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Demystifying Industrial Internet of Things start-ups – A multi-layer taxonomy

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Abstract. Described as a fundamental paradigm shift by researchers, the Industrial Internet of Things (IIoT) is credited with massive potential. In the context of emerging technologies, such as the IIoT, start-ups occupy a crucial role, as new technologies are often first commercialized by start-ups. Because of the rising importance of IIoT start-ups as drivers of industrial innovation, IIoT solutions demand deepened theoretical insights. As existing classification schemes in the industrial context do not sufficiently account for the ever more critical role of IIoT start-ups, we present a multi-layer taxonomy of IIoT start-up solutions. Building on state-of-the-art literature and a sample of 78 real-world IIoT start-up solutions, the taxonomy comprises ten dimensions and related characteristics structured along the three layers solution, data, and business model. The taxonomy contributes to the descriptive knowledge on the IIoT and enables researchers and practitioners to better understand IIoT start-up solutions.

Keywords: Industrial Internet of Things, Industry 4.0, Start-up, Solutions, Taxonomy

1 Introduction

Without a doubt, one can state: The Industrial Internet of Things (IIoT) is among the most discussed industrial business concepts in recent years and is seen as a fundamental paradigm shift in industrial production [2, 3]. Experts are already forecasting a market size of USD 110.6 billion for the IIoT in 2025 [5]. The number of connected devices is expected to exceed the magic mark of 50 billion by 2030, highlighting the potential of the technology [6]. The IIoT refers to the extension and use of the Internet of Things (IoT) in manufacturing, enabling industrial systems' interconnection to improve productivity, efficiency, safety, and intelligence [8]. In the context of emerging technologies, such as the IIoT, start-ups occupy a crucial role, as new technologies are often first commercialized by start-ups and, therefore, are drivers for innovation [9]. Because of that, IIoT start-ups are indispensable partners in the digital transformation

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of incumbent industrial companies, as they often supply the innovative IIoT solutions needed.

In this paper, we understand IIoT start-ups as newly established businesses that offer IIoT solutions for the business-to-business (B2B) market. Examining not IIoT specifically, but IoT in general, IoT start-up venture capital saw a 15% year-on-year increase from Q1 2019 to Q1 2020, with a total of USD 4.7 billion [10]. CrunchBase, an investment platform for start-ups, shows a 27% increase in IoT start-ups and related businesses from 26.792 to 34.120 (as of May 2020) in just one year [11]. Within the IoT, the IIoT is attributed with considerable economic potential [12–15]. The impressive numbers of start-ups in the IIoT sector reinforce the need to analyze IIoT start-up solutions in research.

One example of such an IIoT start-up solution is provided by Aspinity, which patented a unique modular processor technology, enabling a system-level solution that overcomes the power challenge for always-on edge processing [16]. Moreover, TeleSense provides remote solutions for grain storage and transportation monitoring [17]. On the one hand, these two examples show that IIoT startups are forerunners in developing and implementing new IIoT solutions. On the other hand, it shows the variety of solutions offered by IIoT startups, ranging from monitoring solutions to more complex processor technology [9].

Despite the increasing relevance of IIoT as a paradigm shifter, little theoretical insights exist about the companies which often first commercialize IIoT solutions, namely start-ups [9]. Existing IIoT classifications focus on topics such as business models [18], platform features [19], and industrial service systems enabled by digital product innovation [7]. Hence, creating a deepened theoretical understanding of IIoT start-up solutions that drive the global manufacturing paradigm shift is useful and valuable. As existing classification schemes in the field of IIoT do not specifically cover the ever more critical role of IIoT start-up solutions, we investigate the following research question:

How can IIoT start-up solutions be classified?

To answer the research question, we propose a multi-layer taxonomy to understand and structure the solutions offered by IIoT start-ups. Following the taxonomy development process by Nickerson et al. [20], we derived ten dimensions and their related characteristics along three layers, analyzing relevant literature and 78 IIoT start-up solutions. Addressing the research question with a multi-layer taxonomy seems promising, as we do not fully understand yet how the solutions of IIoT start-ups can be characterized, what they have in common, and how they differ. Thus, laying a foundation towards a theory for analyzing the emerging field of IIoT start-up solutions holds considerable potential and contributes to the descriptive knowledge of the IIoT [21]. Further, our multi-layer taxonomy provides a foundation for a market overview that could help practitioners analyze the range of solutions offered by IIoT start-ups.

This paper is structured as follows: Section 2 starts with the theoretical foundation, highlighting IIoT and IIoT start-ups on the one hand and relevant taxonomies on the other. In Section 3, we present the research methodology concerning the taxonomy development technique. Section 4 presents our taxonomy of IIoT start-up solutions. In Section 5, we perform the evaluation and application of the taxonomy. We finish in Section 6 with a conclusion and an outlook on future research opportunities.

2 Theoretical Background

2.1 (Industrial) Internet of Things

The term "Internet of Things" was first coined in 1999 to describe uniquely identifiable, interoperable, connected objects using radio frequency identification technology in the supply chain [22]. Oberländer et al. [23] define IoT as "the connectivity of physical objects equipped with sensors and actuators to the Internet via data communication technology" (p. 489). Using these sensors and actuators, it becomes possible to connect the physical world to the Internet [24]. These technology-embedded objects are also called "smart things" [1]. IoT can be categorized into three domains, namely Consumer, Commercial, and Industrial [15]. Consumer IoT addresses the business-to-consumer market and refers to use cases such as smart refrigerators or smart thermostats [1]. Looking at the IoT B2B market, a distinction between Commercial and Industrial IoT can be made [15]. Use-cases such as connected medical devices or inventory controls refer to the Commercial IoT [15]. In contrast, the Industrial IoT connects industrial devices, production facility systems, and manufacturing processes [25, 26].

A widely used definition of the term IIoT is provided by Boyes et al. [27]: "A system comprising networked smart objects, cyber-physical assets, associated generic information technologies and optional cloud or edge computing platforms, which enable real-time, intelligent, and autonomous access, collection, analysis, communications, and exchange of process, product and/or service information, within the industrial environment, so as to optimize overall production value" (pp. 3-4). Thus, IIoT – or Industry 4.0, as it is known in the German-speaking community [25, 28] – refers to the application of IoT in industrial manufacturing and has the potential to improve productivity, efficiency, safety, and intelligence of industrial operations [3, 8, 29]. The improvement is made possible by the interconnection of different industrial systems (machines, control systems, and information systems) and collected data, enabling analytic solutions leading to optimized industrial processes [30].

As IoT and IIoT rise in popularity and importance globally, start-ups actively participate in the IoT and IIoT industry [31]. Start-ups represent fast-growing ventures that serve a need in the marketplace by offering innovative solutions [31, 32]. As indicated above, IIoT holds considerable market potential, also reflected in start-up funding [10]. Since there is no commonly agreed-on definition of IIoT start-ups, we define IIoT start-ups in the context of this paper as a composite of the two terms IIoT and start-up: *IIoT start-ups are newly established businesses that offer IIoT solutions for the B2B market.* An IIoT solution is an integrated offering that can be either a product, a service, or both to create a smart industrial environment that delivers value for the B2B customer [33, 34].

2.2 Related Work Informing the Taxonomy of IIoT Start-up Solutions

Taxonomies help understand and analyze complex domains by grouping objects based on common characteristics and analyzing the relationships between the taxonomy's characteristics [20, 35, 36]. Thereby, the terms for structuring concepts – taxonomy, framework, or typology – are used as synonyms [4, 37]. Taxonomies are especially suitable when little knowledge exists [21]. A taxonomy is excellent for analyzing the multitude of IIoT start-up solutions since IIoT start-ups are an emerging phenomenon and, thus, little theoretical understanding exists. Below, we briefly introduce relevant existing taxonomies for our purpose.

In terms of taxonomy design, we were able to incorporate several things from existing taxonomies. First, a second-level grouping allows for better comprehensibility of a taxonomy; for instance, Gimpel et al. [37] use a second-level grouping to classify FinTech start-ups' service offerings. Second, we learned that some taxonomies include non-exclusive dimensions. For example, Püschel et al. [1] present a taxonomy with non-exclusive dimensions to understand the non-technical characteristics of smart things to tap the full potential of smart things.

Concerning the layers, dimensions, and characteristics of the selected taxonomies, we were able to identify the following aspects. Since most IIoT start-ups consider data a critical resource for their business operation, the taxonomy of Hartmann et al. [38] on data-driven business models of start-ups was particularly relevant in terms of data sources. As IIoT start-ups operate in an industrial context, the taxonomy of industrial service systems by Herterich et al. [7] was suitable, as we could generate further insights about the relevance of data from an industrial perspective. Furthermore, Rizk et al. [39] take a data analytics perspective to classify data-driven digital services, which was helpful because analyzing data is an essential part of IIoT start-up solutions. Paukstadt et al. [4] provide a taxonomy to classify smart services along the three layers service concept, service delivery, and service monetization, focusing on the specific characteristics of smart services. Thereby, smart services are defined as services enabled by smart products [4, 40]. The taxonomy by Paukstadt et al. [4] was especially relevant, as it fosters an understanding of possible descriptions and forms of smart services. Since smart things are also part of the range of solutions provided by IIoT start-ups, relevant dimensions could be obtained from the taxonomy about smart things of Püschel et al. [1]. We used the existing taxonomies as a starting point to develop a new taxonomy, enabling the classification of IIoT start-up solutions.

3 Research Method

To answer our research question and address our target users, such as IIoT researchers and practitioners, we opted for a rigorous method approach already well established in the literature for taxonomies by Nickerson et al. [20]. The iteration-based approach by Nickerson et al. [20] combines qualitative and quantitative research [41]. Thus, it is allowed to use both academic literature and empirical objects to develop layers, dimensions, and characteristics. Furthermore, this iterative approach is widely used to structure complex and emerging fields where little knowledge exists [21, 42].

A taxonomy describes a classification strategy for grouping objects [20]. Before starting with the individual iterations, the meta-characteristic and the corresponding objective and subjective ending conditions have to be set, which serve as the foundation of the taxonomy and describe when the iterative process can be terminated [20]. For each iteration, the conceptual-to-empirical or the empirical-to-conceptual approach can be chosen [20]. In a conceptual-to-empirical iteration, the layers, dimensions, and characteristics are based on the literature or the author's knowledge. In an empirical-to-conceptual approach, a sample of real-world examples gets analyzed. After finishing an iteration, an initial or revised taxonomy is obtained, and the authors must check whether the ending conditions are met. The taxonomy development process continues until the objective and subjective ending conditions are met.

The purpose of our taxonomy is to enable researchers and practitioners to understand and classify the diverse solutions offered by IIoT start-ups. To start the taxonomy development process, we first defined the meta-characteristic of our taxonomy. In line with our research question, our meta-characteristic was *"classification of IIoT start-up solutions offered in the context of B2B"*. Second, we decided on the ending conditions. By choosing from a list of proposed objective ending conditions by Nickerson et al. [20], we came up with the following objective ending conditions: (1) each characteristic is unique within its dimension, (2) each dimension is unique and not repeated within the taxonomy, and (3) at least one object is classified per characteristic and dimension. Further, we chose five subjective ending conditions, which are met if the authors agree that the taxonomy is concise, robust, comprehensive, extendible, and explanatory [20]. Additionally, Nickerson et al. [20] require characteristics to be mutually exclusive. However, it is not possible for some dimensions to restrict the choice of characteristics to be mutually exclusive, as relevant information would be lost. In line with other published taxonomies, e.g., Gimpel et al. [37] and Püschel et al. [1], we allowed non-exclusive dimensions.

Our taxonomy development process comprised four iterations. ***1 Iteration:*** In the first iteration, we opted for the conceptual-to-empirical approach, as IIoT start-up solutions comprise a relatively young and dynamic field of research. We conducted a short literature review to accumulate sufficient information about taxonomies related to IIoT start-ups solutions and adjacent or overlapping research fields (see Section 2.2). In line with the proposed meta-characteristic, we extracted initial dimensions and related characteristics to capture the first distinct features of IIoT start-up solutions. The conceptual-to-empirical approach led to a rudimentary taxonomy and built the foundation for the upcoming iterations. Since the rudimentary taxonomy depicted the taxonomy's characteristics at different granular levels, the subjective ending condition "concise" was not met. Hence, a second iteration was conducted. ***2 Iteration:*** We enhanced and validated our taxonomy's structure by applying the empirical-to-conceptual approach. To find real-world objects, we relied on CrunchBase, which claims to be the primary source of start-up insights listing over one million start-ups [43]. As part of generating a randomized sample from CrunchBase, we used several keywords ("IIoT" AND "Industrial Internet of Things" AND "Industry 4.0") in our search string. This approach led to a representative sample size of 90 randomly drawn IIoT start-ups from a total of 626 hits. However, to guarantee comparability among IIoT start-ups and their respective solutions, we reduced the number of suitable IIoT start-ups according to the following criteria: (1) the CrunchBase website or the IIoT start-up website must provide sufficient information, and (2) the IIoT start-up must comply with our definition of IIoT start-ups: *IIoT start-ups are newly established businesses that offer IIoT solutions for the B2B market.* Therefore, we limited the initial sample to 78

IIoT start-ups, which we included in the taxonomy development process (see Appendix A.1). Throughout the following iterations, we analyzed the sample independently from each other. In the second iteration, we analyzed the first five IIoT start-up solutions from the sample. Given that some dimensions within the revised taxonomy were not unique and, thus, the second objective ending condition was not met, we conducted a third iteration. ***3 Iteration:*** We analyzed a greater variety of solutions in the third iteration by picking ten out of 78 IIoT start-up solutions. Since the revised taxonomy could not comprehensively depict the selected IIoT start-up solutions' features and, thus, the taxonomy's subjective ending condition "comprehensive" was not met, a fourth iteration was conducted. ***4 Iteration:*** In the fourth iteration, we analyzed the remaining 63 IIoT start-up solutions. With minor modifications of the taxonomy, we agreed to have met both the objective and subjective ending conditions and terminated the taxonomy development process.

For the evaluation and application of the taxonomy, we (1) surveyed ten doctoral researchers to calculate hit ratios (*Evaluation*) and (2) generated additional insights about the frequencies of the taxonomy's characteristics by classifying all 78 IIoT start-up solutions to the taxonomy (*Application*). ***Evaluation:*** First, to evaluate the validity of the taxonomy via hit ratios, we surveyed ten doctoral researchers. In the survey, seven IIoT start-up solutions had to be classified into the taxonomy [44]. Selecting seven IIoT start-up solutions for the survey allowed us to cover a broad spectrum of solutions while giving the doctoral researchers enough time to complete the classification. We calculated the agreement within the survey group using dimension-specific and object-specific hit ratios to provide a quantitative value for the validity of the taxonomy [45]. To calculate the agreement for exclusive dimensions, we rated 1 as agreement and 0 as disagreement. As non-exclusive differ from exclusive dimensions, the surveyed authors' agreement was rated differently, using an agreement scale from 0 to 1 [46]. ***Application:*** Second, we applied all 78 IIoT start-up solutions to the taxonomy by calculating frequencies for the taxonomy's characteristics to generate additional insights. By calculating the frequencies, we made distributions within the used sample quantifiable and, thus, easier to recognize patterns and trends.

4 Taxonomy of IIoT Start-up Solutions

This section presents the layers, dimensions, and characteristics of our multi-layer taxonomy of IIoT start-up solutions. As shown in Table 1, our taxonomy encompasses ten dimensions and their related characteristics along the layers solution, data, and business model. Additionally, Table 1 indicates if a dimension is exclusive or non-exclusive. Combining the three layers and ten dimensions with their respective characteristics leads to our multi-layer taxonomy of IIoT start-up solutions, which lays the foundation towards a theory for analyzing, enabling the classification of IIoT start-up solutions [21]. In the following, we present the taxonomy's dimensions and their respective characteristics in detail. Dimensions and characteristics are defined by using justificatory references.

Table 1. Taxonomy of IIoT start-up solutions

	Dimension	Characteristics					
Solution	*Solution focus*	connecting	monitoring	controlling	optimizing	securing	N
	Personalization	not personalized	personalized				E
	Hybridization	product	service				N
Data	*Data source*	none	existing	new			E
	Time horizon	none	current	predictive			E
	Analytics	none	basic	extended			E
Business Model	*Value proposition*	thing-centric	service-centric	platform-centric			E
	Business relationship	short-term	long-term				E
	Business cooperation	stand-alone	third-party integrable				E
	Pricing	single payment	consumption-based	subscription-based			N

E = Exclusive dimension (one characteristic at a time); N = Non-exclusive dimension (potentially multiple characteristics observable at a time)

4.1 Solution Layer

The first layer – Solution – describes the core of IIoT start-up solutions and comprises three dimensions, i.e., solution focus, personalization, and hybridization.

Solution focus – The solution focus dimension differentiates between connecting, monitoring, controlling, optimizing, and securing [4]. Connecting enables the interconnection of formerly isolated industrial devices (e.g., machines, sensors). Monitoring enables the display of information concerning the condition, operation, and external environment or can alert when changes occur, e.g., displaying grain temperature and moisture [17, 47]. Controlling enables the control of industrial devices, e.g., via an app to control the grain temperature and humidity [17, 47]. Optimizing enables the execution of analyses (e.g., predictive analytics of whether and when to lower the grain temperature and moisture) and/or actions (e.g., automatic lowering of grain temperature and moisture) to improve the performance [4, 17, 47]. Securing includes ensuring the data security of industrial assets by protecting them from accidental or unauthorized access, modification, or destruction [48].

Personalization – Personalization describes the customization of IIoT start-up solutions. The possible solution can be either not personalized or personalized. If a solution is not personalized, it is offered in a standardized way without considerable possibilities for individualization. If a solution is personalized, it can be considerably adapted to the client's individual needs [37].

Hybridization – The hybridization dimension refers to the possible combinations of solutions offered by IIoT start-ups [4, 37, 49, 50]. An IIoT start-up can either provide a product (e.g., sale of sensors), a service (e.g., an app for the visualization of already existing data), or a product and service in combination (e.g., sale of sensors in combination with an app for visualization of the sensor data).

4.2 Data Layer

The second layer – Data – focuses on how IIoT start-ups use data to deliver their solution and comprises three dimensions, i.e., data source, time horizon, and analytics. In the context of IIoT start-up solutions, data plays an essential role, as many IIoT start-ups rely on the use of data to provide comprehensive solutions [51].

Data source – The data source dimension differentiates between the origin of the data used to provide the IIoT start-up solution [7, 37, 38]. The data source is described as none if no data source is required for the IIoT start-up solution (e.g., sale of sensors). Existing refers to using existing customer data sources to provide the solution, e.g., already existing sensors or tracking data devices of the customer. New refers to the use of new data sources combined with the deployment of the solution, such as newly installed sensors.

Time horizon – Data's time horizon is divided into none, current, and predictive [37]. The characteristic none defines a situation in which the time horizon of data does not play a role in the solution of IIoT start-ups (e.g., self-charging batteries, which convert ambient energy from the environment into electrical power for wireless sensors [16]). If current data is used, e.g., to measure and display temperature or other current equipment status information, the characteristic is defined as current [7]. Lastly, it is defined as predictive when statistical techniques are used to predict the future [52].

Analytics – If the IIoT start-up solution has no analytical element, analytics is classified as none. Basic analytics refers to descriptive data usage, e.g., capturing a product's or system's condition, environment, and operation [1, 53, 54]. Extended analytics refers to diagnostic, predictive, and prescriptive data usage [1]. Diagnostic analytics allows examining the causes, e.g., of reduced performance or failure [53]. Predictive analytics enables the detection of patterns that signal impending events [53, 54]. Lastly, prescriptive analytics seeks to determine the optimal measures given a set of objectives, requirements, and constraints to improve business performance [54].

4.3 Business Model Layer

The third layer – Business Model – describes the underlying business logic of IIoT start-up solutions [55]. It comprises four dimensions, i.e., value proposition, business relationship, business cooperation, and pricing.

Value proposition – This dimension differentiates between thing-centric, service-centric, and platform-centric [1]. The physical product represents the core element in a thing-centric value proposition and primarily serves a thing-related purpose, possibly supplemented by digital services, e.g., an industrial tablet [1, 56]. Thus, even without supplementary digital services accessible, the industrial tablet can operate its primary function, mobile computing [56]. In a service-centric value proposition, the service represents the core element. Even though a physical underlying is possible, it cannot or hardly be used independently from the service. For example, wrist bands that briefly vibrate to notify wearers that another wrist band is nearby [57]. The primary value of these wrist bands is service-oriented, as the physical underlying has no practical value independently from the digital service [1, 57]. Platform-centric means that the platform provided represents the core element of the value proposition. IIoT platforms try to ease connecting various industrial assets by incorporating these into a digital infrastructure to facilitate data-driven services [19, 58].

Business relationship – A short-term business relationship is classified by a single point of interaction of the B2B customer with the IIoT start-up. A long-term business relationship is characterized by reoccurring direct or indirect contact with the IIoT start-up (e.g., through a subscription).

Business cooperation – This dimension differentiates between stand-alone and third-party integrable [7, 37, 59, 60]. If an IIoT start-up solution is non-integrable with third-party solutions, it is defined as stand-alone. The business cooperation is defined as third-party integrable if the solution is integrable with a third party's service.

Pricing – We used Osterwalder and Pigneur [61] to identify the pricing models of IIoT start-up solutions. A single payment is defined as a one-time payment to receive full ownership rights over an asset. In a consumption-based model, a usage price per unit (e.g., transactions, data volume) is charged for granting the right to use an asset. Lastly, in a subscription-based model, a fixed fee is charged for temporarily granting the exclusive right to use an asset for a defined period regardless of actual usage [4].

5 Evaluation and Application of the Taxonomy

In this section, we want to (1) evaluate the validity of our taxonomy via hit ratios (*Evaluation*) and (2) generate additional insights into the taxonomy by calculating the frequencies of the taxonomy's characteristics (*Application*).

First, we evaluated the taxonomy's validity by calculating the dimension-specific and object-specific hit ratios (Table 2) [62]. The survey group achieved a dimension-specific hit ratio of at least 74% per dimension and an average dimension-specific hit ratio of 83%. Further, all object-specific hit ratios achieved at least 72%, and on average 83%. Dimensions with a high degree of correct placement of objects within them can be considered to have a high degree of construct validity, with a high potential for good reliability scores [62]. As all hit ratios exceed 72% and, thus, have a high degree of correct placement, we can expect a high degree of construct validity and a high potential for good reliability [62].

Table 2. Evaluation (dimension-specific and object-specific hit ratios)

ID	Solution Focus	Personali-zation	Hybridi-zation	Data source	Time horizon	Analytics	Value proposition	Business relationship	Business cooperation	Pricing	Hit ratio[1]
63	74%	70%	100%	90%	100%	78%	80%	80%	100%	90%	86%
45	78%	100%	100%	100%	100%	100%	90%	100%	100%	93%	96%
42	74%	50%	100%	90%	80%	100%	60%	100%	100%	67%	82%
34	78%	80%	100%	50%	80%	50%	70%	90%	70%	67%	73%
44	92%	90%	100%	80%	90%	90%	70%	100%	100%	97%	91%
24	90%	80%	50%	90%	70%	100%	90%	80%	100%	73%	82%
5	72%	50%	70%	70%	70%	60%	70%	90%	80%	87%	72%
Hit ratio[2]	80%	74%	89%	81%	84%	83%	76%	91%	93%	82%	

[1] = Hit ratio start-up (object-specific hit ratio); [2] = Hit ratio dimension (dimension-specific hit ratio)

Second, we generated additional insights about the taxonomy by classifying all 78 IIoT start-up solutions from the sample into the taxonomy, calculating the frequencies of the taxonomy's characteristics (Table 3).

Table 3. Frequencies of the characteristics among the IIoT start-up solutions

	Dimension	Characteristics					
Solution	*Solution focus*	connecting 51 (65%)	monitoring 59 (76%)	controlling 32 (41%)	optimizing 33 (42%)	securing 11 (14%)	N
	Personalization	not personalized 69 (88%)	personalized 9 (12%)				E
	Hybridization	product 46 (59%)	service 68 (87%)				N
Data	*Data source*	none 12 (15%)	existing 43 (55%)	new 23 (30%)			E
	Time horizon	none 12 (15%)	current 48 (62%)	predictive 18 (23%)			E
	Analytics	none 14 (18%)	basic 22 (28%)	extended 42 (54%)			E
Business Model	*Value proposition*	thing-centric 15 (19%)	service-centric 34 (44%)	platform-centric 29 (37%)			E
	Business relationship	short-term 24 (31%)	long-term 54 (69%)				E
	Business cooperation	stand-alone 44 (56%)	third-party integrable 34 (44%)				E
	Pricing	single payment 22 (28%)	consumption-based 1 (1%)	subscription-based 59 (76%)			N

E = Exclusive dimension (one characteristic at a time); N = Non-exclusive dimension (potentially multiple characteristics observable at a time); no brackets = absolute number; ( ) = frequency in %

When analyzing the frequencies in Table 3, additional insights about the taxonomy can be generated: 76% of the classified IIoT start-up solutions offer monitoring as part of their solution. The high frequency of monitoring is in line with the high degree of basic and extended analytics within the sample, as monitoring is a prerequisite to enable analytic services. With regards to personalization, almost all (88%) of the IIoT start-ups exclusively offer not personalized IIoT solutions. The high degree of not personalized IIoT start-up solutions overlaps with our observation, as many applications are specifically designed to accommodate various settings and, thus, have no need for personalization. While only 59% of all IIoT start-up solutions offer a product component, 87% offer a service component. Surprisingly, not all IIoT start-ups offer a service component as part of their solution. Hence, there are also IIoT start-up solutions that consist only of a physical product, e.g., Aspinity [16]. In 55% of all sampled IIoT start-up solutions, existing data is used as a data source to provide the IIoT start-up solution. The dominant use of existing data shows that most IIoT start-ups in our sample focus on offering solutions, which work with existing data sources, as companies already possess a wide variety of tools to collect data [63]. Additionally, the time horizon of utilized data is dominated by the characteristic current. Notably, IIoT start-ups offer basic (28%) and extended (54%) analytics to deliver their respective solutions. This finding overlaps with the increased market demand for service offerings in data utilization in the industrial context [51, 64]. Since 87% of the sampled IIoT start-up solutions include a service component, it is no surprise that 44% have a service-centric value proposition and 37% a platform-centric value proposition. The frequencies show that the physical product mainly serves as a vehicle for service provision. Thus, the added value of the IIoT start-up solution is mainly defined by its service component. The business relationship is again dominated by one characteristic, as 69% of all sampled IIoT start-up solutions offer a long-term business relationship. Furthermore, the business cooperation is split into 56% stand-alone and 44% third-party integrable. The high number of third-party-integrable solutions indicates the industry's demand for IIoT start-up solutions for existing industrial infrastructure [65]. Lastly, the pricing dimension is dominated by the characteristic subscription-based. The observed dominance is in line with the general dominance and increase in subscription-based pricing models in industrial and non-industrial settings [66]. As we had to deal with publicly non-transparent pricing information in 77% of the cases, the frequencies of the pricing model's characteristics can be even higher or lower than observed.

In summary, the IIoT start-up solutions of our sample occupy diverse positions across the taxonomy, again emphasizing the value of establishing a basic theoretical understanding of IIoT start-up solutions.

6 Conclusion and Outlook

Despite the increasing relevance of IIoT as paradigm shifter, little insight exists about the companies which often first commercialize IIoT solutions, namely start-ups [9]. IIoT start-ups are indispensable partners in the digital transformation of incumbent industrial companies, as they offer a wide variety of IIoT solutions.

To answer the research question of how IIoT start-up solutions can be classified, we proposed a multi-layer taxonomy that follows Nickerson et al.'s [20] established taxonomy development process. First, we reviewed existing literature to identify relevant dimensions and characteristics of IIoT start-up solutions [1, 4, 7, 37–39]. We then analyzed a randomized sample of 78 IIoT start-ups solutions from CrunchBase in four iterations until the objective and subjective ending conditions were met.

From a theoretical perspective, our taxonomy contributes to the descriptive knowledge on the IIoT start-up phenomenon, exploring a not yet well-understood research field. Our main contribution is a theoretically well-founded and empirically validated taxonomy. The taxonomy serves as a starting point for researchers for further theorizing, e.g., for deriving archetypes (e.g., [18]) and theories for analyzing or explaining. On the one hand, archetypes help to understand higher-order configurations of IIoT start-up solutions and to anticipate trends within IIoT and related industries. On the other hand, the taxonomy constitutes a building block for developing a theory for analyzing IIoT startup solutions, e.g., by describing the phenomena, relationships, and boundaries [21].

From a practical perspective, our taxonomy serves as a tool for various players within the field of IIoT. Our taxonomy provides transparency from the perspective of an industrial company looking for a partner to implement an IIoT initiative. Our taxonomy enables the analysis of the various solutions offered by IIoT start-ups, e.g., how many IIoT start-up solutions are third-party integrable. From the viewpoint of an IIoT start-up, our taxonomy could serve as a basis for creating a market overview, finding niches, and examining them for their respective market potential, e.g., our taxonomy shows that certain areas are hardly addressed within the field of IIoT. In addition, our taxonomy helps to understand the phenomenon of IIoT start-ups better, identify core solutions, and define typical solution characteristics.

Although this paper provides initial theoretical and practical implications, our study has its limitations and, thus, stimulates further research. First, our sample of IIoT start-ups is not exhaustive, as we only classified 78 randomly drawn IIoT start-ups. Future research should analyze more IIoT start-ups from different databases. Second, in some cases, the pricing information was non-transparent, possibly causing characteristics frequencies to be even higher or lower than observed. Third, the field of IIoT start-up solutions is dynamic. Therefore, our taxonomy represents a snapshot, as emerging types of IIoT start-up solutions may be underrepresented. Re-evaluating the dimensions and characteristics after a certain period is recommended, as this will provide longitudinal insights regarding the development of IIoT start-up solutions. To address the limitations above in further research, we developed the taxonomy as Nickerson et al. [20] suggested. Hence, the taxonomy is revisable and expandable. Further, we believe that this paper is of theoretical and practical relevancy. Thus, we hope to inspire fellow researchers to continue the research on IIoT solutions in the context of start-ups.

Appendix

A.1. Overview of Crunchbase sample

ID	Website
1	www.adlinktech.com
2	www.alleantia.com
3	www.altizon.com
4	www.andium.com
5	www.aspinity.com
6	www.automationintellect.com
7	www.bayshorenetworks.com
8	www.behrtech.com
9	www.calumino.com
10	www.carlsolutions.com
11	www.cartasite.com
12	www.corrosionradar.com
13	www.cryptalabs.com
14	www.datanomix.io
15	www.ddriven.io
16	www.decisyon.com
17	www.dragos.com
18	www.elmodis.com
19	www.emiia.ai
20	www.eoi-technologies.com
21	www.exacterinc.com
21	www.falkonry.com
23	www.flutura.com
24	www.foghorn.io
25	www.glartek.com
26	www.go-arc.com
27	www.govimana.com
28	www.greenbird.com
29	www.harperdb.io
30	www.ia3.io
31	www.igrid.tech
32	www.intranav.com
33	www.ioterop.com
34	www.iotgearbox.com
35	www.iotium.io
36	www.ligado.com
37	www.linemetrics.com
38	www.mobodexter.com
39	www.mzt.one
40	www.narrativewave.com
41	www.nexiona.com
42	www.petasense.com
43	www.praemo.com
44	www.proaxion.io
45	www.proxxi.co
46	www.qiio.com
47	www.qio.ai
48	www.quartic.ai
49	www.quaychain.com
50	www.qylur.com
51	www.rimot.io
52	www.runsafesecurity.com
53	www.sensemetrics.com
54	www.sensewaves.io
55	www.sensire.com
56	www.sibsolutions.com
57	www.smartcloudinc.com
58	www.sparkcognition.com
59	www.sparksdynamics.com
60	www.sqwaq.com
61	www.srtlabs.com
62	www.ssmcoltd.co.jp
63	www.telesense.com
64	www.teskalabs.com
65	www.thelatiumgroup.com
66	www.threadinmotion.com
67	www.toolsense.io
68	www.triomobil.com
69	www.twinthread.com
70	www.ulalalab.com
71	www.ursaleo.com
72	www.utvyakta-solutions.com
73	www.versatile.ai
74	www.wibase.com
75	www.xidasiot.com
76	www.xompass.com
77	www.zerokey.com
78	www.zuuliot.com

References

1. Püschel, L., Röglinger, M., Brandt, R.: Unblackboxing Smart Things - A Multilayer Taxonomy and Clusters of Nontechnical Smart Thing Characteristics. IEEE Transactions on Engineering Management, vol. , 1–15 (2020). doi: 10.1109/TEM.2020.2988981
2. Gilchrist, A.: Industry 4.0. The Industrial Internet of Things. Apress, New York (2016) (Accessed: 10.11.2021)
3. Lasi, H., Fettke, P., Kemper, H.-G., Feld, T., Hoffmann, M.: Industrie 4.0. Wirtschaftsinformatik, vol. 56, 261–264 (2014). doi: 10.1007/s11576-014-0424-4
4. Paukstadt, U., Strobel, G., Eicker, S.: Understanding Services in the Era of the Internet of Things: a Smart Service Taxonomy Proceedings of the 27th European Conference on Information Systems (2019)
5. Statista Research Department: Industrial IoT - market size worldwide 2017-2025 (2020), https://www.statista.com/statistics/611004/global-industrial-internet-of-things-market-size/
6. Strategy Analytics: IoT connected devices worldwide 2030 (2019), https://www.statista.com/topics/2637/internet-of-things/ (Accessed: 10.11.2021)
7. Herterich, M., Buehnen, T., Uebernickel, F., Brenner, W.: A Taxonomy of Industrial Service Systems Enabled by Digital Product Innovation 49th Hawaii International Conference (2016). doi: 10.1109/HICSS.2016.157
8. Xu, H., Yu, W., Griffith, D., Golmie, N.: A Survey on Industrial Internet of Things: A Cyber-Physical Systems Perspective. IEEE Access, vol. 6, 78238–78259 (2018). doi: 10.1109/ACCESS.2018.2884906
9. Criscuolo, P., Nicolaou, N., Salter, A.: The Elixir (or Burden) of Youth? Exploring Differences in Innovation between Start-Ups and Established Firms. Research Policy, vol. 41 (2012). doi: 10.1016/j.respol.2011.12.001
10. Venture Scanner (2020), https://www.venturescanner.com/2020/04/22/iot-q1-2020-funding/ (Accessed: 10.11.2021)
11. Forbes (2020), https://www.forbes.com/sites/louiscolumbus/2020/05/25/the-top-20-iot-startups-to-watch-in-2020/ (Accessed: 10.11.2021)
12. Baltuttis, D., Häckel, B., Jonas, C.M., Oberländer, A.M., Röglinger, M., Seyfried, J.: Conceptualizing and Assessing the Value of Internet of Things Solutions. Journal of Business Research, vol. (2021)
13. Bowen, P., Goel, A., Schallehn, M. and Schertler, M.: Choosing the Right Platform for the Industrial IoT (2017), https://www.bain.com/contentassets/c4b8bbd38c5948afbc829d2f1f67d625/bain_brief_choosing_the_right_platform_for_the_industrial_iot.pdf (Accessed: 10.11.2021)
14. Manyika, J., Chui, M., Bisson, P., Woetzel, J., Dobbs, R., Bughin, J., Aharon, D.: The Internet of thing: Mapping the value beyond the hype McKinsey Global Institute (2015)
15. Munirathinam, S.: Chapter Six - Industry 4.0: Industrial Internet of Things (IIOT). In: Raj, P., Evangeline, P. (eds.) Advances in Computers : The Digital Twin Paradigm for Smarter Systems and Environments: The Industry Use Cases, vol. 117, pp. 129–164. Elsevier (2020). doi: 10.1016/bs.adcom.2019.10.010
16. Aspinity (2021), https://www.aspinity.com/ (Accessed: 10.11.2021)
17. TeleSense (2021), https://telesense.com/ (Accessed: 10.11.2021)
18. Müller, J., Buliga, O.: Archetypes for data-driven business models for manufacturing companies in Industry 4.0 International Conference on Information Systems (2019)

19. Arnold, L., Jöhnk, J., Vogt, F., Urbach, N.: A Taxonomy of Industrial IoT Platforms' Architectural Features Wirtschaftsinformatik 2021 Proceedings
20. Nickerson, R.C., Varshney, U., Muntermann, J.: A method for taxonomy development and its application in information systems. European Journal of Information Systems, vol. 22, 336–359 (2013). doi: 10.1057/ejis.2012.26
21. Gregor, S.: The Nature of Theory in Information Systems. MISQ, vol. 30, 611–642 (2006). doi: 10.2307/25148742
22. Ashton, K.: That "Internet of Things" thing. RFiD Journal, vol. (2009)
23. Oberländer, A.M., Röglinger, M., Rosemann, M., Kees, A.: Conceptualizing Business-to-Thing Interactions - A Sociomaterial Perspective on the Internet of Things. European Journal of Information Systems, vol. , 486–502 (2018)
24. Xu, L.D., He, W., Li, S.: Internet of Things in Industries: A Survey. IEEE Trans. Ind. Inf., vol. 10, 2233–2243 (2014). doi: 10.1109/TII.2014.2300753
25. Geißler, A., Häckel, B., Übelhör, J., Voit, C.: Structuring the Anticipated Benefits of the Fourth Industrial Revolution. In: AMCIS (2019)
26. Ransbotham, S., Fichman, R.G., Gopal, R., Gupta, A.: Special Section Introduction - Ubiquitous IT and Digital Vulnerabilities. Information Systems Research, vol. 27, 834–847 (2016)
27. Boyes, H., Hallaq, B., Cunningham, J., Watson, T.: The industrial internet of things (IIoT): An analysis framework. Computers in Industry, vol. 101, 1–12 (2018). doi: 10.1016/j.compind.2018.04.015
28. Matthiae, M., Richter, J.: Industry 4.0-Induced Change Factors and the Role of Organizational Agility European Conference on Information Systems (2018)
29. Lee, I., Lee, K.: The Internet of Things (IoT): Applications, investments, and challenges for enterprises. Business Horizons, vol. 58, 431–440 (2015). doi: 10.1016/j.bushor.2015.03.008
30. Sisinni, E., Saifullah, A., Han, S., Jennehag, U., Gidlund, M.: Industrial Internet of Things: Challenges, Opportunities, and Directions. IEEE Trans. Ind. Inf., vol. 14, 4724–4734 (2018). doi: 10.1109/TII.2018.2852491
31. Lim, S., Kwon, O., Lee, D.H.: Technology convergence in the Internet of Things (IoT) startup ecosystem: A network analysis. Telematics and Informatics, vol. 35, 1887–1899 (2018). doi: 10.1016/j.tele.2018.06.002
32. Katila, R., Chen, E.L., Piezunka, H.: All the right moves: How entrepreneurial firms compete effectively. Strategic Entrepreneurship Journal, vol. 6, 116–132 (2012). doi: 10.1002/sej.1130
33. Weinberger, M., Bilgeri, D., Fleisch, E.: IoT business models in an industrial context. at - Automatisierungstechnik, vol. 64, 699–706 (2016). doi: 10.1515/auto-2016-0054
34. Sisinni, E., Saifullah, A., Han, S., Jennehag, U., Gidlund, M.: Industrial Internet of Things: Challenges, Opportunities, and Directions. IEEE Trans. Ind. Inf., vol. 14, 4724–4734 (2018). doi: 10.1109/TII.2018.2852491
35. Cook, D.P., Goh, C.-H., Chung, C.H.: Service Typologies: a State of the Art Survey. Production and Operations Management, vol. 8, 318–338 (1999). doi: 10.1111/j.1937-5956.1999.tb00311.x
36. Oberländer, A.M., Lösser, B., Rau, D.: Taxonomy Research in Information Systems: a Systematic Assessment Proceedings of the 27th European Conference on Information Systems (2019)
37. Gimpel, H., Rau, D., Röglinger, M.: Understanding FinTech start-ups – a taxonomy of consumer-oriented service offerings. Electronic Markets, vol. 28, 245–264 (2018). doi: 10.1007/s12525-017-0275-0

38. Hartmann, P.M., Zaki, M., Feldmann, N., Neely, A.: Capturing value from big data – a taxonomy of data-driven business models used by start-up firms. International Journal of Operations & Production Management, vol. 36, 1382–1406 (2016). doi: 10.1108/IJOPM-02-2014-0098
39. Rizk, A., Bergvall-Kåreborn, B., Elragal, A.: Towards a Taxonomy for Data-Driven Digital Services Proceedings of the 51st Hawaii International Conference on System Sciences (2018). doi: 10.24251/HICSS.2018.135
40. Allmendinger, G., Lombreglia, R.: Four strategies for the age of smart services. Harvard Business Review, vol. , 131–145 (2005)
41. Bryman, A.: Integrating quantitative and qualitative research: how is it done? Qualitative Research, vol. 6, 97–113 (2006). doi: 10.1177/1468794106058877
42. Kundisch, D., Muntermann, J., Oberländer, A.M., Rau, D., Röglinger, M., Schoormann, T., Szopinski, D.: An Update for Taxonomy Designers. Bus Inf Syst Eng, vol. (2021). doi: 10.1007/s12599-021-00723-x
43. CrunchBase (2021), https://www.crunchbase.com/ (Accessed: 10.11.2021)
44. Sonnenberg, C., vom Brocke, J.: Evaluations in the Science of the Artificial – Reconsidering the Build-Evaluate Pattern in Design Science Research. Design Science Research in Information Systems, vol. 7286, 381–397 (2012). doi: 10.1007/978-3-642-29863-9_28
45. Nahm, A., Rao, S., Solis-Galvan, L., Ragu-Nathan, T.: The Q-Sort Method: Assessing Reliability And Construct Validity Of Questionnaire Items At A Pre-Testing Stage. Journal of Modern Applied Statistical Methods, vol. 1, 114–125 (2002). doi: 10.22237/jmasm/1020255360
46. Püschel, L., Röglinger, M., Schlott, H.: What's in a Smart Thing? Development of a Multi-layer Taxonomy. In: ICIS (2016)
47. Porter, M., Heppelmann, J.E.: How Smart, Connected Products Are Transforming Competition. Harvard Business Review, vol. 92 (2014)
48. Nakamura, E.T., Ribeiro, S.L.: A Privacy, Security, Safety, Resilience and Reliability Focused Risk Assessment In a Health IoT System : Results from OCARIoT Project Global IoT Summit (2019). doi: 10.1109/GIOTS.2019.8766364
49. Park, Y., Geum, Y., Lee, H.: Toward integration of products and services: Taxonomy and typology. Journal of Engineering and Technology Management, vol. 29, 528–545 (2012). doi: 10.1016/j.jengtecman.2012.08.002
50. Berkovich, M., Leimeister, J., Krcmar, H.: Suitability of Product Development Methods for Hybrid Products as Bundles of Classic Products, Software and Service Elements ASME - International Design Engineering (2009)
51. ur Rehman, M.H., Yaqoob, I., Salah, K., Imran, M., Jayaraman, P.P., Perera, C.: The role of big data analytics in industrial Internet of Things. Future Generation Computer Systems, vol. 99, 247–259 (2019). doi: 10.1016/j.future.2019.04.020
52. Armstrong, J.S.: Principles of Forecasting: A Handbook for Researchers and Practitioners. Kluwer Academic Publishers, New Sork, Boston, Dordrecht, London, Moscow (2002)
53. Porter, M., Heppelmann, J.E.: How Smart, Connected Products Are Transforming Companies. Harvard Business Review, vol. 92 (2014)
54. Delen, D., Demirkan, H.: Data, information and analytics as services. Decision Support Systems, vol. 55, 359–363 (2013). doi: 10.1016/j.dss.2012.05.044
55. Veit, D., Clemons, E., Benlian, A., Buxmann, P., Hess, T., Kundisch, D., Leimeister, J.M., Loos, P., Spann, M.: Business Models - An Information Systems Research Agenda. Business & Information Systems Engineering, vol. 6, 45–53 (2014)
56. WiBASE (2021), https://www.wibase.com/products_list/en/mobility/ (Accessed: 10.11.2021)

57. Proxxi (2021), https://www.proxxi.co/ (Accessed: 10.11.2021)
58. Pauli, T., Marx, E., Matzner, M.: Leveraging Industrial IoT Platform Ecosystems: Insights from the Complementors' Perspective Proceedings of the 28th European Conference on Information Systems (2020)
59. Bharadwaj, A., Sawy, O.A., Pavlou, A.P., Venkatraman, N.: Digital business strategy: toward a next generation of insights. Management Information Systems Quarterly, vol. 37, 471–482 (2013)
60. Lusch, R.F., Nambisan, S.: Service Innovation: A Service-Dominant Logic Perspective. MISQ, vol. 39, 155–176 (2015). doi: 10.25300/MISQ/2015/39.1.07
61. Osterwalder, A., Pigneur, Y.: Business Model Generation. Campus Verlag, Frankfurt am Main (2011)
62. Moore, G.C., Benbasat, I.: Development of an Instrument to Measure the Perceptions of Adopting an Information Technology Innovation. Information Systems Research, vol. 2, 192–222 (1991). doi: 10.1287/isre.2.3.192
63. Lake, P., Crowther, P.: Data, an Organisational Asset. In: Lake, P., Crowther, P. (eds.) Concise Guide to Databases: A Practical Introduction, pp. 3–19. Springer London, London (2013). doi: 10.1007/978-1-4471-5601-7_1
64. Feng, J., Li, F., Xu, C., Zhong, R.Y.: Data-Driven Analysis for RFID-Enabled Smart Factory: A Case Study. IEEE Transactions on Systems, Man, and Cybernetics: Systems, vol. 50, 81–88 (2020). doi: 10.1109/TSMC.2018.2882838
65. Strauß, P., Schmitz, M., Wöstmann, R., Deuse, J.: Enabling of Predictive Maintenance in the Brownfield through Low-Cost Sensors, an IIoT-Architecture and Machine Learning IEEE International Conference (2018). doi: 10.1109/BigData.2018.8622076
66. Dempsey, D., Kelliher, F.: Revenue Models and Pricing Strategies in the B2B SaaS Market. In: Dempsey, D., Kelliher, F. (eds.) Industry Trends in Cloud Computing: Alternative Business-to-Business Revenue Models, pp. 45–82. Springer International Publishing, Cham (2018). doi: 10.1007/978-3-319-63994-9_4