Proceedings of the 57th Hawaii International Conference on System Sciences | 2024

Demystifying the Design of Industrial IoT Platform-Based Business Models – Archetypes and Their Strategic Response to Main Challenges

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Abstract

Platforms are on the rise in the Industrial Internet of Things (IIoT) as they transform industrial manufacturing and change how companies create and capture value. More and more companies are starting to develop IIoT platform-based business models (PBMs), but often face difficulties. Since these difficulties have mainly been discussed in business-to-consumer settings, we study those PBMs in an IIoT environment due to their differences from business-to-consumer environments. Using a mixed method, we first develop a taxonomy for IIoT PBMs based on a systematic literature review of 400 articles, 21 interviews, and 45 real-world PBMs and, secondly quantitatively analyze those real-world examples to derive five archetypes. By drawing conclusions about how these difficulties are addressed differently by the archetypes, our study contributes to the emerging research area of platforms in industrial business-to-business settings and guide firms to inform the design of new IIoT PBMs, ensuring they consider strategic factors.

Keywords: Platform-based Business Model, Industrial Internet of Things, Taxonomy, Archetypes

1. Introduction

The emergence of Industrial Internet of Things (IIoT) transforms industrial manufacturing by connecting industrial machines to cyber-physical networks (Oberländer et al., 2018). IIoT has developed rapidly in recent years. The global market volume of IIoT was valued at $322 billion in 2022 and will increase at a compound annual growth rate of 23.2% (GrandViewResearch, 2023). Possible IIoT use cases resulting from the connection of industrial machines for the end-user include optimizing production through plant monitoring or monitoring machine health through predictive maintenance. By connecting machine data, different sides of the market can now be brought together, leading to network effects and new opportunities for firms to create and to capture value (Adner, 2017). These types of network effects can be achieved with platforms that are characterised by their modular technological architecture (Baldwin, Woodard, et al., 2009; Jacobides et al., 2018), thus connecting multiple market sides to foster innovation and/or facilitate transactions (Cusumano, 2002; Jacobides et al., 2018). Based on platforms, firms can develop platform-based business models (PBMs). A growing number of digital natives, telecommunication firms, start-ups but also machine manufacturers, have begun to develop IIoT platforms, such as Microsoft Azure IoT, Cisco IoT or Siemens Mindsphere platform. However, many firms and especially the traditional industry players are struggling to develop IIoT PBMs since economic expectations are not met. Main challenges for firms are to take strategic decisions to achieve a sufficient user base for network effects, but also to solve the chicken-and-egg problem by bringing both users and complementors onto the platforms and to make strategic decisions about the openness of the platform.

These challenges regarding the design of PBMs have mainly been discussed in digital consumer markets e.g., in the online gaming industry (Cusumano et al., 2020; Hagiu, 2014; Rietveld & Schilling, 2021). However, PBMs in an industrial environment differ from those usually found in the business-to-consumer sector. IIoT platforms in industrial manufacturing are characterized by asset- and process-specific investments, which is in stark contrast to platforms in business-to-consumer settings. This negatively impacts the absolute number of end-users and potential scalability of the platform, which in turn reduces the strength of network effects (Cennamo & Santalo, 2013; Parker & Van Alstyne, 2005; Zhu & Iansiti, 2019). As a consequence, while there are winner-take-all situations in business-to-consumer environments, they do not yet exist in the industrial environment. Further, IIoT is characterized by a complex multi-layered architecture consisting of a device, network, service, and content layer (Yoo et al., 2010). Complementors can be on different layers such as industrial machine

URI: https://hdl.handle.net/10125/107131
978-0-9981331-7-1

manufacturers at the device layer, or application developer at the content layer. In industrial settings those complementors may work in legacy structures with existing relationships and supply chains, which impact the heterogeneity of complementors and influences the decision of which complementors can be used for the common value proposition. In addition those legacy structures, also limit the options in terms of openness decisions since open interfaces and shared resources are vulnerable to strategic exploitation from competitors (Baldwin, 2015). As the environment and requirements for IIOT PBM are different, the criteria and strategies for business-to-consumer PBM cannot simply be transferred. As a result, companies have an increased risk to invest, which creates a high uncertainty of failure. Against this background, we ask the following research question: *What patterns exist for the design of PBM in the IIoT environment and how are main challenges addressed?*

To answer our research question, we use a two-step mixed-methods approach. In the first step, we combine a literature review analyzing 400 academic papers based on Webster and Watson (Webster & Watson, 2002) with qualitative research involving 21 expert interviews and the study of 45 real-world use cases to develop a taxonomy for IIoT PBMs using the iterative process described by Nickerson et al. (2013). In a second step we conduct a quantitative agglomerative hierarchical clustering analysis using Ward's algorithm and the Manhattan distance function based on the 45 real-world IIoT PBMs and our taxonomy to identify five typical archetypes. Finally, we discuss how main challenges are addressed differently by these archetypes.

Our research aims to advance the understanding of PBMs in industrial business-to-business settings. To achieve this, we have developed a comprehensive approach that integrates various elements. Firstly, we have created a taxonomy to categorize and analyze the development of IIoT PBMs in these settings. This taxonomy allows us to identify different types of IIoT platforms and their corresponding business model design characteristics. We can provide a more nuanced understanding of platform configurations and their specific innovation and hybrid manifestations. Next, based on our identified archetypes we derive conclusions about how challenges such as finding a suitable user base or solving the chicken-and-egg problem are addressed in an industrial environment. This enables us to explore and identify the different combinations that are possible within an IIoT environment. Importantly, our approach facilitates strategic decision-making for both new and existing platforms. Firms can leverage our taxonomy and archetypes to inform the design of new IIoT PBMs, ensuring they consider critical factors for success. Existing platform providers can also revisit and validate their strategic decisions regarding IIoT PBM characteristics, ensuring alignment with their goals and the market demands. Ultimately, our comprehensive approach enables end-users and complementors to systematically compare and evaluate different IIoT PBMs. This process empowers stakeholders to make informed decisions and select the most suitable platform that aligns with their specific needs and objectives.

2. Theoretical Background

Platforms connect multiple sides of the market to foster innovation and/or facilitate transactions (Cusumano, 2002; Jacobides et al., 2018). Cusumano et al. (2019) differentiate between transaction and innovation platforms. As an Innovation platform, the platform offers a core technological infrastructure and enables independent but interdependent firms or complementors to co-create value by developing complementary technologies, products, or services (Adner, 2017; Autio & Thomas, 2016; Jacobides et al., 2018). Complementary means that these innovations extend the platform core offering by bringing additional functions to the platform (Cennamo, 2021; Cusumano et al., 2020; Teece, 1986). A Transaction platform acts as an intermediary facilitating exchange or transactions between different actors (Cennamo, 2021; Constantinides et al., 2018). This enables participants to exchange goods, services or information, which would not have been possible without the platform as an intermediary (Cennamo, 2021; Cusumano et al., 2020). The combination of both platform types is called hybrid. The design of those platform types is based on the assumptions of the underlying business model. Platform types differ in the assumptions of the business model characteristics and can also differ within a type. A business model can be broken down into four elements: Value Proposition, Value Architecture, Value Network and Value Capture, where the configuration of these elements describes how a company creates and captures value (Al-Debei & Avison, 2010). The design and interaction of these elements results in a PBM.

The "Value Proposition" describes the logic of creating value with the platform that are offered to all involved actors, such as end-users and complementors. Platforms rely on network effects. Direct network effects indicate how the number of actors on one site can affect the value of the platform (Cennamo & Santalo, 2013; Katz & Shapiro, 1986) and in the case of indirect network effects, the value of the platform increases due to a greater variety of complementary products or services (Parker & Van Alstyne, 2005; Rochet & Tirole, 2003). When companies define their value proposition, i.e. the value logic and platform scope, they need to take these network effects into account.

A key element for designing the "Value Architecture" - the technical concept - is openness. Openness refers to the reduction or elimination of restrictions to participate and collaborate (Eisenmann et al., 2009; West, 2003). The decision to determine the optimal degree of openness is crucial for firms creating platforms (Boudreau, 2010; Eisenmann et al., 2009; Gawer & Henderson, 2007; West, 2003). The platform provider must balance between growth and appropriation (West, 2003). Opening a platform fosters its growth due to network effects and enables new value propositions (Eisenmann et al., 2009; Farrell & Klemperer, 2007). Openness in general contributes to value creation by enabling the integration of third-party innovations (Boudreau, 2010; Gawer, 2014). However, open interfaces of the platforms also boost competition since the platform's own resources are made available to others and open interfaces can also be potential entry points for the competition (Baldwin, 2015).

A platform provider must coordinate the "Value Network" of all actors. For this coordination the governance of the platform needs to be clarified, which can be defined as who decides what regarding the platform and can be viewed from three different facets: platform ownership, incentives and control measures (Constantinides et al., 2018; Tiwana et al., 2010). A central factor for platform governance is ownership of the platform. (Tiwana et al., 2010). The literature distinguishes between different ownership models, depending on the degree of centralization of power (Hein et al., 2020). Platforms need to find an optimal balance between control and generativity when designing platform governance. Generativity is the ability to promote complementary innovation "through unfiltered contributions from broad and varied audiences" (Zittrain, 2008). Mechanisms need to be implemented to constrain complementary behavior, but without constraining generativity too much (Wareham et al., 2014). Furthermore, the type of complementary products is important for the design of the "Value Network". A distinction can be made between generic and specialized complementary products (Teece, 1986). The platform must resolve the trade-off between attracting users through innovation and specialization and attracting users through with a high number of generic complementary products (Panico & Cennamo, 2019; Rietveld & Eggers, 2016).

The platform's pricing strategies include the question of which actors and which revenue model is used to capture value (Dushnitsky et al., 2022). Platforms can generate revenue by charging participants e.g., users or complementors (Wortmann et al., 2022) and they can boost their revenue through monetization tactics (Wortmann et al., 2022).

3. Method

3.1. Step 1: Developing a taxonomy for IIoT PBMs

We first develop a taxonomy for IIoT PBMs using the iterative process of Nickerson et al. (2013). We start by defining meta-characteristics using the business model structure of Al-Debei and Avison (Al-Debei & Avison, 2010) which includes the categories of Value Proposition, Value Architecture, Value Network and Value Capture. The taxonomy development process ends when all ending criteria are met, which we define as per Nickerson et al. (2013).

Our first iteration is conceptual-to-empirical, using a systematic literature review on PBMs based on Webster and Watson (Webster & Watson, 2002). In Web of Science we identify around 400 academic paper with a Boolean search query. We use a manual screening process in a three-step approach, that starts by reviewing only the titles, then the abstracts and eventually the full articles. We finally narrow down the list of publications to 70 relevant ones (a full bibliography can be provided on request), from which we identify 19 design elements and 82 characteristics for our taxonomy.

For the identification of IIoT PBMs needed for the second iteration – an empirical-to-conceptual approach – we use the market research company IoT ONE (IoTOne, 2023). The IoT ONE knowledge database currently include over 3000 firms offering products and services in the IoT ecosystem. To narrow the list down, we filter the database by companies offering platforms as a service for the manufacturing industry. The result are 145 firms. To have a representative sample, we select 45 examples ensuring that the dataset is balanced in terms of firm size. In the second iteration we examine 30 IIoT PBMs and update our taxonomy with the following three new design elements: *Main focus of use case*, *Platform integration* and *Data privacy and security*. Since multiple ending conditions of the taxonomy development are not met after the first iteration, another iteration was necessary.

The third iteration, also empirical-to-conceptual, involves conducting 21 expert interviews with firms' representatives offering IIoT platform solutions at the "Hannover Messe 2023". We select the interviewees based on their expertise in IIoT platforms. Our experts offer insights from different areas and sectors to counteract possible biases. In the interviews with an average length of about 20 minutes, we discuss the results based on the second iteration development of the taxonomy. In the interviews, we identify that new design elements and characteristics need to be introduced.

In the fourth iteration, we evaluate our taxonomy with the remaining 15 IIoT PBMs which we identified in the second iteration. Since no other elements or characteristics were added or changed during this iteration, according to Nickerson et al. (2013), the subjective and objective end conditions of the taxonomy development are fulfilled. The final taxonomy includes 23 design elements and 94 characteristics (see Figure 1).

3.2. Step 2: Deriving archetypes for IIoT PBMs

We use our developed taxonomy to develop different archetypes and identify typical combinations of IIoT PBM characteristics using real-world examples (Arnold et al., 2022; Gimpel et al., 2018). We classify our 45 IIoT use cases from the taxonomy development process based on public information from platform websites. For the clustering of our IIoT real-world examples we apply cluster analysis which is a statistical method for grouping objects that are similar based on their characteristics (Hair et al., 2010). We use hierarchical clustering with Ward's agglomerative algorithm. The algorithm aims to find clusters with high variance between clusters and low heterogeneity within clusters. For the distance measure we apply the Manhattan distance function (Arnold et al., 2022; Gimpel et al., 2018). For the statistical analysis we dichotomize our IIoT taxonomy, that every characteristic is presented by a separate column and displays the value 1 when the IIoT PBM provide the respective characteristics and 0 if not. There is no clear approach in the literature for determining the number of clusters (Gimpel et al., 2018; Wu, 2012). We calculate the Calínski and Harabasz pseudo-F index as well as the Duda and Hart Je(2)/Je(1) index, which propose the use between 2 and 6 cluster, respectively (Calinski & Harabasz, 1974; Duda & Hart, 2006). For visual interpretation and better interpretability, we use a dendrogram. Based on the statistical results, the dendrogram, and the applicability to our real-world examples, we choose 5 as the optimal number of clusters.

4. Results

4.1. Developing a taxonomy for IIoT PBMs

Our IIoT PBM taxonomy consists of 23 design elements (see Figure 1). The elements are structured along our four meta-characteristics.

Value Proposition. Firms can offer a range of *Core platform features* which include hardware for device and network layer, software for connectivity or a marketplace, cloud infrastructure, analytics, and applications. If the platform provides marketplace software and analytic capabilities, it must be defined what kind of *Marketplace* is used and what *Analytics* is provided (Porter & Heppelmann, 2015). An important strategic design factor for the value proposition is which markets and customer groups the platform provider serves through its functionalities (Cennamo, 2021; Eisenmann et al., 2011). Firms can choose different strategies to attract users to the platform. For example, platforms can either target a specific niche or a broader, predominant market (Cennamo, 2021; Khanagha et al., 2022). The *Customer* for an IIoT platform can be end-users (B2B) who directly use the platforms features (e.g., Manufacturing firm) or they can be third-party service providers (B2B2B) offering their services to end-users through the platform (e.g., OEM machine manufacturer). Firms must also define their *Focus of their use cases*, which can be to increase efficiency, reduce cost, improve quality, promote sustainability, increase resilience or enable strategic differentiation through new business models. Further, it is important for the IIoT PBM to define the *Market positioning*. It may target only specific *Industries*, have a *Geographic*

Meta-Characteristics		Design elements	Characteristics of design elements							
Value Prop.	Value Logic	Core platform features	Device Layer Hardware (16%)	Network Layer Hardware (40%)	Software connect-ivity (98%)	Software market-place (38%)	Cloud Infra-structure (29%)	Analytics (73%)	Apps (44%)	
		Marketplace	None (60%)	Application Marketplace (40%)	Data Marketplace (11%)	Services Marketplace (20%)				
		Analytics	None (27%)	Descriptive (73%)	Predictive (56%)	Prescriptive (31%)				
	Platform Scope	Customer	B2B (96%)	B2B2B (76%)						
		Focus of use cases	Efficiency (82%)	Cost (62%)	Quality (33%)	Sust-ainability (24%)	Resilience (27%)	Strategic differentiation (29%)		
		Market positioning	Focus on Manufacturing (33%)	Focus on further functions in value chain (67%)						
		Industry Focus	Single vertical industry (7%)	Multiple vertical industries (93%)						
		Geographic Focus	National (24%)	International (76%)						
Value Arch.	Device Layer	Machine device openness	Open (93%)	Selected suppliers (7%)	Proprietary (0%)					
	Network Layer	Network device openness	Open (51%)	Gatekeeping (13%)	Selected suppliers (11%)	Proprietary (24%)				
	Platform Layer	Platform Source Code	Open Source (4%)	Open Components (38%)	Closed Source (58%)					
		Cloud	Open (47%)	Selected provider (36%)	Proprietary (18%)					
		Platform integration	Vertical (40%)	Horizontal (20%)	End-to-end (40%)					
	Content Layer	Applications development (AD) openness	No AD (40%)	Open (4%)	Gatekeeping (36%)	Selected suppliers (4%)	Proprietary (16%)			
	Privacy and security	Data privacy and security	Standard (67%)	Advanced (33%)						
Value Netw.	Gov-ernance	Platform Ownership	Centralized platform (93%)	Consortia (4%)	Decentralized platform (2%)					
		Incentive mechanisms	None (9%)	SDKs & Standards (49%)	Support (84%)	Forum (49%)	Training / (82%)	Events (47%)	Certification (36%)	Rewards (financial 4%, non-financial 51%)
		Output control mechanisms	None (60%)	Certification of complementor solutions (40%)	Reviews (13%)					
	Actors	Generic complementors (CP)	Hardware CP at device layer (96%)	Hardware CP at network layer (76%)	Cloud Infrastructure CP (89%)	Application CP (82%)				
		Specific complementors (CP)	None (11%)	Service CP (60%)	Solution Provider CP (73%)	Software (code) CP (40%)	Application CP (49%)	Data CP (11%)		
Value Capt.	Revenue Model	End-User	None (2%)	Pay per use (57%)	Subscription (53%)	Pay-once (9%)				
		Application Complementor	None (53%)	Revenue sharing (24%)	Pay per use (9%)	Subscription (13%)	Pay-once (2%)	Individual (16%)		
		Monetization tactics	None (36%)	Freemium (9%)	Free trial (56%)	Add-On (4%)	Discounts (7%)			

Figure 1. Taxonomy for IIoT PBMs.

focus (Cennamo, 2021) or bundle their functionalities to expand into multiple markets.

Value Architecture. A platform in the IIoT environment can be opened at the different layers defined by Yoo et al. (2010), i.e. the device, network, service and content layer. The *Machine openness* of an IIoT platform can range from being open for any machines, enabling an integration with machines from various manufacturers, to being limited to machines from selected suppliers or proprietary machines from the platform provider. At the network layer the *Network device openness* of an IIoT platform can vary from being open for any network device, to gatekeeping mechanisms for network device access, to limiting connectivity to selected suppliers' devices, or to the platform provider's own devices. At the service layer platform providers need to decide how much they open their *Platform Source Code*. Also at the service layer IIoT platforms can either be open to any *Cloud* provider, use the cloud infrastructure from selected providers, or have a proprietary cloud owned by the platform provider. Lastly, firms need to define their *External Applications development openness*. IIoT platforms can be designed to have no application development capabilities, be open to any application development, have a gatekeeping mechanism for application development access, restrict application development to selected partners, or own applications on their own platform. Beside of the openness, *Platform integration* is another element for the value architecture. IIoT platforms can be integrated into the end user's IT system vertically, horizontally, or end-to-end. Vertical integrated platforms route data directly from the industrial machines to the platform. When a platform is horizontally integrated, it integrates data from different horizontal IT-Systems or other platforms. When a platform is both vertically and horizontally integrated, it is characterized as an end-to-end integration. As a last component of the value architecture, IIoT platforms can use basic or advanced *Data privacy and security* methods such as blockchain, or when the platform provides detection of potential threats.

Value Network. Platform provider must create *Incentives* for cooperation between complementors without transferring specific property rights (Chen et al., 2022). This can be achieved through sharing of resources (e.g., Software Development Kits), provision of information to complementors (e.g., communication canals or community events) or by giving rewards (e.g., certification or featuring of complementors). Platform providers can use *Control measures* to influence the behavior of complementors (e.g., screening and certifications of solutions or reviews) (Chen et al., 2022). They can collaborate with complementors on the different layers offering *generic* and *specific* solutions for the platform.

Value Capture. Firms also need to consider how they can capture value. One option is to charge a subscription fee, which actors e.g., users or complementors need to pay to participate in or use the platform (Caillaud & Jullien, 2003; Evans, 2003). Another access-based option is a one-time payment, e.g., by purchasing a license (Wortmann et al., 2022). The platform revenue model can also be transaction-based, in which a transaction fee is applied to actors when they use the platform for transactions (Parker & Van Alstyne, 2005). *Monetization tactics* can also be used such as freemium, free trials, add-ons, and discounts (Wortmann et al., 2022).

4.2. Deriving archetypes for IIoT PBMs

We first derive overall observations on IIoT PBMs considering all 45 use cases (see Figure 1 - the number in brackets indicates the share of PBMs supporting this characteristics). Overall, almost all IIoT PBMs offer software for connectivity (98%) and analytic capabilities (73%). The majority do not offer a marketplace and only 11% provide a data marketplace. Whereas 73% of the examples have descriptive and predictive (56%) analytic capabilities, only 31% offer prescriptive capabilities. The focus of their use cases is on increasing efficiency (82%) and reducing costs (62%), with the majority of the IIoT PBMs also targeting other functions than manufacturing in the value chain (67%). They are mainly designed for multiple vertical industries (93%) with an international geographic focus (76%). The architecture of the platforms is characterized by machine openness (93%), network device openness (51%) and cloud openness (47%). There is also a mix of open-source code components (38%) and closed source code (58%). 40% of IIoT platforms are vertical and 40% are end-to-end integrated. 40% of the use cases do not offer external application development and otherwise there are gatekeeping conditions for access (36%). Data privacy and security is ensured by standard protocols (67%) or advanced measures (33%). Governance is centralized (93%). Incentive mechanisms for almost all platforms include technical support (84%) and training (82%). Only 4% of the use cases offer financial rewards. Output control mechanisms are primarily in the form of certifications of complementor solutions (40%). Generic complementors include hardware complementors at the device and network layer (96% and 76%, respectively), cloud infrastructure (89%) and application complementors (82%), while specific complementors include service and solution provider complementors (60% and 73%, respectively). 49% of the examples offer specific applications and only 11% partner with data complementors. Revenue models for users are pay-per-use (57%) or subscription-based (53%), while revenue models for applications complementors are mainly revenue-sharing (24%) or individual (16%). Monetization tactics include primarily free trial (56%).

Using a cluster analysis, we identify five archetypes (see Figure 2 for details) that show typical combinations of characteristics for the different design elements.

Archetype 1 – Data Connector with Application development. Our first archetype of IIoT PBMs is characterized by its focus on connectivity. These platforms provide a marketplace for applications, some of which offer additional data marketplace capabilities. However, they often do not include analytic capabilities. They are designed for both international B2B and B2B2B customers, with a focus on efficiency, sustainability, and resilience in their use cases along the entire value chain in different industries. The value architecture of these IIoT PBMs is open to any machines and network devices and is based on closed source code with standard security measures. Platforms are open to any cloud provider and are either horizontally or vertically integrated. In addition, there are gatekeeping mechanisms for external application development. Platforms of this archetype are centralized with a single owner. Incentives include SDKs, technical support, forums, training, and tutorials, and output control mechanisms include certification of complementary solutions. Through their openness decisions, platform providers of this archetype 1 try to attract specific as well as generic complementors to overcome chicken-and-egg problems. The value network consists of all generic complementors and service, solution provider and application complementors offering specific complementary products or services. The IIoT PBM offer predominantly pay-per-use for users and revenue sharing, as well as individual pricing settings for application providers. There is no dominant monetization tactic, although some firms offer free trials. In summary, this archetype of IIoT PBM is designed to either connect vertical machines, on the basis of which applications can then be developed e.g., Thinger.IO, or to connect enterprise data horizontally, which then could be shared with other firms, for example Catena-X.

Archetype 2 – Vertical IIoT Connector. The second archetype focuses on hardware and software for connectivity and some platforms provide additional cloud infrastructure. Unlike others, this archetype does not have a marketplace for applications, but provides descriptive analytics. The primary focus of the platform is on efficiency and cost, and it serves B2B and B2B2B customers in a variety of industries with either a domestic or international focus. This archetype of IIoT PBMs is designed to connect any machines with proprietary network devices, which limits the scalability of end-users. Also any cloud provider can be selected. The value architecture is vertically integrated, and there is no external application development. Platforms provide standard security measures, with closed source code or partially some platforms have open software components. Platforms of this archetype are centralized with one owner. Incentives include technical support and training for users, with no mechanisms to control output. The value network consists of generic complementors, such as hardware complementors at the device level and application complementors, as well as cloud infrastructure complementors. However, there are only a few specific complementors, such as solution providers and software complementors. The IIoT PBM offers users usage-based pricing, with free trial options available. Examples of this archetype are Telenor IIoT or Telit DeviceWise, which connect machines with integrated hardware to the IIoT platform.

Archetype 3 – End-to-end IIoT Enabler. The third archetype of IIoT PBMs is characterized by its focus on software for connectivity, analytics, and applications. They do not have a marketplace for applications, but instead provide descriptive and predictive analytic capabilities. Firms have made the strategic decision to provide as much functionality as possible to end users themselves to overcome the chicken-and-egg problem. The main use cases focuses on efficiency, cost, and quality, with B2B and B2B2B customers across multiple industries with a focus on manufacturing and international geographies. The platform is designed to be end-to-end integrated, with a value architecture that is open to any machine or network device, resulting in a large heterogeneous user base for network effects. Their source code is closed and there are standard security measures. The cloud provider is selected by the platform provider, and there is no external application development. Platforms of this archetype are centralized with one owner, and incentives include technical support and training for users. There are no output control mechanism, and the value network consists of all generic complementors, with only solution providers as specific complementors. The IIoT PBMs primarily use subscription-based pricing methods for users, with no monetization tactics. Examples of IIoT PBMs in this archetype include COPA-DATA or BaseN.

Archetype 4 – Representation IIoT Platform. The

		Archetype 1: Data Connector with Application (n=9)	Archetype 2: Vertical IIoT Connector (n=12)	Archetype 3: End-to-end IIoT enabler (n=11)	Archetype 4: Representation IIoT platform (n=4)	Archetype 5: Advanced IIoT analytics platform (n=9)
Value Prop.	**Core platform features**	Software for Connectivity (89%), Software for marketplace (56%)	Hardware for network layer (67%), Software for Connectivity (100%), Cloud Infrastructure (42%), Analytics (50%)	Software for Connectivity (100%), Analytics (100%), Apps (55%)	Hardware for device layer (100%) and network layer (100%), Software for Connectivity (100%) and marketplace (100%), Analytics (100%), Apps (75%)	Software for Connectivity (100%), Software for marketplace (89%), Cloud Infrastructure (56%), Analytics (100%), Apps (89%)
	Marketplace	Application Marketplace (67%)	None (100%)	None (100%)	Application Marketplace (100%), Service Marketplace (50%)	Application Marketplace (89%), Service Marketplace (56%)
	Analytics	None (67%)	None (50%), Descriptive (50%)	Descriptive (100%), Predictive (91%)	Descriptive (100%), Predictive (75%), Prescriptive (50%)	Descriptive (100%), Predictive (100%), Prescriptive (100%)
	Customer	B2B (89%), B2B2B (78%)	B2B (92%), B2B2B (67%)	B2B (100%), B2B2B (82%)	B2B (100%), B2B2B (75%)	B2B (100%), B2B2B (78%)
	Focus of use cases	Efficiency (56%), Sustainability (44%), Resilience (44%)	Efficiency (83%), Cost (67%)	Efficiency (100%), Cost (100%), Quality (55%)	Efficiency (75%), Quality (50%), Sustainability (50%), Resilience (50%)	Efficiency (89%), Cost (67%), Strategic differentiation (67%)
	Market positioning	Focus on further functions in value chain (89%)	Focus on further functions in value chain (75%)	Focus on Manufacturing (73%)	Focus on Manufacturing (50%)	Focus on further functions in value chain (89%)
	Industry Focus	Multiple vertical industries (78%)	Multiple vertical industries (100%)	Multiple vertical industries (91%)	Multiple vertical industries (100%)	Multiple vertical industries (100%)
	Geographic Focus	International (56%) National (44%)	International (58%) National (42%)	International (82%)	International (100%)	International (100%)
Value Arch.	**Machine device openness**	Open for any machines (100%)	Open for any machines (100%)	Open for any machines (82%)	Open for any machines (75%)	Open for any machines (100%)
	Network device openness	Open for any device (78%)	Network device is proprietary (58%)	Open for any device (64%)	Network device is proprietary (75%)	Open for any device (67%)
	Platform Source Code	Closed source (56%) Open components (33%)	Closed source (50%) Open components (42%)	Closed source (91%)	Closed source (50%) Open components (50%)	Open components (67%) Closed source (33%)
	Cloud	Open (78%)	Open (58%)	Cloud provider selected (55%)	Cloud provider selected (75%)	Cloud is proprietary (44%) Cloud provider selected (33%)
	Platform integration	Horizontal (44%) Vertical (33%)	Vertical (83%)	End-to-end (55%) Vertical (36%)	End-to-end (75%)	End-to-end (67%) Horizontal (33%)
	Applications development (AD) openness	Gatekeeping (67%)	No AD (92%)	No AD (45%) AD is proprietary (45%)	Open for any AD (25%) Gatekeeping (25%) AD for selected supplier (25%)	Gatekeeping (100%)
	Data privacy and security	Standard (78%)	Standard (92%)	Standard (82%)	Advanced (75%)	Advanced (78%)
Value Netw.	**Platform Ownership**	Centralized (78%)	Centralized (100%)	Centralized (91%)	Centralized (100%)	Centralized (100%)
	Incentive mechanisms	SDKs (78%), Support (100%), Forum (56%), Trainings (89%)	Support (75%), Trainings (83%)	Support (64%), Trainings (55%)	SDKs (75%), Support (100%), Forum (75%), Trainings (100%), Events (100%), Certification (75%), Featuring (100%)	SDKs (75%), Support (100%), Forum (100%), Trainings (100%), Events (100%), Certification (56%), Featuring (100%)
	Output control mechanisms	Certifications of complementor solutions (67%)	None (92%)	None (91%)	None (75%)	Certifications of complementor solutions (100%), Reviews (67%)
	Generic complementors (CP)	Hardware CP on device layer (100%) and on network layer (100%), Application CP (89%), Cloud Infrastructure CP (89%)	Hardware CP on device layer (100%), Application CP (92%), Cloud Infrastructure CP (100%)	Hardware CP on device layer (82%) and on network layer (91%), Application CP (73%), Cloud Infrastructure CP (64%)	Hardware CP on device layer (100%), Application CP (100%), Cloud Infrastructure CP (100%)	Hardware CP on device layer (100%) and on network layer (100%), Application CP (67%), Cloud Infrastructure CP (100%)
	Specific complementors (CP)	Service CP (67%), Solution Provider (67%), Application CP (89%)	Solution Provider (58%), Software CP (50%)	Solution Provider (73%)	Service CP (100%), Solution Provider (75%), Software CP (50%), App. CP (75%)	Service CP (100%), Solution Provider (100%), Software CP (67%), App. CP (100%)
Value Capt.	**End-User**	Pay per use (56%), Subscription (44%)	Pay per use (58%)	Subscription (73%)	Subscription (100%)	Pay per use (67%), Subscription (44%)
	Application Complementor	Revenue sharing (33%) Individual (33%)	None (92%)	None (82%)	Revenue sharing (75%) Subscription (50%)	Revenue sharing (56%)
	Monetization tactics	None (44%), Free trial (44%)	None (42%), Free trial (42%)	None (64%)	Free trial (75%), Discounts (59%)	Free trial (100%)

Figure 2. Five IIoT archetypes.

fourth archetype offers both hardware for the device as well as for the network layer, software solutions for connectivity, analytics and applications, and often has a marketplace for applications and services. The primary focus of its use cases is efficiency, and they serve B2B and B2B2B customers in a variety of industries, with a focus on manufacturing and other functions along the value chain. The value architecture of these IIoT PBMs is open to all machines, while network devices are proprietary, which in turn makes it difficult to scale end-users. The platforms provide closed source code with open components and the cloud provider is chosen by the platforms. They are end-to-end integrated and offer various types of external application development with advanced security measures. These platforms are centralized with a single owner, and incentives include all types of incentives except financial rewards. The value network consists of generic complementors including device-level hardware complementors, application complementors, and cloud infrastructure complementors and beside of data complementor all types of specific complementors are included. The archetype tries to solve the chicken-and-egg problem by providing as many core functions as possible and by providing specific complementary products and services. The IIoT PBMs offer a subscription pricing model and tree trials for users, with revenue sharing and subscription models for application complementors. Examples of this archetype are Schneider Ecostruxure or ABB Ability Genix.

Archetype 5 – Advanced IIoT Analytics Platform. Core functionalities of this archetype are software for connectivity, analytics and applications, and a marketplace for applications and services. Some of the platforms also offer the required cloud infrastructure. The archetype is characterized by advanced prescriptive analytic capabilities. The primary focus of the use cases is efficiency, cost, and strategic differentiation. The platforms serve B2B and B2B2B customers from various industries and have an international customer focus. The value architecture of these IIoT PBMs is designed to be open to all machines and network devices, with open-source components, end-to-end integration, and advanced security measures. The cloud provider is in most of the case proprietary and there is a gatekeeping mechanism for external application development. IIoT PBMs of this archetype are centralized with one owner and they address the chicken-and-egg problem by being open at all levels, resulting in a high number of generic and specific complementors. They offer all types of incentives, whereas only few IIoT PBMs offer financial rewards. Output control measures are certification of complementor solutions and reviews. Pay per use is the most common pricing method for users, with revenue sharing and custom pricing settings for application complementors. Some firms use free trials as a monetization tactic. Examples of this archetype are Software AG Cumulocity or Amazon Web Services IoT.

5. Discussion

Our results allow us to draw conclusions on how main challenges, namely finding a suitable user base and solving the chicken-and-egg problem in an industrial setting are approached by our archetypes (Hagiu, 2014). To find the appropriate user base for network effects, it is important to understand end-users. Industrial firms are undergoing a digital transformation and need different platforms with a differentiated scope depending on their progress. Adner et al. (2019) describe the shift from non-digital products to a global cyber-physical network with three core processes – representation, connectivity, and aggregation. The first step towards digital transformation is the digital representation of manufacturing firms' legacy products, which for most firms is complete, as a large number of industrial machines are capable of capturing data. Once industrial products are digitally represented, they can be connected in the second step. The connected data can then be aggregated in a third step. Thus, IIoT platforms focuses on the connectivity and the aggregation processes, whereby the archetypes can be differentiated in terms of the type of connectivity and the intensity of aggregation. Both connectivity and aggregation affect the user base and thus network effects. Archetypes 3, 4 and 5 provide end-to-end connectivity, allowing for a larger and more heterogeneous user base, leading to more network effects. The vertical or horizontal connectivity provided by Archetypes 1 or 2 target a more specific user base instead. Also, offering a greater intensity of aggregation like archetypes 4 and 5 leads to a larger and heterogeneous user base and thus more network effects.

Another challenge for IIoT PBM building is that complementary innovations are promoted on the platform, which is called generativity to address the chicken-and-egg problem. We find that there are different level of generativity among the archetypes, which are shaped by openness decisions. Archetypes 2 and 3 are based on innovation platforms, however the generativity of archetypes 2 and 3 is relatively low, as only solution providers offer specific complementary offerings or, in the case of archetype 3, additional software complementors contribute to the value proposition. Archetype 2 IIoT PBMs target specific end-user needs, so they do not need as much generativity, and in the case of archetype 3, they have made the strategic decision to offer as much functionality themselves to balance generativity. On the other hand, archetypes 1, 4 and 5 are highly based on generative platforms resulting from partially open external application development that adds specific complementary applications to the platform. Besides, all archetypes collaborate additionally with solution and service complementors that contribute to a higher generativity of the platform. Since the source code of archetype 5 is partially open, software complementors also adding specific services. Archetypes 1, 4 and 5 are based on hybrid platforms that combine innovation platforms with transactional functionalities by providing a marketplace (Gawer, 2021). Figure 3 shows the differences between our archetypes in their strategic response to main challenges.

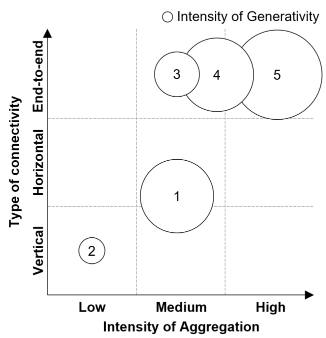

Figure 3. Strategic response of IIoT archetypes

During the detailed examination of the archetypes, we came across a number of specialities in terms of their capabilities and resources. Archetype 1 providers are young digital firms, often operating IIoT platforms as part of a single-product strategy and focusing therefore on either a vertical or horizontal connectivity, low to medium intensity of aggregation, but with the digital capabilities to drive high generativity. Platform providers of archetype 2 are often medium-sized hardware manufacturers from the telecommunications sector that can leverage their existing user base for network effects. Thus, due to their capabilities and with low investment, they focus on vertical connection and low intensity of aggregation. They follow a bottom-up strategy by expanding their existing hardware offerings with an IIoT platform. Archetype 3 providers tend to be young and small-to-medium sized companies by revenue, so their resources and capabilities are limited. As a result, they often follow a single product strategy and have made a strategic decision to provide end-to-end connectivity and a medium level of aggregation intensity by offering predictive analytic capabilities and own applications. Firms offering archetype 4 IIoT PBMs are rather old and from the machine building industry pursuing a bottom-up strategy by expanding their existing hardware offerings with a hybrid platform. Due to their limited digital capabilities, high investment is needed to get the capabilities for a high intensity of aggregation and generativity. Archetype 5 firms are large by revenue and digital natives, which already offering digital products. Therefore, they have the capabilities and resources to offer a high intensity of aggregation and a high generativity.

6. Conclusion and Outlook

The present article developed a taxonomy for IIoT PBM based on a literature review, real-world examples and interviews. We used our taxonomy to identify five concise archetypes for which we described the characteristics of their IIoT PBM and draw conclusions about how main challenges are addressed differently by these archetypes. We believe that our data set accounts for a sufficient number of examples, but future studies may consider additional IIoT PBMs to validate and update the taxonomy and archetypes. Our taxonomy and archetypes relate to the current as-is situation and can change quickly as IIoT evolves rapidly. Future studies could use our taxonomy to revalidate our archetypes in a few years to see how the IIoT PBMs of the firms have changed and which characteristics are the most successful. Our findings suggest development paths for the identified archetypes. Future studies can investigate whether archetypes have evolved from other archetypes.

Acknowledgement

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy – EXC-2023 Internet of Production – 390621612

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