Information Systems and e-Business Management
https://doi.org/10.1007/s10257-024-00676-0

ORIGINAL ARTICLE

Leveraging the industrial internet of things for business process improvement: a metamodel and patterns

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Received: 27 May 2023 / Revised: 28 December 2023 / Accepted: 13 February 2024

Abstract
Industrial organizations of all kinds increasingly recognize the industrial internet of thing's (IIoT) capabilities to enable valuable business process improvement (BPI). However, both theoretically and practically, there is a lack of clarity regarding the systematic and successful identification, specification, and implementation of corresponding applications. This article aims to bridge this research gap by presenting a comprehensive metamodel encompassing all relevant aspects and elements of IIoT applications with BPI propositions. The metamodel is the foundation for deriving generic yet practical patterns that can assist organizations in effectively executing IIoT projects. To evaluate the usefulness of the approach, five initial patterns were designed and applied by a market-leading organization. The metamodel and patterns contribute to the descriptive knowledge of the IIoT and facilitate sense-making, theory-led design, and practical project execution. To ensure rigor, the research endeavor followed fundamental principles of the design science research (DSR) methodology.

Keywords Industrial internet of things · Business process improvement · Business process management · Metamodel · Patterns

1 Introduction

The impact of internet of things (IoT) applications is pervasive, influencing various aspects of daily life and introducing disruptive technologies for private households and businesses across different sectors (Whitmore et al. 2015; Sievers et al. 2021). Besides various smart home, smart grid, and smart city applications, especially industrial organizations can remarkably benefit from integrating IoT technologies

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into their business processes. In this regard, a paradigm denoted as the industrial IoT (IIoT) has evolved that leverages the IoT, albeit transcending the concept of the thing toward industrial applications. By transforming analog information into digital data that can be processed in real-time, the IIoT enables new business models, revolutionizes existing ones (Ng and Wakenshaw 2017; Anosike et al. 2021), and enhances organizations' competitive advantage (Li et al. 2012). Generating and utilizing comprehensive process data and the interconnectedness of process entities offer opportunities for improving various business processes and optimizing value creation (Del Giudice 2016). Hence, integrating IIoT technology into existing business processes can result in valuable business process improvement (BPI), which is particularly relevant for process-oriented organizations (Janiesch et al. 2020). For example, equipping in-stock products with simple radio-frequency identification (RFID) tags can enhance warehouse process traceability and unlock numerous possibilities for improving downstream operations (Fescioglu-Unver et al. 2015). As a result, the pressure on organizations to integrate IIoT technology is growing steadily, so organizations that do not adopt IIoT may not be competitive soon (Liu 2017).

However, a survey of over 500 business executives revealed that 90% of industrial organizations remain in the proof of concept or early-stage planning phases for IIoT projects (Bosche et al. 2016). Many organizations encounter severe discrepancies between the initial expectations of IIoT projects and actual results (Skaržauskienė and Kalinauskas 2015; Zhang et al. 2021). These findings highlight significant barriers and hurdles that impede successful integration into existing business process landscapes. Current literature has also drawn attention to this issue and declared the interaction of IIoT with business processes as one of the least understood phenomena in the business process management (BPM) discipline (Beverungen et al. 2020). Organizations need a novel and effective technology management to exploit the IIoT to improve business process performance (Del Giudice 2016). This motivates reflecting and updating strategies and best practices for redesigning business processes (Beverungen et al. 2020).

For an enhanced IIoT application maturity in industrial organizations, existing business process problems must be investigated, and potential IIoT solutions identified (Sethi and Sarangi 2017). In this regard, the "Act of Improvement", i.e., how existing business processes are transferred to the improved target state by implementing IIoT applications, must be defined precisely. This enhances the plannability and, thus, the chance of a successfully performed IIoT project (Forster 2006). Accordingly, organizations need support for three main challenges: (i) the identification of BPI potentials, (ii) the specification of IIoT applications, and (iii) the actual implementation of these applications. The central research question (RQ) of this article can be formulated accordingly:

RQ1 How can industrial organizations be supported in the identification, specification, and implementation of IIoT-based BPI applications?

One auspicious approach to address this RQ is the development of patterns. Patterns are generic and reusable artifacts that offer suitable solutions to specific problems within a given context (Alexander 1977). Concerning IIoT-based BPI applications, patterns serve as templates or blueprints that can be applied across different industrial organizations (Forster 2006). These patterns encompass all relevant elements of the applications, including underlying challenges, industry examples, performance indicators, and specific characteristics of the technical solutions. To formulate patterns effectively, a well-defined metamodel that captures fundamental design principles is a prerequisite. The metamodel ensures the pattern descriptions' completeness, consistency, and structured representation (Falk et al. 2013). Against this background, an additional RQ can be formulated:

RQ2 Which metamodel enables the illustration of IIoT-based BPI patterns?

The article at hand addresses both RQs by proposing a metamodel containing all elements required to fundamentally comprehend the phenomenon of IIoT-based BPI. To demonstrate the practical application of the metamodel, an initial set of five IIoT-based BPI patterns was derived from a thorough analysis of 34 real-life IIoT applications and illustrated using the metamodel. To evaluate the research approach, the patterns were applied by a market-leading industrial organization.

The remainder of this article is structured as follows. Section 2 presents the theoretical foundations of IIoT and BPI and an overview of patterns and metamodels in information systems research. Section 3 describes the underlying research methodology, which has been applied to develop and evaluate the metamodel and patterns. Subsequently, the design and development of the metamodel is illustrated in Sect. 4, including an extensive Systematic Literature Review (SLR). Section 5 presents the final metamodel of IIoT-based BPI, including all aspects and elements. In Sect. 6, a set of five patterns is derived by an expert panel. Subsequently, in Sect. 7, the patterns are applied in a real-world case study serving as a summative evaluation. Finally, implications, limitations, and future research opportunities are discussed in Sects. 8 and 9.

2 Theoretical foundations

2.1 Industrial internet of things meets business process improvement

There are many approaches for defining IoT, its components, features and capabilities, and the things themselves. According to the IEEE, the IoT is a network that connects uniquely identifiable things to the internet. By exploiting unique identification and sensing, information about the thing can be collected, and the state can be changed from anywhere, anytime, by anything (Minerva et al. 2015). Hence, the term *thing* corresponds to the idea of creating a ubiquitous presence of objects equipped with sensors, actuators, or tags. On the other hand, the term *internet* refers to the ability of these things to build a network of interconnected objects based on several specific network technologies. These two perspectives can be complemented by a semantic view, which represents the ability of IoT to uniquely identify things and store, process, and exchange data (Atzori et al. 2010).

With the increasing prominence of industrial IoT applications, a more specialized paradigm called the IIoT has emerged. Unlike the generic definition of IoT, the IIoT involves utilizing specific IoT technologies, such as particular types of smart objects within industrial cyber-physical systems, to pursue objectives specific to the industrial domain. As a result, the IIoT differentiates itself from the IoT by the purposes for which the technologies are put (Boyes et al. 2018). Current research and implemented applications show that IIoT technology reveals many extensive possibilities for improving business processes (Stoiber and Schönig 2021).

Despite the IIoT's potential to enhance BPI and optimize organizational performance, there is a dearth of research focused on IIoT-based BPI. This research gap can be addressed by developing a metamodel that facilitates the creation of patterns and contributes to the descriptive knowledge of IIoT-based BPI. This approach has proven successful in numerous research disciplines and has gained acceptance across industries (Winter et al. 2009).

2.2 Metamodels and patterns

Patterns, originally introduced by Alexander (1977) in the context of architecture, have found applicability in various domains, including information systems research. They represent recurring problems or challenges in the real world and provide generic solutions that can be applied to similar problems in different contexts. According to Fowler (1996), patterns are ideas that have proven useful in one practical application and are likely to be valuable in others. Following the definition of Gamma et al. (1994), patterns consist of four essential elements. First, a pattern must have a name for identification. Next, the problem should be described, specifying the context in which the pattern can be applied. The third element describes the problem solution, which should not be a concrete solution but rather an explanation of the interaction of different mechanisms leading to a solution. Finally, the consequences of applying the pattern, including positive and negative effects, should be outlined.

Patterns have been extensively researched in different research disciplines, significantly contributing to, e.g., software engineering (Gamma et al. 1994). Furthermore, patterns have proven valuable in designing individual object-oriented software components and composing them into applications (Schmidt et al. 2000). They bridge the gap between high-level integration plans and implementation challenges, providing guidelines that compensate for decision-makers' lack of experience (Hohpe and Woolf 2003), leading to improved project quality, reduced time consumption, and cost savings. Patterns are also applicable to process-related disciplines such as Workflow Management or process-aware information systems (Weber et al. 2008).

However, for the discipline of BPI, the creation of specific patterns has barely been addressed. Forster (2006) built a framework and toolset for creating and structuring BPI patterns while creating the first set of patterns. Another relevant contribution by Falk et al. (2013) proposes a metamodel that facilitates the illustration of BPI patterns. These patterns constitute models derived from an origin metamodel.

Generally, a model can describe objects in the real world and abstract constructs. When the abstract construct described is a model itself, it is called a metamodel (Gonzalez-Perez and Henderson-Sellers 2008). To structure this metamodeling approach, the Meta-Object Facility (MOF) standard of the Object Management Group (OMG) provides a concrete metamodeling architecture illustrated in different layers (Object Management Group 2013). Layer M0 refers to instantiations, real objects or instances. Layer M1 consists of models, and thus mappings of real objects. Furthermore, layer M2 refers to metamodel, for example, written in the Unified Modeling Language (UML). A metamodel describes the types of model building blocks available, the types of relationships between the model building blocks, the rules for linking between model building blocks by relationships, and the semantics of the model building blocks and relationships. The fourth layer M3 provides a meta-metamodel and constitutes the language used by MOF to build metamodels.

2.3 Related work

As described in subSect. 2.2, some works that specifically address the combination of IIoT technology and business processes have been emerging. Hence, BPM research increasingly recognizes the challenges and opportunities of integrating IIoT and vice versa. A recent structured literature review (SLR) of Vukšić et al. (2021) highlighted the topic's relevance by analyzing the temporal distribution of published articles. While research has been relatively scarce from 2010 to 2015, a noticeable growth can be seen since 2016. Consequently, the topic is still in an early scientific research stage but can be considered a growing trend (Suri et al. 2018).

Some general frameworks and reference architectures of IIoT also address business process perspectives. For example, the Reference Architectural Model Industry 4.0 (RAMI 4.0) is a three-dimensional model showing how to approach Industry 4.0, including IIoT, in a structured manner (DIN SPEC 91345, 2016). As one of the main layers of the model, business processes are addressed. Another example is the Industrial Internet Reference Architecture (IIRA), that provides guidance to implementing IIoT technology in organizations (Industry IoT Consortium 2022). Within the guidelines, a specific business view is described that highlights the importance of a business process perspective.

Focusing on IIoT as an enabler for BPI, some articles provide an overview of the capabilities of IIoT for redesigning and improving business processes. A publication by Haller et al. (2009) describes major application areas where IIoT can generate business value. Also, Chui et al. (2010) specifically highlighted the importance of IIoT for improving business processes while defining six emerging applications. Yang et al. (2018) stated that IIoT could be used to redesign production processes and, thus, achieve higher efficiency. A study by Sestino et al. (2020) shows how IIoT can be used for BPI and illustrates several central topics in current literature. Moreover, Arnold et al. (2016) presented the impact of IIoT technology on business models and business processes in different manufacturing industries. More recent research by Drechsler et al. (2022) describes how the emergence of IIoT technologies follows a cascading growth pattern.

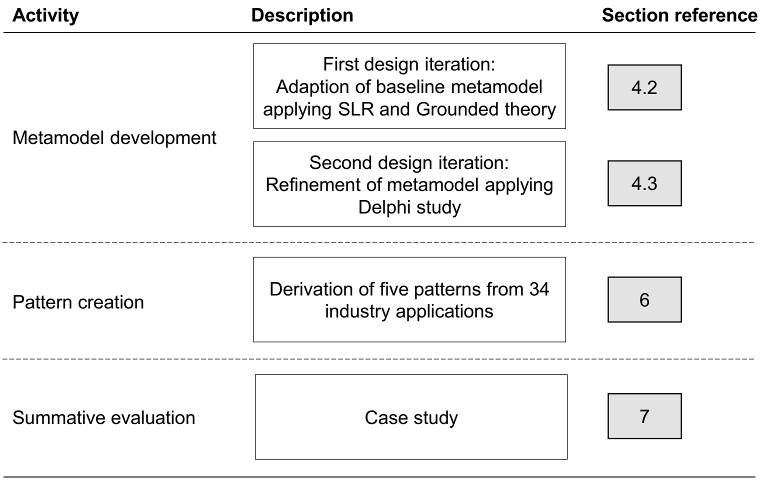
Regarding BPI patterns, especially noteworthy is the contribution of Falk et al. (2013), who created an explicit metamodel that enables the creation and formulation of BPI patterns and can be used as a template and basis for further research. Furthermore, patterns have also been applied to several IoT or IIoT-related topics. As the IIoT consists of different layers, comprising perceiving, networking, or data processing technologies, many different patterns can be formulated that support system engineers with integrating whole applications into business environments. The design and architecture of IIoT systems can eminently benefit from patterns that assist in designing scalable and replicable IIoT applications (Washizaki et al. 2020). Another focus within this research area is on data exchange and network technology patterns along with multiple connected devices, machines, or process entities (Reinfurt et al. 2016). However, a comprehensive conceptualization of IIoT-based BPI that explicitly describes and specifies the phenomenon has not been addressed yet.

3 Research methodology

Since the formulated RQs aim to create novel artifacts, the DSR paradigm was taken as a basis. DSR seeks to guide researchers during the provision of usable artifacts such as constructs, models, methods, or instantiations (Hevner et al. 2004). To develop the metamodel, the structured procedure of Peffers et al. (2007) was applied. This proven method is based on the methodology of Hevner et al. (2004) and provides detailed phases to carry out DSR. In this respect, the conducted research is composed of the following research activities: (i) the design and development of a metamodel, (ii) the derivation of an initial set of patterns, and (iii) a summative evaluation in the form of a case study. Figure 1 gives a brief description of the activities and their section references.

In the first research activity, the metamodel of IIoT-based BPI applications was designed, and a comprehensive formative evaluation was performed. In contrast to creating an entirely new metamodel from scratch, the improvement and revision of an existing and thematically related metamodel enabled the adoption of proven concepts and ideas. Therefore, according to Falk et al. (2013), the metamodel for BPI patterns served as the base for development. It was generic enough to represent all patterns of IIoT-based BPI since these represent a subset of BPI patterns. However, it was not specific enough to appropriately illuminate the aspects of the IIoT domain due to its complexity and unique features. For this reason, the baseline metamodel required adaption concerning IIoT. As in the original metamodel, a class diagram was used for modeling as it provided sufficient semantic expressiveness for metamodeling.

To adapt the base metamodel, two development iterations were conducted. Within the first design iteration, an explorative inductive approach was selected. In this respect, an extensive SLR investigated literature describing IIoT applications with BPI reference. The SLR is further detailed in Sect. 4.2. Subsequently,



Activity	Description	Section reference
Metamodel development	First design iteration: Adaption of baseline metamodel applying SLR and Grounded theory	4.2
	Second design iteration: Refinement of metamodel applying Delphi study	4.3
Pattern creation	Derivation of five patterns from 34 industry applications	6
Summative evaluation	Case study	7

Fig. 1 Performed research activities

the identified literature was analyzed applying Grounded theory and its methods of open and axial coding (Corbin and Strauss 1990). This enabled the identification of indispensable aspects of IIoT-based BPI, which could enrich the base metamodel. Within the author team, the method of inductive reasoning (Hempel 1966) was applied to critically discuss the findings and select the most appropriate metamodel adaptions. Within the second iteration, additional expert knowledge was included in the research approach. Hereof, a Delphi study with nine industry and academia experts was conducted to refine the metamodel. In four rounds, the experts were asked to rate and eventually adapt the metamodel based on their expertise in the research area.

In the second research activity, the metamodel was demonstrated to three organizations in the manufacturing, pharmaceutical, and automotive industries. Seven practitioners from different departments analyzed 34 IIoT applications in their different business areas to derive a first set of patterns. The industry experts used fundamental principles of inductive reasoning to analyze the applications, identify generic aspects, and create five patterns.

To evaluate the usefulness of the design artifacts, the patterns were introduced to an industrial organization in the third and final research activity. In this respect, they served as the basis to fundamentally redesign and improve an important distribution process in the Scandinavian region.

4 Metamodel development

4.1 The base metamodel

The development of the IIoT-based BPI metamodel builds upon prior work of Falk et al. (2013), who designed a BPI metamodel, illustrated in Fig. 2. In their approach,

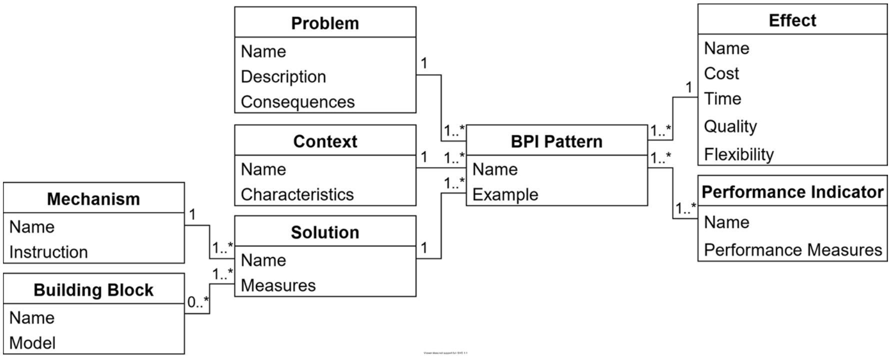


Fig. 2 Base metamodel by Falk et al. (2013)

the BPI metamodel is represented as a class diagram according to UML 2.0, where each pattern element is depicted as a specific class. The properties of these classes are described using attributes, and the relationships between the classes are represented by undirected binary associations with specified multiplicities. These multiplicities define the relationships between individual object classes. At the core of the metamodel is the *BPI Pattern* class, which is instantiated with a unique *Name* and an *Example*. The name describes the pattern's overall purpose and enables its unique identification, while the example gives information on potential instantiations. In addition, there is the class *Problem*, defined by the attributes *Name*, *Description*, and the actual *Consequences* of the problem for the process. Furthermore, the *Context* class is directly related to the class *BPI Pattern*. It is explained by a *Name* and context-specific *Characteristics* and describes the required circumstances for the pattern to be applicable. Each pattern exists in exactly one context, but multiple patterns can exist in the same context.

Each pattern also contains a *Solution*, described by a *Name* and the *Measures* required to achieve the goal. The same solution can again be applied to multiple patterns, but each pattern has only one solution. Bound to the solution are one or more *Mechanisms*, each defined by a *Name* and precise action *Instructions*. In addition, a solution can optionally contain one or more *Building Blocks*. These building blocks are predefined models that can be implemented to solve the problem without customization. In addition, the pattern is related to an *Effect*, which is defined by a *Name* and the BPI dimensions of *Cost*, *Time*, *Quality*, and *Flexibility* (Dumas et al. 2018). Finally, each pattern is related to one or more *Performance Indicators*. These are defined by a *Name* and *Performance Measures* that can be used to represent the improvement after the pattern has been implemented.

4.2 First development iteration

To adapt the base metamodel, a first inductive development iteration was conducted. Inductive approaches involve processing information from subsystems to form a perception of a top-level system. This approach is suitable for analyzing initially unknown data relationships and transferring them to a metamodel. For the identification of appropriate literature, an SLR according to the method of vom Brocke et al. (2009) was performed. To allow a rigorous search and improve the traceability of the literature selection process, the Preferred Items for SLRs and Meta-Analysis (PRISMA) statement has been applied.

Initially, the search string ("IoT" OR "CPS") AND ("BPI" OR "Process Improvement" OR "Process Optimi?ation" OR "Process Automation" OR "Application" OR "Process Improvement") and the written-out forms have been formulated. Figure 3 illustrates the results of the SLR as a PRISMA flow diagram. To include a comprehensive range of relevant journals and conference proceedings in the research area, the databases ACM Digital Library, AISeL, IEEE Xplore, ScienceDirect, Scopus, and Springer Link were queried. In accordance with the PRISMA statement, four criteria were established for paper eligibility in the SLR: (i) the paper must be a peer-reviewed research paper published in a journal or conference proceeding, (ii) it should propose an evaluated solution or real IIoT industry application, (iii) it must have clear links to BPI, and (iv) it should be relevant and up to date. Criterion (ii) and (iii) were assessed in a qualitative manner, while criterion (iv) specified a publication date after 2015 and a minimum of 30 citations. Regarding criterion (iii), the paper must describe a clear reference to a business process and the IIoT application must have the goal of improving it. In this respect, it must be possible for the authors to identify the extent of the process improvement, i.e., whether time, costs, flexibility, or quality are improved.

The literature search and subsequent reference follow-up yielded a total of 81 eligible publications. Once the eligible sample of publications was identified, relevant data was extracted using the Grounded Theory approach and open and axial

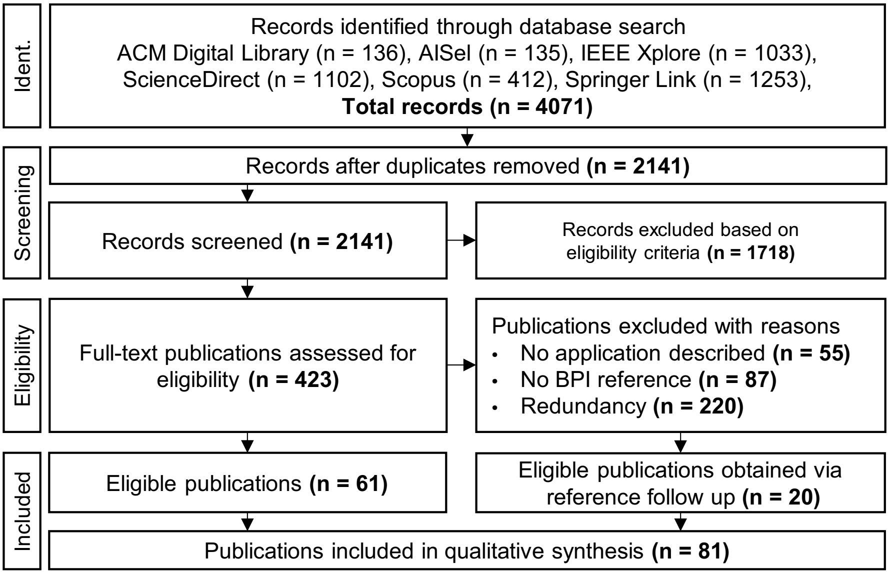


Fig. 3 PRISMA flow diagram

coding methods (Corbin and Strauss (1990). During the first round, each author analyzed 40 publications from the sample using open coding as an interpretive method. Open coding allowed for the analytical breakdown of all IIoT-based BPI applications, aiming to develop substantive categories that enable description, naming, and classification. After this initial round, the identified categories were discussed and harmonized among the authors. In the second round, axial coding was employed to establish relationships among the formulated codes. This process led to the creation of additional categories and subcategories. Subsequently, a second discussion took place to ensure consensus and harmonization of the results. In the third round, the remaining 41 publications were coded using the set of categories and subcategories created in the previous rounds. This coding process served to test the categories and subcategories against new data.

Following the principles of inductive reasoning, as described by Hempel (1966), the categories and subcategories underwent extensive discussions to determine the most relevant ones for adapting the metamodel. These selected categories and subcategories were then used to create a set of classes and related attributes as extensions to the base metamodel. Figure 4 presents the resulting metamodel classes and their evolution throughout both design iterations.

4.3 Second development iteration

A structured four-round Delphi study was conducted to refine the initial draft of the metamodel from the first iteration. A Delphi study is an iterative method commonly used to gather information on a specific topic by administering multiple rounds of surveys. This approach is useful for obtaining expert knowledge and reaching a consensus on complex issues that may lack empirical evidence (Loo 2002).

The participating experts were not introduced to each other to encourage creativity and reduce conflicts and group pressure within the study. Individually, they were tasked with rating or validating the metamodel classes and attributes of the initial draft. After each study round, the results were consolidated and utilized to refine the metamodel. The expert panel consisted of nine individuals, comprising five practitioners and four researchers with expertise in IIoT, BPM, BPI.

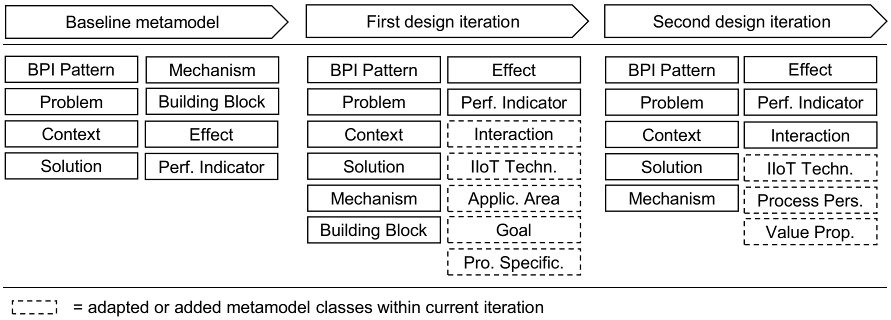


Fig. 4 Design and development iterations

All practitioners had varying work experiences, ranging from four to 21 years, and had been involved in at least one IIoT project. They held positions such as project engineers, project managers, and IT specialists and possessed at least a bachelor's degree. The four researchers in the panel included two professors, one postdoctoral researcher, and one doctoral researcher. They were chosen based on the impact of their research. To ensure a balanced representation and minimize regional bias, the panel of experts was geographically diverse, with members based in Germany, the United States, and the Netherlands. For a detailed overview of the expert panel composition, please refer to Table 1. Figure 5 provides an overview of the four-round Delphi study design, illustrating the information flows between the authors, facilitator, and the expert panel.

During *Round 1* of the study, the expert panel rated the metamodel classes in the initial metamodel draft. Each expert had the option to either *retain*, *adapt*, or *drop* individual classes or propose additional ones. The results from round 1 were analyzed and consolidated using a systematic decision tree successfully applied in previous Delphi studies (Serral et al. 2020). A class would only be dropped if more than 60% of the experts agreed on this option. No adaptations were considered necessary if the percentage to retain a class was at least 80%. Minor adaptations were made for a retain rate between 60 and 80%. However, major adaptations were deemed necessary if the retain rate was below 40% or at least 50% of the experts agreed on the need for adaptation. *Round 2* focused on validating the results obtained from the first round, followed by another consolidation phase. In *Round 3*, the expert panel was requested to rate the attributes of each class. For any new classes introduced, corresponding attributes were proposed by the experts. The consolidated results were then validated in *Round 4*. Following this round, a comprehensive discussion was conducted with all the experts to gather feedback and gain insights into their decisions' reasoning. After this round, a discussion with all experts helped to get feedback and gain insight into the background of the individual decisions. Once the refinement of classes and attributes was completed, relations and multiplicities were defined and added to the metamodel.

5 The metamodel of IIoT-based BPI

The final metamodel of IIoT-based BPI consists of eleven classes and 28 attributes. During the initial development iteration, five classes were added to the metamodel: *IIoT Technology*, *Application Area*, *Interaction*, *Goal*, and *Process Specification*. As the refinement process unfolded, two additional classes, *Process Perspective* and *Value Proposition*, were included based on the expert panel's feedback. However, the classes *Goal, Building Block,* and *Process Specification*, which were originally part of the metamodel, were removed. Figure 6 shows the resulting metamodel, including all classes, attributes, and relations, which will now be explained in detail.

According to Falk et al. (2013), the class *Building Block* can be used for result-oriented patterns, i.e., patterns that directly describe the target process. In contrast, procedure-oriented patterns only describe instructions on improving the process but no direct implementation. Since IIoT systems are very complex and cannot provide

Table 1 Overview of included industry and academic experts during research activities

Research activity	Role of expert	Industry/Academia	Employees (2020)
Delphi study and formative evaluation	Manufacturing technology specialist	Manufacturing industry	[500–5,000]
	Project engineer operations automation	Manufacturing industry	[5000–10,000]
	Project manager digitalization	Chemical industry	[50,000–100,000]
	Head of digital operations	Automotive industry	[50,000–100,000]
	Director of IT operations management support	Aerospace industry	[100,000–250,000]
	Professor of information systems	University—Faculty of Informatics and Data Science	N/A
	Professor of information systems and business process management	University—Faculty of Law, Business and Economics	N/A
	Postdoctoral researcher	University—Faculty of Informatics and Data Science	N/A
	Doctoral researcher	University of Applied Sciences—Faculty of Computer Science	N/A
Pattern creation	Technical project manager operations	Manufacturing industry	[5000–10,000]
	IT support specialist	Manufacturing industry	[5000–10,000]
	Operations automation expert	Pharmaceutical industry	[5000–10,000]
	Digital transformation expert	Pharmaceutical industry	[5000–10,000]
	Senior project manager	Pharmaceutical industry	[5000–10,000]
	Manufacturing technology expert	Automotive industry	[100,000–250,000]
	Senior project manager	Automotive industry	[100,000–250,000]

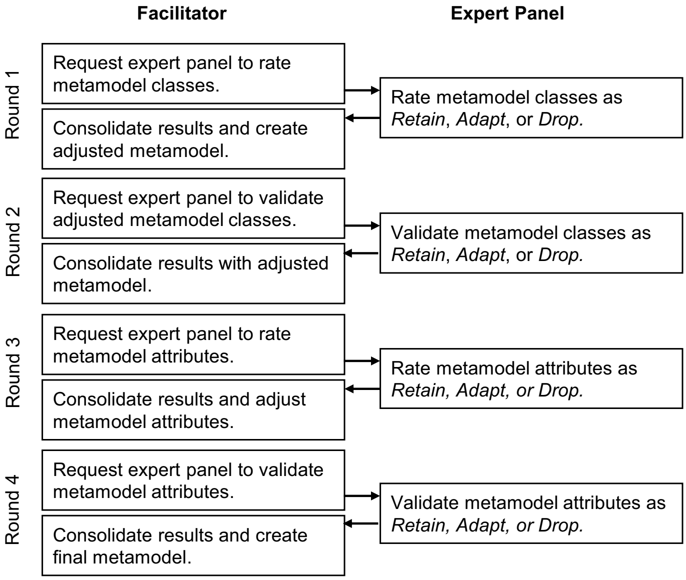


Fig. 5 Delphi study rounds

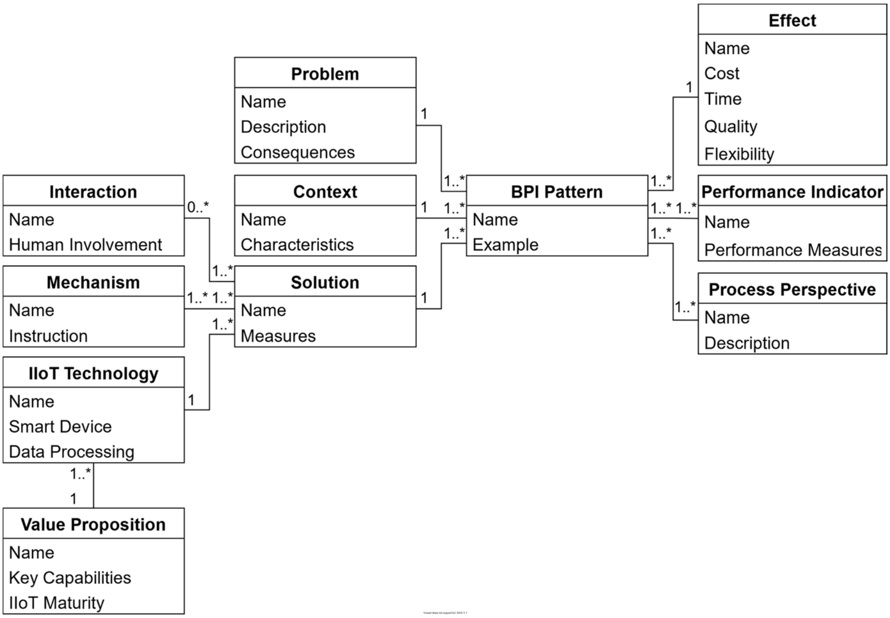


Fig. 6 The metamodel of IIoT-based BPI patterns

any benefit without appropriate integration in the process, it is assumed that patterns for process improvement through IIoT can only be procedure-oriented. Therefore, the expert panel agreed to delete this class from the metamodel. Furthermore, the multiplicity of the class *Mechanism* was revised. In the base metamodel, each solution was limited to having exactly one mechanism. However, this restriction unnecessarily constrained modelers and made it challenging to create domain-specific BPI models. To provide greater flexibility and enable the inclusion of additional implementation details for IIoT applications, the restriction on the multiplicity of the class *Mechanism* was removed. This change allows modelers to define multiple mechanisms within a solution, giving them more freedom and customization options.

The first new class *Interaction* describes human involvement in the IIoT application. This aspect has been discussed by Patterson et al. (2017) and plays a crucial role in describing how the IIoT application interacts with humans within the process. For example, it can specify whether a dashboard is accessible only to the process owner or if all actors in the process are provided with information through wearables, smartphones, or other devices. The interaction class encompasses the interfaces between the IIoT application and humans, including data input and output. By introducing this domain-specific element, the generic BPI metamodel is adapted to an IIoT-based BPI metamodel. Previously, the information output or transfer to human actors had to be modeled using the *Mechanism* class or could not be modeled at all. Each solution can now include one or more interactions, as there may be multiple interfaces for data input or output, or different groups of people may be affected. However, the class is not mandatory, as highly automated IIoT systems may not involve human interaction.

The second new class is *IIoT Technology*. This class addresses the technical requirements of the IIoT application, which could not be adequately represented in the base metamodel. Under this generalized class, the necessary technical specifications are described through two attributes. The first attribute *Smart Device* captures the technological and architectural principles involved. As discussed in subSect. 2.1, sensors, actuators, and network technologies can transform ordinary objects into smart devices or things. Different types of smart devices, such as activity-aware, policy-aware, and process-aware devices, as defined by Kortuem et al. (2010), can be represented within this attribute. A detailed description of specific hardware requirements, such as sensors, actuators, and networking technologies, would be too specific to create generic patterns. The second attribute *Data Processing* describes the basic features of how the collected IIoT data is analyzed and eventually used to improve the underlying business processes. With cloud computing, for instance, the IIoT device is only responsible for generating the data and does not provide any data processing capabilities. In contrast to centralized data processing, edge computing involves processing and analyzing the generated data (or at least parts of it) directly at the network's edge by specially designed devices. Depending on the application and the structure of the IIoT system, hybrid approaches can be possible, too.

Directly connected to the *IIoT Technology* class is the new class *Value Proposition*. This class describes the value that IIoT technology can provide in solving the identified problem. It goes beyond simply outlining technological specifications and highlights the disruptive features and capabilities enabled by the combination of sensors, networking, and data processing technologies. The first attribute of the class is *Key Capabilities*. IIoT technology encompasses novel and disruptive capabilities that set it apart from other technologies. To effectively leverage these capabilities for beneficial BPIs, they must be systematically exploited. While the combination of these capabilities is often relevant in IIoT-based BPI, there are usually distinct key capabilities that are particularly relevant in each case. Such capabilities include universal scalability, comprehensive perception, embedded intelligence, and interoperability. Utilizing specific IIoT technologies and exploiting a set of capabilities can define the *IIoT Maturity*. In this context, maturity refers to the complexity of an IIoT application, its level of integration into the process, and the value it generates. It ranges from simple data collection and analytics to fully automated tasks. Tai Angus Lai et al. (2018) have identified various possibilities for defining IIoT maturity, such as situational awareness, decision-making support, information exchange, and autonomous systems.

Finally, the class *Process Perspective* was added to the metamodel. It describes the perspectives and, therefore, process aspects that are influenced most by the IIoT application. This class is particularly useful for illustrating how the IIoT application affects and redesigns the process. Jablonski and Bussler (1996) have defined six process perspectives that can be applied in this context. The behavioral perspective includes elements such as the correct process workflow or sequence, legal regulations, and internal requirements. The organizational perspective focuses on the personnel involved in process execution, including process owners, administrators, and users. The underlying system, such as the IT environment, is also part of this perspective. The functional perspective encompasses concrete process steps, tasks, and events. In industrial settings, many processes involve multiple machines, tools, and software applications, which can be described from an operational perspective. The data perspective involves all data and documents necessary for process execution. Lastly, the locational perspective describes the specific locations of process entities, such as machines or workers.

6 Creation of initial patterns

Once the metamodel was designed, it was used to illustrate an initial set of patterns. For the pattern derivation, seven practitioners from three multinational industrial organizations were engaged. Their roles included technical project managers, IT managers, automation experts, and digitalization managers, and they were responsible for overseeing IIoT projects within their respective organizations. More details about these experts can be found in Table 1.

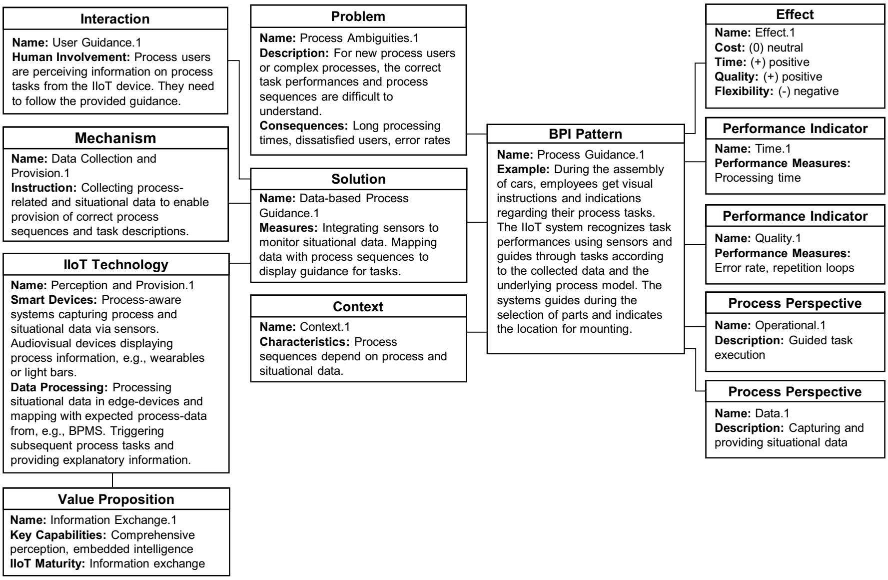
During their analysis, the practitioners identified 34 IIoT applications with BPI propositions that were assessed as suitable for further examination. In a collaborative workshop conducted via video conference in February 2021, six distinct patterns were derived and illustrated using the provided metamodel. These patterns are *Process Guidance*, *Derivation Detection*, *Authentication and Authorization*, *Task Distribution*, and *Activity Automation*. In the following subsections, they are briefly described.

In general, the pattern definition is a creative procedure that is based primarily on underlying data. For example, several different IIoT use cases could be an appropriate basis for this purpose. The actual derivation, or discovering, of patterns could be based on classification or coding techniques. The techniques of open, axial, and selective coding are particularly suitable for this.

6.1 Process guidance

The first pattern *Process Guidance* (see Fig. 7) provides a generic description of applications that focus on enhanced user guidance within a business process. By capturing situational and process-related data, these applications determine the current state of the process and identify the subsequent tasks. The identified tasks can then be displayed to the process participants, for example, through wearables or displays. This pattern primarily affects the operational and data perspectives, involving input and output data to influence task performance.

The smart devices employed in this pattern are process-aware, as they are responsible for capturing process-related data, processing it, and providing it to the process participants based on the current process state. An example mentioned in the pattern is from an automotive organization where employees receive visual instructions and indications that guide them through each process task. The IIoT system, with its integrated sensors, comprehensive perception, and embedded intelligence, enables tracking of the actual process flow. This allows for the provision of information about the current task using different colored light bars,



Interaction
Name: User Guidance.1
Human Involvement: Process users are perceiving information on process tasks from the IIoT device. They need to follow the provided guidance.

Mechanism
Name: Data Collection and Provision.1
Instruction: Collecting process-related and situational data to enable provision of correct process sequences and task descriptions.

IIoT Technology
Name: Perception and Provision.1
Smart Devices: Process-aware systems capturing process and situational data via sensors. Audiovisual devices displaying process information, e.g., wearables or light bars.
Data Processing: Processing situational data in edge-devices and mapping with expected process-data from, e.g., BPMS. Triggering subsequent process tasks and providing explanatory information.

Value Proposition
Name: Information Exchange.1
Key Capabilities: Comprehensive perception, embedded intelligence
IIoT Maturity: Information exchange

Problem
Name: Process Ambiguities.1
Description: For new process users or complex processes, the correct task performances and process sequences are difficult to understand.
Consequences: Long processing times, dissatisfied users, error rates

Solution
Name: Data-based Process Guidance.1
Measures: Integrating sensors to monitor situational data. Mapping data with process sequences to display guidance for tasks.

Context
Name: Context.1
Characteristics: Process sequences depend on process and situational data.

BPI Pattern
Name: Process Guidance.1
Example: During the assembly of cars, employees get visual instructions and indications regarding their process tasks. The IIoT system recognizes task performances using sensors and guides through tasks according to the collected data and the underlying process model. The systems guides during the selection of parts and indicates the location for mounting.

Effect
Name: Effect.1
Cost: (0) neutral
Time: (+) positive
Quality: (+) positive
Flexibility: (-) negative

Performance Indicator
Name: Time.1
Performance Measures: Processing time

Performance Indicator
Name: Quality.1
Performance Measures: Error rate, repetition loops

Process Perspective
Name: Operational.1
Description: Guided task execution

Process Perspective
Name: Data.1
Description: Capturing and providing situational data

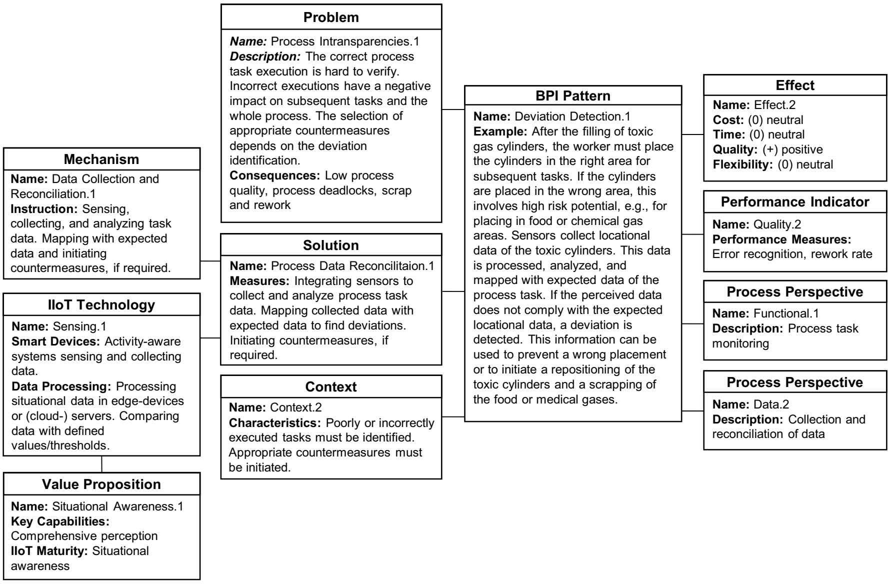
Fig. 7 Process guidance pattern

for instance. Implementing this pattern has shown improvements in processing time and decreased error rates and repetition loops.

An exemplary literature application of this kind is the training of new employees in a manufacturing organization. Employees are guided through process tasks by tracking the current process data and visualizing process descriptions of subsequent tasks. Other organizations have implemented applications to guide employees through production or logistic processes by capturing environmental and process data, processing it, matching it with process models, and providing guidance for tasks (De Vries et al. 2015).

6.2 Deviation detection

The second pattern *Deviation Detection* is illustrated using a gas bottle filling process in the chemical industry, as seen in Fig. 8. The primary challenge faced by organizations is to detect process deviations during runtime, allowing them to identify incorrect task executions and appropriately adjust the subsequent process flows. Deviations in the process can result in low process quality, process deadlocks, or the need for process support. In the case of the gas bottle filling process, it is crucial to ensure that after filling the toxic gas bottles, they are placed in the correct areas as specified by the process description. Incorrect task executions in this context carries a high-risk potential. To address this, the pattern proposes implementing location sensors that collect task execution data and compare it with the expected values derived from the process description. By analyzing this data, deviations from the expected behavior can be detected.



Problem
Name: Process Intransparencies.1
Description: The correct process task execution is hard to verify. Incorrect executions have a negative impact on subsequent tasks and the whole process. The selection of appropriate countermeasures depends on the deviation identification.
Consequences: Low process quality, process deadlocks, scrap and rework

Mechanism
Name: Data Collection and Reconciliation.1
Instruction: Sensing, collecting, and analyzing task data. Mapping with expected data and initiating countermeasures, if required.

IIoT Technology
Name: Sensing.1
Smart Devices: Activity-aware systems sensing and collecting data.
Data Processing: Processing situational data in edge-devices or (cloud-) servers. Comparing data with defined values/thresholds.

Value Proposition
Name: Situational Awareness.1
Key Capabilities: Comprehensive perception
IIoT Maturity: Situational awareness

Solution
Name: Process Data Reconcilitaion.1
Measures: Integrating sensors to collect and analyze process task data. Mapping collected data with expected data to find deviations. Initiating countermeasures, if required.

Context
Name: Context.2
Characteristics: Poorly or incorrectly executed tasks must be identified. Appropriate countermeasures must be initiated.

BPI Pattern
Name: Deviation Detection.1
Example: After the filling of toxic gas cylinders, the worker must place the cylinders in the right area for subsequent tasks. If the cylinders are placed in the wrong area, this involves high risk potential, e.g., for placing in food or chemical gas areas. Sensors collect locational data of the toxic cylinders. This data is processed, analyzed, and mapped with expected data of the process task. If the perceived data does not comply with the expected locational data, a deviation is detected. This information can be used to prevent a wrong placement or to initiate a repositioning of the toxic cylinders and a scrapping of the food or medical gases.

Effect
Name: Effect.2
Cost: (0) neutral
Time: (0) neutral
Quality: (+) positive
Flexibility: (0) neutral

Performance Indicator
Name: Quality.2
Performance Measures: Error recognition, rework rate

Process Perspective
Name: Functional.1
Description: Process task monitoring

Process Perspective
Name: Data.2
Description: Collection and reconciliation of data

Fig. 8 Deviation detection pattern

This detection enables the initiation of countermeasures and improved error recognition rate, positively impacting the overall process quality. The pattern addresses the functional and data perspectives as the execution of the process task is monitored. The IIoT technology includes activity-aware smart devices that process situational data on edge devices or (hybrid) cloud servers. To identify deviations of any kind, the key capability of comprehensive perception must be exploited to enable situational awareness of all process details. The implemented pattern improves process quality in terms of increased error recognition rate and decreased rework rate. Similar industrial applications can be found to detect machine failures where sensor data is used for diagnostics and detection of deviations, e.g., at leakage detection (Ammirato et al. 2019) or other anomalies (Schneider et al. 2019).

6.3 Authentication and authorization

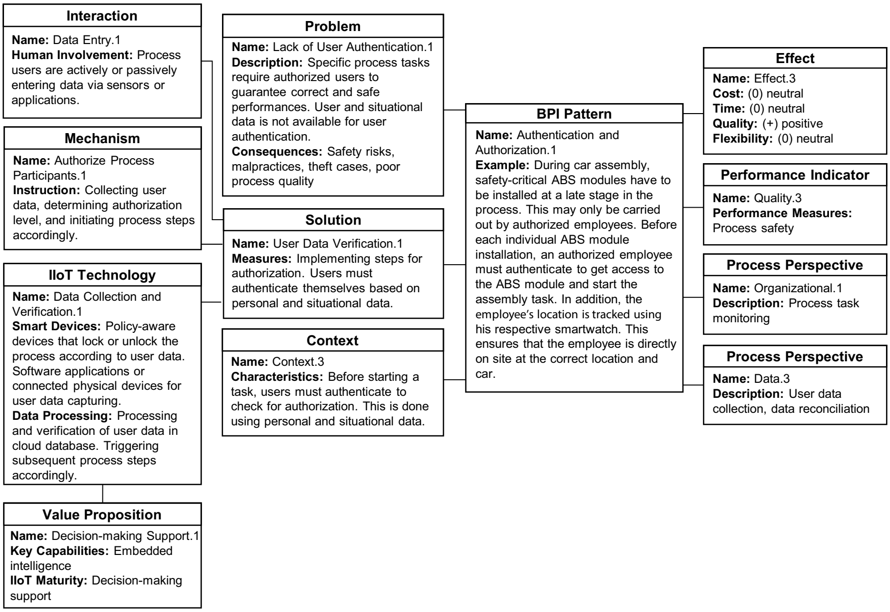
Many business processes require authorized users to guarantee process safety and quality. Thus, potential users must authenticate their identity to check if they are authorized to perform specific tasks. The third pattern *Authentication and Authorization* solves this challenge. The exemplary process is taken from a car assembly process of a major automotive organization. During the assembly process, the safety–critical anti-lock braking system (ABS) module must be correctly placed, fixed, and connected to the car. As this should only be performed by trained personnel, authorization is required. The employee must authenticate to access the respective ABS module storage container. This container is only unlocked if the user has authenticated himself with valid credentials and the employee's location is directly at the respective car. This can be done using smartwatches or other personal IIoT devices (Fig. 9).

The pattern mainly influences the organizational and data process perspectives, as user and process data are collected and used for authenticating the process participant. This has a highly positive impact on process quality as it improves the overall process safety. Similar IIoT applications can be identified in several industry applications aiming at checking customer authorization and authenticating employees in the production area or the logistics sector. For instance, the material handling of special products is only allowed for trained personnel, wherefore an authentication is necessary (De Souza et al. 2020).

6.4 Task distribution

The fourth pattern *Task Distribution* originates from the problem of automated and efficient allocation of process tasks to a multitude of process users with specific knowledge and skills. In the corrugation industry, the different production process tasks must be distributed to workers according to their situational and personal characteristics. This is performed by capturing data on their current location, fatigue, skills, and competencies and matching it with process task requirements (Fig. 10).

The parameters can be mapped with the task data by processing data from activity-aware systems on edge or cloud devices. The task can be displayed via



Interaction
Name: Data Entry.1
Human Involvement: Process users are actively or passively entering data via sensors or applications.

Mechanism
Name: Authorize Process Participants.1
Instruction: Collecting user data, determining authorization level, and initiating process steps accordingly.

IIoT Technology
Name: Data Collection and Verification.1
Smart Devices: Policy-aware devices that lock or unlock the process according to user data. Software applications or connected physical devices for user data capturing.
Data Processing: Processing and verification of user data in cloud database. Triggering subsequent process steps accordingly.

Value Proposition
Name: Decision-making Support.1
Key Capabilities: Embedded intelligence
IIoT Maturity: Decision-making support

Problem
Name: Lack of User Authentication.1
Description: Specific process tasks require authorized users to guarantee correct and safe performances. User and situational data is not available for user authentication.
Consequences: Safety risks, malpractices, theft cases, poor process quality

Solution
Name: User Data Verification.1
Measures: Implementing steps for authorization. Users must authenticate themselves based on personal and situational data.

Context
Name: Context.3
Characteristics: Before starting a task, users must authenticate to check for authorization. This is done using personal and situational data.

BPI Pattern
Name: Authentication and Authorization.1
Example: During car assembly, safety-critical ABS modules have to be installed at a late stage in the process. This may only be carried out by authorized employees. Before each individual ABS module installation, an authorized employee must authenticate to get access to the ABS module and start the assembly task. In addition, the employee's location is tracked using his respective smartwatch. This ensures that the employee is directly on site at the correct location and car.

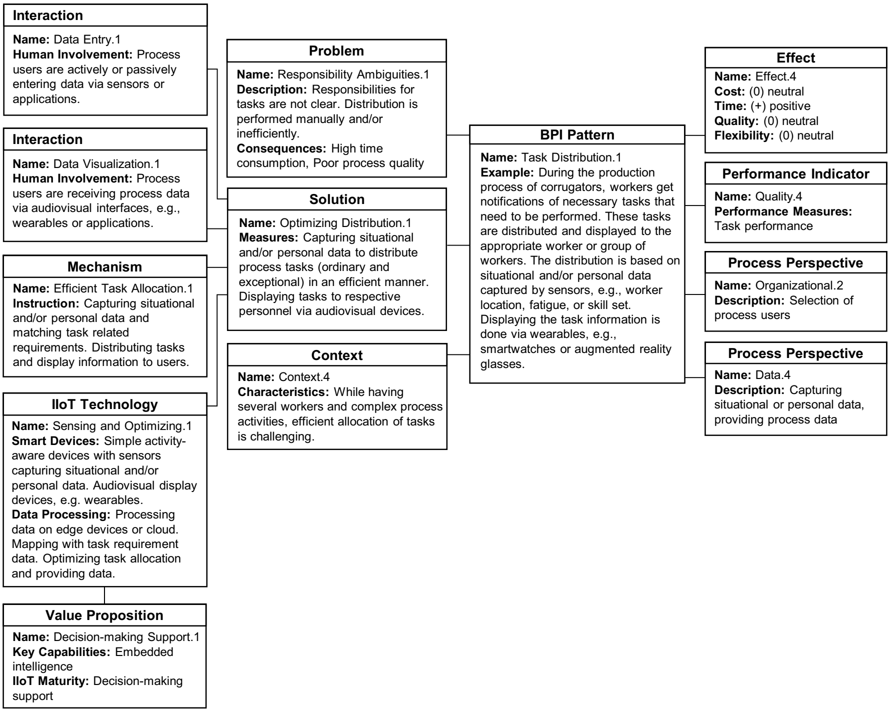
Effect
Name: Effect.3
Cost: (0) neutral
Time: (0) neutral
Quality: (+) positive
Flexibility: (0) neutral

Performance Indicator
Name: Quality.3
Performance Measures: Process safety

Process Perspective
Name: Organizational.1
Description: Process task monitoring

Process Perspective
Name: Data.3
Description: User data collection, data reconciliation

Fig. 9 Authentication and authorization pattern



Interaction
Name: Data Entry.1
Human Involvement: Process users are actively or passively entering data via sensors or applications.

Interaction
Name: Data Visualization.1
Human Involvement: Process users are receiving process data via audiovisual interfaces, e.g., wearables or applications.

Mechanism
Name: Efficient Task Allocation.1
Instruction: Capturing situational and/or personal data and matching task related requirements. Distributing tasks and display information to users.

IIoT Technology
Name: Sensing and Optimizing.1
Smart Devices: Simple activity-aware devices with sensors capturing situational and/or personal data. Audiovisual display devices, e.g. wearables.
Data Processing: Processing data on edge devices or cloud. Mapping with task requirement data. Optimizing task allocation and providing data.

Value Proposition
Name: Decision-making Support.1
Key Capabilities: Embedded intelligence
IIoT Maturity: Decision-making support

Problem
Name: Responsibility Ambiguities.1
Description: Responsibilities for tasks are not clear. Distribution is performed manually and/or inefficiently.
Consequences: High time consumption, Poor process quality

Solution
Name: Optimizing Distribution.1
Measures: Capturing situational and/or personal data to distribute process tasks (ordinary and exceptional) in an efficient manner. Displaying tasks to respective personnel via audiovisual devices.

Context
Name: Context.4
Characteristics: While having several workers and complex process activities, efficient allocation of tasks is challenging.

BPI Pattern
Name: Task Distribution.1
Example: During the production process of corrugators, workers get notifications of necessary tasks that need to be performed. These tasks are distributed and displayed to the appropriate worker or group of workers. The distribution is based on situational and/or personal data captured by sensors, e.g., worker location, fatigue, or skill set. Displaying the task information is done via wearables, e.g., smartwatches or augmented reality glasses.

Effect
Name: Effect.4
Cost: (0) neutral
Time: (+) positive
Quality: (0) neutral
Flexibility: (0) neutral

Performance Indicator
Name: Quality.4
Performance Measures: Task performance

Process Perspective
Name: Organizational.2
Description: Selection of process users

Process Perspective
Name: Data.4
Description: Capturing situational or personal data, providing process data

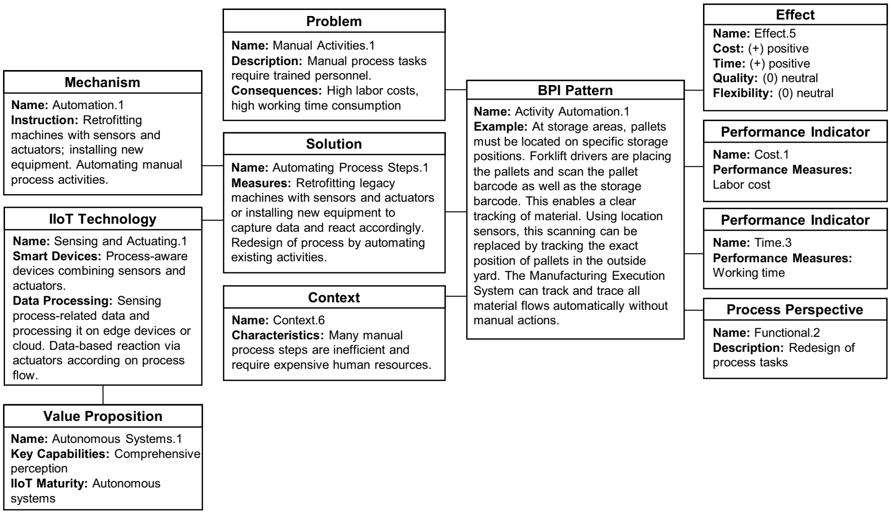
Fig. 10 Task distribution pattern

wearables, e.g., smartwatches or other audiovisual devices, when distributed to a specific worker. This improves the process quality, as the most appropriate person performs the tasks. The pattern can also be identified along whole supply chains to achieve an IIoT-enabled task allocation optimization. By performing information-driven dynamic optimizations based on IIoT data, the distribution of logistics tasks along the supply chain entities can be significantly improved (Liu et al. 2018).

6.5 Activity automation

Replacing manual process tasks with automated tasks contains significant benefits for organizations. As manual process steps require trained personnel, it is associated with high labor costs and high working time consumption. The fifth pattern *Activity Automation* addresses this problem. The example described in Fig. 11 is taken from the manufacturing industry. Here, forklift drivers needed to manually scan pallet barcodes and storage location barcodes to enable effective material tracking. Using location sensors and providing this information to overarching control systems can enable automated tracking and tracing. Sensors capture location data that is processed on edge devices or cloud services. Based on the data input, mechanical or software-based reactions can simulate manual activities. These systems form rather complex process-aware IIoT devices that can reduce labor costs, working time, and overall processing time. As the IIoT technology redesigns the actual process flow, it mainly influences the functional process perspective.

The pattern has a positive impact on labor costs as well as working time consumption. Improving business processes by automating activities is one of the literature's most relevant and frequent patterns. Several use cases have been identified during the literature review describing autonomous systems containing high-complexity IIoT systems. Li et al. (2017), e.g., describe a fully autonomous system in



Mechanism
Name: Automation.1
Instruction: Retrofitting machines with sensors and actuators; installing new equipment. Automating manual process activities.

IIoT Technology
Name: Sensing and Actuating.1
Smart Devices: Process-aware devices combining sensors and actuators.
Data Processing: Sensing process-related data and processing it on edge devices or cloud. Data-based reaction via actuators according on process flow.

Value Proposition
Name: Autonomous Systems.1
Key Capabilities: Comprehensive perception
IIoT Maturity: Autonomous systems

Problem
Name: Manual Activities.1
Description: Manual process tasks require trained personnel.
Consequences: High labor costs, high working time consumption

Solution
Name: Automating Process Steps.1
Measures: Retrofitting legacy machines with sensors and actuators or installing new equipment to capture data and react accordingly. Redesign of process by automating existing activities.

Context
Name: Context.6
Characteristics: Many manual process steps are inefficient and require expensive human resources.

BPI Pattern
Name: Activity Automation.1
Example: At storage areas, pallets must be located on specific storage positions. Forklift drivers are placing the pallets and scan the pallet barcode as well as the storage barcode. This enables a clear tracking of material. Using location sensors, this scanning can be replaced by tracking the exact position of pallets in the outside yard. The Manufacturing Execution System can track and trace all material flows automatically without manual actions.

Effect
Name: Effect.5
Cost: (+) positive
Time: (+) positive
Quality: (0) neutral
Flexibility: (0) neutral

Performance Indicator
Name: Cost.1
Performance Measures: Labor cost

Performance Indicator
Name: Time.3
Performance Measures: Working time

Process Perspective
Name: Functional.2
Description: Redesign of process tasks

Fig. 11 Activity automation pattern

which the production object can automatically coordinate with the production and transportation machines and plan an optimal production process. The object to be processed is equipped with a microchip for this purpose and can receive individual production instructions from the cloud to enable a maximally flexible and fully automated process. Other examples describe the automation of whole activities within food supply chains (Pang et al. 2015). This comprehensive study shows the bandwidth of application possibilities of this pattern.

7 Summary evaluation

To evaluate the *usefulness* of the patterns and the underlying metamodel, they were applied in a real-world case study at a leading market player in the chemical products industry. In this respect, a project team used the patterns to develop a novel distribution channel for chemical products in the Scandinavian region, and thus, fundamentally improving the existing distribution processes. The summative evaluation aimed to assess if the research approach enabled a systematic and successful identification, specification, and implementation of IIoT-based BPI applications. This directly refers to the formulated RQ1 and the prevalent challenges that industrial organizations face.

7.1 Use case setup

Changing customer behavior and expectations have presented substantial challenges for the case study organization within the Scandinavian region. Previously, customers were limited to purchasing products exclusively over the counter from certified retailers or via vending machines. However, these two primary distribution channels were no longer sufficient to cater to the diverse needs of both private and business customers. Nowadays, customers expect online services, a single standardized distribution process, 24/7 availability, or extensive guidance. These and other customer requirements were identified within an extensive survey. Although each of the two channels brings certain advantages, none combines all requirements. As a result, a comprehensive redesign and improvement project regarding the distribution channels and the underlying processes was initiated.

Initially, the organization formed an interdisciplinary project team comprising seven individuals, i.e., process owners, sales staff, engineers, and IT specialists. The authors of this article remained in a consulting position. The initiative commenced in 2019 and concluded in 2022, culminating in a thoroughly new distribution channel, including a redesigned distribution process. Based on the customer survey, a set of design objectives had been derived that constitute fundamental requirements for the new distribution process. The novel solution should be automated, stable, economical, scalable, and enable online services and features. Furthermore, it should replace the existing distribution channels in the long run while combining both advantages.

7.2 Developing the smart vending cabinet

A comprehensive technology analysis determined that the IIoT's capabilities could facilitate the design and implementation of the envisioned distribution channel. Nonetheless, a systematic approach was essential to successfully identify suitable IIoT solutions aligned with the design objectives. In this respect, the presented patterns for IIoT-based BPI applications were applied. During a series of workshops, the design objectives were thoroughly examined and mapped with the pattern catalog. Beginning with detailed descriptions of the design objectives, the team diligently sought problem descriptions within the patterns to address them. Eventually, four patterns were successfully identified, facilitating the attainment of all design objectives. A combination of hardware and software design and development was required to realize the newly designed distribution channel, referred to as the *Smart Vending Cabinet*.

The Smart Vending Cabinet comprises five essential components: a standard 20-feet container, a modular IIoT kit encompassing sensors, actuators, and relays, as well as edge nodes, a cloud server hosting the business process management system (BPMS), offering APIs and handling the analysis and storage of IIoT data for multiple services. The 20-feet container was outfitted with the IIoT sensor and actuator kit, providing sufficient space to accommodate a diverse range of chemical products. It operates autonomously, without needing on-site sales representatives, and adheres to the location requirements of traditional vending machines. This new distribution channel and the novel distribution process are explained in the following.

The first step within the new distribution process is the purchase of chemical products by the customer. Customers can search for specific products at their nearest Smart Vending Cabinet location using an already existing smartphone application. Subsequently, the customers must be physically present at the appropriate location and request access to the cabinet. The cabinet leverages the *Authentication and Authorization* pattern to detect the customer's presence via Bluetooth. The cabinet door is opened by actuators only if the customer has placed a purchase order, ensuring costefficiency by eliminating the need for additional human interfaces. This is based on the *Activity Automation* pattern. These process steps are illustrated in Fig. 12 on the left.

Once the cabinet door is open, the customer is presented with the purchased product and can proceed to remove it. The *Process Guidance* pattern uses lightbars to visually guide the customer to the correct product. This feature proves particularly helpful for customers who are new to the process or unfamiliar with the products. Figure 12 in the center illustrates this step.

To ensure a stable and adaptable process, errors are detected and communicated to the customer using the *Deviation Detection* pattern. For instance, if a customer mistakenly removes the wrong product, the lightbar changes to red, and push messages are sent to the customer's smartphone. The customer receives instructions through the lightbars and the smartphone application to rectify the error. Figure 12 on the right shows two exemplary push notifications. The first indicates that the customer has retrieved the wrong product and should return it to the respective slot. The second

Error at Product Retrieval
You retrieved a wrong product. Please place the cylinder back in slot 16. The red light indicates the correct slot.

Error at Cabinet Locking
Locking of cabinet failed. Please ensure that the cabinet doors are closed properly.

Fig. 12 Smart vending cabinet application

notification alerts the customer that the cabinet was not closed correctly after retrieving the product.

7.3 Results and evaluation

The Smart Vending Cabinet is currently in the rollout phase, with seven existing locations in May 2023. An initial customer survey revealed a significant increase in satisfaction levels. Even customers who had previously relied on a single established distribution channel expressed their satisfaction with the new channel and indicated a preference for it in the future. For the industrial organization, a first analysis showed a 36% decrease in distribution costs compared to the retailer process and 9% compared to vending machines. This is due to lower personnel and maintenance costs compared with the legacy channels.

To evaluate the usefulness of the developed patterns, the authors conducted semi-structured interviews with all project team members. In this regard, the interview questions were formulated to indicate the effectiveness and applicability of the patterns. The interviews showed consistently positive feedback and confirmed the usefulness of the patterns. Particular emphasis was placed on their support for developing IIoT-based technical solutions to existing design objectives. Thanks to the generic representation, the project participants could apply the patterns well to the real scenario and map the exemplary descriptions with the scenario at the chemical organization. In general, the case study proved the usefulness of the metamodel and patterns, wherefore the research approach is critically discussed in the subsequent section.

8 Discussion

Existing research does not provide adequate support for the identification of IIoT applications that enable appropriate BPI. Furthermore, the precise definition of the "Act of Improvement," i.e., how existing business processes are precisely transformed to the improved target state through IIoT integration, remains elusive in most cases. To address these challenges and expand the understanding of IIoT, a metamodel of IIoT-based BPI and an initial set of five patterns were developed. The subsequent subsections outline the theoretical and practical contributions and implications that emerged during the development, demonstration, and evaluation activities. Additionally, the limitations of the research endeavor are presented to provide a comprehensive perspective.

8.1 Theoretical contributions and implications

From a theoretical perspective, this article offers insights into the role of IIoT as an enabler for impactful BPI. The theoretical contribution lies in developing a metamodel that encompasses the essential elements and relationships between IIoT and BPI. The core theoretical implications of the article can be summarized into two main aspects: enhancing the descriptive knowledge of IIoT and BPI and establishing a foundation for future research on patterns.

As a theoretical theory and design artifact, the metamodel and patterns complement the existing descriptive knowledge on IIoT and BPI. Rather than solely emphasizing technology-related characteristics, they also focus on process-related problems. By highlighting the process-related view of IIoT applications, the metamodel and patterns introduce novel perspectives to the predominantly technical and engineering-centric understanding of IIoT. Consequently, they provide a foundation for theory-led design and sense-making (Gregor and Hevner 2013).

The primary objective of the developed metamodel is to serve as a basis for creating and illustrating a comprehensive pattern catalog. Such a catalog would be supportive in specifying, identifying, and implementing IIoT applications more effectively and systematically.

8.2 Practical contributions and implications

The metamodel and patterns offer relevant and applicable insights in real-world scenarios, addressing a gap in existing studies on IIoT. Previous research and surveys among managers have revealed that many IIoT projects remain in the proof of concept or early planning stages and frequently fall short of delivering the anticipated benefits. This underscores the need for support during the project execution phases, including identification, specification, and implementation. In this context, the demonstration and evaluation of the metamodel have highlighted two practical implications.

Firstly, utilizing patterns based on the developed metamodel enables managers to explore and identify suitable IIoT applications. The patterns include descriptions of the underlying process problems, the affected process performance indicators, the impact on process perspectives, and generic illustrations of potential solutions. This might facilitate a goal- and process-oriented identification of applications. Additionally, the patterns help prevent the development of misguided expectations for IIoT projects by clearly describing the benefits derived from the processes. This could also prevent the implementation of poorly planned or erroneously selected projects.

Secondly, the instantiation of the "Act of Improvement" poses a significant challenge for industrial organizations. Moving from a detailed specification to a final implementation involves various complexities, surprises, and hurdles that must be managed. The patterns could support this demanding project phase by describing critical mechanisms and interconnections between the existing problem and the intended solution.

8.3 Limitations

While the research conducted for this article aimed to be thorough and rigorous, it is essential to acknowledge its limitations. First, the application of the patterns is not necessarily limited to IIoT domain, as the distinction between IIoT and IoT is not always clear. Therefore, in many cases, the patterns could also be applied outside the IIoT domain. Nevertheless, the classes and attributes of the patterns are directly referring to scenarios in the industrial area.

In addition, some patterns could be related to challenges and topics of other BPM research fields. For example, pattern *Deviation Detection* could be related to conformance checking. The actual state of a process, often recorded by sensors, is compared with the target state. Deviations are reported accordingly. In conformance checking, a process model is compared with an event log. Consequently, the technique of conformance checking is one way of implementing the pattern, whereby of course the entire IIoT part including sensors and data must be considered.

Regarding pattern *Activity Automation*, a connection could be drawn to Robotic Process Automation (RPA). Yet, RPA only concerns software bots or AI agents, while the entire physical automation potential within processes is neglected. The pattern, however, includes the physical part.

Furthermore, the chosen inductive approach for metamodeling is a well-established concept that offers several advantages by building upon actual observations. However, it is important to note that the underlying SLR may not encompass all available data on the phenomenon being investigated. The selected databases constrained the identification of relevant literature and formulated queries. To mitigate this subjectivity, a comprehensive Delphi study was conducted, which allowed for a formative evaluation and the inclusion of broad expert knowledge.

Another limitation pertains to the type of artifact developed in this research. While the metamodel effectively structures and illustrates essential aspects, facets, and elements of IIoT and BPI, it does not explicitly offer procedural guidance in methods (Hevner et al. 2004). Future research would benefit from developing a methodological artifact to provide explicit guidance throughout project execution phases and activities.

Furthermore, it is crucial to recognize that creating additional patterns should be viewed as an ongoing research endeavor. Technological advancements inevitably lead to new propositions for BPI. Therefore, continuously exploring and developing patterns remains a vital area of investigation.

Ultimately, the metamodel and patterns must be applied in practical scenarios. Until now, the impact of the design artifacts on practice is not clear and there is no scientifically grounded evidence for its usefulness.

9 Conclusion

This article addresses the existing research gap concerning the systematic and successful conduction of IIoT projects with BPI prospects. Insights from industry studies and current literature highlight the need for descriptive design artifacts that practitioners can use. To address this issue, a generic metamodel was developed that contains all indispensable elements of IIoT-based BPI applications. On this basis, patterns can be illustrated that represent applicable blueprints or templates that can be mapped with actual business processes. The research approach was based on the principles for DSR and followed the methodology proposed by Peffers et al. (2007).

First, the metamodel of IIoT-based BPI was developed. The development process involved two iterations, starting with adapting a base metamodel of BPI by Falk et al. (2013). Through an inductive development iteration, which included an SLR followed by open and axial coding, additional classes and attributes were incorporated into the metamodel based on the findings. In the second iteration, a Delphi study involving nine experts from academia and industry was conducted to refine the metamodel. This enabled the inclusion of external expert knowledge into the development. Subsequently, a first set of patterns was illustrated using the final metamodel. Practitioners from three multinational organizations analyzed 34 real-life IIoT applications in their respective business areas and used the insights to derive five concrete patterns.

These patterns were introduced to a market-leading chemical organization to conduct a summative evaluation of the research approach. An interdisciplinary project team used the patterns to fundamentally redesign and improve the existing distribution processes in the Scandinavian region. The successful project execution and the positive feedback proved the usefulness of the research approach and that it effectively tackled the formulated research questions.

Due to the generic representation of the patterns and the lack of separation within all IoT domains, the patterns can also be used in other domains. This could concern the domains Smart Health, Smart City, but also Smart Home and others. In this case, the patterns would have to be considered in detail and domain-specific adaptations would have to be carried out.

The authors express confidence that both the metamodel and the initial set of patterns contribute to extending and advancing existing knowledge, serving as valuable tools for researchers and practitioners. The positive summative evaluations showed that the patterns have the potential to be utilized by industrial organizations of various types. Furthermore, future research should engage in extending the existing set of patterns to create a comprehensive catalog.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10257-024-00676-0.

Funding Open Access funding enabled and organized by Projekt DEAL. No funding was received to assist with the preparation of this manuscript.

Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

References

Alexander C (1977) A pattern language: towns, buildings, construction. Oxford University Press, New York

Ammirato A, Sofo F, Felicetti AM, Raso C (2019) The potential of IoT in redesigning the bank branch protection system: an Italian case study. Bus Process Manag J. https://doi.org/10.1108/BPMJ-04-2018-0099

Anosike A, Alafropatis K, Garza-Reyes JA, Kumar A, Luthra S, Rocha-Lona L (2021) Lean manufacturing and internet of things—a synergetic or antagonist relationship? Comput Ind. https://doi.org/10.1016/j.compind.2021.103464

Arnold C, Kiel D, Voigt K (2016) How the industrial internet of things changes business models in different manufacturing industries. Int J Innov Manag. https://doi.org/10.1142/S1363919616400156

Atzori L, IERA A, Morabito G (2010) The internet of things: a survey. Comput Netw. https://doi.org/10.1016/j.comnet.2010.05.010

Beverungen D, Buijs J, Becker J et al (2020) Seven paradoxes of business process management in a hyper-connected world. Bus Inf Syst Eng. https://doi.org/10.1007/s12599-020-00646-z

Bosche A, Crawford D, et al (2016) How providers can succeed in the internet of things. Bain and Company Inc. https://www.bain.com/insights/how-providers-can-succeed-in-the-internet-of-things/

Boyes H, Hallaq B, Cunningham J, Watson T (2018) The industrial internet of things (IIoT): an analysis framework. Comput Ind. https://doi.org/10.1016/j.compind.2018.04.015

Chui M, Loffler M, Roberts R (2010) The internet of things. McKinsey Q 2(2):1–9

Corbin JM, Strauss A (1990) Grounded theory research: procedures, canons, and evaluative criteria. Qual Sociol. https://doi.org/10.1007/BF00988593

De Souza CA, Szafir-Goldstein C, Aagaard A (2020) IoT in the context of digital transformation and business model innovation: the case of a traditional Brazilian wholesale. In: 2020 global internet of things summit. GIoTS. https://doi.org/10.1109/GIOTS49054.2020.9119527

De Vries J, de Koster R, Stam D (2015) Exploring the role of picker personality in predicting picking performance with pick by voice, pick to light and RF-terminal picking. Int J Prod Res. https://doi.org/10.1080/00207543.2015.1064184

Del Giudice M (2016) Discovering the internet of things (IoT) within the business process management: a literature review on technological revitalization. Bus Process Manag J. https://doi.org/10.1108/BPMJ-12-2015-0173

DIN SPEC 91345 (2016) Reference architecture model industrie 4.0 (RAMI4.0). https://www.beuth.de/en/technical-rule/din-spec-91345/250940128

Drechsler K, Grisold T, Seidel S (2022) Cascading digital options and the evolution of digital infrastructures: the case of IIoT. In: Proceedings of the 2022 International Conference on Information Systems (ICIS)

Dumas M, La Rosa M, Mendling M, Reijers HA (2018) Fundamentals of business process management. Springer-Verlag, Berlin

Falk T, Griesberger P, Johannsen F, Leist S (2013) Patterns for business process improvement—a first approach. In: 21st European conference on information systems. ECIS. https://doi.org/10.18151/7217407

Fescioglu-Unver N, Choi HS, Sheen D, Kumara S (2015) RFID in production and service systems: technology, applications and issues. Inf Syst Front. https://doi.org/10.1007/s10796-014-9518-1

Forster F (2006) The idea behind business process improvement: toward a business process improvement pattern framework. BP Trends 4. https://www.alexandria.unisg.ch/entities/publication/252d0bdb-3ccc-468b-aa76-d2621d292e75/details

Fowler M (1996) Analysis patterns: reusable object models. Addison-Wesley, Boston

Gamma E, Helm R, Johnson R, Vlissides J (1994) Design patterns: elements of reusable object-oriented software. Prentice Hall, Hoboken

Gonzalez-Perez C, Henderson-Sellers B (2008) Metamodelling for software engineering. Wiley, Hoboken

Gregor S, Hevner AR (2013) Positioning and presenting design science research for maximum impact. MIS Q. https://doi.org/10.25300/MISQ/2013/37.2.01

Haller S, Karnouskos S, Schroth C (2009) The internet of things in an enterprise context. In: Domingue J, Fensel D, Traverso P (eds) FIS 2008, first future internet symposium: lecture notes in computer science, vol 5468. Springer, Berlin

Hempel CG (1966) Philosophy of natural science. Prentice-Hall, Upper Saddle River

Hevner AR, March ST, Park J, Ram S (2004) DS in information systems research. MIS Q 28(1):75–105

Hohpe G, Woolf B (2003) Enterprise integration patterns: designing, building, and deploying messaging solutions. Addison Wesley, Boston

Industry IoT Consortium (2022) The industrial internet reference architecture. https://www.iiconsortium.org/wp-content/uploads/sites/2/2022/11/IIRA-v1.10.pdf

Jablonski S, Bussler C (1996) Workflow management: modeling concepts, architecture and implementation. Cengage Learning EMEA, Andover

Janiesch C, Koschmider A et al (2020) The internet of things meets business process management: a manifesto. IEEE Trans Syst Man Cybern Syst. https://doi.org/10.1109/MSMC.2020.3003135

Kortuem G, Kawsar F, Sundramoorthy V, Fitton D (2010) Smart objects as building blocks for the internet of things. IEEE Internet Comput. https://doi.org/10.1109/MIC.2009.143

Li Y, Hou M, Liu H, Liu Y (2012) Towards a theoretical framework of strategic decision, supporting capability and information sharing under the context of Internet of Things. J Inf Technol Manag 13:205–216

Li Z, Liu G, Liu L, Lai X, Xu G (2017) IoT-based tracking and tracing platform for prepackaged food supply chain. Ind Manag Data Syst. https://doi.org/10.1108/IMDS-11-2016-0489

Liu V (2017) Business benefits of the internet of things: Gartner report. Gartner Inc. https://www.gartner.com/en/documents/3806366/business-benefits-of-the-internet-of-things-a-gartner-tr

Liu S, Zhang G, Wang L (2018) IoT-enabled dynamic optimisation for sustainable reverse logistics. Procedia CIRP. https://doi.org/10.1016/j.procir.2017.11.088

Loo R (2002) The Delphi method: a powerful tool for strategic management. Policing. https://doi.org/10.1108/13639510210450677

Minerva R, Biru A, Rotondi D (2015) Towards a definition of the internet of things (IoT). IEEE. https://iot.ieee.org/definition.html

Ng I, Wakenshaw S (2017) The Internet-of-Things: review and research directions. Int J Res Mark. https://doi.org/10.1016/j.ijresmar.2016.11.003

Object Management Group (2013) OMG Meta Object Facility (MOF) core specification. https://www.omg.org/spec/MOF/2.4.1/PDF

Pang Z, Chen QC, Han W, Zheng L (2015) Value-centric design of the internet-of-things solution for food supply chain: value creation, sensor portfolio and information fusion. Inf Syst Front. https://doi.org/10.1007/s10796-012-9374-9

Patterson RE (2017) Intuitive cognition and models of human-automation interaction. Hum Factors. https://doi.org/10.1177/0018720816659796

Peffers K, Tuunanen T, Rothenberger M, Chatterjee S (2007) A DSR methodology for information systems research. J Manag Inf Syst. https://doi.org/10.2753/MIS0742-1222240302

Reinfurt L, Breitenbücher U, Falkenthal M, et al (2016) Internet of things patterns. In: 21st European Conference on Pattern Languages of Programs. https://doi.org/10.1145/3011784.3011789

Schmidt DC, Stal M, Rohnert H, Buschmann F (2000) Pattern-oriented software architecture. Wiley, Hoboken

Schneider M, Lucke D, Adolf T (2019) A cyber-physical failure management system for smart factories. Procedia CIRP. https://doi.org/10.1016/j.procir.2019.03.052

Serral E, Stede CV, Hasić F (2020) Leveraging IoT in retail industry: a maturity model. In: 22nd conference on business informatics. https://doi.org/10.1109/CBI49978.2020.00020

Sestino A, Prete M, Piper L, Guido G (2020) Internet of things and big data as enablers for business digitalization strategies. Technovation. https://doi.org/10.1016/j.technovation.2020.102173

Sethi P, Sarangi SR (2017) Internet of things: architectures, protocols, and applications. Int J Electr Comput Eng. https://doi.org/10.1155/2017/9324035

Sievers F, Reil H, Rimbeck M, Stumpf-Wollersheim J, Leyer M (2021) Empowering employees in industrial organizations with IoT in their daily operations. Comput Ind. https://doi.org/10.1016/j.compind.2021.103445

Skaržauskienė A, Kalinauskas M (2015) The internet of things: when reality meets expectations. Int J Innov Learning. https://doi.org/10.1504/IJIL.2015.067412

Stoiber C, Schönig S (2021) Process-aware decision support model for integrating internet of things applications using AHP. In: 23rd international conference on enterprise information systems. ICEIS. https://doi.org/10.5220/0010400208690876

Suri K, Gaaloul W, Cuccuru A (2018) Configurable IoT-aware allocation in business processes. In: Ferreira JE, Spanoudakis G, Ma Y, Zhang L-J (eds) Services computing—SCC 2018. Lecture notes in computer science, vol 10969. Springer International Publishing, Cham

Tai Angus Lai C, Jackson PR, Jiang W (2018) Designing service business models of the IoT: Aspects from manufacturing firms. J Math Sci 3(2):7–22

Vom Brocke J, Niehaves A, et al (2009) Reconstructing the giant: on the importance of rigour in documenting the literature search process. In: 17th European conference on information systems, ECIS

Vukšić V, Stjepic A, Vugec D (2021) The intersection between IoT and BPM: systematic literature review. In: Proceedings of FEB Zagreb 12th international odyssey conference on economics and business

Washizaki H, Ogata S, Hazeyama A et al (2020) Landscape of architecture and design patterns for IoT systems. IEEE Internet Things J. https://doi.org/10.1109/JIOT.2020.3003528

Weber B, Reichert M, Rinderle-Ma S (2008) Change patterns and change support features—enhancing flexibility in process-aware information systems. Data Knowl Eng. https://doi.org/10.1016/j.datak.2008.05.001

Winter R, vom Brocke J et al (2009) Patterns in business and information systems engineering. Bus Inf Syst Eng. https://doi.org/10.1007/s12599-009-0073-0

Whitmore A, Agarwal A, Da Xu L, (2015) The Internet of Things—A survey of topics and trends. Inf Syst Front 17:261–274

Yang C, Shen W, Wang X (2018) The internet of things in manufacturing: key issues and potential applications. IEEE Syst Man Cybern Mag. https://doi.org/10.1109/MSMC.2017.2702391

Zhang C, Chen Y, Chen H, Chong D (2021) Industry 4.0 and its implementation: a review. Inf Syst Front. https://doi.org/10.1007/s10796-021-10153-5