The influence of Industrial Internet of Things on International Manufacturing Networks

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ABSTRACT

Changes related to the information age or Industrial Internet of Things (IIoT) have led to new opportunities, which not only influence a single plant but the internationally distributed manufacturing network. Based on a single case study, the paper at hand provides insights how IIoT influences the coordination of internationally distributed plants.

The derived results show that IIoT initiatives are based on five dimensions (digital technologies, connectivity, data, capabilities and management), which are highly interrelated and need to be harmonized. In order to exploit the full potential of IIoT, headquarters needs to adapt its network coordination mechanism. More specifically, the analysis reveals that if the level of standardisation in products, processes and systems is high and if headquarters takes the responsibility to centrally manage the network and give little autonomy to the plants, a company can unravel the potential of its IIoT initiatives more than without taking the manufacturing network coordination into account.

INTRODUCTION

The pace of change in information and communication technologies (ICT) is still accelerating and influences every industry (Alcácer et al., 2016). International business literature defines these changes as the information and communication age and discusses influences on the geographical distribution of the international business activities (Freeman and Louçã, 2001). Alcácer et al. (2016) highlight that the changes go beyond location and enfolds, for example, organisational decentralisation or modularisation. Innovations in ICT heavily influences the MNEs international production processes (Chen and Kamal, 2016). Researchers and practitioners agree that ICT influences multinational enterprises (MNEs) and that the transformation is still ongoing.

As many medium and large manufacturing companies have gone from producing at single sites to having multiple production plants spread around the globe, ICT not only influences a single site but the manufacturing network. Manufacturing networks enfold multiple plants of one organisational company, most often, scattered around the globe in order to gain access to new skills or low-cost resources (Ferdows, 1997). If a company is not satisfied with the manufacturing performance, a variety of improvement suggestions is available. These improvement programs are usually on the site level, concentrating on optimising single sites in isolation. The improvement programs seldom take into account that today's companies are often composed of multiple manufacturing sites, which are connected and affect one another (Manyika et al., 2012). Subsequently, there is a need to jointly manage and optimise these sites as a network (Feldmann et al., 2013; Shi and Gregory, 1998). Hence, manufacturing network coordination remains one of the key challenges (Scherrer and Deflorin, 2017).

One of the improvement areas for manufacturing companies results from innovations in ICT. Whereas in international business (IB) the changes related to ICT is widely known as the information age, operations management (OM) summarises similar changes as industrial internet of things (IIoT), digital manufacturing or Industry 4.0. Despite differences in the exact definition, two commonalities are the internet enabled information and communication technologies and the achieved connectivity. Many researchers have analysed the influence of ICT on a single manufacturing site (i.e., Bayo-Moriones et al., 2013; Kang et al., 2016; Lee et al., 2013). Others analysed the influence of new technologies, such as additive manufacturing, on the global supply chain (Laplume et al., 2016). Laplume et al. (2016) conclude that the MNEs may strive for geographically dispersed and closer to the end-users production activities (localisation). On the other hand, Vereecke (2017) shows that the costs of additive manufacturing need to be lowered drastically in order to efficiently implement a localisation strategy. Despite some research on the supply chain level, the influence of ICT or IIoT on manufacturing network coordination is unclear. Hence, we focus on the influence of IIoT on the coordination of internationally distributed plants and shed light into how manufacturing network coordination is influenced. Thus, we answer the following research question: “How does IIoT influence manufacturing network coordination?”.

LITERATURE REVIEW

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.

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, 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 the technical side of IoT. 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). In addition to the capability perspective, the people dimension covers the management perspective. Westerman et al. (2014) highlight that in order to turn technology into business transformation, four dimensions need to be covered from the management: (1) framing the digital challenge (i.e. build awareness, know your starting point, craft a vision and align top team), (2) focusing investments (translate your vision into action, build your governance, fund the transformation), (3) mobilising the organisation (signal your ambitions, earn the right to engage, set new behaviours and evolve culture), (4) sustaining the digital transition (build foundation skills, align incentives and rewards, measure, monitor and iterate). Whereas the discussion of capabilities (i.e. data analytics) is present in all the described concepts, the management perspective did not receive the same attention. Mostly, it is part of the research covering business models. However, we conclude that in order to successfully coordinate new potentials based on IIoT, the management perspective should be included.

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

Manufacturing Networks

Many studies have demonstrated the importance of understanding business networks (e.g. Andersson and Forsgren, 2000; Birkinshaw et al., 2005; Forsgren and Holm, 2010). Business networks are composed of subsidiaries that enfold different functions (e.g. R&D, manufacturing, sales). Manufacturing networks, which are composed of manufacturing plants, have primarily operations-related objectives and are a specific class of the business network. Despite the differences between general business networks and manufacturing networks, the coordination of the subsidiaries or plants is important for both kind of networks. Hence, it is important to understand how the coordination of multiple subsidiaries/plants influences performance.

Studies on networks, especially in the international business area, consider financial/market performance (e.g. return on investment, growth) or strategic performance (e.g. innovation, competence development). This study aims to provide insights into the underlying mechanism of manufacturing network coordination and how changes due to industrial internet of things influences a manufacturing network in improving efficiency and effectiveness. Consequently, this study does not employ measures of performance such as innovation or growth in sales, which would not directly measure operational improvements in efficiency and effectiveness. Instead, the paper focuses on operational performance as defined by Flynn et al. (2010), Vereecke et al. (2006) and Szász et al. (2016). In line with the studies in the strategic management literature (starting from Porter, 1985), we refer to two classes of operational performance: efficiency (cost and lead time) and effectiveness (quality, delivery, flexibility). These categories are also found in the OM literature (Beamon, 1999; Jeong and Phillips, 2001; Szász et al., 2016).

Manufacturing Network Coordination

Coordination defines how to link, integrate, and organise manufacturing plants in order to reach strategic business objectives (Cheng et al., 2011; Meijboom and Vos, 1997). In their literature review on manufacturing networks, Scherrer and Deflorin (2017) distinguish between two main research areas of manufacturing network coordination: (a) how the physical and non-physical flows between sites in the network are designed and managed and (b) how rules and mechanisms for interaction between the sites, the sites and headquarters, or the sites and central network management are designed and established.

(a) A central part of coordination is to answer the question of how to design, plan and manage distinct *flows* between the sites in the network (Bartlett and Ghoshal, 1989; Cheng et al., 2011; Cheng et al., 2008). The literature addresses these flows to a different extent. Bhatnagar and Chandra (1993) provide an overview of the models that are dedicated to solving general coordination issues, such as supply and production planning, inventory and distribution planning, and production and distribution planning. Furthermore, they provide an overview of multi-plant coordination issues by linking and aligning the production plans of all of the manufacturing sites in the network.

Several authors emphasise the design and coordination of flows that are related to information and knowledge as a key managerial task (Chew et al., 1990; Ferdows, 2006; Vereecke et al., 2006). In this, Ferdows (2006) develops a typology of production know-how, which involves the level of codification of knowledge and its change rate between the sites, and recommends appropriate knowledge transfer mechanisms for each type. Vereecke et al. (2006) base their typology of plants' roles on the intra-network flows of people and innovation and the communication between sites. In sum, four types of flows are commonly discussed in the literature: the flow of material and physical goods, knowledge and information, people, and financial resources (Bartlett and Ghoshal, 1989; Vereecke et al., 2006).

(b) Coordination is not only restricted to the management of flows. Porter (1986) tightly connects the coordination of activities that are performed at different plants with the degree of autonomy of each production site. This issue of balancing decision responsibility between plants and central headquarters has been addressed by several scholars (e.g., Gupta and Govindarajan, 1991; Hayes et al., 2005; Netland and Aspelund, 2014). Many studies approach autonomy from two perspectives: operational and strategic (Birkinshaw and Morrison, 1995; Kawai and Strange, 2014; O'Donnell, 2000). Strategic autonomy corresponds with the power to make decisions in the adoption and development of production systems or policies in R&D or marketing (Birkinshaw and Morrison, 1995; Davis and Meyer, 2004). Operational autonomy includes tacit decisions and the management of day-to-day operations (McDonald *et al.*, 2008). Autonomy given to a subsidiary has often been analysed as the counterpart of centralised parental control (e.g., O'Donnell, 2000; Young and Tavares, 2004), and the balance between autonomy and parental control is one of the most challenging tasks for practitioners (Van Dut, 2013). Thus, autonomy is also defined as the distribution of decision-making power between a local unit and an outside unit controlling it, i.e. headquarters (Birkinshaw *et al.*, 2004; McDonald *et al.*, 2008). Feldmann and Olhager (2011) tested the autonomy of selected decision categories. Their results reveal three distinct structures of strategic decision making within manufacturing networks: (1) centralised, (2) integrated, and (3) decentralised. Maritan et al. (2004), furthermore, refer to the possibility that standardisation might affect autonomy, but they do not go into detail. Meijboom and Vos (1997) relate autonomy to the technical competence of a plant. By doing this, they weight the degree of standardisation of R&D, production processes, and quality control in the network and conclude that standardisation does not affect autonomy but that it is a second dimension of autonomy. The degree of standardisation is understood to be the degree of similarity of processes or systems (Rudberg and West, 2008) and products (Knight, 2001).

Luo (2005) refers to the idea of "coopetition" as an important dimension of network coordination. In his sense, coopetition is understood to be the simultaneous competition and cooperation of plants in selected areas. To coordinate a manufacturing network, management has to foster coopetition. Levers that nurture either a competitive or a cooperative attitude between the sites can be the allocation and sharing of limited resources, the design of an appropriate incentive system and the handling and transparency of information (Chew et al., 1990; Luo, 2005).

Although IIoT, due to its very nature, changes the information and knowledge flow of a manufacturing network, we focus on the second research stream, the manufacturing network coordination mechanism. Hence, we use the following dimensions in our analysis: (1) degree of strategic and operational autonomy; (2) degree of standardisation; (3) degree of cooperation and competition; and (4) target setting and incentives.

Table 1 summarises the literature review on the manufacturing network perspective.

Network Coordinatio	Sub-Dimension	Authors
Flows		Bartlett & Ghoshal, 1989; Cheng et al., 2008; Cheng et al., 2011
	Flow of Goods	Bartlett & Ghoshal, 1989; Tsai & Ghoshal, 1998; Rudberg & Olhaber, 2003; Luo, 2005; Vereecke et al., 2006
	Flow of Resources	Bartlett & Ghoshal, 1989; Bhatnagar & Chandra, 1993; Tsai & Ghoshal, 1998; Vereecke et al., 2006
	Flow of Knowledge	Ghoshal & Bartlett, 1988; Chew et al., 1990; Luo, 2005; Ferdows, 2006; Vereecke et al., 2006, Rudberg & West, 2008
	Flow of Information	Ghoshal & Bartlett, 1988; Bartlett & Ghoshal, 1989; Gupta & Govindarajan, 1991; Tsai & Ghoshal, 1998; Chew et al., 1990; Luo, 2005; Ferdows, 2006; Vereecke et al., 2006
Coordination Mechanism		
	Degree of Autonomy	Birkinshaw and Morrison, 1995; O'Donnell, 2000; Van Dut, 2013; Young and Tavares, 2004; Kawai and Strange, 2014;
	Degree of Standardisation	Meijboom & Vos, 1997; Maritan et al., 2004; Rudberg & West, 2008
	Degree of Coopetition	Brandenburger & Nalebuff, 1996; Birkinshaw, 2001; Luo, 2005; Cerrato, 2006
	Target setting and incentives	Chew et al., 1990; Gupta & Govindarajan, 1990; Gupta & Govindarajan, 1991; Bartol & Sirvastava, 2002; Luo, 2005

Table 1: Literature review on manufacturing network coordination (based on Scherrer and Deflorin, 2017)

Industrial Internet of Things and Manufacturing Network Coordination

The literature review on IIoT and the related concepts (information age, digital manufacturing, Industry 4.0) highlights the relevant underlying dimensions. In order to be able to gather and distribute information, there is a need of digital technologies such as sensors and actors, image transmission, software and data storage (Porter and Heppelmann, 2014). In addition, there is the need to connect the devices, products or processes. Connectivity enfolds the ports, antennae and protocols which enable wired or wireless connections (Hermann et al., 2016; Porter and Heppelmann, 2014; Whitmore et al., 2015). The generation, storage and analysis of data builds another relevant cornerstone.

Finally, every transformation has a people side. More specifically, there is a need to develop new capabilities such as data analytics or the human-machine cooperation (Hermann et al., 2016; Posada et al., 2015; Whitmore et al., 2015). Or as Porter and Heppelmann (2014, p.18) conclude: “Engineering departments, traditionally staffed with mechanical engineers, must add talent in software development, systems engineering, product clouds, big data analytics, and other areas.” In addition to the new set of capabilities needed, the new possibilities need to be steered and pushed from top management (Westerman et al., 2014).

Our aim is to understand how the IIoT enabler influence manufacturing network coordination. Thus, based on the above-described dimensions, we derive the research model as demonstrated in Figure 1.

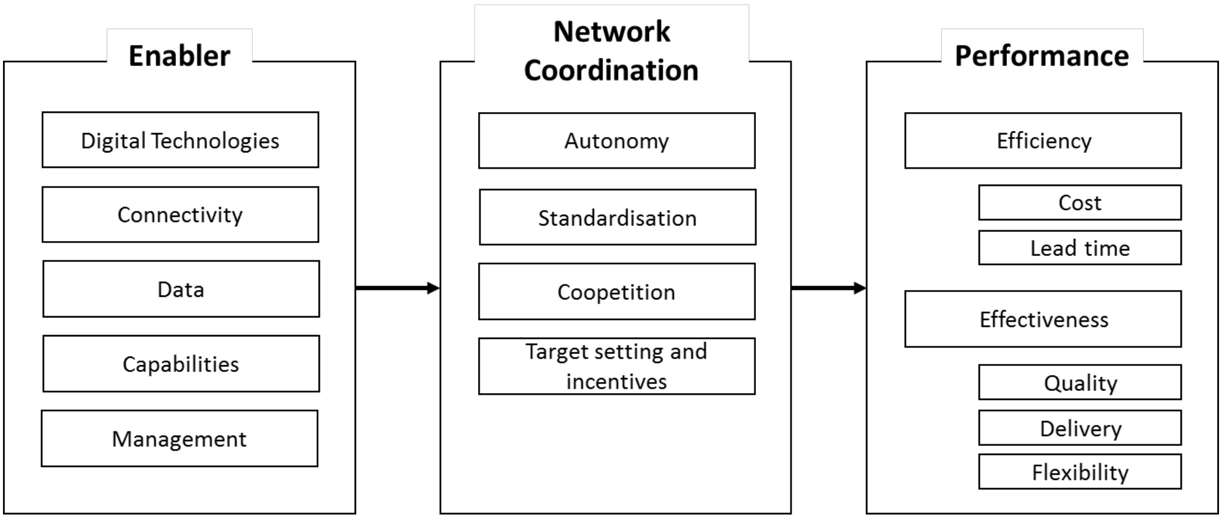

Figure 1: Research model

METHODOLOGY

As we aim at understanding how IIoT influences manufacturing network coordination, we need to gain profound understanding of the relevant elements of IIoT and the manufacturing coordination mechanism. Subsequently, we follow a qualitative research approach (Eisenhardt, 1989). The advantage of gaining deep insight into IIoT ideas of one company was more important than having a broad but superficial data set. In doing so, the company, and more specifically, the manufacturing network level, serves as unit of analysis. The company chosen for analysis is a leading European manufacturer with eight business units, which occupy 2.000 employees in production sites and sales offices around the world. The company was chosen because of its qualification to generate usable results rather than because of its representativeness (Firestone, 1993; Miles and Huberman, 1994). 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 March 2016 and finished in July 2017. It involved eleven semi-structured group interviews with seven employees of the general management board. All interviews were attended by three researchers of the field of operations management to gain as much objectivity in result interpretation as possible. The interviews lasted between two and four 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 analyse 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 content of different IIoT initiatives, and the measures to implement them. 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 categorise 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 ANALYSIS

IIoT initiative “digital workflow and digital product”

The company under investigation faced two challenges, which they want to overcome. First, the assembly process was time-consuming because of missing information, poor quality and search for information. Second, there was a lack of customer specific information. This contained lack of information about the production history of the product, or lack of information about installed software updates since the product was handed over to the customer. Especially, technical and service engineers complained time-consuming information seeking, since customer-specific information was not available across all divisions (R&D, manufacturing, assembly, sales, customer service, etc.). To overcome these issues, the company decided to launch the IIoT initiative *“digital workflow and digital product”*.

The core idea of the initiative “digital workflow and digital product” is to develop and engineer the product virtually and to collect all information of each product of the company’s portfolio digitally. Based on this digital product, a digital workflow is derived. The digital workflow serves as guideline throughout each supply chain step. It steers and monitors the activities as, for example, the assembly employees digitally confirm each process step and save additional data about the production process, if necessary. These data are saved in the customer’s history of the produced product in the product life cycle management (PLM) system. Thus, the company has, at the point of installation at the customer’s site, a virtual dataset of the delivered machine. After installation at the customer’s site, additional data, such as software updates that the customer conducted, are also saved in the customer history of the product. Thus, the initiative “digital workflow and digital product” not only gathers data from production, assembly and customer service but also provides information about the digital product (customer neutral) and the customer specific data. Both data (customer specific and neutral) are saved in the PLM system.

In the case of an incidence at the customer site, customer service employees have the information on the delivered product and conducted updates and in addition, add their activities in the customer history while doing maintenance or repair. The workflow does not end at the company's boundaries but involves activities to be conducted by the customer by displaying, for example, necessary maintenance activities on the display of the control panel at the machine. The issue-tracking systems guarantees the backflow of information from the customer or customer service to the company. This supports the continuous improvement of the processes. However, there is no continuous monitoring of the product's condition at the customer's site and thus, the company cannot exploit the full potential of a digital twin.

Figure 2 summarises the content of the initiative "digital workflow and digital product".

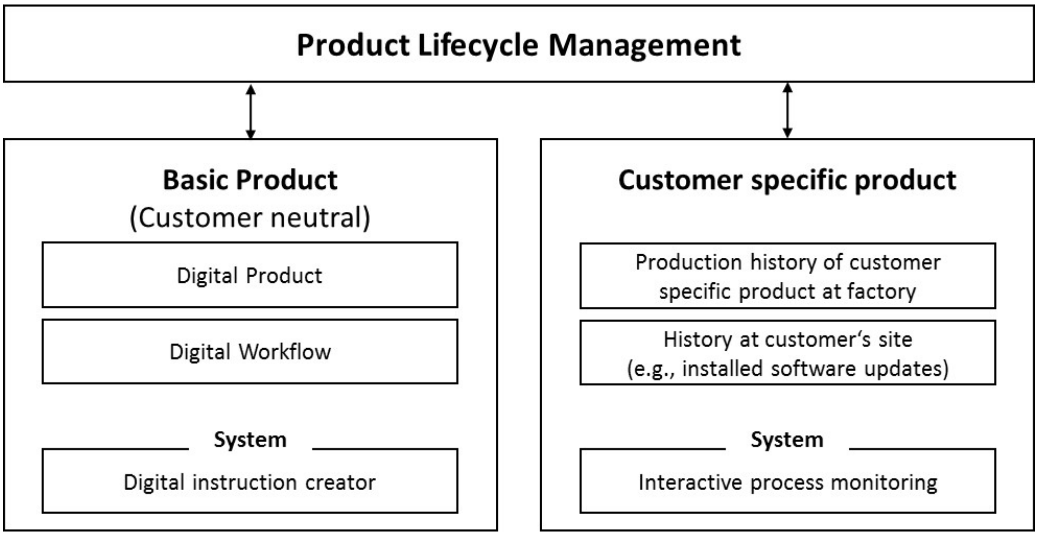

Figure 2: Initiative "digital workflow and digital product"

Headquarters is responsible for the implementation of the "digital workflow and digital product" within each production site. Thus, headquarters is responsible for the definition of the IT-system and its implementation at the sites. In addition, each process step has an assigned owner, responsible for the provision of the needed data and the continuous improvement of the digital workflow and the digital product. The process owner is also responsible to coordinate the operating activities at each production site of the company's network. Thus, headquarters is able to transfer production capacity between their internationally distributed production sites.

The company benefits form having the information where needed and in the quality needed for production, assembly and customer service. The digital workflow also influences quality as it is digitally controlled (digital confirmation of each process step). Customer service has easy access to the information needed (virtual product information) and with adding the maintenance information into the same system guarantees the product life-cycle documentation. The initiative also enables the customer in his own maintenance activities. The digital workflow and digital product information allow the customer to follow the needed maintenance or repair activities without the time-consuming search in a user's manual.

Enablers of the IIoT initiative

The following section summarises the enablers for the IIoT initiative "digital workflow and digital product" according to the five dimensions of the research model: (1) digital technologies, (2) connectivity, (3) data, (4) capabilities and (5) management.

(1) From the technological point of view, the product-lifecycle-management system (PLM) is the backbone of the "digital workflow and digital product", in which all information is accumulated and the product data including the customer specific production, maintenance and service data are stored. Another software needed is the "digital instruction creator", which visualises the production, assembly and maintenance steps. The "digital instruction creator" needs to have up-to-date and high quality data, stemming from each process step until the product is delivered to the customer (development, production, assembly) as well as the customer service. All this information is stored in the PLM system. To gather the customer specific product data, a so called "interactive process monitoring" software is needed.

The visualisation of the digital instructions needs web-technologies, dashboards and interfaces. These technologies are needed internally (i.e., for production, assembly, installation) as well as external (maintenance and service). In case of incidents, the communication via web-technologies (e.g., dashboards) and virtual reality technologies (e.g., augmented reality glasses) allow to guide the operators of the customers through the problem-solving or maintenance process.

(2) Connectivity is one of the key elements of the “digital workflow and digital product”. The PLM-software and the respective interfaces ensure the integration of all functions and process steps over-spanning the complete manufacturing network. In addition, the web-interfaces connects the company with the customer and enables an end-to-end issue-tracking system.

(3) The technologies and the achieved connectivity between systems, processes and functions allows gathering data. The digitally available data, stored in the PLM-system, allows having up-to-date information on products and processes. In addition, the data from the issue-tracking systems allows, based on data-analysis, to derive improvements for processes and products. In the long run, the data allows the derivation of patterns of customer preferences, suppliers or cost structures which provide new insights for the company’s development.

(4) On the human side, requirements on capabilities and management have to be distinguished. In contrast to the traditional manufacturer’s perception, the initiative “digital workflow and digital product” needs a change in the mind-sets of the company’s employees. Earlier, the business units were concentrating on their own processes, with only a few, well-defined exchanges between each other. The new initiative “digital workflow and digital product” is based on three underlying philosophies. The first underlying philosophy, the digital assembly philosophy, consists of a paperless workflow. All data (information and knowledge) of each production step are provided in order to generate the digital instructions. Employees need to learn the handling of paperless working instructions. The second underlying philosophy is a cross-functional information- and knowledge-exchange. The employees should be proud of sharing their knowledge with others to

enhance the workflow within the company, and should not hide information. In order to fully benefit from the “digital workflow and digital product”, it is key, not only to implement information but to hand over as much knowledge as possible. The third philosophy takes all phases of the product-lifecycle into account, from the first ideas up to the disposal of the product. E.g., in the beginning of the development, issues in assembly or recycling already need to be taken in consideration.

The capability of data analysis is inevitable. Especially the capability to analyse and structure all gathered data to generate useful knowledge is key. This capability is central in order to learn from the issue-tracking system and to enhance the knowledge base further. Additional capabilities enclose software and hardware (i.e. sensors) capabilities. Here, strategic partnerships offer possibilities to integrate the new capabilities. However, the company is investing in building up capabilities, which ensure the application of the new technologies.

(5) A key task of the management is the definition of responsibilities. Therefore, system- and process-owners have to be defined and project management has to be set up. Likewise, the management has to picture a clear vision of the three underlying philosophies and to communicate its importance. Besides, the communication within the different business units is part of the management to ensure a consistent picture. Finally, a concept of human resource development is established in order to ensure the development of the needed capabilities.

Another change encountered concerns the project management activities. The stage-gate-related project management (i.e., Cooper et al., 2002) or the very detailed planning requirements of six-sigma or lean management is adapted to an agile project management philosophy. Due to the fact, that many technologies are still new and the cause-effect-relation unclear, the company changed its project-management philosophy to a step-by-step and trial-error approach.

Network Coordination and the “digital workflow and digital product”

The initiative "digital workflow and digital product" is centrally developed (i.e., headquarters) and implemented at each production site. Thus, the initiative influences not only the production site but also the international manufacturing network. The following section covers the manufacturing network coordination mechanism and analyses the influence of the "digital workflow and digital product".

Autonomy vs. parent control

Headquarters drives the initiative and, in cooperation with the production sites, defines the (software) systems and processes. Thus, strategic decisions are all done centrally (high level of parental control). The "digital workflow and digital product" is based on a defined hierarchy of system- and process-owners. There is a process owner for each process step (i.e. assembly of a defined product portfolio) who is responsible to provide the data needed to create the digital workflow. Although the process owner is located at a production site, the responsibility is clearly defined and thus, the level of operational autonomy is low.

Standardisation

Another manufacturing coordination mechanism is the level of standardisation. The level of standardisation enfolds processes, products and systems.

The initiative "digital workflow and digital products" needs a high level of standardisation in processes. The digitised workflow links the main value adding functions of each plant and thus needs to have clearly defined processes and interfaces between each function and between the manufacturing plants. Additionally, the level of standardisation of the products is high. Although there are possibilities for customisation, the products are modularised and the modules are highly standardised. The company has launched different initiatives to standardise the modules but there is still improvement potential.

As described above, the choice of the systems is strategic and done centrally. The systems are one of the main elements for the digital transformation of the company. Only a high level of standardisation of the systems allows the continuous change towards the digital transformation. In addition, to be able to flexibly transfer production capacity between plants, the level of standardisation in systems needs to be high.

Coopetition (degree of cooperation and competition)

In former times, some of the business units that belong today to the company under investigation were competitors in similar fields. Thus, the transfer of knowledge and information was difficult. Different initiatives concerning the level of standardisation have led to a higher level of cooperation between the plants (i.e., product modularisation). The initiative “digital workflow and digital products” asks and enables a high level of cooperation as the products should be transferred easily between the production sites. In addition, the continuous improvement based on the data gathered (e.g., issue-tracking-system) allows every plant to improve. Thus, each plant has an incentive to cooperate.

Target setting and incentives

As described above, the level of standardisation in processes, products and systems is high. To achieve that plant managers accept the high level of standardisation and the low level of strategic and operative autonomy, the target setting and incentive systems need to include network level goals (i.e., improvements of the overall network).

Performance

We discuss the performance effect of the IIoT-initiative based on the two dimensions efficiency and effectiveness. Efficiency consists of cost and lead time, while effectiveness involves quality, delivery and flexibility. The main interest is on performance improvements on a network level as we are interested to know how IIoT initiative influence manufacturing network coordination and performance.

Efficiency

The globally available data allows accessing information wherever needed without searching costs. In addition, the high level of standardisation in processes, products and systems should ensure that the level of quality is high and hence, accessed data can be used without further re-work. Compared to the previous system, product transfer costs between production plants can be neglected due to the digital workflow.

From a manufacturing network perspective, the flexible allocation of production capacity may also improve lead time. The company is an equipment manufacturer of large machines. Hence, the possibility to choose a production site, which is nearest to the customer, allows saving transportation costs and lead time. Furthermore, as the company already produced products in batch size one, there is no loss of economy of scale-benefits after the implementation of the initiative “digital workflow and digital product”, as the batch size is still one.

Effectiveness

One of the key changes from a manufacturing network perspective concerns manufacturing network flexibility. The high level of standardisation and parental control allows to allocate capacity where needed. Although, the flexible allocation of production capacity is possible without a digital workflow, the main improvement is that this flexibility does not negatively influence quality and delivery. In point of fact, the quality at each plan can be increased as the digital instructions and the available technologies enable the employees of each site to produce a high-quality product even without extended training. The key enablers are the new technologies, connectivity, capabilities and management activities of the initiative “digital workflow and digital product”.

DISCUSSION

The IIoT initiative “digital workflow and digital product” highlights the composition of the five IIoT dimensions digital technologies, connectivity, data, capability and management. The digital technologies are needed to feed the product lifecycle management system, the digital instruction creator and the interactive process monitoring.

Connectivity reveals itself in technological solutions (platforms, interfaces, WIFI, protocols) as well as in the process level. The connectivity of processes exists between different functions of the company and between the company and the customer. However, without the underlying technological solutions, the connectivity would not be possible. Hence, we conclude that connectivity is one of the most important enablers of IIoT.

Data is the new oil of the 21st century. To gather data, technology and connectivity are needed. Within the case study, the data is collected throughout every process step and thus allows the generation of the digital customer specific product. In addition, the data are crucial for the lifecycle management of the products and the transparency of the installed machinery base. However, one of the most important aspect is the data from the issue-tracking system, which collects incidents within the company (throughout assembly, production, installation) or at the customers site (maintenance, service). The analysis of this data helps to understand how to improve products and processes. The analysis of the supply chain related data (suppliers, product cost structure, customer preferences) may lead to additional insights. Hence, data is another central dimension of IIoT.

In order to successfully implement the initiative, new capabilities are needed. First of all, data analysis is a IIoT specific capability, which in the case of the analysed company needs to be build up. In addition, there are challenges which are more philosophical in nature and thus, need longer time to adapt. However, it seems that these changes are as crucial to the success of the initiative as the technological developments.

Change needs to be supported from top management. Hence, different management measures, such as communication, involvement, or the definition of the project management accompany the implementation of the initiative. In addition, the need to apply a agile project management philosophy with its trial-and-error culture (Conforto et al., 2014) is another important learning.

The analysis exemplifies that the IIoT enabler are interrelated and hence, need to be taken into account jointly. Thus, an isolated analysis of the new technologies needed is not enough.

The main influence of the IIoT initiative on manufacturing network coordination stems from the digital technologies and connectivity. More specifically, investments in the systems asks for a high level of standardisation. Hence, headquarters need to aim for a high level of standardisation in systems and processes. This is mirrored in the level of plant autonomy which, compared to the beginnings of the initiative, is lower. The higher level of parental control is needed to achieve the high level of standardisation in product, processes and systems and with this to being able to exploit the potential of the IIoT enablers.

The higher level of parental control is also needed when it comes to knowledge exchange. The initiative allows to link different production sites. Due to the high level of standardisation in processes and products, headquarters has a high flexibility in deciding where to produce and assemble the products. As headquarters allocates the production of the products and knows which other plant has produced the product before and consequently already has knowledge in how to produce the product, headquarter can decide which plants need to cooperate. Accordingly, headquarter can set targets for the collaboration between these plants.

Without cooperation, the joint collaboration on the digital workflow and digital product is not possible, as the initiative aims to implement a company wide system with a high level of standardisation. The cooperative behaviour needs incentives as the high level of standardisation does not always fit to the plant management goals.

Finally, manufacturing network coordination should positively influence performance. The analysis reveals that the enablers and the respective measures in manufacturing network coordination positively influences performance. However, without adapting the manufacturing coordination mechanism, the full potential of the IIoT initiative may not be exploited.

CONCLUSION

Even though there exists literature that states that headquarters is a relative outsider of the manufacturing network and with this, not able to know which plants should, for example, exchange knowledge with each other (e.g., Van Dut, 2013), later results show differently (e.g., Golini et al., 2016). Their results show that a low level of autonomy is beneficial if the company aims at profiting from the manufacturing network (Golini et al., 2016). The analysed IIoT initiative reveals a similar relationship as a low level of plant autonomy seems to be needed to exploit the initiatives potential.

The results of Golini et al.'s (2016) study also refer to cooperation. The more a plant embeds itself in its manufacturing network (i.e., collaborates with other plants of the network), the more effectiveness benefits such as increased flexibility, quality and dependability can be achieved. Nevertheless, the company's management needs to pay attention who suitable exchange partners are. There is a lack of openness of plants in developed countries to accept knowledge provided from plants located in emerging countries (Szász et al., 2016). We expect that the connectivity can overcome the not-invented-here syndrome to a certain extent, but the country-context still needs to be taken into account by headquarters when asking for knowledge exchange between plants. An incentive system that takes this fact into consideration can also be beneficial. Possibilities for target settings for knowledge exchange between different plants that proved to be successful are incentives that are set on group achievements of two partnering plants. For example, a more experienced plant supports the less experienced plant in improvement activities (Scherrer-Rathje et al., 2013). This can be adapted in the sense that targets can only be achieved by the knowledge sending plant if the knowledge receiving plant, here the plant that will produce a product for the first time, has successfully produced the transferred product.

From a managerial perspective, the analysis provides interesting insights. In combination with digital technologies, connectivity is needed to gather and store the needed data. Managers need to decide which processes, functions and supply chain steps to connect. Another decision to be made covers the open versus closed system. The closed system only allows the access of clearly defined data whereas the open system closes only the access to the data, which are of high strategic importance. Both philosophies have their pros and cons; most importantly, management has to decide which one to follow.

Data is one of the key enablers of an IIoT initiative and reveals an interesting insight as there is a shift from documents to data. The two systems (interactive process monitoring and digital instruction creator) create and transfer data to the PLM system. In order to visualize the data, the two systems pull the data which are stored in the PLM system. This is only possible if data is gathered and stored and not documents. Thus, in order to implement IIoT initiatives, software providers are needed which are aware of this philosophy shift.

Another understanding reveals itself in the project management philosophy. The shift from stage-gate project to an agile project management supports the successful implementation of an IIoT initiative. This goes along with the need to have managers in place which have the ability for effectual reasoning in order to explore and exploit real opportunities (Sarasvathy, 2001). Finally, as described, IIoT initiatives are based on data, which need to be gathered, stored and analysed. To do so, companies employ data scientists. However, as this job description is fairly new and of growing importance, companies and educational institution should be aware of the growing need and implement respective measures as soon as possible.

The study at hand has its limitations. First of all, it is based on the insights of a single case study. Thus, in order to reach generalisability of the insights presented, more IIoT initiatives and their influence on manufacturing network coordination need to be analysed. In addition, the company under investigation is still in the process of implementation and hence, the performance effects need to be evaluated after the manufacturing network coordination mechanism are adapted to the IIoT's need. Furthermore, the decisions on the manufacturing coordination mechanism are done based on a single IIoT initiative. Further research should consider multiple IIoT initiatives in order to get insights into possible trade-offs.

Overall, the paper at hand shows that companies with internationally dispersed plants can gain benefits from IIoT. It is important to take all dimensions (digital technologies, connectivity, data, capabilities and management) into consideration and to know how to coordinate the manufacturing network. If the level of standardisation in products, processes and systems is high and if headquarters takes the responsibility to centrally manage the network and give little autonomy to the plants, a company can unravel the potential of its IIoT initiatives more than without taking the manufacturing network coordination into account.

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