Supplier interfaces in digital transformation: an exploratory case study of a manufacturing firm and IoT suppliers

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Abstract

Purpose – The purpose of this paper is to characterize the interfaces between manufacturing companies and the Internet of Things (IoT) suppliers involved in their digital servitization.

Design/methodology/approach – This paper builds on an explorative case study of a manufacturing firm and its IoT suppliers. This paper relies on the Industrial Network Approach to study interfaces between buying firms and their suppliers.

Findings – This paper identifies three distinct types of supplier interfaces: connected, digital and digital-physical. They all contain technical resource interfaces with additional organizational and/or technical complexities that need to be managed. Connectivity, an Agile approach to software development and strong technical dependence emerged as key factors that impact the interactions between manufacturing firms and IoT suppliers and how their resources are combined.

Practical implications – This paper offers managerial implications regarding the importance of internal organization (such as appropriate cross-functional teams) to manage the dynamics of collaborations required by digital technologies, maintain interactions with IoT suppliers and identify and manage interdependences between IoT suppliers. Building close relationships with suppliers of crucial infrastructure (e.g. IoT cloud platform and data security systems) can also be beneficial for manufacturing firms to reduce risks. Finally, attention should be given to IoT technology strategy, which impacts both digital and digital-physical supplier interfaces.

Originality/value – In digital servitization, manufacturing firms are heavily reliant on external resources for IoT technology. Despite this, few studies have investigated the characteristics of their interfaces with IoT suppliers, how these can be managed and how resources are combined.

Keywords Supplier relationships, Interfaces, Digitalization, Case study, Digital servitization, IoT (Internet of Things), Digital transformation

Paper type Case study

1. Introduction

In recent years, new digital technologies have created opportunities for companies to develop new services that increase value for customers (Parida *et al.*, 2019). Several manufacturing companies are transforming their portfolio by using digital technologies to shift from product- to service-centric business models and logic. This type of digital transformation (Wessel *et al.*, 2021) has recently been referred to as "digital servitization" (Luz Martín-Peña *et al.*, 2018; Kohtamäki *et al.*, 2019; Kamalaldin *et al.*, 2020; Sjödin *et al.*, 2020; Tronvoll *et al.*, 2020) and refers to "the development of new services and/or the improvement of existing ones through the use of digital technologies" (Paschou *et al.*, 2020 p. 284).

Several authors have pointed out the importance of collaboration between different actors involved in digital servitization to provide new services (Parida *et al.*, 2019; Sklyar *et al.*, 2019; Kahle *et al.*, 2020). Manufacturing companies often need to build relationships with suppliers to access the digital resources and specialized knowledge (Porter and Heppelmann, 2014; Naik *et al.*, 2020) needed when developing new digital solutions. In turn, customers of manufacturing firms are important collaboration partners that may benefit from new value propositions offered through digital solutions (Parida *et al.*, 2019). Related studies point to collaboration and reciprocal value propositions (Zhang *et al.*, 2021).

Recently, several studies have investigated business relationships in the context of digital servitization. Supplier–customer relationships have been explored to understand how manufacturing firms and their customers co-create digital service innovations (Sjödin *et al.*, 2020). Kamalaldin *et al.* (2020) show how providers and customers transform their relationships from a transactional product-centric model to relational service-oriented engagement. Grandinetti *et al.* (2020) examine how digital servitization affects the quality of supplier–customer relationships. Similarly, Galvani and Bocconcelli (2021) identify intra- and inter-organizational tensions that arise during digital servitization and point out that the

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multiplicity and interrelatedness of such tensions call for specific organizational and network capabilities. Although research has been conducted to explore the impact of digitalization and digital servitization on business relationships and networks, studies that investigate collaboration between manufacturing firms and suppliers involved in the development and commercialization of digital solutions remain scarce.

Regarding the supply side of firms, researchers have previously pointed out that the "productivity and innovation performance of firms has increasingly become a function of how they relate to their suppliers" (Araujo *et al.*, 2016 p. 18). In recent years, the role of suppliers that support manufacturing firms to develop and commercialize digital solutions has become important and strategic. At the same time, these suppliers have become more powerful and valuable in the market, for example, Amazon and Microsoft Corporation (Verhoef *et al.*, 2021).

This paper regards how manufacturing companies develop relationships with suppliers in the context of digital servitization and especially in relation to the Internet of Things (IoT). More specifically, the aim of the paper is to analyse the interfaces between a manufacturing company and IoT suppliers. Araujo *et al.* (1999) identify types of interfaces (i.e. standardized, specified, translational and interactive) based on the resources exchanged in supplier relationships. This framework functions as the starting point for analysing the characteristics of the interfaces between manufacturing companies and IoT suppliers. The reasons for selecting the framework developed by Araujo *et al.* (1999) are twofold: the variety of interfaces that the framework can reveal and the importance given to interaction, an aspect that is not always present in interface frameworks (Sobrero and Roberts, 2002). Based on the above, two research questions steer this paper:

RQ1. What are the characteristics of interfaces between manufacturing firms and suppliers that collaborate in the context of digital servitization?

RQ2. How are resources combined by manufacturing firms and suppliers in the context of digital servitization?

The structure of the paper is as follows. First, the theoretical framework is presented, followed by the underlying method. Then, the case company and its supplier relationships are described. Thereafter, an analysis is provided. The paper ends with a concluding discussion, theoretical contributions, implications, limitations and suggestions for future research.

2. Theoretical framework

This paper relies on the Industrial Network Approach to business markets (Håkansson and Snehota, 1995) to study the interfaces between buying firms and their suppliers. Supplier interfaces are conceptualized as the touchpoints between a buyer and its suppliers' resources (Araujo *et al.*, 1999). Accordingly, the theoretical framework below includes a section on supplier interfaces, with a particular focus on different types of supplier interfaces in relation to technology strategy. This is followed by an in-depth section on resource combination and the interfaces between resources to capture the details of the supplier interfaces. This forms the basis for developing the framework, presented as Table 1, with key dimensions for characterizing IoT supplier interfaces.

2.1 Supplier interfaces and technology strategy

Supplier interfaces range from standardized, specified, translational to interactive based on the character of the resources used in the business exchange (Araujo *et al.*, 1999). Standardized interfaces relate to arm's-length relationships, in which neither party has knowledge of the other's context. In a specified interface, buyers provide predefined specifications for their suppliers. Translation interfaces suggest a solution created and produced by a supplier to meet the needs of a buyer, importantly with a degree of freedom for the supplier to decide how to best meet the buyer's specifications. Finally, an interactive interface pertains to a joint development, through which a buyer and supplier are connected in a learning exchange process to develop a solution through open-ended interaction (Araujo *et al.*, 1999).

Studies have shown that the type of interface used in supplier–buyer relationships has direct consequences for how suppliers' resources are accessed and applied (Araujo *et al.*, 1999; Lind and Melander, 2019). Performing a longitudinal study, Andersen and Gadde (2019) explored the dynamic role of supplier interfaces, which were shown to change over time because of joint organizational learning. Each type of interface offers advantages and disadvantages, so buying firms need to carefully select the type of interface to apply in joint, innovative endeavours.

Lind and Melander (2019) investigate supplier interfaces in technological development. Their study analyses resource development and the organizing of supplier interfaces in four technological development projects. The researchers concluded that because of technological and organizational uncertainties, a mix of interfaces is applied between the buyer and supplier. The researchers identified key concerns related to the three types of technological development interface: specified, translational and interactive (these can also be combined).

Companies need to cope with different degrees of supplier involvement (Gadde and Snehota, 2000) and interfaces' impact on this degree of involvement. On the one hand, greater involvement with suppliers is costly, mainly because of coordination, adaptation and interaction. On the other, less involvement with suppliers has hidden costs that should be considered, such as for adapting resources to IoT suppliers' offerings. Moreover, relationships with various other suppliers have to be matched and adapted when managing an entire supplier base (Gadde *et al.*, 2010).

There is no such a thing as a best interface in absolute terms. Different interfaces used across a range of suppliers will have advantages and disadvantages that need to be evaluated on a case-by-case basis (Araujo *et al.*, 1999). The type of interface used is context dependent (Andersen and Gadde, 2019). Uncertain contexts can involve provisional supplier interfaces that need to be periodically revisited (Dubois and Araujo, 2006). To understand the detailed characteristics of supplier interfaces, attention must be given to the resources involved in supplier relationships and their interfaces.

In the context of technological development, there is an important interplay between technology strategy, supplier interfaces and organizing principles (Araujo *et al.*, 2016). Starting with the technology strategy, technological complexity can lead to increased dependence on suppliers as more tasks need to be outsourced (Araujo *et al.*, 2016). Technology strategy refers to whether a company relies on internal technological development, collaborative development or outsourcing of technological

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Table 1 Dimensions for characterizing supplier interfaces

Dimensions of supplier interfaces	Supplier interfaces Standardized	Specified	Translational	Interactive	Key reference(s)
Product/service exchange	Standardized offerings	Customized offerings	Buyer informs its needs and supplier has the freedom to develop the solution	Joint development	Araujo *et al*. (1999)
Resource interfaces (technical, organizational and mixed)	Pure exchange → no resource adaptations	Any type of resource interfaces (technical, organizational and mixed) Empirically derived	Any type of resource interfaces (technical, organizational and mixed) Empirically derived	Any type of resource interfaces (technical, organizational and mixed) Investment in the interfaces and complex procedures Empirically derived	Dubois and Araujo (2006) and Jahre *et al*. (2006)
Interaction pattern (hierarchical, "thin," "thick")	Thin or hierarchical	Thin or hierarchical	Thin or hierarchical	Thick	Waluszewski and Johanson (2008)
Technology strategy	Either internal technological development or external technological development	Technological development performed by the buyer (internal) that determines all the technology features	Outsourced technological development (supplier has the main responsibility)	Technological development performed jointly by the buyer and supplier	Araujo *et al*. (2016)
Organizing principles (how interfaces are organized and how they connect with suppliers' organization interfaces)	Can vary, for example, buyer's internal organization can range from simple to more complex	Can vary, for example, cross-functional collaboration	Can vary, for example, cross-functional collaboration Buyer needs to focus on how to adapt to the supplier's organization interface	Open-ended interactions require close involvement of different team members from both the buyer and the supplier organization	Araujo *et al*. (2016)

development and the resources of suppliers. Selecting compatible technologies and identifying complementary digital technologies is a dynamic process. In a digital context, firms need to be networked and accept that some of the core digital technologies they require will be possessed by suppliers, making supplier relationships important and strategic.

Organizing principles relate to the organization of interfaces within a firm and how these connect with those of suppliers. Organizing can affect the establishment of firm boundaries (Araujo *et al.*, 2003), connections to other companies and development of a company's own resources. This process also presents uncertainty and challenges for a company's outsourcing strategy, as it should be revised frequently (Araujo *et al.*, 2016).

2.2 Resource combining and resource interfaces

A resource can be defined as an object with an actual or potential use that exists in a certain network context and has the potential to be combined with other resources (Baraldi *et al.*, 2012 p. 271). Resource combination is, thus, a key process, as the value of resources depends on how they are combined (Holmen, 2001; Lind, 2006). New combinations of resources often originate through interaction between actors (Håkansson and Snehota, 1995), for example, suppliers, users or partners in an inter-organizational project.

Resource interfaces are "the contact points along a shared boundary between at least two specific resources. These contact points influence the technical, economic and social characteristics of the involved resources" (Prenkert *et al.*, 2019 p. 141). The term "interface" is, thus, commonly used to describe the interplay between internal resource collections and suppliers' resources. The characteristics of any resource are determined by its interfaces with other resources. These characteristics determine the way a resource is used, as well as how it can be combined with other resources (Håkansson and Waluszewski, 2002; Jahre *et al.*, 2006). Not all resource interaction creates adaptations or imprints in resource interfaces. For example, a pure exchange does not constitute the creation of a resource interface despite being an example of resource interaction (Cantillon and Håkansson, 2009; Prenkert *et al.*, 2019).

Resource interfaces can provide both efficiency and effectiveness depending on their interaction pattern (Waluszewski and Johanson, 2008). The type of interaction pattern impacts how challenges and opportunities related to resource interfaces are handled. There are different types of interaction patterns into which a company can be embedded. The company can be dominated by an indirect interaction pattern that is built on the *hierarchy* between companies (this can be seen in the economic system in relation to governments or in networks dominated by large national or multinational companies). In some cases, "thin" interactions, based on traditional market theory, can become predominant and, in others, "thick" interactions, which can lead to resource combinations (Waluszewski and Johanson, 2008).

Dubois and Araujo (2006) explain the difference between technical interfaces, which involve products and facilities, and organizational interfaces, which related to organizational units and relationships. There are also mixed interfaces, which are those between organizational and technical resources (Jahre *et al.*, 2006). An example of a mixed interface is a relationship developed to establish connections between a product and suppliers' expertise (Jahre *et al.*, 2006; Baraldi *et al.*, 2012).

The concept of resource interfaces has been applied in different contexts by researchers aiming to understand shared boundaries between organizations and their impact. In the accounting context, for example, Lind and Strömsten (2006) argue that depending on the type of resource interfaces between a supplier and customer, different accounting methods are applied for customer evaluation. They provide a framework with four different customer relationships, each with its own accounting method: transactional customer relationships, associated with customer segment profitability analysis; facilitative customer relationships, associated with customer profitability analysis; integrative customer relationships, associated with lifetime profitability analysis; and finally, connective customer relationships, associated with customer valuation analysis.

Another example of a study that applies the concept of resource interfaces is that by Bocconcelli *et al.* (2018), who conducted a longitudinal study of resource interfaces and resource interaction patterns between small business-to-business suppliers and large customers. Some of their findings and insights are that new market challenges require that small suppliers implement resource development patterns by upgrading key processes according to the requirements of large customers, and in the evolution of the business relationship, small suppliers adopt specific, standardized and jointly managed resource interfaces (e.g. JIT-related processes).

2.3 Characterizing Internet of Things supplier interfaces

Manufacturing companies that aim to develop, sell and deliver digital services based on IoT technology need resources and infrastructure to build optimal and scalable solutions (Hasselblatt *et al.*, 2018). As some resources are owned by external actors, manufacturing companies need to "use the supplier resources optimally" (Hasselblatt *et al.*, 2018 p. 830) to successfully create and sell IoT services. Examples of key resources needed by manufacturing companies to create digital solutions enabled by IoT are sensors, software, connectivity devices, data storage and algorithms for analytics (Porter and Heppelmann, 2014). Resources offered in the form of services can be provided on a one-time or continuous basis, for example, access to data storage and security. Different supplier interfaces are, thus, needed to access these external digital resources.

In terms of the organizing principle (Araujo *et al.*, 2016), manufacturing companies that create digital solutions based on IoT need to organize their interfaces internally and define how they will interface with the suppliers involved. For example, as knowledge of IT and software becomes increasingly important, a purchasing department will need to collaborate with IT experts within an organization in a dynamic way. Moreover, multi-business companies start to form new units within their organizations to build a critical mass of talent and digital expertise. These new units can emerge as stand-alone business units, centres of excellence [see empirical case in Frick *et al.* (2020)] and/or cross-business units for steering committees (Porter and Heppelmann, 2015).

The supplier interfaces developed by Araujo *et al.* (1999) function as the starting point for the analysis of IoT suppliers (Table 1). Key dimensions have been selected from the literature and presented in this table to provide more details to characterize the different types of supplier interfaces.

3. Method

Supplier relationships between companies involved in digital servitization are a relatively new phenomenon. This is also true for the welding industry, which is the focus of this study. Therefore, an exploratory case study has been applied.

3.1 Exploratory case study

The exploratory case study method is useful when the research aim is to develop new insights about a theoretically novel phenomenon that has not been sufficiently researched (Eisenhardt, 1989). A case study has the benefits of being able to capture detailed phenomena within their context, which is suitable when studying complex organizations and relationships (Easton, 2010).

This case study involves a manufacturing company in Sweden (WeldCorp) that is a customer of IoT suppliers involved in the implementation and commercialization of digital solutions enabled by IoT. WeldCorp is a global manufacturing company in the welding industry. It has more than 8,700 employees and manufacturing facilities on four continents. In 2020, WeldCorp reported net sales of $1.95bn. It supplies equipment and wire to a wide range of companies, including the automotive, civil construction, manufacturing and shipbuilding industries. WeldCorp's customers range from small welding shops to large enterprises. WeldCorp (the focal manufacturing company) was selected for this case study based on its ongoing activities in digital servitization. The unit of analysis in this study is the interfaces between manufacturing companies and IoT suppliers in the context of digital servitization.

Three IoT suppliers are included in the study (SupPlatf, SupGatew and SupDigit). These suppliers were chosen because they play essential roles in ensuring new services and connections between products (e.g. welding machines) and the IoT platform. In other words, the exchanges with these suppliers were key to the product's connectivity, the cloud IoT platform and the development of the respective software applications (e.g. productivity and fleet management). The selection was based on information provided by the respondents from WeldCorp. During the interviews, the R&D manager for digital solutions, the R&D manager for welding equipment and the product manager for digital solutions were asked about their main suppliers for IoT-based digital solutions. Based on their answers, three IoT suppliers came into focus.

3.2 Data collection and analysis

Semi-structured interviews were an important source of data. In total, 14 interviews were conducted during 2020–2021, with an average duration of about 54 min. In all, 11 semi-structured interviews were conducted with respondents from WeldCorp, 1 interview with a respondent from SupGatew, and 2 interviews with an expert from an IT supplier (SME), referred to here as SupIT. Of the 14 interviews, 12 were recorded and transcribed. For the two interviews that were not recorded and transcribed (one interview with the R&D manager welding equipment and one interview with the CEO of SupIT), the two researchers took extensive notes.

Data from the interviews were triangulated (Yin, 1989) with findings from multiple data sources. These multiple data sources included WeldCorp's, SupPlatf's, SupDigit's and SupGatew's websites, data from confidential PowerPoint presentations, documents provided by the interviewees and industry reports. Combined, the data was used as a basis for understanding the components of an IoT cloud platform solution, the exchanges involved in the business relationships and details about the buyer–supplier interactions.

This work relies mainly on WeldCorp's view of its relationships with IoT suppliers, which was seen to be sufficient for the purposes of this study. While one interview was conducted with SupGatew, we purposefully asked several different WeldCorp interviewees questions about these suppliers and triangulated their answers to minimize one-sided interpretations. WeldCorp's openness and willingness to share information on its interactions with suppliers contributed to a robust and reliable view of these business relationships. In addition, interviews were conducted with the CEO of SupIT to gain expert insights into the development of interfaces from the perspective of an IT expert. SupIT is a consultancy of one software used by WeldCorp, and it enabled us to capture more aspects from a supplier perspective.

Details about the companies and respective interviews conducted in this study are presented in Table 2.

Interview guides were used, the themes of which were adapted to each interviewee. The themes broadly focused on business relationships, relationships and working practices with external suppliers, the current business situation and future plans. The following are some examples of questions from the interview guide used for WeldCorp's R&D manager for digital solutions (these questions were posed to gain an understanding of the relationships with the suppliers involved in WeldCorp's digital solutions and the offerings related to WeldCorp's digital solutions): i) Could you explain about the offering – WeldCorp Digital Solutions (current offerings, content, technology, partners and future offerings)? ii) Who are the main partners/suppliers? iii) Could you talk about the relationships between WeldCorp and the suppliers involved in the implementation of WeldCorp Digital Solutions? iv) What do WeldCorp and the suppliers do jointly? Common meetings? Common investments?

Relying on a realism paradigm (Easton, 2010), the interviewees' perceptions were considered by the researchers to be a "window to reality through which a picture of reality can be triangulated with other perceptions" (Healy and Perry, 2000 p. 123). Because of the COVID-19 pandemic and restrictions on physical meetings, all the interviews were performed remotely using software such as Teams or Zoom. Validity and methodological reliability were assured by documenting the interview guides, notes and transcripts of the interviews (Eisenhardt, 1989; Healy and Perry, 2000).

Theoretical concepts were systematically matched and combined with data from the interviews to identify the characteristics of the interfaces between the manufacturing firm and IoT suppliers and how they impact resource combinations (Dubois and Gadde, 2002). While Araujo *et al.* (1999) informed of the starting point of the frame of reference, more dimensions were added to increase understanding of the interfaces with support from empirical data (i.e. resource interfaces, interaction pattern, technology strategy and organizing principles), resulting in the framework in Table 1. Based on the emerging framework and case study, the codes and dimensions were developed interactively, and three types of IoT interfaces emerged from the data: connected, digital and digital-physical (Table 3). The data was analysed and interpreted by the two researchers in collaboration, and quotes were also used to support the evidence and findings from the study.

4. Case study description

WeldCorp initially tried to build its IoT cloud platform in-house, which resulted in limitations for its customers in terms of response time and updates. It then decided to outsource the development of the IoT cloud platform to key suppliers. This way WeldCorp could concentrate on improving the welding performance of its solutions.

WeldCorp found that creating and maintaining an IoT cloud platform is a complex endeavour that requires several actors. Based on the interviews with respondents from WeldCorp, three main suppliers were identified as key to the creation of the new IoT cloud platform and the development of the digital solutions, here anonymized as SupPlatf, SupDigit and SupGatew. Figure 1 shows a simplified model for the IoT suppliers and exchanges related to WeldCorp's IoT solutions.

4.1 Relationship between WeldCorp and SupPlatf

SupPlatf is a leading global IoT cloud platform provider, with its headquarters located in the USA. SupPlatf was established in the 1970s and has more than 170,000 employees around the globe. In 2020, SupPlatf reported $143bn in revenue. It has a vast portfolio of solutions, one of which is for IoT cloud platform infrastructure services. SupPlatf claims that these services aim to enable digital servitization and empower both private customers and organizations. SupPlatf also provides other software and packages used by WeldCorp outside the IoT context, but these business exchanges are beyond the scope of this study. The new IoT cloud platform based on SupPlatf solutions was officially launched by WeldCorp in 2018. "Our main focus is really on cloud-based infrastructure and cloud-based solutions" (WeldCorp Product Manager Digital Solutions). By offering the cloud solutions linked to the platform, WeldCorp can regularly send updates to customers (e.g. weekly) and offer new services (e.g. a productivity module that consists of a stable stream of real-time data). SupPlatf has been selected mainly because it has proven experience of data security and is a well-known supplier with many years in the market. "We wanted to go with one of the leading players" (WeldCorp R&D Manager Digital Solutions). However, the costs of having SupPlatf as a supplier are substantial. WeldCorp considers itself a large client for SupPlatf within its industry.

SupPlatf provides access to an IoT cloud platform that is used by WeldCorp to develop applications specific to the welding industry. Connectivity and security are two key aspects of the IoT cloud platform that impact on the interactions between SupPlatf, WeldCorp's customer and WeldCorp. WeldCorp uses SupPlatf's infrastructure to send updates to end-users at any time (real time data), offer new sets of services and applications and data storage and data security, and conduct maintenance of the digital infrastructure.

Table 2 Interviews conducted in this study

Company pseudonym	Company's business	Company's role in the case study	No. of employees	HQ location		Respondent role	Department	Respondent location	No. of interviews conducted	Interview date	Length of interview (HH:MM)
WeldCorp	Manufacturing in the welding industry	Focal firm	Approximately 8,700	The USA	1	General manager	Digital Solutions	Sweden	1	2020–09-23	01:28
					2	R&D manager	Digital Solutions	Sweden	2	2020–08-12 2020–09-22	00:57 01:02
					3	Product manager	Digital Solutions	Sweden	2	2020–08-26 2020–09-28	00:54 01:02
					4	Product manager	Solid Wires	Sweden	1	2020–09-30	00:37
					5	Global leader	Aftermarket	England	1	2020–09-08	00:42
					6	European leader	Supply Chain	Sweden	1	2020–08-26	00:55
					7	Supplier development manager	Global Purchasing	United States	1	2020–09-11	00:50
					8	R&D manager	Welding Equipment	India	1	2020–09-11	01:04
					9	Product manager	Automation	Sweden	1	2020–09-28	00:54
SupGatew	Designing and manufacturing electronic products	Supplier of the IoT gateway for WeldCorp	Approximately 5,000	India	10	VP Business development	Sales	India	1	2020–09-12	00:50
SupIT	Consultancy for mapping and data visualization	Expert insight	24	Sweden	11	CEO (SupIT)	Management and Sales	Sweden	2	2021–05-05 2021–05-12	00:45 00:40
Total of interviews:									14		

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Table 3 Interfaces with Internet of Things suppliers in digital servitization

	Connected supplier interfaces	Digital supplier interfaces	Digital-physical supplier interfaces
Empirical base	Relationship with SupPlatf	Relationship with SupDigit	Relationship with SupGatew
Supplier interface	Mostly a specified interface with elements of an interactive interface	Standardized (standard software applications) and interactive (complex software applications)	Standardized (off-the-shelf components) and interactive (tailored components)
Product/service exchange	Digital infrastructure, services and access for manufacturing firms (e.g. IoT cloud platform, data security and data storage)	Digital resources (components) needed to implement digital servitization Can be standard or customized digital components (for complex applications)	Digital-physical resources in the form of physical components with embedded software During the development phase of tailored components, exchange can be in the form of design work (drawings and knowledge about connectivity, IoT, etc.)
Resource interface	The connectivity aspect of the interface impacts technical interfaces (machine–machine) and mixed interfaces (human–machine – e.g. software developers can interact with IoT cloud platforms at any time and create new applications) Actors are continuously connected	A technical interface is created when the manufacturing firms incorporate standard digital components provided by digital suppliers in their applications A mixed interface is identified between the developers on the digital supplier side and the complex applications This way the developers apply their knowledge in the creation of customized and complex applications for the manufacturing companies	Digital-physical components that are developed have technical interfaces with other components of the existing physical products of manufacturing firms (e.g. equipment housing and some sensors) The need for adaptations in terms of hardware and software leads to close collaboration between engineers from manufacturing firms and suppliers
Interaction pattern	The interaction pattern is predominantly thin It can be hierarchical when the supplier dominates the business network (which is the case for some IoT platform providers) Some thick interaction patterns can occur when research work is done jointly	The interaction pattern is thin when the business exchange relates to standardized components but thick when developing more complex and industry-specific digital applications These complex developments require that engineers and developers interact more often, especially when applying the agile approach to software development	For tailored physical-digital components, the interaction pattern is thick in the developing phase This interactivity demands suitable governance to coordinate the activities of the involved actors
Technology strategy	The technological complexity of the IT infrastructure and services lead to a high level of dependence from the manufacturing firms on connected suppliers Internal technological development and joint development can be done only in the case of industry-specific infrastructure	Manufacturing firms are somehow dependent on digital components provided by digital suppliers The development of standard digital components is usually outsourced to digital suppliers, while only more complex digital components are jointly developed by the manufacturing firms and the digital suppliers	When tailored digital-physical components are needed, manufacturing firms and suppliers need to develop the components collaboratively
Organizing principle	Manufacturing firms need to profoundly adapt their technical resources according to the connected supplier resources (e.g. proprietary components) This can facilitate (and sometimes hinder) interaction with other suppliers in the network, such as digital suppliers	Manufacturing firms need to adapt their organization (e.g. by hiring software engineers/developers) to effectively interact with developers on the digital supplier side and discuss technical topics in relation to, for example, IoT, connectivity and digital component development	It is common for cross-functional teams, including purchasing, R&D and IT departments within the manufacturing companies, to be organized to handle the relationships with digital-physical suppliers

Most of the time, WeldCorp is developing the top layers and relying on the bottom layers provided by SupPlatf. "The main thing is that we have a partnership with them [SupPlatf] to utilize their platform for our backbone infrastructure. So that's the main collaboration" (WeldCorp Product Manager Digital Solutions). Moreover, SupPlatf has a dedicated team with which WeldCorp can interact, and some research work is done collaboratively. "We used to utilize them [SupPlatf] for some, as I mentioned, some forward-looking research projects" (WeldCorp Product Manager Digital Solutions).

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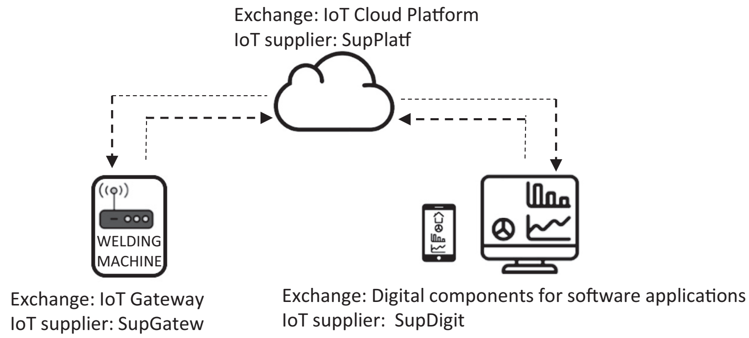
Figure 1 Simplified model for Internet of Things suppliers and exchanges related to WeldCorp's Internet of Things solutions



WeldCorp aims to establish a long-term relationship with SupPlatf, and it had to profoundly adapt its resources to access the proprietary components it provides, characteristics of a heavy resource interface:

> [...] there will always be some type of proprietary component. Okay, I mean, think about it, SupPlatf is developing components all the time. And, you know, this is what gives this company this edge. [...] those type of components that are supposed to make the development easier, they are proprietary (WeldCorp R&D Manager Digital Solutions).

These proprietary components resulted in an increase in technical complexity for WeldCorp. One example occurred when WeldCorp acquired a company that had developed a software application for digital welding documentation and wanted to include it in its digital solutions portfolio. However, this application was built on another IoT cloud platform, which was not compatible with SupPlatf's components. This situation presented a challenge for the company, which had to find the best technical resolution for this incompatibility issue:

> It is a technical decision. Is it worth transferring functionality to, you know, another platform to integrate it or can we, you know, utilize standard APIs and so, on the top connect and integrate the services? (WeldCorp Product Manager Digital Solutions).

In the end, WeldCorp needed to invest in the establishment of cloud-to-cloud communication and add an additional IoT provider to the supplier base to facilitate the integration of the "digital welding documentation" module into the digital solution portfolio.

4.2 Relationship between WeldCorp and SupDigit

SupDigit is an US company in the computer software and services business founded in the 1980s. SupDigit has over 6,000 employees and its portfolio includes services and software related to solutions in IoT, augmented reality, computer-aided design and product life cycle management. Its reported revenue in 2020 was $1.46bn. By using SupDigit's standard digital components, WeldCorp can easily create and customize applications; as the Product Manager for Digital Solutions explained: "we can drag and drop into our front-end interface." However, when developing more complex applications, the standard digital components are not sufficient. In these cases, WeldCorp needs to collaborate further with SupDigit to recode the digital components. This leads to longer development times, with more interactions and extensive collaboration between SupDigit and WeldCorp. "We have been more involved, working closer together with them" (WeldCorp Product Manager Digital Solutions).

For WeldCorp, it is important that applications are user friendly:

> When we compare our efforts and what we do with what our competitors are doing [...] the applications that they are developing, you know, it's developed by engineers, for engineers, more or less. So, it's not user friendly. So, I think I would say our focus is really to, to make sure that the functions that we've developed are user friendly (WeldCorp Product Manager Digital Solutions).

This highlights the critical role of SupDigit in this business:

> You can connect the device, you can, you know, you can draw data from that device, [...] you might have all of the information that is necessary, but if that information is not easy for you to read, then forget about it, that will not be a service that someone is really willing to pay money for (WeldCorp Product Manager Digital Solutions).

To interact with SupDigit, WeldCorp needed to increase its competence in software and digital technologies in several areas of the company, including in the R&D and purchasing teams. "So, WeldCorp didn't have any competency in software before. It started to gain this competency something like three years ago, four years ago, something like that" (WeldCorp R&D Manager Digital Solutions). As SupDigit uses a specific language for programming its components, WeldCorp had to hire personnel to work with the SupDigit framework. However, these skills are not easy to find in the market, and consequently, these specialists get better salaries:

> A SupDigit developer takes much more than, you know, a Java developer for example, and this is something that, you know, one needs to take into consideration when choosing such a platform (WeldCorp R&D Manager Digital Solutions).

To overcome the difficulty of finding these skills in the market, WeldCorp has a strategy to hire and train people to work with the SupDigit framework and interact with SupDigit's developers.

4.3 Relationship between WeldCorp and SupGatew

SupGatew was founded in 2007 and is an expert in designing and manufacturing electronic products, including hardware, software applications, cloud applications and cloud deployment. SupGatew has more than 5,000 employees and engineering centres in a number of different countries. SupGatew works with a wide range of customers from small start-ups to well-established firms. SupGatew works in four business segments: IoT (tracking and monitoring), networking and wireless (data communication products), 5G and data centres and cameras and visualization. SupGatew had established this position through relationships with previous well-known customers. SupGatew's previous record of

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innovation was key in WeldCorp taking the decision to start a new collaboration with them.

WeldCorp previously was buying off-the-shelf gateways, which was expensive and not suitable for the welding context. A few years ago, it decided to develop a tailored IoT gateway with lower costs and that could be used in robust environments and tough conditions (i.e. hundreds of amperes of electrical current), hence the need for an interactive interface between WeldCorp and SupGatew. Lower costs are expected because some functionalities of the off-the-shelf gateway have been identified as not necessary for the welding application and can, hence, be removed during project development.

SupGatew used to be a supplier to WeldCorp for the design of mechanical parts. Learning that SupGatew also had expertise in communication and connectivity, WeldCorp decided to include the company in the supplier selection process for the IoT gateway. Another decisive point for WeldCorp in selecting SupGatew as a supplier was the fact that it could also design and manufacture the IoT gateway:

> So, SupGatew is not just a design house, they also have manufacturing capability. [...]. It's just that there might be more synergies and stuff where they know the detailed workings of it. So, they might be better at manufacturing it and get a better product (WeldCorp Supplier Development Manager).

Integrating the hardware supplied by SupGatew in the welding machine requires mutual technical adjustments. The manager from SupGatew explains how its engineers collaborate with WeldCorp's engineers to agree on the technical interfaces:

> So, actually the boundaries are being set by each of us, right? So, when [...] they say this is the power I can give you, right? This is the space I can provide you in the mechanical space within the system, right? And this is how I can talk to you, right? I can talk to you only on Ethernet, or I can, I can give a serial communication port [...].
>
> We also ensure that our design doesn't contribute anything extra to the other system, right? So, we also do a pre-scanning of all of our electronics to make sure that they don't radiate noise, they don't emit anything additional to jeopardize the existing system, right? (SupGatew VP Business Development).

5. Case analysis

Based on the case description above, three supplier interfaces are identified in the context of digital servitization: the connected supplier interface, the digital supplier interface and the digital-physical supplier interface. The characteristics of these interfaces are analysed below in terms of how they impact on resource combination between buyers (manufacturing companies) and suppliers.

5.1 Connected supplier interface and resource combination

Connected supplier interfaces between manufacturing companies and suppliers allow access to resources that are always connected. The relationship between WeldCorp and SupPlatf forms the basis for this interface. In the context of digital servitization, this type of interface is known as a "connected supplier interface" and refers to suppliers that provide infrastructure and/or an internal backbone (e.g. IoT cloud platform and security systems) for manufacturing companies. Hence, there is connectivity between the actors involved in these relationships.

Those suppliers usually have proprietary components and standards that lock in manufacturing companies. This can facilitate or hinder interaction with other suppliers. As manufacturing companies develop applications and services on top of the infrastructure, changing the connected supplier can be very costly, as it can require significant investments of time and resources to re-route large amounts of data. It can also increase the technical complexity of the backbone.

Connected supplier interfaces often provide services and infrastructure according to manufacturing companies' specifications. However, some research work is also done jointly with the manufacturing companies to develop further features of the infrastructure and adapt it to the needs of different industries. Hence, the connected supplier interface can be categorized as a mix of a specified interface with elements of an interactive interface. The interaction pattern is, thus, predominantly thin, but some thick interactions occur during joint research. Hierarchical resource interfaces can emerge when a supplier dominates the business network (which is the case for some IoT platform providers).

When it comes to the technology strategy, the technological complexity of the IT infrastructure results in greater dependence for the manufacturing firms on connected suppliers. Most manufacturing firms will largely rely on outsourcing the technological development of the IT infrastructure. The organization of the manufacturing firms needs to be adapted to the supplier resource, especially technical resources, because of proprietary components.

In terms of resource combining, industry-specific knowledge (the manufacturing firm's resource) is combined with infrastructure (the connected suppliers' resource) to create new resources in the form of digital solutions. When resources are combined, dependence on a supplier is increased, making it harder and more costly for manufacturing firms to change this type of supplier.

5.2 Digital supplier interface and resource combination

Manufacturing firms need to access digital resources from suppliers to develop their services and applications, and the interaction with these suppliers is done through what is called a "digital supplier interface." In our case study, the relationship between SupDigit and WeldCorp was used to identify this digital supplier interface.

Manufacturing companies that are starting digital servitization need to adapt their organization to effectively interact with different digital suppliers and discuss topics in relation to, for example, IoT, connectivity and digital component development. Moreover, engineers and developers constantly need to interact to find out how to innovate and create new software applications. In our empirical study, even WeldCorp's customers also take part in the development of applications, especially during testing:

> [...] we have an idea, we run it by our customers, we check and then, you know, we develop and test with them, and then, you know, it's an Agile process (WeldCorp R&D Manager Digital Solutions).

Depending on the complexity of the applications being developed, the resources are adapted and combined in two ways. First, when manufacturing companies use standardized digital components from suppliers, resource adaptations occur mainly on the manufacturing company side. Second, for more complex applications, manufacturing firms collaborate with digital suppliers and engage in mutual adaptation of resources and mutual learning. These two ways to combine resources were identified both in interviews with employees from WeldCorp and in the interview with the CEO of SupIT, who mentioned that, in certain contexts, SupIT needs to be flexible and support users with standardized solutions as well be involved in large projects and/or the development of complex digital components.

The digital supplier interface can be considered a mix of a standardized and an interactive interface. The interaction pattern is thin for business exchanges over standardized components and thick when developing more complex, industry-specific digital applications. Interfaces with digital suppliers have this mixed characteristic, as developing interactive interfaces is expensive but necessary in uncertain contexts.

The result of this interaction is the combination of the suppliers' digital resource with the manufacturing companies' resources, which usually include products and organizational resources (such as knowledge about the industry). As manufacturing firms can now regularly introduce new software applications and updates to their connected products, more interactions with suppliers involved in software development and digital components is expected. This Agile approach to software development has been identified as a key factor in the interface and impacts the frequency of the resource combining process and interactions.

5.3 Digital-physical supplier interface and resource combination

Manufacturing companies need to continue developing relationships with suppliers of digital and physical components to access resources that are needed for digital servitization. This has been identified as the "digital-physical supplier interface," and the relationship between WeldCorp and SupGatew forms the base for this interface. Examples of necessary components are sensors, connectivity devices, antennas and gateways. While these components can sometimes be bought off the shelf, tailored hardware and software components are also needed, especially when launching new products. Therefore, both standardized and interactive interfaces are usually developed through relationships with different digital-physical suppliers in the context of digital servitization.

Digital-physical components have strong technical interdependencies with existing components of the manufacturing firm's products, and this factor affects the combination of resources (e.g. equipment housing and some sensors). Manufacturing firms often have a physical product before they embark on digital servitization. Hence, new jointly developed resources (digital-physical components) need to be adapted to and compatible with those existing resources (physical products). This way engineers from suppliers and manufacturing companies need to jointly establish the technical interfaces such that the new components do not interfere with existing components/products. This requires thick interaction patterns in the developing phase. In the process of digital servitization, it is common that a cross-functional team within the manufacturing company, including purchasing, R&D and IT, handles relationships with digital-physical suppliers.

Interactive interfaces with digital-physical suppliers also demand suitable governance to coordinate the activities and efforts of the involved actors combined with ad hoc interactions. Weekly meetings, joint risk analyses and executive meetings for health checking are some examples of efforts needed in this type of interface. Informal meetings are also very common during the development of digital-physical components:

> And then you will also have informal meetings between the engineers. So, my hardware engineer, if he has to have some questions, he will write an email and you'll get it clarified now and then (SupGatew VP Business Development Manager).

5.4 Main characteristics of Internet of Things supplier interfaces in digital servitization

The main characteristics of the identified IoT supplier interfaces (connected, digital and digital-physical) in the context of digital servitization are summarized in Table 3.

The suggested supplier interfaces in digital servitization point to different levels of interaction, ways of interacting, types of resource interfaces and resource combinations. Both technical interfaces and mixed interfaces are identified. Aspects such as connectivity and an Agile approach to software development lead to more frequent interactions between suppliers and manufacturing companies, especially those based on technical interfaces.

The connectivity aspect can impact technical interfaces (machine–machine, e.g. data exchange) and mixed interfaces (human–machine, e.g. software developers can, at any time, interact with IoT cloud platforms and create new applications). High technical resource dependence on suppliers requires individually managed interfaces. This interdependence between resources in the interfaces is further discussed below.

6. Concluding discussion and implications

The aim of this paper was to investigate the interfaces between manufacturing companies and the suppliers involved in digital servitization. Based on the case analysis of WeldCorp and three IoT suppliers, it is concluded that the relationships were characterized by a number of different interfaces.

6.1 Concluding discussion

The identified IoT supplier interfaces (connected supplier interface, digital supplier interface and digital-physical supplier interface) showed unique characteristics, summarized in Table 3. Our study suggests that these three types of supplier interfaces and underlying resource interfaces should be seen as interdependent. This is because the infrastructure of the connected interfaces needs to function with the digital components, physical equipment and software needed in the products. Creating value by achieving this functionality will require interaction not only in the three supplier relationships but may also require interaction between the suppliers. One positive aspect of potential collaboration among IoT suppliers is that manufacturing firms can select partners that have proven functional resource interfaces between their solutions. On the other hand, it can lead to thick interaction in individual interfaces as well as lock-in effects across several suppliers. Hence, the functionality and interdependence of IoT suppliers, including several different factors, might make it difficult and expensive to change them later on.

This empirical case reaffirms previous findings that there is no such a thing as a best interface in absolute terms, and different interfaces applied to a set of suppliers will have pros and cons that need to be evaluated case by case (Araujo *et al.*, 1999). The choice of interface is context and content dependent and conditional on the particular situation (Andersen and Gadde, 2019). IoT technology brings different aspects to supplier interfaces (such as connectivity) that need to be considered by manufacturing firms and suppliers.

We observed that the connected suppliers are key and strong actors in the network who benefit from the proprietary components and the establishment of standards to lock manufacturing firms into their systems. WeldCorp is a large company, but the supplier involved in the connected supplier interface is even larger. Similar contexts, in which there are relationships and interactions between buyers and suppliers of different sizes with varied potential power dynamics, have also been studied by other researchers (Bocconcelli *et al.*, 2018). As a supplier, being a strong actor in the network does not seem to permit thick interaction (Waluszewski and Johanson, 2008). However, when or if a supplier relationship becomes interactive, it may mean that the manufacturing company has also grown in importance for the IoT supplier. This would suggest that the counterparts may become mutually interdependent, though this is not the situation observed currently.

Manufacturing companies starting digitalization should be prepared to develop not only a strong but also a flexible and interactive way of dealing with IoT suppliers. Based on Araujo *et al.* (1999), a mix of interfaces have been identified in the interactions between the manufacturing firm and IoT suppliers (also seen in the findings by Lind and Melander, 2019). In a digitally and technologically uncertain context, new roles, interdependencies and technology strategies are not well defined, and they are not expected to be in the near future. Hence, manufacturing companies will need to develop and re-configure their relationships and interfaces with IoT suppliers over time.

6.2 Theoretical contributions

This paper contributes to the conceptualization of supplier interfaces by recognizing important supplier interfaces when sourcing IoT technologies. Our study develops a novel perspective by relating supplier interfaces to key exchanges involved in developing digital solutions based on IoT technology. Therefore, we extend the existing understandings of supplier interfaces (Araujo *et al.*, 1999; Andersen and Gadde, 2019; Lind and Melander, 2019) by proposing a framework with three types of IoT supplier interfaces: connected, digital and digital-physical. This framework explains some different types of supplier interfaces that manufacturing companies experience when developing and commercializing new digital services based on IoT technology.

Previous studies have showed that companies need to apply a variety of interfaces when interacting with different suppliers (Araujo *et al.*, 1999). We add aspects related to IoT technology in the analysis of the supplier interfaces to understand how this technology affects the interfaces and interactions. By doing this, we aim to extend perspectives on the interactions between buyers and suppliers involved in digital exchanges. For example, we found that the connectivity aspect of the connected supplier interface means actors are continuously connected but exhibit a predominantly thin interaction pattern.

This study also illustrates how digital and digital-physical supplier interfaces are impacted by technology strategy and the complexity of components in terms of interaction patterns, organizing principles and resource interfaces. It is important to highlight that Araujo *et al.* (1999) conducted their study on supplier interfaces within the steel industry in a period when connectivity and software development were not as prominent in business exchange as today. Consequently, our study complements theirs by adding the perspective of digitalization to the conceptualization of supplier interfaces.

6.3 Managerial implications

There are managerial implications for buying firms involved in the development of interfaces and relationships with IoT suppliers that follow from this study. First, technological uncertainty makes it difficult to predict new digital and physical resources that will be needed in the development of future digital services, which should increase managers' attention on the dynamics of collaborations. Managers should be aware that collaborations will change over time, and there is not a one-size-fits-all interface to use when interacting with IoT suppliers. These changes will require an internal organization that can manage the dynamics of the collaborations (e.g. working collaboratively with Agile software development). Second, digital servitization requires different competences of manufacturing firms when interacting with IoT suppliers (e.g. purchasing, IT and R&D). Hence, cross-functional teams can be an important organizational arrangement to cover the different topics that need to be discussed and handled in these interactions. Third, there are interdependencies across the supplied digital components. Here, cross-functional teams can also be useful to identify these interdependencies and manage the range of IoT suppliers and interdependencies involved in IoT-based offerings for manufacturing companies.

Fourth, regarding the connected supplier interface, our case study shows that this interaction pattern tends to be thin. Suppliers provide access to key infrastructures (e.g. IoT cloud platform, data security and data storage), and in general, they have considerable power as the primary resource layer in the IoT structure. Therefore, trying to invest in closer relationships, for instance by conducting joint research, can be beneficial and reduce risks for manufacturing companies. Fifth, it is key to understand how the development of supplier interfaces is impacted by the technology strategy for IoT and cloud technologies. Managers should know that decisions about how and which actors will be involved in the development of IoT technologies affect digital and/or digital-physical supplier interfaces in terms of resource interfaces, interaction patterns and organizing principles.

6.4 Limitations and future research

By relying on a case study method, our paper has certain limitations in terms of specific and contextualized findings. Our study was restricted to supplier interactions involving IoT, and although several different sources have been used, another limitation is that the main perspective is that of the customer. Those limitations also form the basis for further avenues of research. There is potential to expand this study by exploring the interfaces from the perspective of IoT suppliers. Do IoT suppliers handle a mix of interfaces with different customers or do they have similar interfaces with the majority of their customers? How is the level of interaction between buyers and suppliers influenced by the industrial network structure? Given that some suppliers, such as Amazon and Microsoft, hold powerful network positions, investigating business models in light of digital servitization and transformation dilemmas

(Carlborg *et al.*, 2021) would be another interesting future research area.

Our study emphasizes the IoT cloud platform and its related suppliers as an enabler for the development and commercialization of new digital solutions (including physical products and services). It would be interesting to conduct additional studies in contexts where other digital technologies (such as AI and three-dimensional printing) are used as a base. Here, new interface characteristics could be identified, depending on the resources of the suppliers that support the development of different digital technologies. Such studies could bring further understanding of the variety of buyer–supplier interaction taking place in digital servitization.

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