might be ascribable to the high novelty of the IIoT, its technological fundamentals, and its potential. Hence, manufacturers implementing the internet into their production environment have a high demand for knowledge, which is not available internally (yet). Interestingly, our findings show no significant difference between IIoT adopters and non-adopters with reference to cooperation with competitors. This shortage of extensive utilization of IIoT's potential associated with a joint, complementary product and service portfolio (Weill & Woerner, 2015) might arise from the companies' early state regarding adopting and applying the IIoT. To date, they concentrate on themselves and traditional value chain partners, while the required trust in direct competitors still has to be built. With reference to temporal development, this study shows a clear expectation of intensified of ecosystem integration in all dimensions, independently from the adoption state. Also, we learn that companies that have already adopted the IIoT or intend to do so in the medium term expect higher increases in all ecosystem aspects than do non-adopters.

The findings also provide valuable insights for practitioners since we present insights from manufacturers of different industries who already had advanced experience with the implementation of the IIoT. This serves as a source of learning for companies that are on the cusp of integrating the IIoT into their value creation activities. The IIoT-inherent digital connection of entire value chains necessitates a rethinking with reference to a company's relationships to customers as well as suppliers. Manufacturers should establish an open mindset toward both upstream and downstream value-added steps and establish a common willingness to proceed with the next wave of digital transformation of manufacturing. Moreover, we recommend that manufacturers increasingly cooperate with external research institutions, e.g., universities to benefit from a larger knowledge base, which enables them to quickly and establish targeted and required know-how. Although past behavior in competition has been characterized primarily by rival thinking, manufacturers are well-advised to increasingly cooperate with competitors with regard to a joint product and service offering. This does not necessarily mean giving up distinguishing and unique features, but leaving room to facilitate the full exploitation of the IIoT's potential.

Although the paper at hand provides several contributions, it also faces some limitations. The sample consists only of German manufacturing companies. Since the IIoT is also relevant for companies originating in other industry sectors, e.g., service providers, and other countries, future studies should consider respective companies. Particularly with regard to foreign companies, examining potential cultural influences and backgrounds might reveal interesting findings with reference to a company's business ecosystem. Moreover, this study does not differentiate between small and large companies. It is reasonable that large companies operate in a more complex ecosystem with a multitude of participants. Further, smaller companies might go with the flow rather than proactively develop their ecosystems. Therefore, future research should, in particular, differentiate between company sizes. Regarding the ecosystem perspectives, we based our examination on the results of thoroughly

analyzed expert interviews. Nevertheless, this cannot represent a company's business ecosystem in its entirety. Hence, future studies should consider other ecosystem perspectives and items as well.

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