Platform Ecosystems for the Industrial Internet of Things – a Software Intensive Business Perspective

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Abstract. The global competition requires the machine tool industry to provide more flexibility and productivity to its manufacturing customers, enabled through software-intensive services. A platform approach receives an increasing attention within the machine tool industry, offering a solution to provide such services. Software platforms, adapted to the needs of the industry and used in the industrial application are also known as industrial internet of things (iIoT) platforms. Despite the growing interest among manufacturing companies in iIoT platforms, they have been limitedly researched from the economic perspective. Consequently, a further in-depth analysis of platform-based business models in the area of iIoT is still needed. Firstly, this paper offers new insights on technical and economical criteria for business models and design of existing iIoT platforms and transforms them into a taxonomy. These merged criteria provide a detailed perspective on iIoT platforms and support machine tool companies in their decision process of suitable iIoT platforms. The criteria are based on the results of 17 qualitative interviews with companies from the machine tool industry. Secondly, the identified criteria are summed up in a morphological box, in order to reduce the selection complexity of an iIoT platform by the machine tool companies and sharpen the software-intensive business models of the platform providers.

Keywords: Industrial IoT, IoT Platform, IoT Ecosystem, Business Model Analysis, Morphological Box.

1 Introduction

The machine tools industry nowadays experiences an increasing competitive pressure due to the globalization and the individualization in manufacturing, requiring more efficient manufacturing processes [1]. The German Mechanical Engineering Industry Association (VDMA) together with McKinsey have surveyed the machine tool companies and identified the customer demand for customized systems and solutions as the most relevant trend. Another finding was the increasing importance of the after-sales, ranking it as the third most relevant trend in the market [2]. Digital services are provided remotely and modularly during the whole life cycle of a machine tool, creating a steady revenue source in after-sales for a machine tool company [3-4]. The platform approach enables the provision of digital services for a variety of customers, fulfilling the flexibility needs and even building new software-intensive business models. The services are provided through enterprise applications, which are developed on specific software platforms [5], classified as iIoT platforms. Such a platform interacts with smart connected machine tools and its components across companies' borders, processing the data it receives from the machine tool. Based on the processed data the platform triggers microservices, changing the parameters of the machine tool through the data feedback loops. Accordingly, platforms play coordinating roles for connected machine tools, acting as a digital infrastructure [6-7]. Gawer and Cusumano coined the understanding of open technological platforms [8]. iIoT platforms also act as multi-sided markets [9], as machine tool companies provide applications, based on the platform, for the machine operating companies in different industries.

The current state shows, that a successful platform initialization in a machine tool industry remains a high complexity challenge for both: the platform providers and the machine tool companies, acting as a collaborating customer for a platform provider in an iIoT ecosystem [10]. The complexity is partially caused by the variety of the specific functional characteristics offered by each platform provider, by the iIoT platform evolving the machine tool company into an ecosystem and by the variety of the market-available platform solutions [11-13]. In addition, various iIoT platform providers describe only a fuzzy value proposition, without meeting the specific customer needs of the machine tool industry, as mentioned by Herzwurm [14]. However, a selection process for a suitable iIoT platform is a major challenge [15] and highly interdisciplinary, as it is crucial for the product servitization and affects stakeholders from multiple departments throughout the whole company [7, 16]. Despite the recognized potential of iIoT, machine tool companies experience difficulties to identify which iIoT platform best suits their own requirements and the current state of market hinders the formation of a "platform leader" in the machine tool industry. The current state indicates an industrial problem setting, revealing the lack on relevant technical and economic criteria for the choice of iIoT platforms from the perspective of a machine tool company as a collaborative customer. This paper is based upon the assumption, that the fragmented market for iIoT platforms (offering up to 450 market-ready solutions) causes problems for the manufacturing companies to choose the right platform. On the other hand, the practical relevance of the problem is present, as new studies conducted by the VDMA, show an increase of interest in iIoT platforms by machine tool companies. Although more than 60% of surveyed companies indicated iIoT platforms as an unknown topic or irrelevant in 2016, for 75% of surveyed companies iIoT platforms are important in 2018 [17].

Considering the current state of research on platforms, Gawer has already bridged economic and technical perspectives on platforms and offered a platform classification. However, this classification is not specific to iIoT platforms. In addition, the scientific papers about concrete design or business model patterns within the industrial application of platforms and platforms specifically used for the machine tools industry (see Chap 2.1) are still rare. As stated by Kude in the Dagstuhl position statement, the existing literature on the iIoT has mainly focused on the technical implementation and the platform literature has been mainly too generic [18]. This indicates a research gap on relevant business model criteria of iIoT platforms, which if known, collaborative customers in the iIoT ecosystems could use for interdisciplinary platform selection decisions. Hence, the overall goal is to provide relevant criteria for this selection process through a more in-depth analysis of design and business models of market-ready iIoT platforms for the industry of smart connected machine tools. Hence, this article answers the following two research questions:

- RQ1: What are the relevant criteria in the selection process of iIoT platforms by manufacturing companies for data-driven maintenance services?
- RQ2: Which market-ready iIoT platforms fulfill the identified criteria?

The structure of this paper consists of three parts. The second section of the article presents conceptual foundations and current state of research on iIoT platforms. The third section addresses both research questions, presenting at first the identified technical and economic design criteria of iIoT platforms. Criteria are based upon a multiple case study analysis of qualitative data, collected in interviews with machine tool companies. Afterwards, each elaborated criterion is applied on the market-ready iIoT platforms, in order to ensure the transferability of the identified criteria to the current state of the market for iIoT platforms. The final part presents the future research outlook and limitations.

The main result is a characteristics taxonomy for iIoT platforms, both technical and economical, integrated in Zwicky's morphological box. The morphological box could act as a decision support tool for the cross-department collaboration during the iIoT platform selection, building the main artefact of the paper. Morphological analysis as a method has been already used to gain a holistic understanding of business model concepts within a certain context [19-20]. Researchers and practitioners from the platform provider perspective could use the taxonomy for a further business model analysis of iIoT platforms, in order to better understand currently existing or even build new configurations and develop new business model patterns [21] for iIoT platforms. Practitioners from the machine tool industry could use the results in a selection process of a suitable iIoT platform. Moreover, the results can support the iIoT platform providing companies in a more precise communication of their platform design to the collaborative customers or complementors. As a result, this could increase the transparency on the design and the business models of the offered platforms, therefore involving additional collaborators in the platform-based iIoT ecosystems and stimulating the network effects [9]. Taking the research context of previously mentioned business models into account, this paper provides integrable criteria for the business model dimensions of the St. Gallen Business Model Navigator [21].

2 Industrial Internet of things and prior work

Following paragraph describes the theoretical background in the area of iIoT platforms. IoT integrates information and communications technology (ICT) with objects, connecting them with wireless and wired technologies and extending them by real-time analytics. iIoT integrates these technologies in the industrial area of application

[22]. The relation to the concept of Industry 4.0 is close, which means iIoT can be understood as the vertical and horizontal connection of people, machines, objects and ICT systems, which are real-time capable and intelligent, for dynamic management of complex systems [23]. Hence, connected machine tools act as cyber-physical systems (CPS) [24] and this transition could greatly increase the productivity and the flexibility. It is estimated, that it is possible to increase the productivity and the lifespan of machine tools up to 5%, to lower the maintenance costs between 10 and 40% and reduce the energy consumption up to 20%, if the machine tools are connected and monitored [25]. The listed benefits could be achieved through processing and analysis of machine-generated data. An intelligent machine tool could stream data considering its condition and its energy consumption, the current process or the quality of the workpiece and combine them with a cross-domain analytics. Lastly, the processing of the data appears in scalable iIoT platforms [26]. Moreover, if an iIoT platform provides open interfaces, the information could be enriched with external information sources and enable integration of third-party companies, [7, 9] thus enabling ecosystems in the area of iIoT. Compared to the customer branches, iIoT ecosystems are significantly smaller, have different requirements for platforms [27] and possess more complex structure of collaborating complementors, compared with traditional software ecosystems [28].

This paragraph shows the current state of research on the business models for iIoT and platforms. Gawer has created a unified view on open digital platforms and classified supply-chain and industry platforms as open [9]. This classification framework was only applied in the area of industrial robotics, to extract business model patterns and its dependency from the right degree of openness [29]. Besides the previously mentioned IoT stack [7], important work on business models also considered different revenue patterns in the area of iIoT [30]. Ehret and Wirtz identified a variety of potentials for IoT in the industrial application and concepts of iIoT business models [31]. Previous research has also discussed the appropriate organization structures and the required capabilities for non-standard partnerships and the make-or-buy decisions for iIoT platforms for manufacturing companies [32]. Some research also has identified iIoT related changes in business model elements [33]. Many research papers propose strategy frameworks, either for an integration in an existing IoT ecosystem [34], or for a classification of business models in IoT ecosystems including platforms [35]. Important work also explored of specific IoT platforms. Wortmann and Flüchter achieved a first classification of iIoT platforms [15]. Agarwal and Brem investigated the IT-enabled transformation of General Electric to an iIoT platform provider [36]. Sandberg et al have described the platform-based transformation of ABB [37]. Ardolino et al researched the capabilities for a successful service transformation in industrial companies [38].

Previous research on iIoT did not focus on the challenges of selecting the right platform from the perspective of a collaborative customer or a complementor. Accordingly, further research on concrete design criteria of iIoT platforms is required, addressing this challenge is required [15]. This paper fills this gap and extends the existing research in two directions. Firstly, the proposed taxonomy could extend the currently existing research on business model patterns for the growing area of iIoT platforms. Secondly, the proposed taxonomy provides a focused view on the machine tool industry in the iIoT and its characteristics of openness, which despite the increasing relevance of platforms, stays little investigated in the broad area of IoT.

3 Evaluating the business model criteria of iIoT platforms

3.1 Methodology

Qualitative research is suitable to analyze business decisions, which in our case was the decision for a certain iIoT platform. The database for this purpose contained primary data, which was obtained during qualitative interviews with practitioners. The interviews were conducted between March and August 2018 using a predefined interview guide and were thus semi-structured. The guide ensured the comparability, simultaneously offering enough freedom to create new specific or more in-depth questions, based on the answers. The interviews were compared and analyzed and the received information was recognized as single subjective dimensions of expert knowledge, which build a conceptualization and can be used for a theory generation [39]. As stated previously, data-driven maintenance was chosen as a platform-based service, to support the understanding of the interviewees, consequently defining the qualitative case study context. In the pre-selection process, suitable companies from the machine tool industry were identified based on publicly accessible company blogs, product presentations and press reports looking for digital services in the field of data-driven maintenance and related software-intensive services. The core target group consisted of mechanical engineering companies for various manufacturing processes in the metalworking, plastics processing and woodworking industries, as the initiators behind data-driven maintenance services. The interviewed representatives of the companies are specialized on processes such as milling, honing, turning, laser cutting and welding, injection molding wood construction joinery and others. An additional clustering of the identified companies includes machine makers, toolmakers, component makers and providers of automation solutions and software solutions for the automation or machine tools. Despite the heterogeneity of the processes and the companies, there are certain similarities between the studied companies. All these companies count as collaborative customers or complementors from the platform-provider perspective. At first, they all use iIoT platforms to build applications for software-intensive services as data-driven maintenance or similar. Consequently, the data-driven maintenance efforts of the studied companies and the applications built by them increase the overall value of the used iIoT platform and has impact on the iIoT ecosystem. The data collection process included interviews with machine tool companies (n=8), component suppliers including toolmakers, end effector manufacturers and automation solution providers (n=6), as well as manufacturing-related system integrators and consulting companies (n=3). The overall sample size consists of 17 interviews. After the evaluation of the 17th interview, the study has reached a theoretical saturation due to repetitive statements of the interviewees. The interviews were conducted with representatives working in the area or leading the digital service projects for their company’s products. The second requirement towards the representatives was to have at least 5 years of experience in their industry and in the digitization to ensure the qualification of the interviewees. The potential representatives were screened towards these two requirements, in order to count as experts on specific issues from the researcher's perspective [40]. The following table depicts the full list of interviewed experts during the data collection process of the study:

Table 1. Information on interviewed experts and their companies

ID	Position of the interviewee	Rounded no. of employees	Company profile
1	Head of Product & Services	50	Consulting and system integration
2	Product manager After Sales	350	Machine tools
3	Head of Industry 4.0 Campaign	7000	Components supplier
4	Head of Digitization	2000	Machine tools
5	Business Developer	800	Components supplier
6	Head of Maintenance	1300	Special machine tools
7	Managing Partner	10	Consulting
8	Corporate Innovation Management	900	Components supplier
9	Head of Technical Sales – E-conception	250	Machine tools
10	Technology manager Industry 4.0	2150	Machine tools
11	Head of industrial Data Services	500	Machine tools
12	Head of Development and Standardization Control	200	Components supplier
13	Head of Product Management	150	Machine tools
14	Head of Product Management	220	Components supplier
15	Lead Architect Industry 4.0	14000	Components supplier
16	Head of Product Management	70	System integration
17	Product manager Technical Support	11500	Machine tools

Predefined questions of the interview guide focused on the following topics:

- Which challenges of current importance do you experience during the implementation of data-driven maintenance?
- To what extent do you collaborate with partners during the implementation of data-driven maintenance?
- Which role do iIoT platforms take for data-driven maintenance?

The received information contained the project experience of the machine tool industry on iIoT platforms, including the challenges, the potentials and the value of the platform usage for data-driven maintenance and similar services. Hence, the data contains empirical evidence from companies about particular decisions on data-driven maintenance and iIoT platform selection and implementation, thus underlining interpretive research [41]. The analysis process of the recorded data included the transcription and coding processes of the interview recordings. During the coding process the answers were labeled, based on the interpretive identification of themes. The extraction of results underlies inductive reasoning [41], as the criteria and the characteristics are built from individual statements of the interviewed experts.

3.2 Building the taxonomy for iIoT platforms

The comparative analysis of coded transcripts returned five business model criteria for iIoT platforms. Each criterion can be aligned with the business model dimensions "How?" and "Value?" defined by Gassmann [21]. The first criterion provides a more detailed classification of platform openness and complies with the "How?" dimension. The taxonomy classifies this criterion in three additional characteristics:

- **Hardware integration openness:** While every iIoT platform mentioned by the interviewees was advertised as open, the least open iIoT platforms did not allow third-party application development at all. This means the business model of the iIoT platform provider also included the development of platform-based software. Openness on the other hand affects only the hardware integration. That means there are no strict exclusions of certain machine tools or electrical control components for process automation. Lastly, with this degree of openness the ecosystem can arise over the hardware components, as the platform provider develops the software-intensive services. The iIoT platform tapio, used in the wood working industry, currently shares this characteristic.
- **Project-related software integration openness:** This degree of openness allows external third-party development. The iIoT platform providers make the necessary resources for software development either available for a machine tool company (for its own IT department) or for an external system integrator on a project basis, a machine tool company can contract. The main distinctive feature of this certain degree of openness is that specific platform-based applications are developed in projects, without the orchestration of the integration or the distribution processes of the application through an app store by the platform provider. This degree of openness shares similar aspects as the supply-chain platform classification, shaped by Gawer [9]. However, the interviewed practitioners, who used an iIoT platform with this degree of openness, did not see any necessity in a further standardization in terms of an app store, due to the high specificity of their software-intensive services. Extending the hardware ecosystem, the software developing complementors can for instance be system integrators, either close to the machine tool company or to the platform provider company [28]. General Electric for instance shares this degree of openness for its platform Predix, maintaining a software ecosystem with

complementors for software development and integration [42], without the provision of an application store.

- **App store supported software integration openness**: This degree of openness means sharing of software development resources, consequently enabling external third-party development for a platform. The ecosystem evolves in terms of both hardware and software. Main distinctive features are the transparency of the service offerings and the standardization of applications driven by the app store. Though this degree of openness also requires checks and audits of complementors by the platform provider, the complementors can use the transparency of an app store for their advantage, for instance to screen it for missing software-intensive services. In addition, the machine tool companies can search for third-party partners for specific scenarios through the app store more precisely. That is why this degree of openness can be considered as the most open for a platform-based ecosystem. Siemens and SAP decided to share this degree of openness with their iIoT platforms Mindsphere and Leonardo, which are connected to enterprise application stores.

The next two identified characteristics concern the revenue stream of a platform provider and include the integration options and the revenue stream structure of the business model. As various iIoT platform providers also include the application development supplementary to the iIoT platform offering, they generate additional revenue streams, besides the infrastructure usage expenses. However, some platform providers offer free applications or pilot integration projects. The differences in the integration conditions belong in two dimensions of the Business Model Navigator: “How?” and “Value?”. The following list depicts the taxonomy:

- **Free integration:** In this context, it is important to understand the variety of strategies of provided iIoT platforms for the industrial application. There are some machine tool companies, which were able to introduce their own iIoT platforms and provide them within their industry. The interviewed representatives stated that the main goal of their company is to increase their end customer’s loyalty through additional value. The value is provided through iIoT platform-based applications for the machine tools, which are developed and integrated for free. The iIoT platform tapio for the wooden branch provides such integration conditions.
- **First integration free:** This integration allows the machine tool company to carry out a pilot use case without a financial risk. The first initial integration with a machine tool’s control unit and the development of an application are provided for free to lock-in the complementor on the iIoT platform and get additional revenue streams through the follow-up IoT projects. The Bosch IoT Cloud offers such an integration condition for the machine tool companies.
- **Paid integration:** This type of integration is different from the previous one, because the first application development is already a paid project. According to the interviewed representatives, Siemens offers this integration option for its iIoT platform Mindsphere.

Differing integration options also affect the revenue streams of an iIoT platform provider. The differing revenues belong in the "Value?" dimension of the Business Model Navigator. The taxonomy consists out of two characteristics, depicted below:

- **Indirect revenues:** The free integration generates additional indirect revenues in the business model of a platform provider through increased customer loyalty and access to customer's specific problems in the production, consequently allow an improvement of the next generation of machine tools.
- **Direct revenues:** Integration conditions, which require direct payments for platform-based applications, whether from the beginning or from the second project on, generate direct revenue streams. Such a revenue structure differs significantly from the typical platform-based business models, which typically generate revenues through app store transactions or usage of infrastructure. These revenue streams differ from the typical platform-based business models for instance in the market for mobile OS.

The next two characteristics consider the differences in the service model architectures of the iIoT platforms. Although the iIoT platforms mostly seem as a PaaS model, an in-depth analysis reveals significant differences. Often, the cloud service model architecture of a focal iIoT platform is not evident from the perspective of a machine tool company. Nevertheless, this criterion plays an important role in the decision process for the right platform, as it has an impact on future partnerships of the machine tool company. Consequently, it affects different departments and lastly the whole platform-based iIoT ecosystem. The cloud hosting model complies with the "How?" dimension in the Business Model Navigator. The following list presents six most important out of eight characteristics of this criterion (see Fig. 1):

- **IaaS + PaaS:** This combination is mentioned separately due to its influence on the ecosystem growth. If the iIoT platform is bound to a predefined infrastructure provider, the machine tool company lacks the flexibility of provider change. Consequently, the vertical cooperation of the machine tool company with the infrastructure of choice and the ecosystem growth are restricted. If a machine tool company chooses for instance the Bluemix service by IBM it also uses IBM's infrastructure.
- **PaaS + SaaS:** If the iIoT platform restricts third-party development and the platform provider is developing application in addition to the iIoT platform on its own, such a business model as a result restricts the horizontal cooperation of the machine tool company for instance with software development companies for future software-intensive services.
- **Partly IaaS + PaaS:** This type of cloud service model allows the machine tool company to choose, whether to buy the infrastructure additionally to the platform from the same provider or not. This optional offer extension could potentially restrict the selection of a third-party infrastructure partner and thus influencing the vertical ecosystem growth. Hewlett Packard Enterprise provides such a type of cloud service model.
- **PaaS + partly SaaS:** Some iIoT platforms as Mindsphere or Cumulocity allow third-party development. However, they also offer software development for their platforms by their own departments, competing with their business model in the

horizontal cooperation of a manufacturing company. That means applications could be developed by an external complementor or a platform provider. The platform provider could be more efficient in terms of adoption and integration of the application, while the complementor could have more knowledge about the specific process. Mindsphere app store represents this characteristic, as one can find there some basic applications developed by Siemens.

- **Partly IaaS + PaaS + partly SaaS:** This level of cloud services means that the iIoT platform can optionally be extended by the own infrastructure and application development, obtained from the iIoT platform provider. The machine tool company can decide about the restrictions, whether it chooses the full cloud computing stack from one source or not. SAP for instance shares this level of flexibility in the cloud service model for its iIoT platform Leonardo.
- **IaaS + PaaS + SaaS:** If the whole cloud computing stack is provided by one company, the iIoT platform business model restricts the horizontal and the vertical cooperation of a machine tool company. Bosch for instance offers the whole cloud computing stack, hosting its IoT Cloud on its own infrastructure and providing the implementation and the application development on their own.

Besides the cloud service model, the ability of iIoT platforms to be installed on-premise or support on-premise installations is also an important criteria for the machine tool companies. Connectivity and hosting possibilities were mentioned as an important criterion by many interviewed companies. This criterion is assigned to the "How?" dimension of the Business Model Navigator, divided as follow:

- **Cloud only:** This characteristic contains the iIoT platforms which are only hosted in the cloud. Additional connectivity modules could connect the iIoT platform with on-premise systems. However, the functionalities of the iIoT platform remain in the cloud. Most iIoT platforms typically provide this type of installation.
- **Hybrid installation:** This type of iIoT platforms allows an on-premise installation of modules and functionalities, if certain use case requires this. That means the iIoT platform is modularly divided between the cloud and the on-premise infrastructure. This type of installation is also commonly seen, as some functionalities or applications are installed in the edge and communication with the cloud, where historical data analysis is possible. Hybrid installations of iIoT platforms are commonly seen, if the platform provider offers additional hardware modules with certain pre-installed proprietary applications.
- **Possible on-premise installation:** This type of iIoT platforms allows to run the whole iIoT platform on-premise, if it meets the customer's requirements as an alternative to the cloud. This type of installation was a clear expressed requirement for some manufacturing companies and iIoT platforms such as edbic or Cumulocity allow this type of installation.

To sum up, the analysis of iIoT platform business models contains five criteria of iIoT platforms, extracted from single dimension statements of the interviewed experts. Each identified criterion is assigned to the dimensions "How?" or "Value?" of the Business Model Navigator [21]. The dimension "What?" represents the value proposition, which is regardless of the identified characteristics does not differ and has the goal to provide technologies for data-driven maintenance. This unifying dimension finding makes it possible to bridge different (economic and technical) criteria. Furthermore, each single characteristic of the taxonomy is assigned to at least one market-ready iIoT platform, additionally increasing the validity of the identified business model criteria, as it shows their occurrence on the market. The following structure of the identified criteria in a morphological box is the second artefact of this paper:

Dimensions	Business model taxonomy of industrial IoT platforms
What?	Technologies for data-driven maintenance

How?				
How?	**Openness classification**	Hardware integration openness – software development done only by the platform provider	Project-related software integration openness	App store supported software integration openness
	Exemplary iIoT platform	tapio	Predix, Cumulocity	Mindsphere, Adamos

How? Value?				
How? Value?	**Integration options**	Free integration	First integration free	Paid integration
	Exemplary iIoT platform	tapio	Bosch IoT Cloud	Leonardo, Azure

Value?			
Value?	**Revenue streams**	Indirect revenues	Direct revenues
	Exemplary iIoT platform	Tapio	Mindsphere, Cumulocity

How?									
How?	**Cloud service model**	IaaS	PaaS	IaaS + PaaS	PaaS + SaaS	Partly IaaS + PaaS	PaaS + partly SaaS	Partly IaaS + PaaS + partly SaaS	IaaS + PaaS + SaaS
	Exemplary iIoT platform	AWS	Predix, Thingworx	Bluemix, edbic	Tapio, FactoryTalk	HPE	Mindsphere, Cumulocity	Leonardo, Azure	Bosch IoT Cloud, Oracle IoT Cloud

How?				
How?	**Connectivity and hosting**	Cloud only	Hybrid installation	Possible on-premise installation
	Exemplary iIoT platform	Azure, AWS	Leonardo, Bosch IoT Cloud, Mindsphere	Edbic, Cumulocity

Fig. 1. Business model taxonomy of iIoT platforms

4 Conclusion

4.1 Findings and Limitations

This paper presents a taxonomy of iIoT platform criteria in the machine tool industry, based on dimensions of the St. Gallen Business Model Navigator and assigned to market-ready iIoT platform solutions. With the increasing relevance of the platform approach within the manufacturing industries, the identified criteria could help researchers and practitioners during further investigation of successful platform-based business models or suitable platform design in the iIoT. The demonstrated classification within the degree of openness could support the on-going benchmarking of the iIoT platforms, and by showing the differences supports the unanswered question about the right degree of openness and appropriate governance for manufacturing industries. Besides the classification of the openness degree, its interpretation by the potential complementors is even more important. The hardware integration openness may look as the least open alternative for iIoT platforms, but the interpretation by the complementors could be different. If for instance, the software integration openness provided by the app store is somehow restricted by the support of particular protocols or supports only platform-related proprietary standards and modules as certain programmable logic controller (PLC) systems are excluded on the hardware level, it may be the most closed alternative for a machine tool company at a second glance.

The morphological box forms a decision support tool for the important process of platform selection, which can be extended by additional platforms, not mentioned in the interviews. As the artefact contains economical and technical criteria, it could support heterogeneous stakeholders within a company, (for instance different departments), who are affected by the selection of a platform. In terms of the ISO 16355 the morphological box could assist the voice of the customer [43], providing a unifying artefact for affected stakeholders in different departments. Furthermore, manufacturing company at the early stage of entrance in the iIoT ecosystem could profit from the clearly assigned characteristics to market-ready platforms.

The morphological box features practical implications for platform providers to clarify their value propositions, because the criteria list represents the view of collaborative customers and complementors. In addition, the platform providers could use the morphological box to compare their iIoT platform against the competition and identify future niches for their branch of industry for the extension of their current offering.

Nevertheless, the results are limited, regarding the sample size of the qualitative interview study and the specific case study context (data-driven maintenance for machine tools) as the case study setting for IoT platforms. These limitations refer to the lack of generalizability of the findings. Furthermore, the interviews are subjects of subjective influence of the researcher and his understanding of the iIoT platform, thus forming the interview questions. As the conducted interviews were semi-structured, the follow-up questions, triggered by the answers of the practitioners could have led to an incomplete or wrong understanding of iIoT platforms – after all not every interviewed manufacturing company has already been using an iIoT platform for its software-intensive services. Some of the studied companies have developed their own software without using an iIoT platform and some companies have just managed to initiate pilot projects in the area of iIoT. Consequently, their knowledge on platforms could be limited, affecting the quality of the data sample.

4.2 Future research

The limitations of this paper require further research work on extension, generalization and evaluation of the taxonomy. The maturity of the platforms used in the cases has not been considered during this research, although the criteria evolvement during the platform lifecycle [44] could be a potential research area for a follow-up research. In addition, future research could also consider the sizes of the manufacturing companies as the collaborative customer and their impact on the selection of iIoT platforms and their criteria. A follow-up multiple case study analysis based on the taxonomy could also be a useful extension of the current result to check the completeness and the dependencies of the business mode criteria. During the given time, it was not possible to evaluate the taxonomy. Thus, future research should provide evaluation mechanisms, based on the performance of the utilized iIoT platforms for the manufacturing companies or on the impact of the identified criteria on the growth performance of the complete platform-based iIoT ecosystem.

Further research towards the customer's or complementor's interpretation of openness in the industrial application context is required. The interviews showed a varying and non-uniform understanding of platform openness from the practitioner's perspective. Moreover, the openness criteria of the taxonomy could also support a deeper research on optimal organizational capabilities of platforms in the field of iIoT and their interdependency with the identified criteria.

As the findings of this paper provide a conceptional base for a further research on iIoT platforms, a follow-up work should consider the platform governance. Especially an in-depth study of the currently used architecture and management of the application programming interfaces (API), software development kits (SDK) [45] and other boundary resources [46] in the field of iIoT platforms could make progress towards its impact on building an iIoT-platform based ecosystem.

Finally, the identified criteria could support the software-intensive business research on the development of new revenue streams for platform providers, beyond the ordinary pay-per-use models and traffic billing and have impact on the development of new business model patterns for iIoT.

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