Business Process Improvement in Industry 4.0: An Interorganizational Perspective

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Abstract. Industry 4.0 calls for end-to-end digital integration of supply chains and a new boundary-spanning logic of process design. The shift is from shared operation to shared transformation. Design science research was chosen to (1) propose an approach for interorganizational business processes improvement in decentralized contexts of Industry 4.0 (IOBP 4.0) and (2) draft a BPMN extension for IOBP 4.0. The results are relevant to guide the fourth industrial revolution with increasingly shared and digitalized business processes. For theory, our work contributes to the emerging business process management logic of digital transformation: support for coordinated touchpoints, flexible infrastructure, and empowered participants. For practice, we propose a continuous improvement approach for IOBP 4.0 that ensures manufacturing visibility in collaboration networks. Managing the punctuated equilibrium of boundary-spanning business processes will be a priority for this decade.

Keywords: Interorganizational business process · Industry 4.0 · Business process improvement · BPMN extension

1 Introduction

Business process management (BPM) has enabled organizations to move beyond functional boundaries. Much has changed since the pioneer contributions of BPM, but the boundaryless nature of business processes is more evident than ever. Furthermore, in the digital transformation era of industry (alias Industry 4.0 or I4.0), cooperation, communication, and integration within and between organizations become priorities. Therefore, process models representing "how work is done" must support downstream planning of operations, upstream assessment, and decentralized continuous improvement.

Industry 4.0 is leveraged by multiple technologies such as the Internet of Things (IoT), cyber-physical systems, cloud computing, mobile systems, or artificial intelligence shaping the smart factory infrastructure. The overall aim is to integrate and digitalize distributed business processes and redesign supply chains. For example, a company may be manufacturing final products with 3D printers, while, at the same time, their partners produce accessories and raw materials needed to satisfy the customer's order. It is now clear that a new agenda is necessary to promote synergies between BPM and digital innovation in the industry [1, 2].

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The collaborative nature of Industry 4.0 highlights the need to manage interorganizational business processes (IOBP) [3]. The study presented by [4] is an example of this trend. The authors present an approach to merge different process models collaborating in the production of artifacts. However, the resulting process models are often incomplete (e.g., some parts may be private) and challenging to share in organizations that need to compete in collaborative production networks. BPMN (OMG's Business Process Model and Notation - BPMN 2.0) is one of the primary standards in process modeling, including elements like tasks, events, and data objects [5]. However, BPMN cannot represent all the details of interorganizational practices [3]. This shortcoming is particularly relevant in two aspects of decentralized manufacturing: (1) details on the process interfaces with third party entities and (2) the specification of the enabling technologies of digital transformation in Industry 4.0. Therefore, BPMN extensions emerge as a promising solution to extend the vocabulary of the notation [6].

Contacts with industry managers revealed that rudimentary practices are still the norm, with process models (1) created independently by each organization in the supply chain, (2) supported by separate documentation (e.g., procedures and requirement lists), and (3) lacking a boundaryless approach to the design, improvement, and audit of IOBP. Moreover, despite the ISO 9001 requirements to adopt a process approach [7], the traditional focus of quality audits tends to be the internal documentation, missing crucial details in distributed environments. Two research objectives are formulated to address this gap: (1) create the foundations for a BPMN extension, more precisely a Conceptual Domain Model of the Extension (CDME) and (2) devise a set of design principles to continuously improve interorganizational business processes in companies adopting Industry 4.0.

The remainder of this paper is structured as follows. Section 2 presents background literature on Industry 4.0 and business processes. Next, the research approach is introduced. The results of the DSR cycle follow. Afterward, the discussion enumerates design guidelines for IOBP 4.0 design and continuous improvement. Finally, Sect. 6 presents the conclusions, limitations, and an outlook for the future.

2 Background

2.1 Decentralized Manufacturing Networks and Interorganizational Business Processes in the Industry 4.0 Era

Shifting from single-site to multi-site manufacturing comes with the need for decentralized decisions and more complex flows of data and activities. Collaborative networks also call for autonomous teams of humans and machines equipped with advanced computing power. Therefore, new process modeling languages and methods are necessary for the Industry 4.0 era [8]. However, when "parts" of manufacturing processes are enacted in different locations/settings, it is necessary to deal with moments of disruption (e.g., when a new system implemented) and stability [9], exploiting manufacturing capabilities not restricted to a single organization.

Modeling and improvement in BPM are two sides of a single coin, and popular quality standards like ISO 9001:2015 suggest a process approach to management. Following this standard, companies can adopt the PDCA cycle [7] and, for each step in Plan (P) – Do (D) – Check (C) – Act (A), continuously improve their business processes. BPM is "*the art and science of overseeing how work is performed in an organization to ensure consistent outcomes and to take advantage of improvement opportunities*" [10]. However, "*shifting from strategic interactions (driven by reduction of transaction costs) to transformational interaction (driven by collaborative transorganizational development) appears to be difficult to achieve in practice in a network setting*" [11].

Process, infrastructure, and people are fundamental building blocks of BPM culture [12] and quality culture. First, organizations should focus on the lifecycle of process identification (1), discovery (2), analysis (3), redesign (4), implementation (5), monitoring, and controlling (6), in which the process models assume a crucial role [10]. Second, BPM promotes the alignment between the process goals and the organizational infrastructure. Third, actors are expected to follow the processes as documented and modeled [1]. Nevertheless, the complexity of BPM in the digital transformation era needs to balance the traditional stability and predictability of work practices with the uncertainty and dynamic nature of change [2, 9]. Moreover, the emerging cyber-physical infrastructure must maximize process exploitation and leverage exploration capabilities to foster continuous improvement in decentralized manufacturing.

Recent research points to the necessity to move beyond the organization borders in modeling process details, incorporating process deviations and the constraints/opportunities for sociotechnical change [13] while keeping the process compliant and traceable. Representing social, technical, and transformational elements in process models is one of the challenges for research in this area.

Interorganizational business processes are interrelated activities shared and executed by two or more entities to achieve an objective of value to the partners [14]. Globalization and technological advances increase the need for collaboration within supply chains [15]. Therefore, entities involved in IOBP 4.0 development need to establish a relationship supported by technical, behavioral, legal, and strategic mechanisms [16].

However, balancing the needs of real-time control and compliance with decentralized decision-making and flexibility can be challenging [17]. As stated by [18], this type of collaboration arrangement offers "*significant opportunities at strategic level, as well as significant challenges at tactical level, in order to properly combine flexible and effective inter-organization collaborations with traditional internally managed processes*". Examples include the need for transparency between internal business processes and the "external part" [19], coordination and management of process interdependencies [3], and a clear definition of responsibilities [20]. In addition, companies must address the semantic gap caused by diverse internal process language/specifications [21] and the autonomy that each organization requires to implement their strategies at a different pace. Therefore, mechanisms to reduce the degree of coupling between the internal and external interfaces must be put in place [22].

The investments required by partnering across organizations in the digital transformation era require agility and joint innovation mechanisms to support continuous improvement [14]. However, when business process management is geographically dispersed [23] and transversal to different power structures, it is crucial to deploy innovative policies to allow traceability metrics for each activity [24].

The IOBP modelling activities involve the identification of the behavioural and functional aspects, for the execution of activities (what is done), occurring events and their visibility (e.g., private, public) [15]. Additionally, organizational aspects must be considered to identify the several business partners, their roles and responsibilities, and the resources used and exchanged [15]. Despite the essential contributions recently proposed to synthesize IOBP in a unified visualization [4], we could not find an approach in the literature to assist the entire lifecycle of IOBP 4.0 transformations at both design-time and run-time (operation).

2.2 Business Process Modelling and Extensions for Industry 4.0

The main goal of BPMN is to support BPM activities with a straightforward notation comprehensible by different domain experts. BPMN can be used to represent complex processes, for example, in manufacturing [25]. Another advantage is that BPMN has a well-defined language meta-model that facilitates model exchangeability [6]. Moreover, the BPMN meta-model contains a specification of elements for the definition of language extensions [6], which is particularly useful for adapting to new contexts.

Diagrams can be shared across organizations and partners using an XML-based interchange format. Therefore, our research gathers inspiration in:

- BPMN extensions for industry: PyBPMN extension [26] for cyber-physical systems is the most cited. Additional studies in this area include modeling industrial internet-of-things scenarios [27], business process fragments for manufacturing [28], requirements of process synchronization [25] and ubiquitous business process modeling [29]. Nevertheless, "*business process modelling remains unproven for all the processes encountered in manufacturing enterprises*" [28].
- BPMN extensions for interorganizational contexts: Some studies focus on time-aware business process modeling. For example, processes must "*adhere to a wide range of temporal requirements which rise from legal, regulatory, and managerial rules*" [30]. Notably, the first contribution with an approach for IOBP model design was presented by [31], using messages and pools for each organization. [32] presents a comprehensive BPMN extension for collaborative business processes, focusing on concepts related to the execution of collaborative tasks, privacy, confidentiality, state of execution of tasks, data management, and activity monitoring. The authors propose a set of new elements and illustrate them with examples.

It is now possible to extend these important contributions to the field of manufacturing, IOBP, and Industry 4.0 adoption. The following section describes the research approach towards IOBP4.0: interorganizational business processes for Industry 4.0 that balances compliance and change by design, adhering to the needs of multiple manufacturing organizations sharing a common production aim.

3 Research Approach

Design science research (DSR) is a problem-solving paradigm that relies on kernel theories to produce innovative artifacts [33]. The authors of [33] suggest an iterative process starting with the problem identification and motivation, define objectives of a solution, design and development, demonstration, evaluation, and communication [33]. Complementarily, the FEDS framework [34] was proposed to evaluate DSR projects, which considers the possibility of a "quick & simple" summative evaluation.

The DSR cycle reported in this paper includes a review of synergies between Industry 4.0 and IOBP – summarized in Sect. 2. First, we obtained 80 hits in Google Scholar using the keyword combination "BPMN extension" AND ("industry 4.0" OR "digital transformation"), excluding patents and citations. Only ten results were found in using "BPMN extension" AND ("inter-organizational business process" OR "interorganizational business process". Then, we searched for recent papers focusing on Industry 4.0 and digital transformation in BPM to understand the trends in these fields.

The methodology to design the artifacts [33] was adapted from [35], using UML profiles, and later improved by [36], with the analysis and conceptualization of the domain [6]. First, we conceptualized what continuous improvement means in the context of IOBP. Second, we identified key attributes in the literature to represent IOBP 4.0 and support (decentralized) digital transformation. Third, we created a CDME as a UML class diagram. Finally, we conducted a summative evaluation [34] of the results with two companies adopting Industry 4.0.

Company CC1 is a major European paper pulp production company, and CC2 is a small technical metal coatings provider. CC1 had an ongoing digital transformation project for the forest management process (integrating companies in production, logistics, inspection, transformation). CC2 created a new product line partially executed by external partners. Both companies are ISO 9001-certified and interested in continuously improving their processes in collaborative environments.

4 Modeling and Improving IOBP 4.0

The team created three foundational artifacts. We were first aggregating the necessity of "change" in digital transformation and gathered inspiration in the PDCA to describe how interorganizational business processes can continuously improve (Table 1).

After describing the lifecycle of IOBP 4.0 improvement, we extracted attributes to create the IOBP 4.0 extension from the literature (Table 2). These attributes highlight specific concepts that adhere to Industry 4.0 decentralized scenarios, such as the need to trace resources and activities, share information, execute distributed decisions and promote transformation in the technological infrastructure.

Table 1. Continuous improvement of IOBP 4.0: a Plan-Do-Check-Act approach.

Lifecycle	Description	Ref.
Shared planning (P)	IOBP 4.0 requires preparation and commitment from the different parties. Companies may compete for the same resources (e.g., machines) that must be scalable and optimized. Each "part" of the process must ensure flexibility by design. The organization involved in collaborative improvement must specify goals to achieve (e.g., IT investments and expected results for the overall shared goal)	[1, 14, 24, 27]
Shared execution (D)	IOBP 4.0 can be described by core BPMN elements (e.g., processes, tasks, events, resources, and data objects). Messages are important but insufficient to detail (1) interorganizational execution (e.g., who decides to cancel the process, quality criteria, performance indicators) and (2) particularities of Industry 4.0 (e.g., new technologies adopted in decentralized process parts)	[15, 25, 30, 37]
Shared monitoring (C)	IOBP 4.0 requires monitoring the performance of shared elements (e.g., process execution-level agreements). In addition, new challenges emerge from decentralized manufacturing (e.g., real-time data sharing) and protected logs for auditability purposes	[24, 37]
Shared digital transformation (A)	IOBP 4.0 improvements can be implemented by each actor independently or in cooperation. Thus, mindful actors and digitalization are inseparable	[1, 2, 9]

Table 2. Key attributes of IOBP 4.0.

Attribute	Description	Ref.
Confidentiality	Organizations may have restrictions on sharing information or managing customer-owned data. As a result, decisions may occur under incomplete information	[15, 19, 32, 38]
Responsibility	Shared processes require shared responsibility for innovation, execution, and monitoring	[15, 20, 37]
Authority	Global and local actors must be defined, and their decisional capacity specified in different scenarios	[3, 37]
Touchpoint	It is necessary to define when a message is required and the impact on all the stakeholders of the main process (e.g., customers may interact with the process at specific points, assessors' touchpoints, or interaction between cyber and physical elements of the process)	[28, 31]
Transparency	Partner organizations should embrace transparency to improve trust and process activities synchronization	[19, 38]
Compliance	Multiple regulations (voluntary and enforced) may compete in different geographical locations	[3, 23]
Traceability	Activities, resources, data, and decisions must be traceable within the entire process lifecycle	[24]
Interface	Shared elements (e.g., task, data) must have an interface to enable actors' intervention (e.g., app)	[22, 32]
Collaborative	Collaborative BPMN elements are critical. Parallel or sequential execution may be in collaboration	[32, 39]
Autonomy	Autonomous tasks and decisions (e.g., single-organization process improvement) must be identified	[37]
Digital infrastructure	Digitalized activities require technological devices to retrieve data (e.g., sensors), interact (mobile devices) and produce value with data	[8, 26]
Digital transformation phase	BPMN elements (e.g., task) have specific transformation stages (planned, development, deployed)	[1, 2, 11]

(*continued*)

Table 2. (*continued*)

Attribute	Description	Ref.
Target innovation	BPMN elements can be classified in terms of innovation status (state-of-the-art, outdated, actual, stable)	[1, 2, 11]

Finally, we produced the CDME for IOBP 4.0 (Fig. 1).

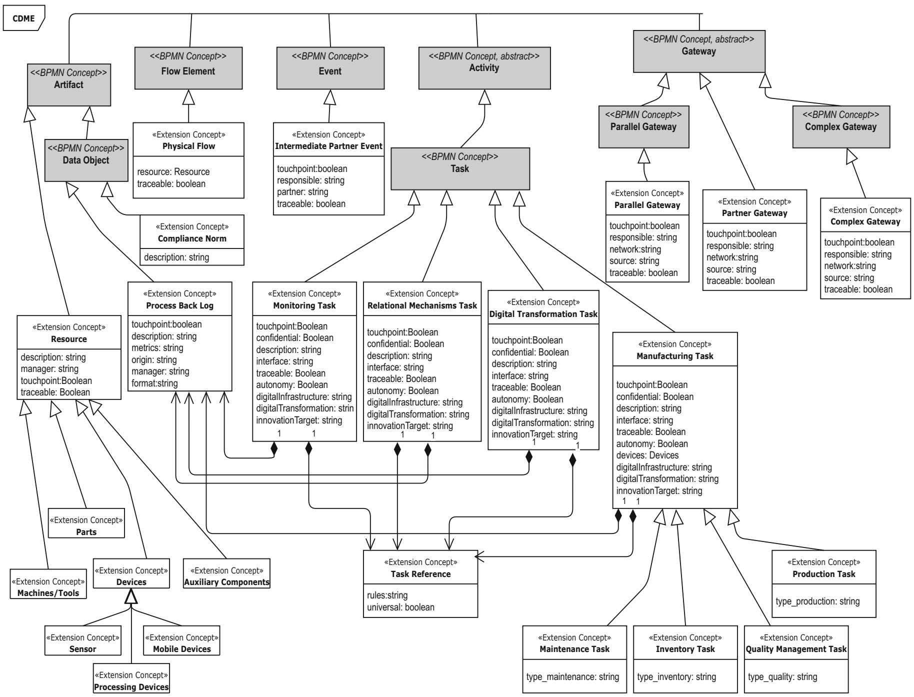

Fig. 1. Conceptual domain model of the extension for IOBP 4.0.

Four types of resources (on the bottom-left of Fig. 1) are essential in the context of Industry 4.0 [40]: machines/tools parts; devices (e.g., sensors, mobile devices); and auxiliary components that may be used and shared by the business partners in the manufacturing activities, each with a visibility classification (e.g., touchpoint, traceable). In addition, the task concept was extended with (1) manufacturing particularities and supplemented with (2) IOBP tasks for monitoring, (3) managing relationships, and (4) digital transformation. The latter three concepts are aimed at creating synergies among process partners. Moreover, the manufacturing-related tasks can be quality control, inventory control, production, and maintenance [28]. The goals is to cover the scope of operational and management activities of IOBP 4.0. Additionally, each task has a classification regarding visibility (e.g., private, touchpoint, traceable) and technological strategy (e.g., digital infrastructure, innovation target).

Finally, the data object was extended to represent (1) the several compliance regulations that each actor must follow while executing their activities [23]. Moreover, this object can also be broadened to represent the process backlog: information related to the monitorization of the business process [24] and analysis. The "Partner Gateway" extends the gateway concept, representing the actor involved in the gateway path decision. The event concept was extended with the intermediate partner event (event raised by a partner's decision in specific moments of the business process) [3, 37]. The flow element extension represents the physical exchange of resources across business processes [28]. The following section discusses the main findings of this DSR cycle and suggested guidelines for the continuous improvement of IOBP 4.0.

5 Discussion

Process activities need to be monitored and controlled across the collaboration network involved in Industry 4.0 investments. For example, some activities may need to comply with specific regulations (affecting one or multiple partners). The manufacturing stages may also require transport/sharing resources, represented by the physical flow. At the same time, partners' (independent/agreed) decisions raise the necessity to include the partner gateway and the partner event. Moreover, Industry 4.0 adds new challenges to traditional interorganizational process management because companies are changing their digital infrastructure in cycles of stabilization (exploitation) and destabilization (digital exploration), affecting each partner's BPMN element in particular ways.

PDCA cycle was considered suitable by the project participants familiar with ISO 9001, suggesting simple steps for continuous improvement in distributed environments. However, Table 1 also reveals issues when operating in collaborative networks. For example, governance, risk, and compliance (GRC) are more complex and involve interdependencies between partners [31], which is challenging to represent in traditional BPMN models. Nevertheless, we agree with [23] that GRC management is an opportunity to improve business processes, achieve genuine cost savings, and improve their competitive positions.

Due to the complex and dynamic nature of organizations, markets, and technologies in Industry 4.0, more complete models are necessary to represent work practices and the stage of digital transformation to design new systems or improve the operation of existing ones. According to the domain experts contacted during our DSR, a standard notation can assist the global process actors to manage activities and coordination of tasks (e.g., similarly to how Gantt-charts are usually adopted in project management to share information between partners). Furthermore, those models can be included in a common repository, shared by all actors, and integrate into their contractual agreements. Thus, the models can be helpful for the "top-down" communication of the global process owner and to collaboratively design, change, and promote innovation and improvement in boundary-spanning processes of Industry 4.0. However, despite the popularity of

BPMN (as happens in ISO 9001 certified industries), we cannot confirm the acceptance by the industry at this stage.

The artifacts developed in this cycle and the discussion with practitioners allowed us to derive the following design principle on how to develop IOBP 4.0 models:

- Adopt a top down IOBP 4.0 modeling approach for BPMN elements. Then, choose a bottom-up description of digital transformation attributes. While the former address the common (shared) business objective, the latter emerges from the negotiated contribution of all partners in the network and a trade-off between individual strategies and overall collaboration value;

Additionally, this cycle allowed the identification of process improvement activities that may be supported by the IOBP 4.0 models:

- Use business process models to negotiate continuous improvement initiatives among the partner organizations and establish an integrated digital transformation program;
- Continuously update IOBP 4.0 models. Industry 4.0 investments must be communicated to all interested parties and its performance monitored over time;
- Identify priorities for shared innovation in specific parts of the process. Industry 4.0 is enabled by end-to-end digital integration of supply chains, local weak points (e.g., partners not producing as expected) may need adjustments;
- Explore business process simulation techniques to evaluate the impact of changes.

6 Conclusion

This paper presents the results of a design science research project aiming to create (1) a shared PDCA approach to continuously improve interorganizational business processes in Industry 4.0 contexts and (2) the grounds for a BPMN extension for IOBP 4.0. Five main design guidelines are suggested to create IOBP 4.0 models that portray how industries collaborate and support shared continuous improvement planning, execution, and evaluation.

There are also limitations that need to be stated and opportunities for the next DSR cycle. First, although we have identified a lifecycle for the digital transformation of IOBP 4.0 and an extension, we have used a specific combination of keywords in our literature review. Other attributes may be included via search improvements and insights from the practitioners. Second, the artifacts produced in this cycle are essential to change the traditional (separate) process models. However, we do not yet have evidence of its benefits in the entire collaboration network. Our contribution includes the proposal of design guidelines for the creation/transformation of boundary-spanning IOBP 4.0, balancing the needs of digital transformation, which is essential, but also challenging when we evaluate change "over time" [2]. Third, the companies that agreed to participate in our work sharing their models are not representative of the entire industry. Other companies adopting Industry 4.0 can be added to the study. Fourth, the focus of this cycle was on manufacturing-related IOBP 4.0, but the model can be extended to other interorganizational business processes, for example, purchasing, marketing, or services.

Fifth, further evaluation will need an external ISO 9001 process audit. This limitation was already considered in preparation for the next cycle. We have included ISO 9001-certified companies adopting industry 4.0 with processes that need to be shared by at least another organization with an independent decision hierarchy. Moreover, it will be essential to evaluate synergies of BPMN extensions for Industry 4.0 and enterprise architecture approaches for digital transformation [41]. For example, Archimate [42] supports high granular modeling, viewpoints relevant for interorganizational contexts (e.g., business process cooperation viewpoint), and representation of both physical and digital layers of digital transformation.

The next DSR cycles will focus on developing the graphical representation for the extension and evaluating the organizational (e.g., synergies in identifying process improvements) and social (e.g., the usability of the IOBP 4.0 models) implications of its adoption by the case companies.

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