The relationship between IIoT and Supply Chain Integration

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Abstract
IIoT may influence supplier, internal and customer integration. However, the influence may not be described with the usual items of SCI but instead needs to be adapted.

The analysis is based on 11 IIoT initiatives and reveals that the overarching changes related to people, data and technologies can be summarized into measures concerning condition monitoring and predictive maintenance. Thus, the respective factors seem to be relevant in order to analyse the influence of IIoT initiatives on SCI. Despite the decision where to start (internal or external), the IIoT initiatives seem to lead to a higher level in both dimensions.

Keywords: Industrial Internet of Things, technologies, Supply Chain Integration

Introduction
Even though the relationship between supply chain integration (SCI) and information technology has been analysed from different researchers (e.g., Rai, Patnayakuni et al. 2006, Liu, Wei et al. 2016), the influence of Industrial Internet of Things (IIoT) and SCI has not been given enough attention. Whereas agreement exists that SCI covers the integration of internal operations within a firm and external integration with customers and suppliers, less agreement consists on the items describing integration (Ataseven and Nair, 2017). Liu et al. (2016) conclude that SCI refers to information sharing, synchronized planning, operational coordination, and strategic partnership but does not differentiate between activities concerning the supplier, customer or internal functions. Another very common operationalisation describes SCI as three kinds of flows: information, physical and financial flow (e.g., Flynn et al., 2010).

Widely cited articles are Frohlich and Westbrook (2001) with arcs of integration as well as the revisiting version of Schoenherr and Swink (2012). Although SCI is broadly analyzed, many different items are used to operationalize SCI and it remains open, how the industrial internet of things (IIoT) influences SCI.

Industrial internet of things (IIoT) provides different opportunities for companies to develop. IIoT enfolds initiatives belonging to a higher degree of intelligence with the power of advanced computing, analytics, low-cost sensing, and new levels of internet connectivity (Posada et al., 2015).

We aim to get a deeper understanding of how IIoT initiatives influence SCI. Thus, the following research question is answered: “How does IIoT influence SCI?”. We add to literature as we show which factors of IIoT need to be considered in order to understand the influence of IIoT on SCI. In addition, we provide insight into how IIoT influences SCI as we show how the

IIoT factors relate to inward-, periphery-, supplier-, customer- and outward-facing. We further discuss possible configuration trajectories.

Information Age, Industrial Internet of Things, Industry 4.0, Digital Manufacturing

New technologies influence the way industrial companies compete. The changes are labelled information age, industrial internet, digital manufacturing or industry 4.0. The information age started with the third industrial revolution, also known as the digital or ICT revolution, at the end of the twentieth century (e.g., Castells, 2011; Dosi and Galambos, 2013). The technologies, mainly ICT, lay new foundations for companies, economies and societies. Especially the methods of interaction with other people and machines have changed the manufacturing world and facilitated new trends in organisations (Alcácer et al., 2016; Österle, 2013). In addition, Musso (2013) concludes that the information age has sped up the transition from manufacturing to services, highlighting the influence of the technological changes on business models.

In industrial companies, these changes are labelled as industrial internet, industrial internet of things (IIoT) or Industry 4.0. The main approach of the industrial internet or industrial internet of things (IIoT) is to bring software and machines together (Bruner, 2013). The term stems from the US and was first introduced by General Electric. IIoT enfolds initiatives belonging to a higher degree of intelligence with the power of advanced computing, analytics, low-cost sensing, and new levels of Internet connectivity (Posada et al., 2015). Posada et al. (2015) highlight three key elements of IIoT: (1) intelligent machines, (2) advanced analytics and (3) people at work.

Industry 4.0 belongs to a similar initiative, mainly pushed from Germany. The core elements of Industry 4.0 are embedded systems, smart objects, cyber physical systems (CPS), the concept of a Smart Factory, robust networks, cloud computing, and IT-security (Bauer et al., 2014). The coexistence of the physical and virtual worlds, with the use of emerging ICT, opens possibilities such as “enhanced human-machine cooperation (including human interaction with robots and intelligent machines), connected machine networks that follow paradigms of Internet connectivity and social networks, improved human-in-the-loop interaction between the cyber and physical worlds, networked and decentralized value chain transnational scenarios, and emergence of product-service networks based in intelligent, smart products, and associated services” (Posada et al., 2015, p.27).

Another definition, not receiving as much attention as industrial internet or industry 4.0, refers to opportunities of new technologies in digital manufacturing. Digital manufacturing describes the use of an integrated, computer-based system that enfolds simulation, three-dimensional (3D) visualisation, analytics and various collaboration tools to create product and manufacturing processes simultaneously (Wang and Wang, 2016).

One commonality of the concepts is the internet of things (IoT) (Annunziata and Evans, 2012). Although there is not yet a common definition, the core concept is “that everyday objects can be equipped with identifying, sensing, networking and processing capabilities that will allow them to communicate with one another and with other devices and services over the Internet to achieve some useful objective” (Whitmore et al., 2015, p.261). Hence, central to this perspective is the connectivity or interconnection (Hermann et al., 2016). In a survey Whitmore et al. (2015) summarise 127 articles on IoT, based on six dimensions: (1) technology (hardware, software and architecture), (2) applications, (3) challenges, (4) business models, (5) future directions and (6) overview, survey. With 53 articles, the majority focuses on IoT *technologies*. The hardware upon which the IoT is being built include for example radio-frequency identification (RFID), near field communication (NFC) and sensor networks.

In addition, software enables the interoperability between the numerous heterogeneous devices and searches the data generated by them (Whitmore et al., 2015). Thus, another central dimension of each of the described concepts is the generation, analysis and storage of *data* (Hermann et al., 2016; Posada et al., 2015; Whitmore et al., 2015).

Analysing the key components relevant to the information age, industry 4.0, industrial internet of things and digital manufacturing highlights similarities, which can be grouped into *technology, data* and *people*. Technology enfolds the hard- and software needed (i.e. sensors and actors) and the connectivity (i.e. interfaces, WLAN and protocols). The digital technologies combined with the connectivity allows the generation of data which are the key driver of the information age. The combination of digital technologies, connectivity and data build the basis for visual analytics, augmented reality or simulation/visualisation (Posada et al., 2015). Besides the similarities in technologies and connectivity, another cross-cutting theme is the people at work, enfolding the changes in capabilities or human-machine cooperation (Hermann et al., 2016; Posada et al., 2015; Whitmore et al., 2015).

Hence, we conclude that although the main vision of the concepts differ, the underlying factors related to technology, data and people are similar. Hereafter, we use the term Industrial Internet of Things (IIoT) to summarize the dimensions, which serve as triggers for changes in companies.

Supply Chain Integration (SCI)

Supply chain integration refers to the flows of information and materials that help firms to create smooth processes (Mackelprang et al., 2014). Many researchers focus on three main dimensions: internal integration within an organization, external integration with customers and external integration with suppliers. Internal integration refers to "the cross-functional intra-firm collaboration and information sharing activities that occur via interconnected and synchronized processes and systems" (Schoenherr and Swink, 2012). Supplier integration refers to "coordination and information sharing activities with key suppliers that provide the firm with insights into suppliers' processes, capabilities and constraints, ultimately enabling more effective planning and forecasting, product and process design, and transaction management" (Schoenherr and Swink, 2012). Customer integration represents "… close collaboration and information sharing activities with key customers that provide the firm with strategic insights into market expectations and opportunities, ultimately enabling a more efficient and effective response to customer needs" (Schoenherr and Swink, 2012). Mostly supply chain integration refers to reducing uncertainty in the supply chain created through the bullwhip effect. However, the description of Schoenherr and Swink (2012) shows that also other needs of customers may lead to supply chain integration and performance effects.

Schoenherr and Swink (2012) use the following, often used, items to measure SCI: (1) access to planning systems, (2) sharing production plans, (3) joint EDI access/networks, (4) knowledge of inventory mix/levels, (5) packaging customization, (6) delivery frequencies, (7) common use of logistical equipment/containers and (8) common use of third-party logistical services. However, other items exist in order to measure SCI and it remains open which factors to consider in order to understand the impact on IIoT on SCI.

Supply chain integration and the relationship with information technology has been analysed from different researchers (e.g., Liu et al., 2016; Rai et al., 2006). The current literature review from Ataseven and Nair (2017) summarizes the empirically investigated relationship between dimensions of supply chain integration and the different performance measures. Whereas agreement exists that supply chain integration covers the integration of internal operations within a firm and external integration with customers and suppliers, less agreement consists on the items describing integration. Liu et al. (2016) concludes that SCI refers to information sharing, synchronized planning, operational coordination, and strategic partnership. There is no distinction between activities concerning the supplier, customer or internal functions (Flynn et al., 2010). Another very common operationalization describes supply chain integration as three kind of flows: information, physical and financial flow integration (e.g., Flynn et al., 2010; Rai et al., 2006). Here, authors differ between the supply chain function, however, the items to operationalize the flows differ.

SCI researchers have mostly followed one of the two approaches: configuration or contingency. Most of the studies follow a contingency approach, analysing the pairwise relationship between, for example, SCI and performance. The configuration approach describes the fit between SCI and, for example, performance. It applies a holistic view with the assumption of interrelated organizational elements, whereas contingency approaches analyse the pairwise relationship between these elements (Flynn et al., 2010). One of the widely cited articles is Frohlich and Westbrook (2001) with arcs of integration as well as the revisiting version of Schoenherr and Swink (2012). They derive five configurations of SCI: inward-, periphery, supplier-, customer- and outward-facing (Frohlich and Westbrook, 2001; Schoenherr and Swink, 2012).

Another configuration approach is applied from Liu et al. (2016), analysing the supply chain integration and IT competency fit. They discuss the particular patterns of IT competency that fits with the degree of SCI. SCI is described through the three flows (information, physical and financial) and IT competency is defined as flexible IT infrastructure, IT assimilation, and managerial IT knowledge. They support prior studies in concluding that IT competency and SCI interacts in influencing firm performance (Liu et al., 2016). We agree with Liu et al. (2016) that IT needs to be considered as influencing factor. However, looking at the dimensions of IIoT, there is a need to get an understanding of relevant factors

Research framework

Taking the above described dimension into account, we aim to shed light which factors need to be considered in order to understand how IIoT interrelates with SCI. We refer to the three dimensions of supplier, internal and customer integration. Thus, in order to get further insights, we study 11 IIoT initiatives in order to get an in-depth understanding of the underlying factors which influence supply chain integration.

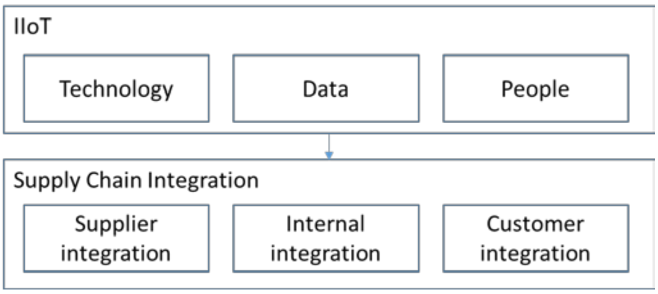

Figure 1: Research framework

Research methodology

As the goal of this research is to get more insights into how IIoT and SCI are linked, we chose a case study based approach (Yin, 1994). We analyse existing literature focusing on IIoT and SCI and derived a framework that served as basis to develop an interview guideline (Eisenhardt, 1989).

The advantage of gaining deep insight into IIoT projects was more important than having a broad but superficial data set. In doing so, the IIoT project serves as unit of analysis. We had access to three European manufacturer, labeled as companies A-C. The companies were chosen because of their qualifications to generate usable results rather than because of their representativeness (Firestone, 1993; Miles and Huberman, 1994). Details about the chosen companies are depicted in Figure 2.

Company	A	B	C
Industry	Industrial Machinery (ISIC code 35)	Industrial Machinery (ISIC code 35)	Fabricated metal products (ISIC code 34)
No. of employees	115	2300	690
Turnover (€)	50 mio	500 mio	110 mio

Figure 2: Overview case companies

Eisenhardt and Graebner (2007) recommend that the case study approach is particularly suitable for topic areas not well documented and rather unknown, which suits our topic of interest. We have conducted an explanatory research approach (Eisenhardt, 1989; Eisenhardt and Graebner, 2007; Stuart et al., 2002) that started in January 2016 and ended in September 2017. It involved 9 to 13 semi-structured group interviews per company. The interviewees were the general manager, the R&D manager, the production manager, the service manager and the responsible for IIoT. All interviews were attended by at least two researchers of the field of operations management to gain as much objectivity in result interpretation as possible. The interviews lasted between two and five hours. In addition to the interview data, we used multiple data sources such as archival data, industry publications, manuals, and company documentation.

We used Miles and Huberman's (1994) four-step approach to analyze the collected data. First, we developed a contact summary sheet in which the main themes of each interview were recorded. One researcher identified the main themes, while the other two researchers checked these themes using the interview minutes. The themes covered, for example, the current situation in each relevant function, the idea generation procedure and the IIoT implementation measures. Second, a complete theme list was developed based on the contact summary sheet. Third, all interviews were coded using selective coding (Strauss and Corbin, 1990) to categorize the answers into the main themes. One researcher was responsible for coding the interview minutes, while the other two researchers checked the coding. In the event of disagreement, the point was discussed until agreement was reached. If no agreement was reached, the point was referred to the interviewee for clarification. This procedure ensured a high level of inter-rater reliability (Voss et al., 2002). Fourth, we wrote the case study and performed a final validity check, which was done by presenting the results to the interviewees and to the top management of the company.

Case study analysis

In order to get an in-depth understanding of the IIoT initiatives, we chose 11 cases from three manufacturing companies. The three companies are currently implementing the analysed initiatives and to do so, have outlined the needed changes related to people, data and technology. In addition, to get a better understanding of the initiatives, the value proposition (Chesbrough and Rosenbloom, 2002) of the IIoT initiatives were discussed to get a better understanding of the respective goals (see Table 1).

Three of the initiatives aim at providing the customers an offering based on predictive maintenance (i.e. guaranteed machine availability). Only two of the initiatives focus on activities in order to achieve a smart factory (digital working instructions and dynamic planning and production system). Company A and C focus solely on initiatives focusing on external value creation. Company B has one initiative with external and two with an internal focus.

Table 2 summarizes the changes in people, data and technologies needed in order to implement the IIoT initiatives. The implementation of the initiatives of company A and C follows a sequence. In both companies, the initiatives predictive maintenance/guaranteed machine availability build the base for further investments such as pay per use, smart services or global service. This sequence as well as the analysis of the eleven initiatives reveal that the foundation builds the changes concerning condition monitoring. From a technological side, the respective investments cover sensors, connectivity investments between machines/devices, data storage, data analysis software and web application technologies (e.g. dashboards). Based on these technological investments, performance, condition and environmental data can be collected, stored, analysed and turned into additional service to customers. In addition, investments are needed to build up capabilities concerning data analysis and interpretation and developments of algorithms. As described, the investments concerning condition monitoring build the foundation for predictive maintenance. Whereas no additional changes are required technology and data wise, there is a need to build up capabilities concerning virtual support.

The rest of the changes, summarized in Table 2, concern single different initiatives but do not build other clusters.

		Value Proposition		
		What?	Why?	To Whom?
Case A1	Guaranteed machine availability	Insurance contract	Reduction of unsceduled down-time; risk transfer	OEM (with high volume)
Case A2	Pay per use	Produced product (not machine)	Calculable manufacturing costs; no upfront investment costs; no maintenance costs	Job shopper, project based investments
Case A3	Smart Services	Service contracts	Garantied reaction time, 24/7 virtual support, optimization of Overall Equipment Effectiveness	OEM (with high volume)
Case A4	Smart factory of the customer	Machines with interface to allow digital integr. into customers production process	Process security; flexibility; reduction of change over time	OEM with high level of automatisation
Case B1	Guaranteed machine availability	Insurance contract with two different service levels	Reduction of unsceduled machine down time; risk transfer	OEM with high level of integration, high utility rate, no internal maintenance
Case B2	Digital working instructions	Real-time and user specific information for operator, assembler, service employee, …	Mainly internal reasons such as reduction of search time, loss of knowledge, issue tracking, quality of information.	Internal: Production and assembly, engineers, trainings-academy External: Operator, maintenance trainees
Case B3	Smart Factory (Dynamic Planning and Production System)	Real-time matching of planning and execution processes and derivation of action alternatives	Cost-optimized ressource utilization under consideration of a high level of delivery dependability, short through-put time and reduction of working capital (e.g. inventory level)	Internal: production planning, production
Case C1	Preventive and predictive maintenance	Machine availability	Minimisation of unscheduled tool down-time; Higher trasparency of tool usage; Enable customer to produce higher quality products; Service outsourcing possibility	All external customers; Internal (sales and development)
Case C2	Global Service	Service contracts; worldwide service coverage	Increased OEE; Reduction of unscheduled down-time; fast problem solving	Customers with high production volume; OEM's in mature markets
Case C3	Life-Cycle Management	Life-cycle-management of tool; maintenance log book	Increased performance of tool; Higher problem solving quality; on time maintenance (as last as possible; as early as necessary)	External customers; Internal (Service and Engineering)
Case C4	System capability	Integrated tool - machine system	Higher performance; better OEE; reduction of unscheduled down-time; faster start-up of system; possibility for predicitive maintenance	OEM

Table 1: IIoT case description

The initiatives are also analysed concerning their influence on internal, customer and supplier integration. As the analysis of the value proposition reveals, the initiatives focus on providing additional customer value or, in the case of company B internal efficiency and effectiveness improvements. Table 2 summarizes the connectivity that is a crucial part of any IIoT initiative. The connectivity describes how different activities are linked. These activities describe the connection between different machine/information systems and activities done in functions (e.g. data analysis). It also describes if the activity or machine/system is internally based (within the company) or externally (customer or supplier). Nine initiatives focus on integrating customers based on the information flow. However, in order to fulfil the services, there is also a need to integrate internal functions. Thus, whereas the main focus lies on customer integration, internal integration is also needed and thus the second important relationship we found. Only in one case, the "dynamic planning and production system" leads to collaboration with suppliers.

	Case A1	Case A2	Case A3	Case A4	Case B1	Case B2	Case B3	Case C1	Case C2	Case C3	Case C4
	Guaranteed machine availability	Pay per use	Smart Services	Smart factory of the customer	Guaranteed machine availability	Digital working instructions	Smart Factory (Dynamic Planning and Production System)	Preventive and predictive mainten-ance	Global Service	Life-Cycle Manage-ment	System capability
People (capabilitities)											
Data analysis & interpretation	x	x	x	x	x	x	x	x	x	x	x
Development of algorithms	x	x	x	x	x	x	x	x	x	x	x
Virtual support	x	x	x	x	x			x	x		x
Insurance statistics	x				x						
Sales capabilities		x	x	x	x			x		x	x
Augmented reality				x					x		
Management of interfaces					x						
Change of mindset for digital and cross-functional development						x					
(Information)-System capabilities						x	x				
Human machine interaction							x				
Application ability of sensors								x			
New service qualifications										x	
3D printing capabilities										x	
Process capabilities											x
Application ability of M2M communication				x			x				x
Technologies											
Data analysis software	x	x	x	x	x		x	x	x	x	x
Data storage	x	x	x	x	x		x	x	x	x	x
Secure connectivity between devices/machine interfaces	x	x	x	x	x		x	x		x	x
Web applications/technologies (e.g. dashboards)	x	x	x	x	x	x	x		x		
Sensors	x	x	x	x	x		x	x	x	x	x
Digital twin	x	x			x						
Counter		x							x		
Cloud					x						
Online spare parts catalogue			x								
Augmented reality				x							
Virtual reality						x					
3D CAD						x					
Issue tracking						x					
Information systems (Planning, Execution, Coordination)							x				
Tracking system							x		x		
M2M communication				x			x				x
Data											
Performance data	x	x	x	x	x	x	x	x	x	x	x
Condition data	x	x	x	x	x	x	x	x	x	x	x
Environmental data	x	x	x	x	x	x	x	x	x	x	x
Product data						x	x				
Production process data						x	x				
Service data						x					
Customer order							x				
Amount of use		x							x	x	x
Supply chain integration											
Impact on integration (first level)	Customer	Customer	Customer	Customer	Customer	Internal	Internal	Customer	Internal	Customer	Customer
Impact on integration (second level)	Internal	Internal	Internal	Internal	Internal	Customer	Customer and Supplier	Internal	Customer	Internal	Internal

x	Condition Monitoring	x	Predictive Maintenance

Table 2: Analysis of IIoT factors and relation to arcs of integration

Case A1	Guaranteed machine availability	Connectivity between Machine usage (e) –> data storage –> data analysis (i) –> functions (development, service, …) (i)
Case A2	Pay per use	Connectivity between Machine usage (e) –> data storage –> data analysis (i) –> functions (development, service, …) (i)
Case A3	Smart Services	Connectivity between Machine usage (e) –> data storage –> data analysis (i) –> functions (development, service, …) (i) Customer order (e) –> customer portal (e) –> ERP (i)
Case A4	Smart factory of the customer	Connectivity between machine usage (e) –> data storage –> data analysis (i) –> functions (development, service, …) (i) machine usage (e) –> operator interface (e)
Case B1	Guaranteed machine availability	Connectivity between machine usage (e) –> data storage (e/i) –> data analysis (i) –> functions (development, service, …) (i)
Case B2	Digital working instructions	Connectivity between sales, development, production, assembly and maintenance through plattform (e.g. PLM tool). (i)
Case B3	Smart Factory (Dynamic Planning and Production System)	Connectivity between sales (i), planning (i) and production (i) through the three systems. Additional connectivity with partners (suppliers) (e) and customers (e)
Case C1	Preventive and predictive mainten-ance	Connectivity between customer order (e) –> sales (i) –> ERP (i) tool usage (e) –> data storage (e/i) –> data analysis (i) –> functions engineering; service, …) (i)
Case C2	Global Service	Connectivity between maschine usage (e) –> data storage (i) –> data analysis (i) Customer order (e) –> e-store (i) –> ERP (i)
Case C3	Life-Cycle Management	Connectivity between tool usage (e) –> data storage (i) –> data analysis –> functions (engineering,
Case C4	System capability	Connectivity between system usage (e) –> data storage in MES (e) –> data analysis (i) –> functions (enginerring, sales, …) (i) –> user database (i) MES (e) <–> user database (i)

(i) = internal activity; (e) = external activity

Table 3: Description of connectivity of the IIoT initiatives

Discussion and Conclusion

SCI is often described with flows (information, financial and material flows) or the internal, customer or supplier integration. We have analysed 11 IIoT initiatives in order to understand how IIoT and more specifically, people, data and technology influence internal, customer or supplier integration.

The key components relevant to the IIoT initiatives can be grouped into technology, data and people. Technology enfolds the hard- and software needed (i.e. sensors and actors) and the connectivity (i.e. interfaces, WLAN and protocols). The digital technologies combined with the connectivity allows the generation of data, which are central for service offerings. The people dimension enfolds changes in capabilities or human-machine cooperation (Hermann et al., 2016; Posada et al., 2015; Whitmore et al., 2015).

The analysis reveals that changes related to condition monitoring build the foundation for many other initiatives. The condition monitoring can be externally or internally, e.g. the condition monitoring within the own or the customer's factories. The respective people, data and technology related factors may be build relevant influencing factors in order to understand the influence of IIoT on SCI. Whereas condition monitoring builds the foundation, predictive maintenance is the next level in order to provide internal or external value. Based on the analysis, we summarize that condition monitoring and predictive maintenance and more specifically, the factors related to people, data and technology need to be considered in order to understand the influence of IIoT on SCI.

Nine analyzed IIoT cases influence the integration with the customer and enable information flow between the customer activities and the company. However, in order to provide the envisioned customer value, there is also a need for internal integration. Thus, we conclude that in order to profit from customer integration, internal integration is needed as well. In addition, two of the analyzed IIoT initiatives start with a focus on internal integration, however, also have an influence on customer integration.

Based on the selection of IIoT initiatives analyzed, there was no direct relation to supplier integration.

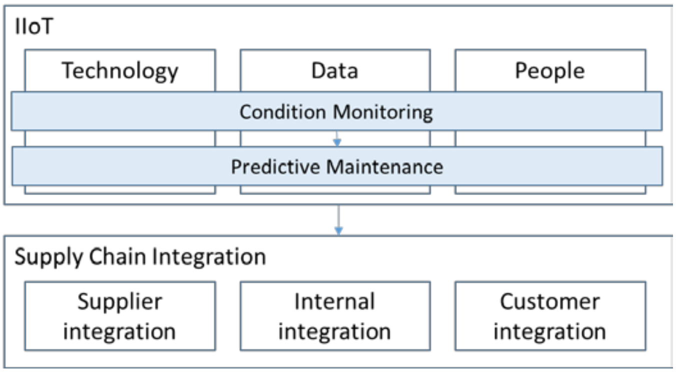

Figure 3: Analysis of IIoT factors and relation to arcs of integration

The analysis did not reveal the common items describing SCI as used by Schoenherr and Swink (2012) but shows possible factors related to people, data and technology and especially condition monitoring and predictive maintenance. Thus, we argue that in order to understand SCI of the future, the factors need to be enhanced with those relevant to IIoT.

The conclusions are limited to the results of eleven IIoT initiatives implemented by the three companies. A larger analysis of other initiatives most likely may show that IIoT initiatives influence supplier, internal and customer integration. For example, there are many prominent examples of IIoT which enhances supplier integration (e.g. SmartBin from the Bosshard Group).

To conclude, based on the eleven IIoT inititatives, there seems to be different trajectories of the companies. The data imply that, despite the decision where to start (internal or external), the IIoT initiatives lead to a higher level in both dimensions. In addition, based on the in-depth analysis of the changes in customer, supplier and internal integration, we derive SCI factors, which should be covered in further SCI related literature.

The findings that condition monitoring and predictive maintenance build on each other and serve as basis for the majority of IIoT initiatives can serve as a starting point for further research attempts in analysing trajectories to implement internally and externally focussed IIoT initiatives.

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