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CHALLENGES OF ORGANIZATIONS' ADOPTION OF INDUSTRIAL IOT PLATFORMS – RESULTS OF A DELPHI STUDY

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Companies are still reticent about adopting IIoT platforms, and research has not yet explained the underlying challenges that impede such adoption. Uncovering these obstacles can open avenues for research and practice to realize the intended potential. We take a holistic perspective on technological, organizational, and environmental challenges that impede organizations' adoption of IIoT platforms, which we identify in a Delphi study with 22 international experts from academia and practice. Besides identifying 29 challenges, our research reveals the comparative relevance of individual challenges, uncovering differences in perceptions between academics and practitioners. The study contributes to the diffusion of IIoT platforms in research and practice.

Keywords: Industrial IoT; IIoT Platform; Adoption; Challenge; Delphi Study.

1. Introduction

The integration of information and communication technologies (ICT) into industrial assets enables a new concept known as the industrial Internet of things (IIoT) [Boyes *et al.* (2018); Pauli *et al.* (2021)]. The IIoT incorporates multiple technologies, such as (robotic) automation, sensing, and communication technologies, big data analytics, or machine learning [Sisinni *et al.* (2018)]. By making their machines smart [Püschel *et al.* (2020)], companies can increase their productivity, flexibility, or scalability while reducing their

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operating costs or their power consumption [Kiel *et al.* (2017)]. Further, customer demand for customized solutions can be met by offering digital or smart services [Huber *et al.* (2019)]. To achieve these improvements, industrial firms require digital platforms, referred to as IIoT platforms, to extend their machines' ICT capabilities with external analytical skills and connect them to enterprise applications [Arnold *et al.* (2022); Petrik and Herzwurm (2020); Wortmann and Flüchter (2015)]. IIoT platforms provide the digital foundation for integrating industrial devices into digital networks and collecting and analyzing the data generated. This plays a crucial role in the digital transformation of industrial organizations and has had a significant impact on the engineering and manufacturing industry in the past decade [Lasi *et al.* (2014); Pauli *et al.* (2021)].

However, while digital platforms in the business-to-consumer (B2C) domain have been a remarkable success, they have not yet lived up to the associated expectations in the business-to-business (B2B) domain, especially in the industrial market [Graff *et al.* (2018)]. Compared to digital platforms in the B2C domain, IIoT platforms face various and complex obstacles, such as technological complexity due to elevated security requirements, highly heterogeneous platform users (e.g., end users, device manufacturers, complementors), or are hampered by organizational barriers [Pauli *et al.* (2021)]. Given the enlarging curiosity towards involving IIoT technologies in different industrial settings, research so far has mainly focused on understanding how to set up IIoT platforms [Arnold *et al.* (2022); Moura *et al.* (2018); Mirani *et al.* (2022)], govern the ecosystem of complementors for value creation [Pauli *et al.* (2020); Petrik and Herzwurm (2020); Jacobides *et al.* (2018)], or guide incumbents in their transformation toward digital industrial platforms [Hanelt *et al.* (2020); Tan *et al.* (2020)]. Further, research and practice[†] have worked on identifying the different challenges when implementing a novel technology such as the IIoT. Yet, despite this extensive research, companies are still reticent about adopting IIoT platforms, as underlined by the immature state of the market (i.e., the inability of IIoT platform providers to establish dominant market positions or the difficulties to enable a large number of potential platform users to make the functionalities of IIoT platforms utilizable for themselves) [Petrik and Herzwurm (2020)]). This spotlights critical challenges that platform providers and potential users face when determining whether to establish or use IIoT platforms. Current research has identified different challenges but comes up short in three ways: First, many challenges known so far have been mainly identified in either isolated or different contexts, missing out on their interdependencies and implications, which especially IIoT platforms have to cope with. Second, many challenges known so far are technical-oriented, leaving IIoT platform providers and users in the dark about organizational and other overarching topics they might have to address. Third, a compilation of the status quo and its assessment regarding the actuality and validity of different challenges, as IIoT platforms constantly face new challenges due to more and new devices, technologies, and a continuously evolving environment, is missing. Therefore, we ask: *What challenges impede industrial organizations' adoption of IIoT platforms?*

To answer this question, we conducted a ranking-type Delphi study with IIoT experts from academia and practice. Exploratory in nature, this Delphi technique is suitable as it

[†] See, for example, the variety of blog posts by industrial companies or tech-focused news websites.

aims to uncover issues [Schmidt (1997); Okoli and Pawlowski (2004); Paré *et al.* (2013)] and has proven its applicability for this effort on different occasions [Hanelt *et al.* (2020); Hodapp *et al.* (2019); König *et al.* (2019)]. Specifically, we followed the study of Martin *et al.* [(2021)] in conducting the Delphi method. We surveyed 22 experts over five rounds (brainstorming, validation, narrowing down, and two rating rounds) and devised a holistic set of 29 challenges. Of these challenges, nine items have been previously unmentioned by the literature, thus, providing novel insights into the field. We structure the challenges along the technological, organizational, and environmental perspectives according to Tornatzky and Fleischer´s [(1990)] TOE framework. We thereby explicitly distinguish whether a respective challenge is faced by the platform provider, platform user, or complementor. Further, we provide insights into the comparative relevance of the challenges through two rating rounds, uncovering differences between academia and practice when judging the challenges' importance. The distinction between academics and practitioners is precious in giving our research theoretical relevance and illuminates its potential for real-world impact by recognizing IIoT platforms as complex, rapidly evolving socio-technical phenomena. Given the potential value of the industrial evolution enabled by IIoT platforms, these insights are essential to guide research by uncovering existing barriers and identifying the necessary pathways to contribute to successful IIoT platform initiatives. Further, platform providers and users may benefit from being fully aware of the prevailing challenges to shape the roadmap for future activities and thus unleash the full potential of IIoT platforms.

2. Related Work and Theoretical Background

2.1. *The recent trend toward the IIoT*

The IoT is a network of physical objects with various sensors and actuators, all of which are connected by means of advanced technology and standardized communication protocols [Sisinni *et al.* (2018)]. Of late, it has drawn notable attention by virtue of its significant economic potential in industrial settings [Pauli *et al.* (2021)]. As recent trends in manufacturing have aimed to leverage traditional production methods by integrating digital technologies and process automation, the resulting systems are often known as the industrial IoT [Kiel *et al.* (2017)]. The IIoT has been linked with multiple terms, such as Industry 4.0 or industrial Internet [Boyes *et al.* (2018); Jing *et al.* (2014); Wortmann and Flüchter (2015)]. The IIoT is perhaps best described as a means of "connecting all the industrial assets, including machines and control systems, with the information systems and the business processes" [Sisinni *et al.* (2018)]. Accordingly, the IIoT has paved the way for the mechanical engineering industry to make a smooth transition into the digital age [Kiel *et al.* (2017); Martínez de Aragón *et al.* (2018)]. By making it possible to extract and use machine data, the IIoT facilitates the creation of novel digital value networks for manufacturing, ultimately expediting the integration and the economization of a smart production system [Pauli *et al.* (2020)].

2.2. *IIoT platforms and their adoption*

The IIoT uses digital platforms, known as IIoT platforms, as a middleware solution to manage the diverse landscape of IIoT devices. These platforms serve as the technological foundation upon which machines, control systems, and enterprise software systems can be connected in what is effectively a conduit for interoperability [Henfridsson *et al.* (2014); Petrik and Herzwurm (2020)]. The applications built on these platforms extend the technological infrastructure to offer various data-based services [Arnold *et al.* (2022); Ayala *et al.* (2020); Schüritz *et al.* (2017)]. What makes this especially valuable in economic terms is that these applications also extend the machines' functionalities by accruing a new host of data and processing it with regard to untapped value propositions. This evolution enables manufacturing and other associated industry organizations to enhance their productivity through optimization and automation and become more user-centric, faster, and reliable while simultaneously reducing, for example, their operating costs or energy consumption [Kiel *et al.* (2017)].

In terms of their structure, IIoT platforms comprise three groups: the platform provider, platform complementors, and platform users. The platform provider manages and oversees the platform and its infrastructure. Complementors use this infrastructure to create new services that expand its capabilities, while users benefit from these additional services by using them to create value for themselves [Parker *et al.* (2016)].

Within the IS domain, technology adoption has been studied extensively with regard to why and how certain information systems are adopted or rejected [Salahshour Rad *et al.* (2018)]. Adoption is the often complicated process of acceptance or first use of a technology or product [Legris *et al.* (2003)]; the following study focuses on the adoption inhibiting factors of IIoT platforms, meaning the challenges that prevent platform users from taking first or indeed full advantage of the platforms' functionalities. Such obstacles can be studied from different perspectives as IIoT platform adoption depends on the positive interplay of three factors: first, the platform provider who must make a suitable service offer; second, the platform users who take advantage of the platform and its services; and third, the platform complementors who furnish the platform with new modules and thus expand its services. Accordingly, the perspectives on which we will focus in the following sections are not limited to the individual level (i.e., either the platform provider or platform user). They extend to an analysis of how adoption-inhibiting factors can appear on an ecosystem level, where such factors simultaneously affect the platform provider, users, and complementors.

A narrow perspective on challenges in the IIoT platform and IIoT systems domain

To date, research in the emerging IIoT and IIoT platform domains has revealed several issues that have inhibited efforts to maximize IIoT platform benefits, yet so far these challenges have primarily been technical. They can be classified into three domains: heterogeneity and interoperability, data integration and management, and data and cyber-security. First, it is worth noting that IIoT systems are a collection of different heterogenous and multi-vendor technologies, all of which must be integrated to work harmoniously. The heterogeneity of the underlying technologies (i.e., different hardware and software, dissimilar standards) can significantly complicate their interoperability [Khan *et al.* (2020);

Alabadi *et al.* (2022)]. Second, the ever-increasing amount of data accrued at ever higher velocity is hard to handle and analyze efficiently with current data management models [Sisinni *et al.* (2018)]. This becomes even more complex as industrial machine data is integrated with other enterprise data to be leveraged for organizational benefits [Christou *et al.* (2022)]. Third, data security is one of the gravest concerns associated with the IIoT, as any systems thus connected do not only produce and analyze the most critical and sensitive business data; they also share it [Chowdhury and A Raut (2019); Serror *et al.* (2021); Werner and Petrik (2019)]. Cybersecurity and privacy requirements for the use of such deeply embedded and near-enough ubiquitous systems are inherent challenges that remain largely unsolved.

While these challenges are undoubtedly valid, the critical attention they have received eclipses other relevant obstacles encountered within organizations and their wider environments. To achieve the vision of IIoT, one must also understand the organizational perspective. Studies that have done so are few and far between, especially those that have identified the non-technical challenges that beset the IIoT and IIoT platform adoption. These include organizational challenges, such as the development of a platform mindset or suitable business model innovations [Dattée *et al.* (2018); Hanelt *et al.* (2020)]. Further significant challenges that have only received cursory attention are of an environmental nature, such as the high system complexity [Sisinni *et al.* (2018)], the difficulty of safeguarding trust across platform complementors [Khan *et al.* (2020)], and the unclear distribution of generated revenues [Pauli *et al.* (2021)]. Meanwhile, the few researchers who have explored the substantial challenges faced by industrial firms transforming into an IoT platform business, such as Hanelt *et al.* [(2020)], have certainly identified several business obstacles, for example, the difficulty of juggling business model ambidexterity or developing the right platform mindset. However, their results merely address the transformation-driven challenges of becoming a platform and cannot explain why so many organizations are still struggling or refusing to adopt the many platform-as-a-service market offerings.

A broader perspective on IIoT technology adoption in general

Taking a broader perspective, research in other areas of technology adoption has already dealt with certain challenges that may affect organizations in their efforts to adopt complex technology like the IIoT [Arnold and Voigt (2019); Prieelle *et al.* (2020); Sivathanu (2019); Reis and Camargo Júnior (2021)]. For instance, Chowdhury and A Raut [(2019)] looked further than the lucrative opportunities afforded to organizations by the IIoT, and in doing so, they cast a spotlight on some obstacles that can get in the way of IIoT adoption. While their focus remained largely on the familiar technical challenges, such as cybersecurity, data security concerns, and the heterogeneity of the machinery and facilitating technologies at work in the IIoT, they also identified a few organizational challenges, chief among them the high investment costs and lack of qualified staff [Chowdhury and A Raut (2019)]. Meanwhile, the likes of Lis and Otto [(2020)] and Prieelle *et al.* [(2020)] have considered various contextual factors of IIoT adoption, yet they, too, focused on technical factors (i.e., data governance).

2.3. *Technology-Organization-Environment framework*

The TOE framework proposes a generic set of perspectives to give a more nuanced view of why and how technological innovations are adopted [Tornatzky and Fleischer (1990)]. These perspectives include technological, organizational, and environmental factors [Wang *et al.* (2010)]. The first covers the various technologies favored by the company in question, the internal (i.e., the existing technologies in a firm) as well as the external (i.e., the pool of available technologies in the market) [Zhu *et al.* (2004)]. The organizational perspective takes account of the company's specific characteristics, including its size, formalization, managerial structure, human resource quality, and the number of slack resources available to it [Wang *et al.* (2010)]. The environmental perspective focuses on the conditions in which a company operates. This encompasses wider industry factors, such as competitors, partners, regulations, or interactions with government agencies [Tornatzky and Fleischer (1990); Zhu *et al.* (2004)].

To track the diffusion pace of innovation, scholars have proposed a variety of models, such as the technology acceptance model (TAM) [Davis (1989)], diffusion of innovation (DOI) theory [Rogers (1983)], or the TOE framework. Yet while the TOE and TAM both focus on technology adoption at the organizational level, the TAM's explanatory value is limited by its narrow focus and, indeed, its disregard for social and alternate parameters, which is why it is often used in combination with other frameworks [Gangwar *et al.* (2014)]. DOI seeks to make up for the TAM's limitations by postulating that a company's adoption and use of innovations are affected by multiple characteristics specific to the respective innovation and company [Ilin *et al.* (2017)].

As the TOE model is derived directly from the DOI theory, it extends these characteristics by integrating the environmental context into its framework. Specifically, it focuses on the multiple facets of company-level adoption of IS or IT products and services, which makes it more holistic, adaptable, and industry-friendly than previous models [Wen and Chen (2010)]. Several scholars have examined the TOE framework's application in various IS domains [Kuan and Chau (2001); Wang *et al.* (2010); Zhu *et al.* (2003)]. Further findings in the wider fields of innovation and technology adoption research have been consistent with the TOE framework [Cooper and Zmud (1990); Iacovou *et al.* (1995); Thong (1999)], providing it with a wealth of empirical support [Hsu and Yeh (2017); Oliveira *et al.* (2014)]. As opposed to prior studies, the narrower focus of which was limited to factors that support the adoption of technological innovations, the TOE framework's generic setup gives it the added advantage of being able to identify a broad range of additional factors, specifically those that inhibit organizational adoption. As we identify and structure these challenges in the following pages, we do so with reference to the TOE framework, not only because it is perhaps the most comprehensive with regard to the multiple relevant perspectives but also because it is deemed to be among the most comprehensible methods when presenting these findings.

3. Method

3.1. *Delphi study method*

We conducted a Delphi study to identify and rank the challenges that hinder organizations' adoption of IIoT platforms. This exploratory method is appropriate for research topics as relatively new as IIoT platforms since it enables one to draw on the collective knowledge gained by experts with first-hand experience of the subject. The method is also particularly suitable when "the problem does not lend itself to precise analytical techniques but can benefit from subjective judgments on a collective basis" [Lindstone and Turoff (1975)]. Indeed, Delphi studies have become well-established in technology management research and proven their value in numerous applications [Hodapp *et al.* (2019); König *et al.* (2019); Kerpedzhiev *et al.* (2021)].

In a Delphi study, experts participate in multiple survey rounds, providing their answers to carefully designed questionnaires with the benefit of anonymity. This prevents peer pressure, distortions of answers caused by certain participants dominating group discussions, or biases emerging in the course of such discussions [Lindstone and Turoff (1975)]. After each round, the research team anonymizes and consolidates all answers. The experts are then informed how the entire panel answered each question, allowing them to rethink their own answers and make potential amendments [Rowe and Wright (2001)]. This iterative approach takes full advantage of the panelists' collective intelligence as they have multiple rounds to capitalize on one another's creativity and expertise until they can reach a consensus on a given topic. In light of the multiple guidelines and rigorous criteria proposed by other researchers to ensure sound use of the Delphi technique [Keeney *et al.* (2006); Okoli and Pawlowski (2004); Paré *et al.* (2013)], we used those best practices while setting up and conducting our own Delphi study.

3.2. *Delphi study structure*

Given the generalist purpose of this study – to identify and rank the barriers that can get in the way of a company's adoption of IIoT platforms – we chose the most widely used blueprint of a ranking-type Delphi study [Paré *et al.* (2013); Schmidt (1997); Martin *et al.* (2021)]. This involves three rounds, the first of which is dedicated to a brainstorming session, the second to a narrowing-down of ideas, and the third to a ranking process. Since we were not interested in the relative significance of the various factors that may complicate a company's IIoT platform adoption but rather in their aggregate effect, we decided to rate the challenges (i.e., grading the challenges with a pre-defined ordinally-scaled measurement) instead of ranking them (i.e., giving each challenge an ordered rank in line with their relevance). This method is consistent with previous Delphi studies with a similar purpose [Martin *et al.* (2021); König *et al.* (2019)].

To ensure the comprehensive identification of challenges in the context of organizational IIoT platform adoption, we did not restrict the experts' input by setting any formal requirements, such as IIoT-specificity or platform relevance. Instead, experts were provided with a conceptual definition that established a shared understanding of what is deemed to be a challenge in this context. Accordingly, a challenge is a difficulty or an obstacle that hampers organization's adoption of IIoT platforms and requires considerable effort and determination to overcome.

During the first brainstorming round, we followed a greenfield approach to ensure that responses would not be constrained to pre-defined categories. From the second round onward, we used the TOE framework, which had a dual benefit. Not only did it encourage the participating experts to consider a variety of perspectives on current obstacles to adoption. It also guided them in mentally processing the consolidated challenges. To represent the multiple views on IIoT platform adoption, we invited experts from both academia and practice to take part in this Delphi study. These experts were selected from different professions, industries, and communities, and all of them were included on the condition that they had relevant experience in the IIoT domain, related fields, or recent involvement in this subject area. This inclusion of researchers as well as practitioners had the further advantage of informing the study with knowledge of the relative importance of the various challenges encountered by both groups. Since prior research indicated that there is often a difference in the perceptions of academics and practitioners, particularly in complex and fast-evolving fields [Lilien (2011)], we split the panel into subsamples of academics and practitioners to elucidate such differences in the rating phase.

Finally, we tracked the convergence of the study's results through qualitative and quantitative feedback from the participants. Qualitatively, panelists could provide open-ended feedback at the end of each round. Underlining this feedback, we followed the common practice of measuring satisfaction with the coding of the challenges and the overall study, each graded by the experts on a seven-point Likert scale (ranging from 1 = extremely dissatisfied to 7 = extremely satisfied) (cf. König *et al.* [(2019)] or Martin *et al.* [(2021)]). This also gave us the tools to safeguard the panel's consensus against selection bias as it allowed us to ascertain that satisfaction with the coding or overall study did not rise because unsatisfied experts dropped out but rather because the experts recorded greater approval of the outcome [Heckman (2010); Martin *et al.* (2021); Paré *et al.* (2013)].

3.3. *Panel composition*

Rather than attempt to assess a representative and, therefore, large sample of the entire population, the Delphi method focuses on information provided by a select group of designated experts with wide-ranging knowledge of the examined domain. Composing the appropriate panel of experts is, therefore, a critical challenge in the Delphi process. In line with the aforementioned selection criteria [Okoli and Pawlowski (2004)], we filtered extensive professional as well as academic networks for suitable participants. We also searched the academic (i.e., journal and conference publications) and the practitioner literature (i.e., blogs, web articles, and business journals). Once we had confirmed multiple participants, we allowed them to nominate additional experts [Okoli and Pawlowski (2004)]. This yielded a sample of 145 experts, 66 of them academics and 79 of them practitioners. Of these, 27 agreed to participate in the study (an 18.2% initial response rate), although five of them did not ultimately do so. Nonetheless, with 22 participants, the panel size complies with the best practices of Delphi studies [Paré *et al.* (2013)].

The panel comprised a balanced sample of 11 academics and 11 practitioners. Similarly well-balanced was the mix of competencies among those experts, as some were clearly technology-focused while others were rather business-oriented. In keeping with this spirit of diversity, the experts had varied educational backgrounds (cf. Fig. 1). As for their industry experience in the IIoT domain, this averaged an impressive 10.7 years during which most of the practitioners had held a leading position, such as C-level, Head of IoT, or Senior Manager (cf. Table 1). Specifically, four practitioners have a background in the platform provider area, and seven are active in the platform user domain. More background information on the panel can be found in Appendix A.

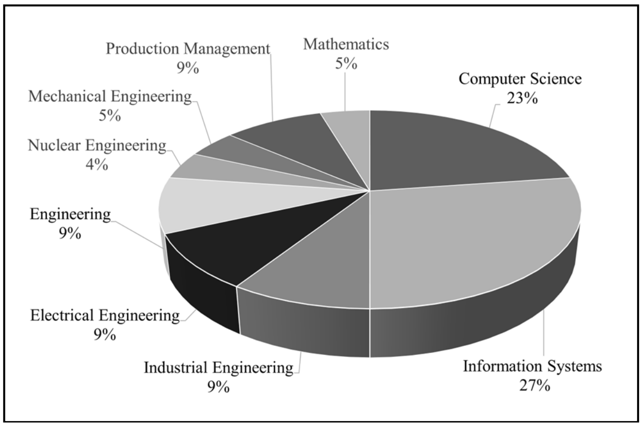


Fig. 1. The educational backgrounds of the study's participants

Table 1. The experts' IIoT domain experience

Years	Distribution
1 to 2 years	9%
3 to 5 years	32%
6 to 10 years	14%
>10 years	45%
Mean	10.7 years

3.4. *Delphi study procedure*

This Delphi study consisted of five rounds: brainstorming, validation, narrowing down, rating round 1, and rating round 2. Data collection was conducted with an online survey tool (Qualtrics). Experts received individual invitations to each round's survey. To ensure this process was as understandable as it was reliable, especially with regard to the initial brainstorming round, we ran a preliminary test with several knowledgeable experts who were not on the final panel. Each questionnaire followed a common structure, providing the experts with detailed instructions, responses from the previous round, and an overview of any amendments made to the previous round [Martin *et al.* (2021); Skinner *et al.* (2015)]. First, participants were given an introduction to the survey goal, its procedure, and, from round 2 onward, detailed information on the last round's results (e.g., satisfaction scores). Second, a general information section let them appreciate the study's core issues, those being its overall purpose, the definition of challenges as perceived by companies attempting to adopt IIoT platforms, the categorizations of the TOE framework along with its descriptions (from round 2 onwards), and all necessary information on the TOE category assignment process. Third, the current rounds required activity (e.g., the ratings of individual challenges). Fourth, participants were given space to make general remarks and provide their satisfaction with the study.

In the first round (brainstorming), the experts were asked to name current challenges experienced by companies in their endeavor to adopt IIoT platforms, and each of these challenges was to be annotated with a brief description. This process also revealed information on the preoccupations of the 22 experts, who named a total of 110 challenges. To consolidate this input, it was first anonymized [Paré *et al.* (2013)]. We then encoded all of the responses by means of iterative coding to identify overlapping and multiply stated challenges [Krippendorff (2013); Schmidt (1997)]. Those we merged under a shared umbrella definition. We kept discussing the results among the author team and fellow researchers until we reached a consensus on a total of 36 specific and separate challenges.

To validate these results, we performed a second brainstorming round (validation). The experts were shown the consolidated results of their prior brainstorming session and asked to comment on them. They were also asked to note any absences among the challenges and comment on their proposed definitions. To prevent any bias, the presentation order of the challenges was randomized in every round [Paré *et al.* (2013)]. At the end of this process, we consolidated 31 challenges.

In the subsequent narrowing-down round, we sought to identify the most relevant of these challenges, so we asked the experts to deselect the 10 least relevant. We chose this negative selection approach because it requires less cognitive effort, given that fewer items have to be chosen. In line with previous Delphi studies, we provided no formal guidance, leaving the assessment of the challenges and their relative importance entirely to the experts' judgment (e.g., König *et al.* [(2019)]). By applying a simple majority rule (i.e., a challenge was deselected if it was deemed to be among the 10 least relevant by more than 50% of the experts) [Paré *et al.* (2013)], we compiled the final list of 29 challenges.

In the rating phases (rounds 4 and 5), the experts rated these 29 challenges according to their comparative relevance [Schmidt (1997); Martin *et al.* (2021)]. We provided the following ordinal scale: ER (extremely relevant), MR (moderately relevant), SR (slightly relevant), and IR (irrelevant). By including the option to rate a challenge as irrelevant, we accounted for the possibility that some panelists may still deem one or even several of these challenges to be unworthy of making the final list, even though they had not been eliminated in the prior narrowing down round. All participants were informed of this purpose, ensuring they did not perceive the rating scale to be non-equidistant [König *et al.* (2019)]. As in the narrowing down round, however, they were given no guidance on how to judge the importance of individual challenges. In rating round 2, the panel was separated into subpanels of academics and practitioners to reveal potential variations between the two groups with regard to how they evaluated the significance of particular challenges. In view of the qualitative feedback we received and the fact that only negligible deviations from the results of rating round 1 were noted, we concluded that a third round of ratings would yield no further insights [Paré *et al.* (2013)].

To elucidate the differences between the academic and practitioner subpanels, we analyzed the median and mode values of rating distributions. By means of Fisher's exact test, we were then able to determine whether there was a significant association between the two subpanels. We applied Fisher's exact test, rather than Pearson's chi-squared test, due to our relatively small sample size and this testing method being the best practice when >20% of cells of a contingency table have expected values <5 [Kim (2017)]. While the chi-squared test calculates p-values by using an approximation to the actual distribution (e.g., normal or X2-distribution), Fisher's exact test yields exact values, which makes it the more accurate method when testing small sample sizes [Bland (2010); Martin *et al.* (2021)].

Table 2 provides an overview of key figures, including the number of active panelists, the number of challenges, the satisfaction scores for coding, and the overall study. In total, between 22 (round 1) and 19 (round 5) experts participated in each round, which equates to a 14% dropout rate. Given the study's requirement of prolonged commitment, with five surveys being answered over two months, this rate is within normal bounds [Martin *et al.* (2021)].

As for the overall satisfaction rates regarding the study and its coding, both were very high from the outset and increased further toward the end, while the respective standard deviation (SD) decreased steadily. One minor exception was the coding satisfaction in round 3. Since this score evaluated the coding of round 2, we believe that some experts were dissatisfied with some of the changes we made, and this is consistent with the feedback from the total sample. However, the positive trend of the participants' overall satisfaction, accompanied by their high satisfaction with the coding after round 3 and their positive feedback, led us to conclude that our results had stabilized after five rounds.

Table 2. Overview of the study's participation, results, and satisfaction, broken down by each round

Phase	Brainstorming		Narrowing down	Rating	
Round	1	2	3	4	5
Active panelists	22	21	20	19	19
Academics	11	11	10	10	10
Practitioners	11	10	10	9	9
Number of challenges[a]	36	31	29	29	29
Satisfaction study overall (mean)[b]		6.05	6.10	6.32	6.26
Satisfaction study overall (SD)[b]		1.17	1.09	0.46	0.44
Satisfaction coding (mean)[b, c]		5.90	5.65	6.26	
Satisfaction coding (SD)[b, c]		1.23	1.11	0.44	

[a] ***After coding or voting;*** [b] ***Likert scale from 1 to 7 (not assessed before round 2);*** [c] ***Likert scale from 1 to 7 (only assessed until round 4; reflects the satisfaction with the coding results of the previous round).***

4. Results

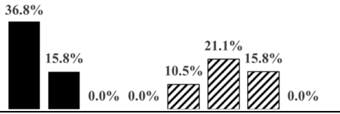
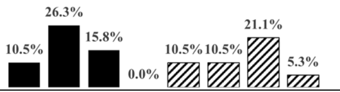
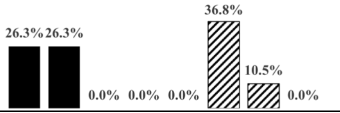
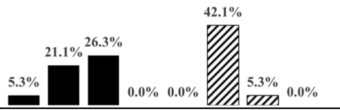
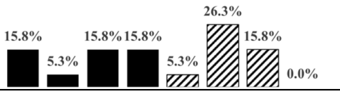
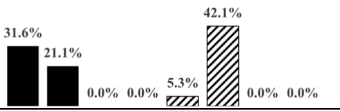
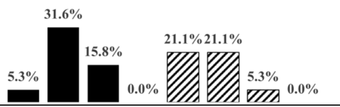
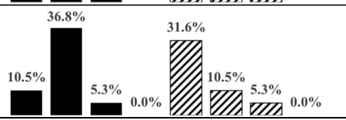
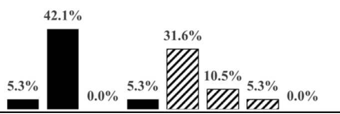
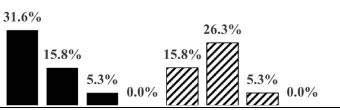
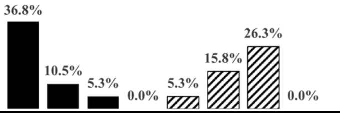
In total, we identify 29 challenges that currently hinder organizations' adoption of IIoT platforms. To improve understandability, we structure the challenges along the TOE framework, with 13 challenges stemming from the technological perspective (44%), eight from the organizational perspective (28%), and eight from the environmental perspective (28%).

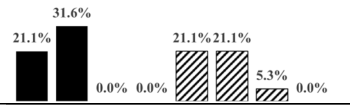
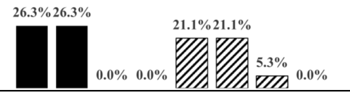
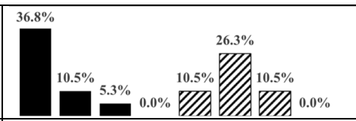
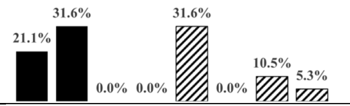
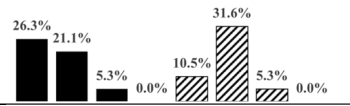
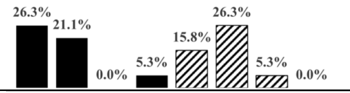
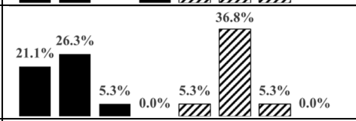
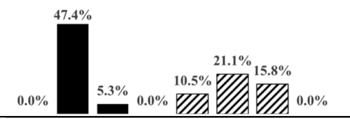
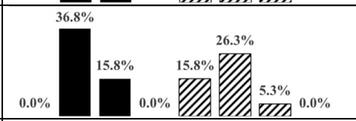
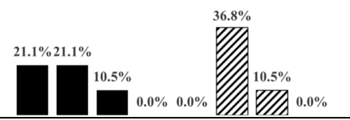
4.1. *Overview and description of the results*

Table 3 summarizes the results, with short descriptions, the corresponding perspective, and the rating distributions for each challenge in the academic and practitioner subpanels. Further, it presents the median, mode, and p-values of Fisher's exact test. Asterisks in column 2 indicated the denomination of an item in cases where academic and practitioner rating distributions showed significant non-homogeneity. When discussing the subpanel ratings, we used the median as the primary criterion [Gracht (2012)] and referred to the mode and Fisher's exact test statistics to examine whether the difference was significant [Martin *et al.* (2021); König *et al.* (2019)].

Table 3. Shortlisted challenges to organizational adoption of IIoT platforms

ID	Perspective	Academics ER	Academics MR	Academics SR	Academics IR	Practitioners ER	Practitioners MR	Practitioners SR	Practitioners IR	A: median	P: median	A: mode	P: mode	p-value
	The technological perspective													
1.T	**Connectivity issues of old machines (Ecosystem)** The legacy infrastructure (e.g., old machines) does not provide the necessary connectivity for IIoT technologies.	15.8%	36.8%	0.0%	0.0%	26.3%	15.8%	5.3%	0.0%	MR	ER	MR	ER	0.2426
2.T	**Insufficient system interoperability (Ecosystem)** IIoT platforms and third-party systems rely on different interfaces and protocols, which impede system interoperability.	36.8%	10.5%	5.3%	0.0%	21.1%	26.3%	0.0%	0.0%	ER	MR	ER	MR	0.1698
3.T	**Complex data preparation*** (Users)** Substantial effort is required for IIoT data extraction and pre-processing.	42.1%	10.5%	0.0%	0.0%	5.3%	31.6%	10.5%	0.0%	ER	MR	ER	MR	0.0059
4.T	**Difficult exceptions handling (Ecosystem)** Handling exceptions such as false data or data from other systems (ERP, SCADA..) is complex.	5.3%	26.3%	15.8%	5.3%	5.3%	10.5%	31.6%	0.0%	MR	SR	MR	SR	0.3635
5.T	**Poor data security (Ecosystem)** Sensitive machine data must be adequately protected.	31.6%	21.1%	0.0%	0.0%	15.8%	31.6%	0.0%	0.0%	ER	MR	ER	MR	0.3699
6.T	**Insufficient semantic interoperability (Ecosystem)** Data processing requires applications to exchange data with agreed syntax and semantics.	26.3%	26.3%	0.0%	0.0%	26.3%	21.1%	0.0%	0.0%	ER, MR	ER	ER, MR	ER	1.0000
7.T	**Limited reliability*** (Ecosystem)** Connectivity breakdowns often jeopardize an IIoT platform's functionality.	15.8%	36.8%	0.0%	0.0%	10.5%	5.3%	26.3%	5.3%	MR	SR	MR	SR	0.0052
8.T	**Insufficient real-time data provision (Ecosystem)** Specific industrial use cases require low latency to ensure the performance of services.	26.3%	26.3%	0.0%	0.0%	10.5%	31.6%	0.0%	5.3%	ER, MR	MR	MR	MR	0.3499

9.T	**Poor platform security* (Provider)** IIoT platforms need to be secured and protected against cyber-attacks and malfunctions.		ER	MR	ER	MR	0.0621
10.T	**Lack of development and testing environment (Provider)** IIoT platform providers must supply testing environments with digital representation (e.g., digital twins) of objects for overarching IIoT use case development.		MR	SR	MR	SR	0.5014
11.T	**Lack of a unified architecture** (Ecosystem)** IIoT platforms lack a standardized architectural concept.		ER, MR	MR	ER, MR	MR	0.0218
12.T	**Long service development times* (Ecosystem)** Developing platform services based on the latest technology (e.g., machine learning) can take long.		MR , SR	MR	SR	MR	0.0894
13.T	**Difficult service customization (Provider)** For IIoT platform providers, it is challenging to supply services generically to enable scalability while simultaneously make them customizable to ensure adaptability to potential users' unique requirements.		SR	MR	SR	MR	0.1022
	The organizational perspective						
14. O	**Employees' insufficient technical skills* (Users)** Platform users' employees lack sufficient technical skills, which impedes the implementation of IIoT technologies.		ER	MR	ER	MR	0.0573
15. O	**Inflated expectations (Users)** Platform users project more on to IIoT platforms than can realistically be achieved, leading to false expectations.		MR	MR	MR	ER, MR	0.2342
16. O	**Unwillingness to adopt platform thinking* (Users)** Platform users resist adopting novel ways of doing business in a platform economy.		MR	ER	MR	ER	0.0552
17. O	**Lack of management support*** (Users)** Platform users have to make a clear assignment of roles and a strong management commitment to initiate and fund IIoT platform adoption.		MR	ER	MR	ER	0.0073
18. O	**High investment and an unclear NPV (Provider)** Developing an IIoT platform requires long-term and high investments with an unclear net present value (NPV).		ER	MR	ER	MR	0.6563
19. O	**Changing technological standards and methods** (Ecosystem)** It is challenging for IIoT platforms to continually adopt new technical standards and methods.		ER	SR	ER	SR	0.0349

20. O	**Lack of understanding of users' business problems (Provider)** Platform providers often poorly understand their users' business problems and are unable to address these through their services.		MR	MR	MR	ER, MR	0.8091
21. O	**Lack of a viable business model (Provider)** Platform providers often lack an appropriate business model to monetize their platform services.		ER, MR	MR	ER	ER, MR	0.8281
	The environmental perspective						
22.E	**Unclear data access and usage rights (Ecosystem)** Regulation on data access and usage rights within IIoT platforms is unclear.		ER	MR	ER	MR	0.1057
23.E	**Unclear business privacy*** (Users)** Data being processed and stored on the cloud may leave a specific jurisdiction, threatening users' business privacy.		MR	ER	MR	ER	0.0089
24.E	**Complex ecosystem coordination (Provider)** Platform providers must coordinate an ecosystem with various third-party complementors.		ER, MR	MR	ER	MR	0.5544
25.E	**Lack of unique value propositions (Provider)** Platform providers lack unique value propositions to stand out from competitors.		ER, MR	MR	ER	MR	0.5608
26.E	**Platform users' insufficient digitalization (Users)** Platform users' low digital maturity hampers simple platform integration.		MR	MR	MR	MR	0.3570
27.E	**Balancing platform participation (Provider)** Platform providers must balance the tradeoff for IIoT platforms to accept enough partners that fit their quality requirements without excluding too many, restricting innovation outcomes.		MR	MR	MR	MR	0.1177
28.E	**Absent network effects (Provider)** Platform providers must convince the demand-side to join the platform without an installed supply-side base and vice versa.		MR	MR	MR	MR	0.1841
29.E	**Unclear revenue distribution (Provider)** Platform providers lack clear concepts to ensure that complementors receive a fair share of the co-created value.		MR	MR	ER, MR	MR	0.1412

*A: academics; P: practitioners; ER: extremely relevant; MR: moderately relevant; SR: slightly relevant; IR: irrelevant; significance codes: p<0.01: *** (highly significant); p<0.05: ** (very significant); p<0.1: * (significant).*

The technological perspective is the largest cluster and includes 13 challenges that cover topics regarding the IIoT and its functioning. The experts conclude on various challenges that inhibit organizations' IIoT platform adoption, from purely technical to governance-related topics of the IIoT. Concerning technical issues, they describe insufficient system interoperability as a challenge, owing to missing interface standards and communication protocols that impede simple data exchange between disparate devices and systems (e.g., from different domains or vendors) and thus hamper platform providers as well as platform users. Further, they describe, among others, connectivity, reliability, and real-time data provision issues that may jeopardize IIoT platform functionality as technical issues that platform providers, as well as platform users, face. They also mention governance-related issues, referring, for instance, to the substantial effort of potential platform users that is necessary to prepare machine data for further analytics or the fact that many IIoT services are highly customized to ensure adaptability to unique user requirements, which impedes the scalability of such services for platform providers over a large number of users.

From the organizational perspective, the experts subsume eight challenges that focus either on the platform provider's business model or on potential platform users' managerial issues. In the context of the business model, the panel describes three challenges. First, IIoT platform providers often poorly understand potential users' business problems, which their services then subsequently fail to address. Second, platform providers often lack an appropriate business model to monetize their services. Third, platform providers face long development times and high investments, often with an unclear net present value, leading to adoption insecurity. In contrast, the experts describe human-centered challenges hampering platform users, such as poor technical skills of firms' employees, or managerial challenges, such as a firm's willingness to adopt platform thinking.

Finally, the environmental perspective consists of eight challenges that deal with market regulation and the platform's orchestration. Concerning market regulation, the experts mention unclear data access and usage rights within IIoT platforms and unclear business privacy as challenges that hamper platform providers and users. The latter refers to the fact that firm data processed and stored on the cloud may leave a specific jurisdiction (e.g., the European Union), threatening a firm's business privacy, as they may lose sovereignty over their data. Concerning platform orchestration, they describe various challenges, from the complex coordination of third-party contributors for platform providers, vague concepts of fair revenue distribution among all platform participants, or the fairly weak manifestation of network effects in B2B environments such as the IIoT domain.

4.2. *Analysis of the results*

The fact that 16 of the 29 (55%) challenges are nontechnical supports our goal of identifying issues beyond the technical focus of the current computer science or engineering IIoT literature. Given the holistic nature of our study, we did not require every challenge to be exclusive to IIoT platforms. In line with other studies, we also sought to incorporate more general challenges – for instance, a lack of management support (17.O) or unclear data access and usage rights (22.E) – to elucidate how, for instance, the management literature can help to overcome them.

Focusing on the comparative relevance of the challenges enables us to determine the most urgent ones. By applying a simple majority rule, we derive three challenges that are rated as extremely relevant overall: Insufficient system interoperability (2.T), insufficient semantic interoperability (6.T), and unclear business privacy (23.E). It is noticeable that all three challenges mentioned concern both platform providers and platform users, which emphasizes the importance of an integrated ecosystem view of the challenges.

When analyzing the academic and practitioner subpanels, we compare the median distributions of their respective ratings (Table 4). Fisher's exact test indicates no significant differences in their rating distributions. Yet, there is no challenge where the academics' and practitioners' ratings (median and mode values) are identical. Further, the results show that the academics tend to rate challenges overall as more relevant than the practitioners (i.e., the academics consider 11 challenges to be extremely relevant, and the practitioners only five). We will elaborate on these insights in the discussion section.

Table 4. Rating distribution (median) among the academics and the practitioners

	Academics	Practitioners
Extremely relevant (ER)	11	5
Moderately relevant (MR)	16.5	20
Slightly relevant (SR)	1.5	4
Irrelevant (IR)	-	-

Table 5 provides an overview of the challenges that are considered extremely important by the majority of the academic and practitioner subpanels. It elucidates how different the subpanels assessed the challenges' relevance. There was no agreement on the key challenges. While academics tend to focus on technical issues (e.g., data preparation, system interoperability, data security, or platform security), the practitioners tend to focus on organizational issues, such as the non-adoption of platform thinking, the extent of managerial support for IIoT platform projects, or the risk of disclosing sensitive information (i.e., business privacy).

Table 5. Challenges rated as extremely relevant by each subpanel

Academics		Practitioners	
Challenge	ER ratings	Challenge	ER ratings
Complex data preparation (3.T)	80%	Unwillingness to adopt platform thinking (16.O)	66.7%
Insufficient system interoperability (2.T)	70%	Lack of management support (17.O)	66.7%
Poor platform security (9.T)	70%	Unclear business privacy (23.E)	66.7%
Changing technological standards and methods (19.O)	70%	Connectivity issues of old machines (1.T)	55.6%
Unclear data access and usage rights (22.E)	70%	Insufficient semantic interoperability (6.T)	55.6%
Poor data security (5.T)	60%		
Employees' insufficient technical skills (14.O)	60%		
High investment and an unclear NPV (18.O)	60%		

4.3. *Comparison of results to related literature*

Our study is connected to related literature by confirming and extending previously identified challenges. We mapped concepts from different studies that are directly or indirectly related to our challenges (for a detailed overview, see Appendix B). Thereby, we identify nine challenges directly related to other studies and thirteen that are only indirectly related while disclosing nine challenges previously unmentioned by the literature. Further, we explicitly state whether a challenge addresses the platform provider, platform users, or the entire ecosystem.

Our results confirm prevalent technical challenges in the context of IIoT platforms (2.T, 7.T, 9.T, 13.T). Although engineering and computer science researchers have widely addressed the technological perspective of the IIoT, our results also indicate some challenges that have not yet been described. First, connectivity issues of old machines (1.T) hamper ecosystems' participants as it is more intricate to integrate sophisticated technologies into industrial assets than traditional M2M and networked devices. Second, the extraction and pre-processing of industrial data from various machines and information systems (3.T) is an underestimated but critical challenge for platform users as such data can be structured or unstructured and highly heterogeneous. Third, the complexity and insecurity of long service development times of IIoT applications must be managed (12.T), and, last, the lack of development and testing environments for IIoT applications (10.T) hinders platform providers from experimenting with applications and assets when developing new services.

From the organizational perspective, some challenges described by Hanelt *et al.* [(2020)] and Pauli *et al.* [(2021)] re-occur in our study. When investigating challenges to building platform ecosystems for the IoT, Hanelt *et al.* [(2020)] found that adjusting a company's mindset from product logic to a platform logic (16.O) as well as designing and developing successful business models for the IoT (21.O) are critical inhibitors of organizations' adoption of IoT platforms. Further, Pauli *et al.* [(2021)] mentioned insecurity owing to an unclear return on investment as an adoption inhibitor (18.O). Nonetheless, the organizational perspective has received much less attention than the technological, leading to the exposure of new challenges. Such challenges include: first, platform providers lack an understanding of the business problems of users (20.O), meaning that IIoT platform providers must individually assess user settings to make a valuable service offering; second, inflated expectations of IIoT solutions (15.O), meaning that users falsely understand or underestimate pre-requisites and limits of, e.g., machine learning solutions; and third, changing technological standards and methods in the emerging IIoT domain (19.O), meaning that IIoT platform providers and users must be able to continuously adapt to the technological advances.

In the environmental perspective, the most critical challenges of security and privacy are already being discussed in the context of IIoT [Khan *et al.* (2020); Sisinni *et al.* (2018)]. Further, the digital platform literature has investigated challenges regarding fair revenue distribution across the platform owner and the platform complementors [Pauli *et al.* (2021)], network effects in the context of the so-called chicken-and-egg problem [Oh *et al.* (2015); Zhu and Iansiti (2012)], or platforms' openness [Broekhuizen *et al.* (2021); Hodapp *et al.* (2019)]. Our results extend these challenges by elucidating further regulatory challenges in the context of data access and usage rights concerning platform providers and platform users (22.E), the lack of unique value propositions by various platform providers (25.E), and the platform users' insufficient digitalization (26.E), which hamper the integration of IIoT solutions in their IT/OT landscape.

5. Discussion

The Delphi study identifies 29 challenges that are described, evaluated, and compared to existing literature. The analysis of these data displays multiple interesting results. In what follows, we first discuss the different perspectives of academia and practice on the challenges and then turn to the roadmap ahead of IIoT platform research and practice.

5.1. *Consideration of different perspectives on the challenges*

We find interesting differences when investigating the ratings of the academic and practitioner subpanels. Overall, our results show consensus (with varying levels of difference) among most challenges between academics and practitioners. However, their judgment diverges significantly on some key topics. For instance, the academics rate data preparation (3.T), insufficient system interoperability (2.T), or platform security (9.T) higher than the practitioners, indicating a focus on more technical challenges. In contrast, the practitioners rate challenges that reflect a broader organizational and environmental perspective higher – such as the unwillingness of potential platform users to adopt a platform thinking (16.O), lack of management support (17.O), or unclear business privacy (23.E). There may be several possible explanations for these differences. One might be that researchers of the currently overrepresented computer science and engineering domains focus per se on the technical side of the IIoT and not on its organizational implications. They, therefore, emphasize the relevance of such technical obstacles. Practitioners, on the other side, are more concerned and experience the transformational effects of the IIoT on their companies, which results in a higher focus on the organizational and environmental perspective. Another explanation might be that (manufacturing) firms have always dealt with implementing innovative technologies into their businesses. Consequently, they are used to facing respective technical challenges and have learned to overcome them [Arnold and Voigt (2019)].

From a practitioner's perspective, adopting an IIoT platform involves extremely relevant challenges along all the TOE framework's perspectives and cannot focus mainly on technical challenges. Table 5 confirms this impression since most of the challenges rated as extremely relevant by academics belong to the technical perspective (5/8), while the practitioners perceived the key challenges to be in the organization and the environment. In addition, practitioners see challenges that affect platform users or the entire ecosystem as extremely relevant, in contrast to academics, who also see platform provider-specific challenges as extremely relevant. Our results show that a holistic view of the challenges across all the perspectives of the TOE framework is crucial to paving the way for the successful adoption of IIoT platforms.

5.2. *Interpretation of key findings in their larger context*

Coping with the challenges of interoperability, privacy, and data management

Our results confirm and extend the challenging technological nature of IIoT platforms [Hanelt *et al.* (2020); Hodapp and Gobrecht (2019)]. One of the grand challenges remains the interoperability (in terms of both semantic interoperability and between systems) of IIoT solutions. For IIoT platforms to unfold their economic potential, achieving interoperability across such solutions and platforms is crucial [Sisinni *et al.* (2018)]. While on the Internet, platforms are built on common standards (i.e., uniform addressing, common protocol, and format negotiation of the exchanged information [Negash *et al.* (2019)]), the IIoT domain is shaped by new and proprietary devices and technologies that are (in part uniquely) developed by an IIoT vendor for specific use cases [Ganzha *et al.* (2017)]. As typical for early-stage technologies [Featherston *et al.* (2016)], no actual (accepted by most companies) standards can be found yet, and it will be challenging to materialize some in the near future [Ganzha *et al.* (2017)]. While this currently limits adoption, it fosters competition between proposed solutions, which may lead to the identification of a more beneficial one that eventually accelerates adoption in the future. In the meantime, there is increasing work to reach agreements on standards by organizations known for this (e.g., IEEE) and novel IoT-specific ones (e.g., Open Connectivity Foundation, oneM2M). Further, there are increasing open-source activities to promote more collaboration in the IIoT (e.g., Eclipse IoT Foundation). On the other hand, research is working on alternative ways of dealing with the interoperability challenge. The EU-funded INTER-IoT project, for example, aims at the design and implementation of an open cross-layer framework to provide voluntary interoperability among heterogeneous IoT platforms [Ganzha *et al.* (2017); INTER-IoT (2019)]. Another approach to reach interoperability without common standards may be the virtualization of IoT devices, as shown by Negash *et al.* [(2019)], who present the idea of a web of virtual things server. Many more researchers are also working on such alternative solutions [Blackstock and Lea (2014); Kiljander *et al.* (2014); Sarkar *et al.* (2015)].

Another crucial challenge for IIoT platforms remains security and privacy. Dealing with this issue includes addressing two things: First, the highly sensitive machine and customer data require IIoT platforms to meet much higher security and privacy requirements than consumer-oriented platforms [Gerber *et al.* (2018)]. Second, as the IIoT is characterized by a high number and heterogeneity of interconnected devices and technologies, it creates new entry points and targets for IT attacks [Berger *et al.* (2020)]. Further, many IIoT devices and nodes are resource constrained, which makes protection even more difficult [Frustaci *et al.* (2018)]. Multiple remedial frameworks and methods using the features of emerging technologies, such as fog computing or blockchain, are available, but they often come with new challenges [Wang *et al.* (2020); Yazdinejad *et al.* (2022)]. Thus, IIoT platform adoption will likely depend on how successful challenges in both dimensions, the individual security of devices, and the ecosystem privacy and protection against cyber-attacks and malfunctions of the IIoT platform as a whole, can be solved. We will return to this topic when discussing new regulations and modes of governance for IIoT platforms.

Last, we find evidence of more fine-grained challenges concerning data management on IIoT platforms. While previous works already mentioned that current methods for dealing with the amount and heterogeneity of device data are not sufficient anymore, recent trends for data management are mainly concerned with big data analytics tools, machine learning, or further business intelligence solutions [Atanasova (2019); Abu-Elkheir *et al.* (2013)]. Our results, in contrast, show that data management in the IIoT concerns much more than this, such as complex data pre-processing, lacking connection reliability of devices leading to incomplete data, or developing fault-tolerating techniques that can deal with such incomplete data. We find similarities with studies in related domains, such as process mining, that also describe such challenges of data management for organizations [Martin *et al.* (2021)], underlining the need for more research on preceding data management steps.

Adopting new organizational routines and cultures

Learning the new logic of digital platforms for organizations is challenging. While most industrial firms focused on a straight pipeline business model for decades, the platform business requires them to transition to a services logic and accordingly change routines and open up more to leverage outside contributions and innovation [Besharov and Smith (2014); Altmann and Tushman (2017)]. As previous works showed, organizations must successfully manage this transition, as integrating two distinct business models leads to tensions and potential underperformance [Altmann and Tushman (2017)]. Accomplishing this transformation in the IIoT requires not only an evolution in culture and routines but also an evolution in human capital. Employees must bring enough new technical expertise to not only deal with the technology but also to develop new digital business models on top of the new insights [Arnold *et al.* (2016)]. Therefore, understanding changing business models is a prerequisite for adopting an IIoT platform and for its long-term maintenance and further use. The management and IS literature have already come up with insights on how these organizational and employee-related obstacles can be successfully tackled [Neumeyer and Liu (2021); Urbach and Ahlemann (2019)]. Further, platform providers must learn to develop more suitable service offerings that fit potential platform users. Pauli *et al.* [(2020)] have already described the fact that the reusability of platform modules will not necessarily scale for many users as in the B2C context. Therefore, finding a solution to make viable customized offerings to users remains important.

Defining the new rules of B2B platform governance

IIoT platforms show significant differences from previously studied digital platforms, leading to the emergence of new challenges and the need to adapt its governance. It is the nature of digital platforms to bring together different stakeholders that would otherwise probably not find together. In the fairly unregulated internet, many consumer-oriented platforms did not necessarily care about reaching into different jurisdictions, while users (i.e., people) did not demand regulations, e.g., for securing their rights for privacy [Gerber *et al.* (2018)]. Within the B2B domain, IIoT platforms spanning different legal and juridical areas (i.e., countries) demand such regulation. Our results show that missing regulations and policies on how business privacy is handled as data are being processed and stored in clouds underlying different jurisdictions are a major concern affecting the adoption decision of industrial firms. Further, organizations demand self-determined control over how they share and handle data. A prominent example tackling this issue is the current Gaia-X initiative [Gaia-X (2022)], which aims at standardizing legal regulations and keeping data processing and storage within European boundaries.

Besides changing regulations, IIoT platforms have to adjust to new rules in the B2B context concerning value distribution among platform stakeholders, network effects that may not play out as strongly as in the B2C domain [Pauli *et al.* (2021)], or more complex coordination of the ecosystem as more and different stakeholders are involved. While insights on platform governance mainly stem from consumer-oriented platforms or their underlying assumptions, the B2B domain comes with several new implications (e.g., for marketing and sales processes, supplier-customer relationships, and potential certification processes [Brennan (2014)], or technical complexity making consultancy often necessary [Pauli *et al.* (2021)]). Research has already begun to develop such new insights, but it is still in its infancy.

6. Conclusion and Implication

Digital platforms have been highly discussed in technology management research in the past two decades. However, research regarding digital platform concepts and success factors has mainly stemmed from the B2C domain. Thus, B2B platform concepts, like IIoT platforms, have been poorly understood. Especially the question of why IIoT platforms, although they promise significant economic value-add, are not being successfully adopted by industrial companies remains unanswered. Against this backdrop, we set up our Delphi study to consolidate and extend state-of-the-art knowledge concerning IIoT platforms. Our explorative study collected extensive inputs from academic and leading industry experts to identify a holistic set of challenges that impede organizations' IIoT platform adoption. Our work contributes to the literature and practice by summarizing and ranking technical, organizational, and environmental challenges, surpassing the scope of the existing related literature.

We contribute a comprehensive list of 29 challenges considered crucial by academic and industry experts regarding organizations' adoption of IIoT platforms. We sharpen the knowledge in this field by confirming pertinent challenges and disclosing novel ones, which we categorize in terms of the TOE framework. Our empirical results indicate that IIoT platform adoption is determined not only by characteristics of the underlying technologies but also by factors relating to the readiness of platform providers and platform users and the external environment. Further, our results present an update and analysis of the literature with the most current knowledge from researchers and industry experts. Since many works in the IoT and IIoT literature streams already date some five to ten years back and with regard to ever-shorter digital technology cycles, such amendment is crucial to guide researchers' focus on resolving existing barriers and identifying the necessary pathways to contribute to successful IIoT platform initiatives. Further, we contribute insights into the comparative relevance of challenges perceived by the academic and practitioner communities. The literature had not yet considered this perspective, which opens new perspectives for diverse IIoT platform research strands by elucidating the commonalities and differences of these groups.

6.1. *Implication for academics*

Our study results have implications for the research into the diffusion of IIoT platforms and may serve as the basis for an IIoT platform adoption research agenda. The differently perceived relevance of the challenges by academics and practitioners in the TOE domains could further contribute to refocusing on the most urgent research topics or those that have not been tackled at all.

Looking at the TOE categories and the identified challenges reveals ample potential for future research, especially in tackling the nontechnical obstacles in the organizational and environmental domain. Since the practitioners in our Delphi study highlight the importance of these nontechnical challenges (e.g., 16.O., 17.O, or 23.E), they are valuable for future research since they provide guidance to tackle significant real-world problems. This includes specific research foci on understanding organizations' unwillingness to change their business thinking when adopting an IIoT platform and how this can be overcome (16.O), investigating how IIoT platforms must be structurally embedded in organizations (17.O, 19.O, 19.O), or determining how IIoT platforms may address users' individual business problems (20.O). Given the relatively young research territory on IIoT platforms, these challenges and related topics provide a fertile ground for research. When investigating the organizational domain, valuable inspiration and knowledge can be transferred from the rich body of literature on digital platforms, (I)IoT and IT adoption [Arnold and Voigt (2019); Prieelle *et al.* (2020); Salahshour Rad *et al.* (2018); Sivathanu (2019)]. For example, investigation on challenge 16.O may build upon knowledge in the digital platform domain, which emphasizes the importance of companies shifting from their current focus on competition to a balance of collaboration and competition in platform ecosystems [Hannah and Eisenhardt (2018); Hein *et al.* (2019)]. Careful investigation is necessary, though, to assess whether such knowledge from other domains is right away applicable to the specific context or whether peculiarities require unique approaches.

While our results urge more focus on organizational and environmental perspectives in IIoT platform adoption research, it simultaneously highlights the technical perspective as a key concern associated with the diffusion of IIoT and IIoT platforms. In particular, attention should be paid to the still unresolved challenges of standardization with regard to protocols, frameworks, and interfaces (2.T, 6.T, 11.T), security (5.T, 9.T), or data management (3.T, 4.T). As many of these challenges have been persistent for many years, it implies that important research challenges remain.

6.2. *Implication for practice*

From the practitioner's perspective, our results provide a comprehensive summary of the challenges that companies must address when adopting IIoT platforms. Thus, companies may use our results to structure their IIoT initiatives and set priorities to maximize the benefits in light of pertinent challenges. Our results show that it is not necessarily the technical dimension that companies as platform users have to consider, but especially the organizational one. Further, many challenges, such as access and usage rights or regulations on technical standards, may not be solvable by one company alone but require a collaborative effort. To enable, for example, reliable (mobile) connectivity in a country´s rural areas, organizations must work closely together with policy makers and other companies.

Besides platform users, our result may also allow highlighting specific recommendations for IIoT platform providers. To be successful, platform governance concepts for IIoT platforms need to be reconsidered. It is evident that a copy-paste approach of successful business model concepts from the B2C domain will not work in the B2B domain. Careful reconsideration of, for example, value creation and value appropriation mechanisms, as well as a more fine-grained understanding of individual platform users' business problems, is necessary. Our results may help identify promising starting points, e.g., by knowing users' current pain points when adopting IIoT platforms and offering guidance in solving them or presenting pre-defined solutions.

7. Limitations and Future Research

Although the study was carried out with great care and precision, the results need to be viewed with certain limitations of Delphi studies and the design choices made. First, as with any Delphi study, the findings are built on evaluating the answers of a limited number of experts. Although our sample size was consistent with other studies and the Delphi method does not require a representative sample, the selection of experts may bias the results. Further, as with any qualitative research, the results may be affected by the design choices, which include the TOE selection over other frameworks, our initial structuring of challenges, and the decision about the initial number of challenges after round 1. Thus, we cannot claim generalizability of the challenges, even if the targeted composition of our sample (i.e., through selection criteria) and the feedback we received throughout the study, as well as the high satisfaction of and consensus among the experts, make us confident of the results' validity. Second, while the sample was large enough for a Delphi study, it was too small for statistical purposes. Thus, the comparative relevance of the challenges should be seen as a trend statement that needs to be substantiated by further research rather than as a robust measurement.

As the IIoT domain has received limited consideration in the platform literature, our results describe various challenges when organizations seek to adopt IIoT platforms, laying the foundation for further empirical research. On the one hand, researchers may cross-validate the results, enabling better generalizability of the challenges. Since IIoT platforms operate in different industries and networks, challenges may play out differently, which needs further clarification. Thus, researchers can conduct confirmative studies and methods to elucidate different organizational contexts and setups in which particular challenges are weak or strong. On the other hand, researchers may look at the challenges in more detail (e.g., through in-depth interviews with experts) to elaborate on their comparative relevance and interconnectedness. Understanding why experts perceived a specific challenge as more relevant than other challenges (i.e., the experts' individual motivations) would help explain and resolve the discrepancy between academics and practitioners and could enable a better understanding of each item. Further, studying the relationships between the challenges would be valuable to elucidate possible dependencies that may enable integrated solution approaches to overcome them. Finally, we consider a regular updating of the challenges valuable to keep track of which challenges are being mastered and how the comparative relevance of the items changes as the research in this domain matures.

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Appendix A: Demographic Information about the Delphi Panel

Table 6. Detailed demographic information about the Delphi panel

	Academics	11	Practitioners	11
Education	*Highest degree*		*Highest degree*	
	High school diploma	-	High school diploma	1
	Bachelor's degree	-	Bachelor's degree	3
	Master's degree	3	Master's degree	5
	Doctorate	8	Doctorate	2
	Discipline of degree		*Discipline of degree*	
	Computer science	3	Computer science	3
	Information systems	4	Information systems	4
	Engineering	3	Engineering	4
	Mathematics	1	Mathematics	0
Experience	*Years holding a PhD*		*Years of work experience*	
	1 to 5 years	4	1 to 5 years	3
	6 to 10 years	0	6 to 10 years	1
	>10 years	7	>10 years	7
	Years of IIoT research		*Years of IIoT experience*	
	1 to 5 years	4	1 to 5 years	5
	6 to 10 years	3	6 to 10 years	2
	>10 years	4	>10 years	4
Job position			C-level	2
			Head of X	1
			X manager	4
			Developer	2
			Consultant	2
Company size			<100	5
			100 to 1,000	2
			>1,000	4
Location	Europe	7	Europe	10
	North America	4	Asia	1

Appendix B: Mapping of Results and Related Literature

Table 7 maps the challenges identified in our Delphi study to closely related literature from the IIoT and the digital platform domains. We focused on two recent papers on challenges in the IIoT generally [Khan *et al.* (2020); Sisinni *et al.* (2018)] and three recent papers on challenges in digital platforms in the IoT/IIoT domain [Hanelt *et al.* (2020); Hodapp *et al.* (2019); Pauli *et al.* (2021)]. We consider these papers to be central and the most up-to-date analysis of the literature in this field.

Mapping the identified challenges to those of other studies was difficult owing to studies' various granularity levels. Thus, we followed Martin *et al.* [(2021)], differentiating between items that are directly related and those that are indirectly related. Such indirectly related items refer to papers and items that broadly referred to the challenge in question but did not explicitly mention it.

We identified nine challenges that were directly related to the literature and eleven that were only indirectly related; eleven challenges identified in our Delphi study could not be referenced to any of the considered papers.

Table 7. Mapping of challenges to related literature

ID	Challenge	Synthesis Directly related	 Indirectly related	Related studies [1] Hanelt et al. 2020	 [2] Hodapp et al. 2019	 [3] Pauli et al. 2021	 [4] Khan et al. 2020	 [5] Sisinni et al. 2018
	The technological perspective							
1.T	Connectivity issues of old machines		[5]					Retrofitting
2.T	Insufficient system interoperability	[2], [3], [5]			Structural flexibility through open standards	Mitigating the issue of heterogeneity		
3.T	Complex data preparation		[4]				Efficient data management	
4.T	Difficult exceptions handling							
5.T	Poor data security		[4]				Trust in IIoT systems	
6.T	Insufficient semantic interoperability		[5]					
7.T	Limited reliability	[4], [5]						
8.T	Insufficient real-time data provision		[5]					Real-time performance
9.T	Poor platform security	[4]					Security of IIoT systems	
10.T	Lack of development and testing environment							
11.T	Lack of a unified architecture							
12.T	Long service development times		[3]			High development effort		
13.T	Difficult service customization	[3]				User vs. generic service solutions		
	The organizational perspective							
14.O	Employees' insufficient technical skills		[2]		Acquiring technical know-how			
15.O	Inflated expectations							
16.O	Unwillingness to adopt platform thinking	[1]	[2]	Platform mindset development	Corporate mindset change			
17.O	Lack of management support		[2]		Long-term investments			
18.O	High Investment and an unclear NPV	[3]				Adoption insecurity due unclear ROI		
19.O	Changing technological standards and methods							
20.O	Lack of understanding of users' business problems							
21.O	Lack of a viable business model	[1]	[3]	Digital business model innovation		Business model		
	The environmental perspective							
22.E	Unclear data access and usage rights							
23.E	Unclear business privacy	[5]	[1], [4]	Platform data management			Trust in IIoT systems	Privacy assurance
24.E	Complex ecosystem coordination		[1]	Platform ecosystem complexity				
25.E	Lack of a unique value proposition							
26.E	Platform users' insufficient digitalization							
27.E	Balancing platform participation		[2]		Interaction in ecosystem			
28.E	Absent network effects	[3]				Network effects		
29.E	Unclear revenue distribution		[3]			Value distribution		