



The influence of IIoT on Manufacturing Network Coordination

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The influence of IIoT on Manufacturing Network Coordination

Abstract

Purpose - The coordination of a manufacturing network is a challenging task and may be contingent upon the manufacturing environment. The research at hand analyses how IIoT and manufacturing network coordination relate.

Design/methodology/approach - Based on a single case study, the paper at hand provides insights on IIoT enablers and the relationship to manufacturing coordination mechanism. The data sample is based on fifteen group interviews with overall eight employees from headquarters and business units.

Findings – The derived results show that the IIoT enablers (digital technologies, connectivity, data, capabilities and management) are highly related to the manufacturing network coordination mechanism. The results indicate that IIoT initiatives and manufacturing network coordination should be designed to support each other.

Originality/value – The implementation of IIoT initiatives is often analysed in isolation without considering the manufacturing network and more specifically the manufacturing network coordination mechanism. The results highlight how the implementation of IIoT initiatives may act as trigger to adapt formal manufacturing network coordination mechanism.

Keywords – Manufacturing Network Coordination, IIoT, Industry 4.0

Paper type – Research paper

1. Introduction

The pace of change in digital technologies continues to accelerate and influence every industry (Alcácer et al., 2016; Ben-Daya et al., 2019). International business literature defines these changes as the information and communication age, and discusses influences on the geographical distribution of international business activities (Freeman and Louçã, 2001). Alcácer et al. (2016) highlight that the changes go beyond location and rather, for instance, encompass organisational decentralisation or modularisation. Such changes further enable integration within the intra- and inter-company manufacturing network, leading to higher efficiency in manufacturing networks (Ben-Daya et al., 2019). Accordingly, there is a general consensus among scholars and practitioners that innovations in digital technologies heavily

influence the international production processes of multinational enterprises (MNEs) (Ben-Daya et al., 2019; Chen and Kamal, 2016).

As many medium and large manufacturing companies have multiple production plants spread around the globe, digital technologies not only influence a production site in isolation, but rather the entire manufacturing network. Especially the global dispersion of manufacturing networks can have drawbacks. For example, improvement programs usually occur on the site level, concentrating on optimising one solitary site. The programs seldom take into account that today's companies are often composed of multiple manufacturing sites, which are connected and affect one another (Arellano et al., 2019; Manyika et al., 2012).

One of the improvement areas for manufacturing companies and their plants result from innovations in digital technologies. For instance, many researchers have analysed the influence of digital technologies on a single manufacturing site (i.e., Bayo-Moriones et al., 2013; Kang et al., 2016; Lee et al., 2013). Others focus on the influence of single technologies (i.e., additive manufacturing) on the global supply chain (Laplume et al., 2016; Vereecke, 2017). In their literature review on digital supply chains, Büyüközkan and Göçer (2018) illustrate that most studies focus on the technological enablers (e.g. RFID, Big Data, Virtual Reality) and highlight the need to move from industry reports to empirical research. Considering the extensive and cost intensive changes required by industrial internet of things (IIoT) implementation initiatives, headquarters often takes the role of pursuing the implementation. This may result into a central orchestration of activities through headquarters. This change is not discussed in the broad literature yet, as research on IIoT implementation focuses most often on the implementation at shop floor level within one plant without considering the manufacturing network as a whole (Arellano et al., 2019; Manyika et al., 2012).

Despite the existence of research at the supply chain level (e.g., Ben-Daya et al., 2019) the relationship between IIoT and manufacturing networks, and more specifically, on manufacturing network coordination, remains underdeveloped and consequently unclear. Hence, it is our goal to shed light on the relationship between IIoT and manufacturing network coordination mechanism.

2. Literature Review

2.1 Coordination in manufacturing networks

If the joint management, i.e. coordination, of sites in a manufacturing network is done successfully, the network can serve as a source for competitive advantage (Olhager and Sternberg, 2015). Coordination emphasises how manufacturing sites should be linked through

distinct flows such as material, information or knowledge, integrated and organised to fulfil the strategic objectives of their manufacturing network (Cheng et al., 2011; Meijboom and Vos, 1997; Mishra et al., 2019; Scherrer and Deflorin, 2017). Coordination is often discussed as the coordination between sites with headquarters as a relative outsider. The paper at hand includes the results from Golini et al. (2016) and Olhager and Feldmann (2018), stating that headquarters plays an important role in manufacturing network coordination if the level of autonomy of the plants is low.

Manufacturing network coordination can be separated into two basic mechanisms, which are the formal and informal coordination mechanisms (Sayem et al., 2019). On the one hand, informal coordination mechanisms, such as inter-unit visits and team meetings, contain activities between sites to increase the knowledge base of the different sites (Bergek and Bruzelius, 2010; Noorderhaven and Harzing, 2009). On the other hand, formal coordination mechanisms involve how the sites must work together to exploit the potential inherent to a manufacturing network. For the paper at hand, we are interested in the formal coordination mechanisms and how the design of formal coordination is related to IIoT. We focus on formal coordination mechanism as these are defined by management whereas informal coordination mechanism develops over time.

2.2 Formal coordination mechanism

There are several formal coordination mechanisms discussed in literature, ranging from the degree of autonomy of the different plants, over the level of standardisation, to the degree of competition and subsequent target settings and incentive systems.

Porter (1986) tightly connects the formal coordination of activities that are performed at different plants with the *degree of autonomy* of each production site. This issue of balancing the decision-making responsibility between sites and central headquarters has been addressed by several scholars (e.g., Gupta and Govindarajan, 1991; Hayes et al., 2005; Netland and Aspelund, 2014; Olhager and Feldmann, 2018). Many studies approach autonomy from two perspectives: operational and strategic (Birkinshaw and Morrison, 1995; Kawai and Strange, 2014; O'Donnell, 2000). Strategic autonomy corresponds to the power to make decisions in the adoption and development of production systems or policies (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). Autonomy can also be defined as the distribution of decision-making power

between a local unit and an outside unit controlling it, i.e. headquarters (Arellano et al., 2019; Birkinshaw et al., 2004; McDonald et al., 2008).

Maritan et al. (2004) refer to the possibility that *standardisation* might affect autonomy, but they do not go into greater 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 rather 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) and Flanagan et al. (2018) refer to the idea of *coopetition* as an important dimension of formal network coordination. Coopetition is understood to be the simultaneous competition and cooperation of plants in selected areas. Literature on the topic suggests that to coordinate a manufacturing network, management need 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). The degree of cooperation and coopetition can be fostered through an appropriate *target setting and incentive system* (Scherrer and Deflorin, 2017).

Based on these deliberations, we derive the following dimensions as cornerstones of formal manufacturing network coordination mechanism: (1) degree of autonomy; (2) degree of standardisation; (3) degree of coopetition; and (4) target setting and incentives.

2.3 Industrial Internet of Things and Industry 4.0

The main approach of the industrial internet of things (IIoT) is to bring software and machines together (Bruner, 2013). Besides the network of physical objects, it includes the digital representation of products, processes and manufacturing infrastructure (Jeschke, 2017).

Industry 4.0 (I4.0) belongs to a similar initiative, mainly pushed from Germany. From a technical perspective, I4.0 is the integration of cyber-physical systems (CPS) into production processes (Wagire et al., 2020). It connects people, machines and objects both horizontally and vertically. CPS enables real-time data transfer through the technological infrastructure of the Internet of Things, enfolding sensors, microprocessors and actuators (Müller et al., 2018).

Several literature reviews exist, reflecting the increasing interest in I4.0 and IIoT and covers the technical foundations of the concepts as well as general business implications (e.g., Liao et al. (2017); Moeuf et al. (2018); Wagire et al. (2020); Xu et al. (2018)). In a comprehensive

literature review, Wagire et al. (2020) identify 13 principal research areas and 100 research themes. Kang et al. (2016) compare the initiatives from Germany, USA and South Korea and summarise the key technologies for IIoT/I4.0 as CPS, IoT, cloud computing, big data, additive manufacturing (3D printing), sensors, energy saving, and holograms. Moeuf et al. (2018) define similar technologies but add simulation, virtual reality, cyber security, machine-to-machine and collaborative robots. Based on a cluster analysis of I4.0 related literature, Brettel et al. (2014) define individualisation of production, horizontal integration in collaborative networks and end-to-end digital integration as the key research themes. Similarly, Xu et al. (2018) define four themes: (1) IoT and related technologies (i.e., RFID, Wireless Sensor Networks, ubiquitous computing), (2) cloud computing, (3) CPS and (4) industrial integration, enterprise architecture and enterprise application integration (i.e., service-oriented architecture, business process management and information integration and interoperability).

When looking at extant literature, it can be derived that there is a common understanding that IIoT and I4.0 is concerned with applying *digital technologies* to revolutionize current production. The extant literature exemplifies that there is no exclusive list of technologies but that there is a need to get an understanding what set of technologies a company specific initiative enfold (Bosman et al., 2019). Hence, we focus on the identification of the set of digital technologies of a specific IIoT initiative. In addition, we do not elaborate on the distinction between IIoT or I4.0 but refer solely to IIoT initiatives in the remainder of the article. Many researchers argue that discussions of IIoT should not only cover digital technologies, but needs to enfold the whole concept of how to acquire, transfer, analyse and organise data (Hermann et al., 2016; Piccarozzi et al., 2018; Posada et al., 2015; Whitmore et al., 2015). The digital technologies enable the transmission of *data*. Real-time data analysis allows for a more effective and efficient monitoring and controlling of processes and activities throughout the business operation. It also builds the basis for autonomy, i.e. the self-organisation with other systems, processes or products, a self-diagnosis and autonomous product/process operation (Ben-Daya et al., 2019; Moeuf et al., 2018).

The extant literature covers another theme which Seetharaman et al. (2019) describe as perpetual *connectivity*. Lu (2017) uses the term interoperability to describe the capability of an entity to engage in data exchange as well as information sharing among systems. Other refer to integration (Qin et al., 2016; Xu et al., 2018), highlighting three main dimensions: (1) horizontal, (2) vertical and (3) end-to-end integration. Horizontal integration refers to the integration of various IT systems within value networks, covering the different manufacturing and planning processes within a company and between the partners along the value network

(i.e. suppliers and customers). Conversely, vertical integration describes the alignment of different hierarchical levels (from actuators and sensors to manufacturing and execution level, to manufacturing and corporate planning level). Moreover, end-to-end integration describes the combination of the digital and real world across a product's entire product life cycle (Liao et al., 2017). In our article, we use the term connectivity, as it enfoldes the more technological aspects (interoperability) as well as the management perspective of integration.

Additionally, various others argue that these IIoT enablers needs to be enhanced in order to allow organisational change (Bruch et al., 2020; Kiel et al., 2017; Nosalska et al., 2019; Snow et al., 2017; Veile et al., 2019). Veile et al. (2019) highlight that besides the value creation process itself, changes are needed with respect to management activities and capability development. For example, there is a need for adequate training and development approaches for employees as well as management tasks such as interdisciplinary and open communication in order to achieve a consistent semantic understanding of the IIoT (Kiel et al., 2017; Moktadir et al., 2018). Hence, we add *management* and *capabilities* as two important enablers of IIoT.

Against this background and the deliberations from extant literature, we conclude that five themes are relevant to understand the changes related to I4.0 and IIoT: (1) digital technology, (2) connectivity, (3) data, (4) capabilities and (5) management.

2.4 Linking IIoT and Manufacturing Network Coordination

Extant literature on IIoT suggests that the concept may enable MNEs in the manufacturing sector to have a better coordination with partners, a higher accuracy of information related to operational processes and more effective decision-making (Ben-Daya et al., 2019). It is interesting to note, however, that despite the potential benefits of IIoT throughout an organisations business operations, research on IIoT tends to focus on the shop floor level (i.e. smart factory) and do not discuss the manufacturing network level (see the above discussed literature reviews from Liao et al. (2017); Moeuf et al. (2018); Wagire et al. (2020); Xu et al. (2018)). Furthermore, when looking at benefits from IIoT, the overall network is kept as a black box (Schroeder et al., 2019).

Although it is not discussed how manufacturing network coordination and IIoT relates, there is some literature focusing on single coordination mechanism and the relationship to IIoT. For example, it is concluded that a high level of parental control (opposite of autonomy) fosters the implementation of similar digital technologies (Inkpen and Tsang, 2005). Partanen et al. (2020), although on a supply chain level, discuss that standardisation is a prerequisite for connectivity and the usability of data. Other articles discuss the opposite direction and show that IIoT

influences specific manufacturing network coordination mechanism. For example, Porter and Heppelmann (2014) discuss that IIoT influences the needed level of autonomy of a plant to be able to integrate processes and actors in a suitable manner. Within manufacturing network coordination and supply chain, IIoT furthermore leads to an increase of the level of process and system standardisation (Coreynen et al., 2017; Partanen et al., 2020; Porter and Heppelmann, 2014) and supports cooperation activities (Wamba, 2012). Laya et al. (2018), although in a study focusing on health care networks, conclude that a higher level of connectivity within the network leads to a higher level of collaboration. Connectivity furthermore can influence the level of standardisation within a manufacturing network. This is due to the fact that a higher level of connectivity leads to a mutual coherence and subsequently to a higher level of standardisation (Fatorachian and Kazemi, 2018). The availability and use of data can foster cooperation and incentive programs as knowledge can be gained out of data, which, in consequence, can lead to product improvements or closer collaboration with customers which can lead to cooperation. This cooperation can then be fostered or restrained by a well-defined incentive system (Schroeder et al., 2019). Capabilities to work with the generated data and to derive knowledge out of it is considered as a key capability for manufacturing companies working with IIoT. With relation to supply chain coordination, Arunachalam et al. (2018) discuss that data analysis needs targets and incentives set at network level.

Literature on IIoT implementation highlights the need of top management attention (Kiel et al., 2017; Moktadir et al., 2018). From a manufacturing network coordination perspective, some sources discuss the need for tactical level decisions made by management (Bhatnagar et al., 1993; Cheng et al., 2011). However, empirical studies discussing the link between management decisions as part of the IIoT initiative and manufacturing network coordination are missing.

Overall, existing literature analyses in detail the application possibilities of IIoT on the shop floor level and within one single manufacturing site or discuss how IIoT can support tracing the flow of material from the production site downstream towards the customer. However, the manufacturing network level is largely omitted. Although there is literature discussing single dimensions of IIoT and manufacturing network coordination mechanism, it does not cover the orchestrated coordination of a manufacturing network. To gain some more insights, we had to rely on supply chain literature or other literature covering networks, exemplifying the need to get more insights into the relationship between manufacturing network coordination and IIoT. In addition, many of the cited literature only describe the relationship between IIoT and the manufacturing coordination mechanism but did not study it empirically (see Table 1).

please insert Table 1 here

Against this background, we strive to answer the following research questions: “How are IIoT initiatives and formal manufacturing network coordination mechanism related?”

Figure 1 summarises the dimensions which, based on the extant literature, are relevant to understand IIoT enablers and formal manufacturing network coordination mechanism. The research framework guides the research analysis.

please insert Figure 1 here

3. Methodology

As we aim to gain a greater understanding of how IIoT and manufacturing network coordination are related, we need to gain profound understanding of the relevant elements. Subsequently, a qualitative research approach has been followed (Eisenhardt, 1989). In doing so, one MNE from the manufacturing sector was selected to be the focus of the present research. The sampling strategy applied followed the logic of intensity sampling. Intensity sampling involves selecting studies that are ‘excellent or rich examples of the phenomenon of interest, but not highly unusual cases... cases that manifest sufficient intensity to illuminate the nature of success or failure, but not at the extreme’ (Patton, 2002, p. 234). Due to the length of IIoT implementation, we selected a company that already had started an IIoT implementation and the management and project employees were able to provide in-depth information on the IIoT initiative as well as the manufacturing network coordination. Although this approach divests us from the opportunity to measure quantitative effects of the implemented changes, it provides the opportunity to get an in-depth understanding of the argumentation and decision making of manufacturing (network) managers.

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 and respective plants, with approximately 2,000 employees in production and sales. The explanatory research, conducted between March 2016 and September 2017 and a follow up interview in February 2019, involved fifteen semi-structured group interviews with eight employees of the general management board (see Table 2). Each of the interviewees were highly involved in the implementation of the IIoT project. The business unit leader involved, for instance, represented the plant’s perspective. Within the implementation project, he was,

together with the head of global operations, responsible to coordinate the requirements and activities of each of the plants.

Although, the project was led centrally, each of the business units (i.e. plants) were involved in workshops and monthly meetings. To get as much insight as possible, the research interviews were conducted with employees from headquarters as well as business units. The fifteen group interviews were conducted parallel to the implementation of the IIoT projects.

please insert Table 2 here

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. All interviewees were heavily involved in the design and implementation of the IIoT project and were able to recount the decisions about the IIoT project and the manufacturing network coordination. Table 3 provides an overview of the analysed content and the respective tools and documentation.

please insert Table 3 here

Despite the differences researcher apply in qualitative data analysis, there are a few basic commonalities in the process of making sense of qualitative data. Miles and Hubermann {Miles, 1994 #1005} describe these commonalities based on a four step approach, which we followed in our research. The four steps enfold data reduction, data display, and conclusion drawing and verification). First, we developed a contact summary sheet in which the main themes of each interview were recorded, using the research framework as guideline. One researcher identified the main themes, while the other two researchers checked these themes using the interview minutes. The themes covered, for example, the descriptions of the digital technologies or the decisions concerning the level of autonomy (see Figure 1). 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 and company materials, 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). We then 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.

4. Case Analysis

4.1 Initial situation

The manufacturing network of the selected company consisted of eight production plants, producing grinding machines for manufacturing companies (B2B). Throughout the years, the company bought multiple plants, which produced similar machines. The company only recently started to coordinate the manufacturing network. Almost all production plants had different IT systems, which raised challenges to achieve effective coordination across the plants. One exception was the product life cycle management (PLM) system, which headquarters decided to roll-out in all plants. However, there was no data exchange between the plants; instead, all worked in isolation with their PLM system. Accordingly, the manufacturing network had a high level of autonomy, whereby each plant coordinated its own capacity. Headquarters did not set targets or incentives to coordinate the plants. Figure 2 summarises the manufacturing network coordination mechanism prior to the implementation of the IIoT initiative.

please insert Figure 2 here

In addition, the plants were facing problems. First, the assembly processes were time-consuming because of missing information, poor quality and the time required to search for information. Second, there was a lack of customer specific information; this includes a lack of information about the production history of the product for each customer or about the installed software updates and maintenance activities after the point when the product was handed over to the customer. Thus, an end-to-end integration of processes and the access to production and customer data was not present. In vein of the challenges faced, a plant manager took the initiative and started to analyse how to overcome these issues with the help of IIoT technologies. Upon informing headquarters of these endeavours, a decision was made at headquarters to roll-out and implement the IIoT initiative which they called “*digital workflow and digital product*”, within the manufacturing network. This decision was made as the decision-makers understood that the IIoT initiative could allow the company to benefit from sharing capacities between the eight individual production plants and thus to be able to react more flexibly to changing market needs.

However, besides the aim to support the manufacturing plants, the decision makers at headquarters also realised that they needed to understand how to adapt the formal manufacturing network coordination mechanism in order to fully exploit the IIoT initiative. Thus, the following sections focus on the initiative and the design of the formal manufacturing network coordination mechanism.

4.2 IIoT initiative “digital workflow and digital product”

The core idea of the initiative “*digital workflow and digital product*” was to develop and engineer the product virtually, to digitally collect all information of each product in the company’s product portfolio, and to have a dynamic capacity planning for all manufacturing plants. The respective data stems from the internal production and assembly processes and from the machine at the customer site. The core IT system is the product lifecycle management (PLM), with interfaces to three systems: the digital instruction creator, the issue tracking and the dynamic capacity planning (see Figure 3). The following section covers the description of the systems to understand the idea of the IIoT initiative.

The first part of the IIoT initiative enfolds the data of the digital product and the digital workflow. The digital workflow serves as a guideline throughout each supply chain step (i.e. production, assembly, customer service) and contains information regarding the activities required from both personnel resources and machine resources in each process. In this part of the IIoT initiative, there is a need for machine-to-machine communication, which allows for the autonomous steering of shop floor activities. The respective data involved are referred to as basic data, as they do not contain customer specific adaptations but instead generic information about the product and the digital workflow.

The customer specific data made up the second part of the IIoT initiative. First, the basic digital product is adapted according to the customer specific requirements (i.e. digital twin of the customers product), which allows the process coordination and monitoring according to customer requirements. The system to do so was labelled “digital instruction creator”.

In addition, any occurring issue during production is saved (i.e. issue tracking system). The compiled data collected throughout the production process is stored as part of the customer’s history of the product produced. After installation at the customer’s site, additional data, such as software updates are also saved in a digital twin.

In the case of an incident involving the machine at the customer site, customer service employees have all the information on the delivered product whilst doing maintenance or repair.

Further, the IIoT initiative influences the end-to-end integration, as 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 (i.e. on the dashboard). In this light, end-to-end integration is guaranteed by a backflow of condition data from the running machine at the customer site. In addition, every issue is tracked, allowing for the continuous improvement of the product and processes. Subsequently, all data are stored in a digital twin of the customer's product.

The third dimension of the IIoT initiative covers the system "dynamic capacity planning". This system coordinates the production capacity of each plant. To do so, it matches the digital product and workflow with the plant's free capacities. In contrast to the former planning tool, the plant's free capacities are derived from real-life data, as each machine of each plant is connected with the industrial internet of things (IIoT) in order to monitor its condition. Figure 3 summarises the content of the initiative "digital workflow and digital product".

please insert Figure 3 here

4.3 Roles and responsibilities

Headquarters is responsible for the implementation and operation of the "digital workflow and digital product" within each production site. Thus, headquarters is also responsible for the definition of the IT-system, its subsequent implementation and improvement at all sites.

Each production process 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 for coordinating the operating activities at each production site in the company's network. Hence, this role enfoldes the coordination of the plants process improvements. The process owners are assigned by headquarters yet are still working at one of the plants in order to have the necessary in-depth knowledge of the plant's production processes.

4.3 Enablers of the IIoT initiative

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

(1) The implementation of the IIoT initiative enfoldes different kinds of digital technologies, ranging from IT systems to actors and sensors as well as augmented reality glasses. The 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, service and machine condition data are stored. Another software required to successfully implement the IIoT initiative at the company is the “digital instruction creator”, which has the function of visualising and coordinating the production, assembly and maintenance steps needed to produce and maintain each product.

The visualisation of the digital instructions requires web-technologies, dashboards and interfaces. These digital technologies are needed both internally (i.e., for production, assembly, installation) as well as externally (i.e., maintenance and service). In case of incidents with the products at the customer’s site, communication via web-based technologies and augmented reality glasses allow to guide the operators of the customers through the problem-solving or maintenance process. To do so, it is vital that the machines have sensors and actors, which monitor the production activities. In order to be able to access and transfer the machine data, an edge-box that gathers data from the machine when being operated at the customer site is required.

Finally, from a more holistic perspective, the company’s dynamic capacity planning needs to have real-life data about the condition of the production machinery needed to produce the machines. Thus, the machines are part of the company’s IIoT.

(2) The following section covers the *connectivity* achieved through the “digital workflow and digital product”. The PLM-software and the respective interfaces ensured the integration of all functions, production machinery and process steps over-spanning the complete manufacturing network. In addition, web-interfaces are used to connect the company with the customer and to enable an end-to-end issue-tracking system. Whereas in-house, the connectivity from the IIoT initiative facilitates the accessibility to data in real-time, the link with the customer is often asynchronous (only in the case that the customer actively allows data to be transferred). Since, under the IIoT initiative, all plants are run under the same IT systems, the connectivity facilitates the horizontal integration of data and vertical integration of different functions (i.e. R&D, assembly, production and service) not only along the company’s downstream supply chain, but also between the individual production plants.

(3) The technologies and the achieved connectivity between systems, processes and functions enables data gathering. Thus, the following section describes the third IIoT enabler; *data*. The digitally available data, stored in the PLM-system, fosters the creation of a database consisting

of up-to-date information on products, processes and production capacity. In addition, data-analysis of the data from the issue-tracking system allows to derive process and product improvements. In the long run, the data collection and analysis facilitates the derivation of patterns of customer preferences, suppliers or cost structures, which provide new insights. The data gathered from the customer's machine at site (condition and contextual data from the running machines) allows monitoring the condition of the machine as well as the derivation of predictive maintenance services.

(4) The following section describes the fourth enabler of an IIoT initiative; *capabilities*. The implementation of the IIoT initiative has led to various changes in the needed capabilities. First, company representatives highlight the need to have employees, which can develop and handle paperless working instructions. Second, the employees need to learn how to cooperate across functional silos. As the data is derived and used throughout the whole value chain, changes in the data gathering process or system needs to be coordinated between all relevant functions. Third, the capability of data analysis is a pre-requisite for a sustainable implementation and operation of the IIoT initiative. Being able to accurately and effectively analyse the relevant data is considered to be central in order to learn from the issue-tracking system and the customer data. Additional capabilities required under the IIoT initiative enclose capabilities relating to software and hardware (i.e. sensors).

(5) The fifth IIoT enabler, *management*, covers the following aspects in relation to the IIoT initiative of the company. First, system- and process-owners need to be defined and a project management set up. Second, the company's management team need to ensure a consistent picture within the different business units by ensuring coherent communication throughout all locations. To ensure this, the project team involved headquarters and business units (i.e. plant management) representatives. Finally, a concept of human resource development is needed in order to ensure the development of the capabilities of employees to meet the new requirements under the IIoT initiative. Figure 2 summarises the IIoT initiative.

4.4 The Adaptation of Formal Network Coordination Mechanism

The initiative "digital workflow and digital product" is primarily centrally developed at headquarters and subsequently implemented at each production site. The following section highlights the change of the formal manufacturing network coordination mechanism due to the IIoT implementation. Figure 2 summarises the different designs of the manufacturing network coordination mechanism prior and during the implementation of the IIoT initiative as described by the interviewees.

4.4.1 *Autonomy vs. parent control*

The IIoT initiative is driven by the company's headquarters and, in cooperation with the production sites, headquarters also defines the (software) systems and processes. Thus, strategic decisions are conducted centrally (high level of parental control). The "digital workflow and digital product" is based on a defined hierarchy of system- and process-owners, whereby the system-owners are headquarter employees and the process owners production site employees with assigned responsibility to coordinate the operating activities. The process-owners, i.e. for the assembly of a defined product portfolio, are responsible for the standardisation of the respective processes and, in a first step, to provide the needed data to create the digital workflow. Process improvement suggested by the process owner needs confirmation by headquarters in order to ensure a coordinated roll-out and the adaptation within the "digital workflow and digital product". Hence, in order to allow continuous and joint improvement of the *digital technologies* and *connectivity* within each of the plants, to be able to access *data* of the overall installed machine base and to enable capacity sharing between the plants, the studied company decided on a high level of parental control. Thus, all decisions on technologies, capacity, improvement programs etc. were made centrally, leading to a lower level of plant autonomy.

P1: The implementation of a centrally developed IIoT initiative (i.e., digital technologies, connectivity and data) requires a high level of parental control of a manufacturing network.

4.4.2 *Standardisation*

Another formal coordination mechanism is the level of standardisation, enfolding processes, products and systems.

The initiative "digital workflow and digital products" requires a high level of standardisation in each process as it is not only a plant specific project but includes all business units. For example, the digital instruction creator that guides the production processes within the plants needs standardised processes throughout each of the plants. Otherwise, there would be a need to adapt each instruction to the plant specifications.

The new *connectivity* and *digital technologies* (i.e. sensors and actors) of the shop floor machines within each manufacturing plant enables the gathering of real-life *data* and with this, the ability of the company to undertake dynamic capacity planning. To be able to implement the dynamic capacity planning for all plants, the interviewees conclude that there is the need of a high level of *standardisation* in processes, products and systems.

Although there are possibilities for customisation, the products are primarily modularised, with each module being highly standardised. The company launched different initiatives to standardise the modules but there is still improvement potential.

Hence, management acknowledges the need for a high level of standardisation in processes, products and systems in order to be able to coordinate the manufacturing network and to successfully implement the IIoT initiative.

P2: The implementation of centrally developed IIoT initiatives (i.e., digital technologies, connectivity and data) requires a high level of manufacturing network standardisation in product, processes and systems.

4.4.3 Coopetition (degree of cooperation and competition) and target setting

The *digital technologies, connectivity and data* from each production plant and the respective shop floor activities enables headquarters to coordinate each production site. As headquarters knows which production location had produced the product module in question previously and thus has the relevant information and skills to conduct the task, headquarters decides which plants need to cooperate for knowledge exchange. Because of these holistic insights into the production of each plant, headquarters accordingly set targets for the collaboration between these plants.

Without cooperation, improvements on the “digital workflow and digital product” initiative would not be possible. The cooperative behaviour requires incentives to achieve the overall desired coopetition as the high level of standardisation and low level of autonomy does not always fit to the plant management goals.

The implementation of the IIoT initiative and its effectivity in the long run necessitates different *capabilities*, which some of the plants are required to build up or improve. Hence, a prior lack of capabilities within production plants led to the overall need to cooperate with other plants within the organisation with the aim to share required capabilities between plants and to learn from each other.

The interviewees are convinced that having only plant performance incentive may lead to an optimisation of the own processes in order to optimise the own plant result. Thus, new goals set from headquarters covers for example the number of process and data improvement suggestions concerning the IIoT initiative and the number of successful capacity sharing situations. However, the interviewees highlight that the outcome of target setting and incentives need to be investigated in a few years in order to understand the achieved result.

P3: The implementation of centrally developed IIoT initiatives (i.e., digital technologies, connectivity, data and capabilities) requires a higher level of manufacturing network cooperation.

P4: The implementation of centrally developed IIoT initiatives (i.e., digital technologies, connectivity, data and capabilities), requires common targets and incentives on manufacturing network level.

4.5 The Adaptation of the IIoT initiative

The following section shows how the chosen level of manufacturing network coordination mechanism influences the IIoT initiative. First, setting a high level of standardisation in products, processes and systems to be able to successfully coordinate the manufacturing network influences the IIoT initiative. Whereas plant management (i.e. business unit leaders) asked for plant specific adaptations of the *digital technologies* and *connectivity* in order to fulfil their plant specific goals, headquarters overruled those needs and centrally decided which technologies to implement. Similar decisions were made with relation to *data* (i.e. data structure) in order to allow data transfer and analysis throughout the manufacturing network. Hence, we summarise the following proposition:

P5: A high level of standardisation to coordinate the manufacturing network influences the implementation of the IIoT initiative (i.e., digital technologies, connectivity and data).

As described above, business unit leaders had some own ideas how to implement IIoT in their plants. However, in order to be able to benefit from the manufacturing network and to avoid the optimisation of the single plants, headquarters set up a project team to develop and implement IIoT for the whole manufacturing network. Decisions concerning digital technologies, connectivity and data were centrally done with participation of the business units. In addition, it was decided to keep the strategic and decision autonomy of the plants low and to centrally coordinate every IIoT initiative. Thus, the project team was staffed with headquarters and business unit representatives, providing top *management* attention.

Finally, the capabilities of the employees at the plants differed, leading to a concept of human resource development, orchestrated from headquarters.

P6: A high level of parental control to coordinate the manufacturing network influences the implementation of the IIoT initiative (i.e., digital technologies, connectivity, data, capabilities and management).

5. Discussion

Extant literature in the field of IIoT has a strong focus on individual smart factories (Liao et al., 2017; Moeuf et al., 2018; Wagire et al., 2020; Xu et al., 2018) and at the supply chain level (Ben-Daya et al., 2019). With respect to manufacturing network level, there is a need to understand how IIoT is related to the manufacturing network coordination mechanism.

The case study highlights an IIoT initiative that the company under investigation implements. To describe the IIoT initiative, five key dimensions were considered: digital technologies, connectivity, data, capabilities and management. To get insights into the relation between IIoT initiatives and coordination mechanism, the management decisions on how to adapt manufacturing network coordination mechanism are presented. We conclude with an overview on how manufacturing network coordination relates to IIoT initiatives. The case analysis led to six propositions, which highlight the relationship between IIoT initiatives and manufacturing network coordination.

Overall, the propositions imply that the implementation of IIoT initiatives seem to require changes in the formal manufacturing network coordination mechanism. With this, the data gathered indicates that the implementation of IIoT initiatives should not only be analysed from a single plant perspective but also from the manufacturing network level perspective. Most of the literature emphasising the relationship of IIoT and coordination mechanism focuses on the influence of IIoT on a single coordination mechanism (see Table 1). To a lesser extent, literature discusses the influence of coordination mechanism on IIoT. Most of the relationships identified in the case study at hand describe how IIoT influence coordination mechanism (see propositions one to four). The analysis indicates for example that digital technologies, connectivity and data (see for example, the changes related to dynamic capacity planning) requires a high level of parental control, of standardisation in product, processes and systems and of manufacturing network coordination.

However, it should be noted that the decisions on how network coordination is designed may also influence the implementation of the IIoT initiative. More specifically, in support of Partanen et al. (2020) and Inkpen and Tsang (2005), propositions five and six summarise that the mechanism parental control and standardisation influence the implementation of IIoT. This is presented with headquarters decisions to overrule the plant managers initiatives to design the IIoT project according to the individual plant goals. Hence, it can be argued that new IIoT opportunities should not be implemented without the discussion of possible adaptations of the manufacturing network coordination. In addition, having set the manufacturing coordination mechanism, the influence on future IIoT initiatives should be considered as well. Hence, there

is a need to continuously analyse the fit between manufacturing network coordination and IIoT initiatives. Figure 4 summarises the relationship.

please insert Figure 4 here

With respect to parental control and plant autonomy, Olhager and Feldmann (2018) analyse 14 decision categories, covering for example manufacturing technology, capacity planning and improvement programs. The study at hand reveals the management decision to keep most of these decision categories centralised and to minimise plant autonomy. Olhager and Feldmann (2018) did not find any performance differences between the range of control and plant autonomy but argue, based on their finding of the influence of product volume and process type that decision-making seems to be contingent upon the manufacturing environment. Considering the IIoT initiative as change in the manufacturing environment supports this argumentation. However, as the data analysed suggest, not only the level of autonomy in decision-making seems to be contingent upon IIoT initiatives but the formal network coordination mechanism in general.

With respect to headquarters control some studies suggest that a company's headquarters is a relative outsider of the manufacturing network and with this, is not able to know which plants should, for example, exchange knowledge with each other (e.g., Van Dut, 2013). Later results suggest otherwise (e.g., Arellano et al., 2019; Golini et al., 2017; Golini et al., 2016). The deliberations from these studies argue that if a company wants to completely benefit from the manufacturing network, then a low level of autonomy should be maintained (Golini et al., 2016). This is in line with the findings from our case-study, whereby the analysed IIoT initiative revealed a similar relationship, illustrating that a low level of plant autonomy seems necessary in order to exploit the initiatives potential.

Literature agrees that the implementation of IIoT initiatives benefit from a high level in standardisation on manufacturing network level and vice versa (Coreynen et al., 2017; Partanen et al., 2020; Porter and Heppelmann, 2014). The study at hand clearly supports the relationship between IIoT and a high level of standardisation. For instance, the IIoT initiative of the studied company allows a dynamic capacity sharing between plants based on machine data. The sharing however, needs a high level of standardisation in products, processes and systems as a higher level of individualisation would not allow the production of the products in multiple plants.

The results of Golini et al.'s (2016) and Golini et al.'s (2017) studies 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 goals (i.e., flexibility, quality and dependability) can be

achieved. With respect to IIoT, Laya et al. (2018) also argue the need for a high level of collaboration. The study at hand confirms this relationship but whereas the level of standardisation and autonomy are factors that can be directly changed from headquarters, the level of collaboration is much more dependent upon the plant management behaviour. However, the long-term outcome was not measured in the case study and therefore remains unknown. The effect of IIoT enablers and higher levels of cooperation on manufacturing network coordination mechanisms could thus be a potential area for future research.

Finally, management attention seems to be an important success factor for IIoT implementation. Having decided on a centralised approach, the studied company set-up a project team with headquarters and business unit representatives. This allowed the company to provide the needed management attention. The IIoT initiative benefitted from clear management decisions, for example, with regards to standardisation in products, processes and systems.

6. Conclusion

This study contributes to the research streams on manufacturing networks by exploring how manufacturing network coordination mechanism are contingent upon IIoT initiatives. The results provide empirical evidence on how a company designs coordination mechanism to be able to exploit the potential of IIoT. Thus, we add to literature as we not only describe the link between IIoT and manufacturing network coordination but provide empirical data.

Whereas Olhager and Feldmann (2018) discuss the need to study plant autonomy as contingent upon the manufacturing environment, we expand on this notion and argue that IIoT initiatives and manufacturing network coordination need to be studied as contingent upon each other.

Further, the information summarised from the interviews provides insights into what kind of management decisions need to be taken in order to implement an IIoT initiative (i.e. IIoT enablers). We argue that the management decisions concerning the IIoT initiative are contingent upon the choice of manufacturing network coordination and vice versa. A topic not yet covered in literature.

From a managerial perspective, the presented analysis provides interesting insights. The implementation of IIoT initiatives could occur individually at each single plant. However, as the case study exemplifies, the implementation of IIoT initiatives on a manufacturing network level provides additional benefits (i.e. centralised data analysis for detection of anomalies and improvement suggestions, the implementation of new services such as predictive maintenance and the flexible sharing of capacities between plants). Thus, companies could benefit from the implementation of IIoT initiatives at the manufacturing network level but should also consider

adapting the coordination mechanism to support the new needs of the initiative. In addition, the study at hand provides decision categories (IIoT enabler and manufacturing network coordination mechanism) which management can use as guide in order to design their own fit between the two dimensions.

The research conducted is not without limitations. First, it is based on the insights of a single case study and generalizability of the findings is not without question. To reach conclusive ubiquitous applications of the insights presented, more IIoT initiatives and their relationships with manufacturing network coordination mechanisms should be analysed. In addition, the company under investigation has some open projects task, which need to be completed in order to be able to analyse the performance effects. Additionally, the paper at hand concentrates on formal coordination mechanisms. Manufacturing network coordination can also be described with distinct flows (Bartlett and Ghoshal, 1989; Cheng et al., 2011; Cheng et al., 2008). The case study provided insights that the flow of information and knowledge is influenced by the implementation of the IIoT initiatives. Further research on how the IIoT influences the flow of knowledge and information would enrich the body of literature on manufacturing network coordination. Finally, manufacturing network coordination was not analysed from a plant's perspective but focused on the headquarters role to coordinate the manufacturing network (Golini et al., 2016; Olhager and Feldmann, 2018). Adding the plants perspective would allow to gain more insights into the formal and informal manufacturing network coordination.

7. Literature

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Table 1: Literature based relationships between IIoT enablers and manufacturing network coordination mechanism

	Autonomy	Standardisation	Coopetition	Target Setting and Incentives	Digital Technologies	Connectivity	Data	Capabilities	Management
Autonomy									
Inkpen and Tsang (2005)					d				
Standardisation									
Partanen et al. (2020)*						(s)			
Coopetition									
Schroeder et al. (2019)				(c)					
Target Setting and Incentives									
Digital Technologies									
Porter and Heppelmann (2014)	d	d							
Coreynen et al. (2017)		(c)							
Partanen et al. (2020)*		(s)							
Wamba (2012)*			c						
Connectivity									
Laya et al. (2012)*			(c)						
Fatorachian and Kazemi (2018)		d							
Data									
Schroeder et al. (2019)			(c)	(c)					
Capabilities									
Arunachalam et al. (2018)*							I		
Management									

d: descriptive

s: survey

c: case study

I: literature review

*focus on supply chain or non-manufacturing networks

(x) = brackets indicates that the mechanism was mentioned but not part of the empirical study of the cited paper

Figure 1: Research Framework

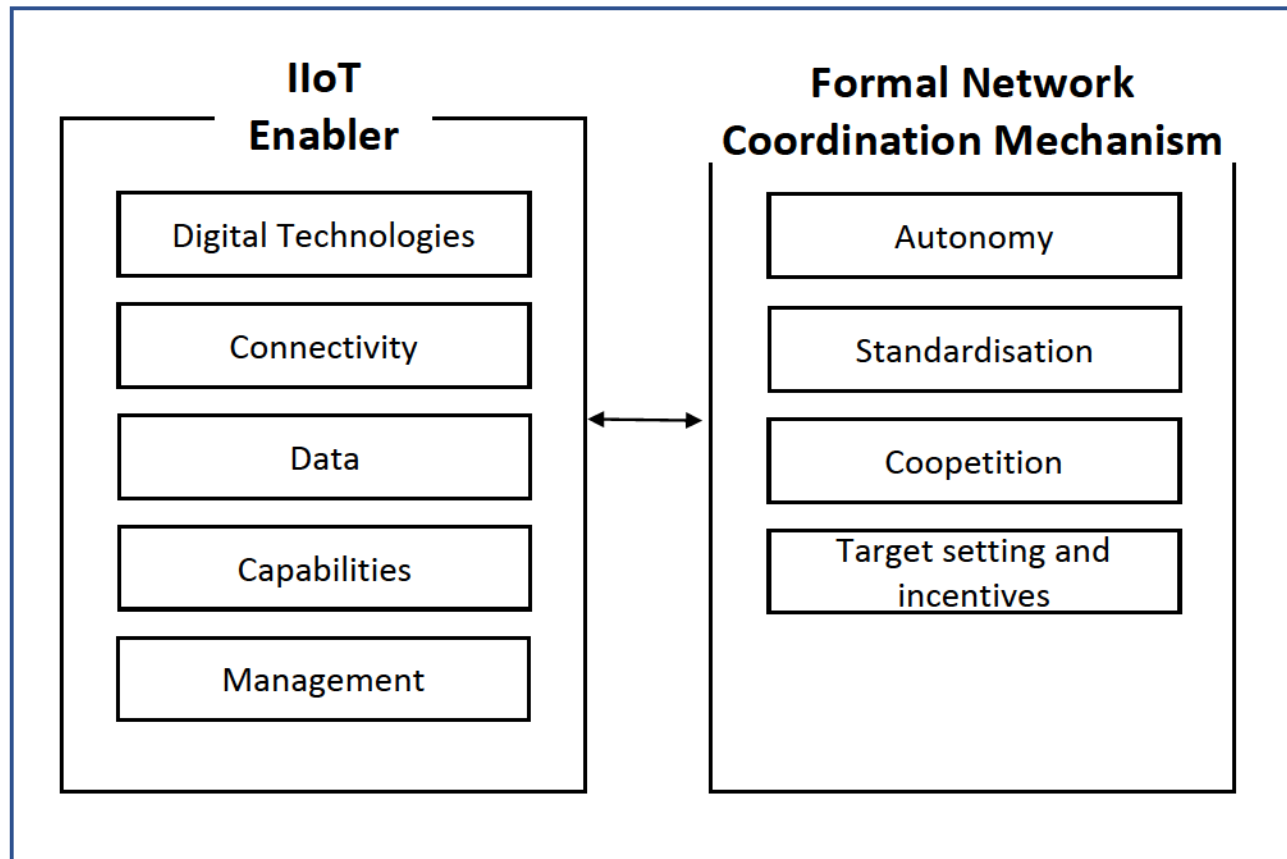


Table 2: Interviews and timetable

Function	Unit	14.03.2016	15.03.2016	23.05.2016	06.06.2016	14.06.2016	22.06.2016	14.11.2016	03.02.2017	14.03.2017	24.03.2017	02.05.2017	08.06.2017	23.06.2017	29.06.2017	25.03.2019
COO	Head Quarters	X	X													
Business Unit Leader	Business Unit A			X	X		X			X						
Director Strategic Projects	Head Quarters		X	X	X	X	X	X	X	X	X	X	X	X	X	X
Project Manager	Head Quarters			X	X						X					
Head of Global Operations	Head Quarters			X	X		X	X	X	X	X	X	X	X	X	
Leader Customer Service	Business Unit B								X	X	X		X	X	X	
Assistant Technical Director	Head Quarters								X	X	X	X	X		X	
Assistant to CEO	Head Quarters										X	X	X			

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Table 3: Analysed content and documentation

Analysed content	Concrete tools/ documentation	key outcome
Analysis of the processes and IT systems prior to the implementation of the IIoT initiative	Process Map and IT Systems	Initial situation of processes, IT systems and manufacturing network coordination mechanism
Analysis of technologies of each part of the value network (as-is and to-be)	Value Network Analysis (as-is and to-be)	Overview of technologies in plants
Analysis of capabilities of each part of the value network (as-is and to-be)	Value Network Analysis (as-is and to-be)	Overview of capabilities in plants
Analysis of strength and weaknesses of each part of the value network	Value Network Analysis	Visualization of needed change
Discussion of goal, value analysis, enablers (capabilities and technologies), connectivity, profit and loss	IIoT initiative analysis based on business model dimensions	Dependencies of the dimensions and needed alignments
Concretization of the IIoT initiative	Lotus Blossom	Overview of new technologies. First draft of the three systems and related technologies.
Discussion of the expected changes due to IIoT initiative and implementation activities	Analysis of Absorptive Capacity	Understanding of change within the manufacturing network
Analysis of the customer expectations and customer relevant processes and systems	Customer Journey	System "issue tracking": digital twin of the customer product (data, technologies, connectivity, ...), issue tracking system
Analysis of internal processes (incl. network of plants)	Service Blueprint	End-to-end integration System "dynamic capacity planning" System "digital instruction creator" Processes, system and interdependencies within the manufacturing network
Detailed analysis of technologies and capabilities	System Dynamics (causal loop diagrams)	Detailed technologies, dependencies of implementation activities
Changes related to market activities, product/service, connectivity, capability, management, organisation, strategic partners	Roadmap and detailed Project Charter	Summary of management decisions, i.e. manufacturing network coordination mechanism
Follow-up interview	Roadmap	Changes in roadmap

Figure 2: Summary of IIoT initiative and manufacturing network coordination mechanism

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Network Coordination (before IIoT implementation)

Autonomy: Business units plan and produce (almost) independently. Capacities are not shared across the manufacturing network.	Standardisation: Low level as each manufacturing plant has distinctive systems and processes.
Coopetition: No cooperation between the business units and plants.	Target setting and incentives: no need to set targets as the manufacturing plants are managed independently.

Network Coordination (after IIoT implementation)

Autonomy: Clearly defined systems and process owners. Shared capacities. Strategic and operational autonomy is low (high parental control).	Standardisation: Highly standardized processes and systems , modularized products and services.
Coopetition: Cooperation between plants because of capacity transfer and continuous improvement aspects.	Target setting and incentives: Strong focus on continuous improvement activities across manufacturing plants.
Digital Technologies: Product life cycle management (PLM); digital instruction creator; interactive process monitoring; web-technologies, dashboards and interfaces; virtual reality technologies, sensor and actors, edge-box	Capabilities: handling of paperless working instructions; cross-functional information- and knowledge-exchange; taking into account all phases of the product-lifecycle; data analysis; hard- and software capabilities (i.e. sensors)
Connectivity: integration of all functions, production machinery and process steps over-spanning the complete manufacturing network in order to gather real-time-data (through PLM and respective (web)-interfaces).	Management: management of responsibilities (system- and process owner); communication; human resource development; agile development
Data: process, product, machinery and context data (historical and real-life data) resulting in services (predictive maintenance), improvements for processes and products, derivation of patterns of customer preferences, suppliers or cost structures which provide new insights for the company's development.	
IIoT Enabler	

Caption : Figure 3: Overview of IIoT initiative

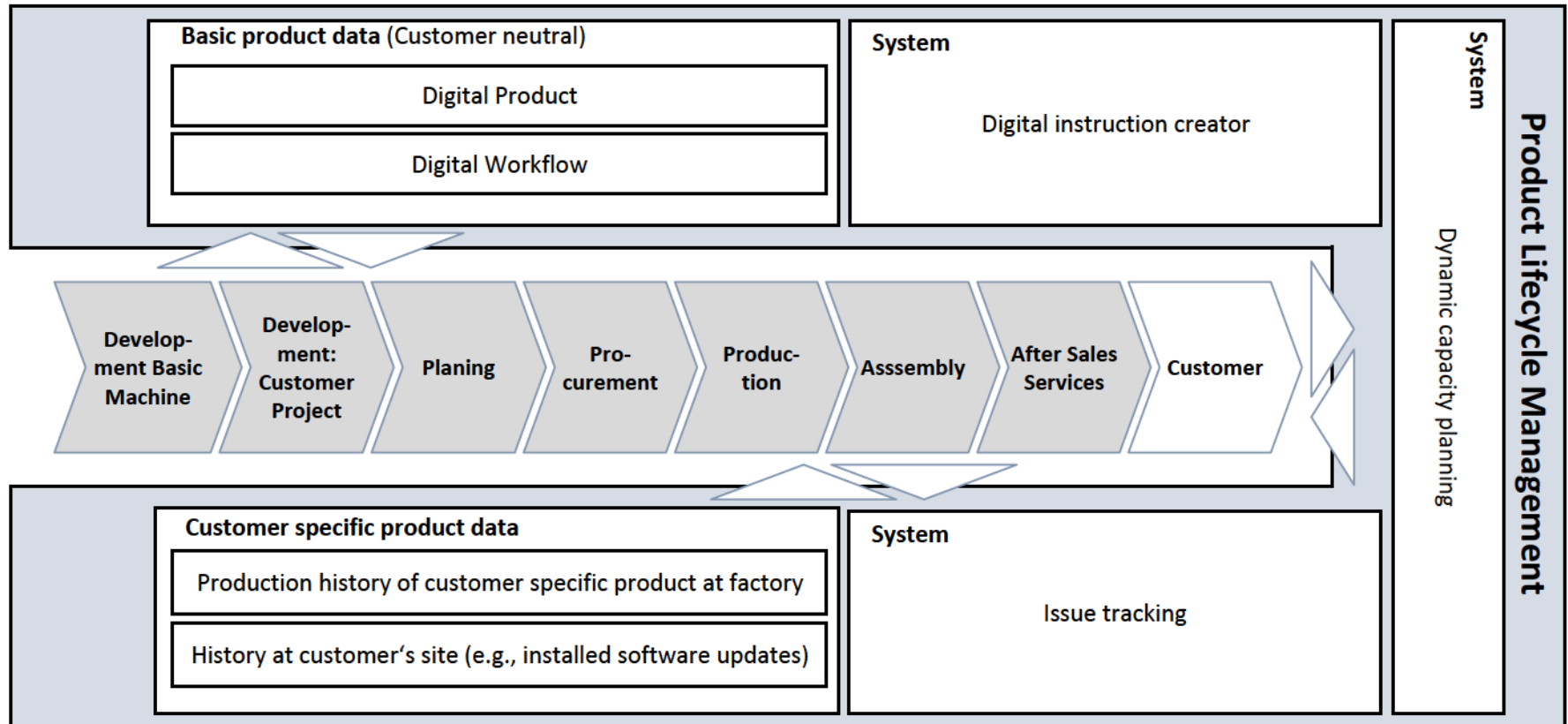


Figure 4: Contingent view of manufacturing network coordination and IloT

