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Modeling Boundary-Spanning Business Processes in Industry 4.0: Incorporating Risk-Based Design

Vítor Ribeiro, João Barata and Paulo Rupino da Cunha

Abstract. Industry 4.0 brings new challenges to the digitalization and decentralization of business processes. This paper contributes with a Business Process Modeling and Notation (BPMN) Extension that addresses the inter-organizational nature of the fourth industrial revolution and the need to address risk-by-design since the early stages of industrial collaboration. The proposal results from two design science research cycles. The extension named IOBP 4.0 provides an integrated description of (1) private/shared process elements, (2) local/distributed manufacturing stages, (3) technology incorporation strategy in the production network, and (4) risk situations. IOBP 4.0 can be useful for companies certified by the ISO 9001 quality standard that need to disclose their processes and third-party collaborations, following a risk-based approach. Moreover, incorporating risk-based process design in Industry 4.0 may improve business process resilience in manufacturing networks.

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1 Introduction

Digital transformation requires a new logic for risk-aware business process management (BPM). The work of [1] highlights three emerging BPM priorities, namely, agile and more configurable "light touch routines," infrastructure flexibility (e.g., increasing adoption of the Internet-of-Things (IoT)), and mindful actors more prepared to make decisions in different parts of the process. Industry 4.0, the high-tech strategy introduced by the German government, is a paradigmatic example of digital transformation [2]. Manufacturing processes now rely on IoT, mobile systems, or artificial intelligence techniques to improve production flows [3]. However, modeling business processes in Industry 4.0 is challenging, requiring new approaches to represent how digitalized companies are changing their operations [4] and the possible risks involved.

Risks are a key topic in the information systems (IS) research agenda, entangled in BPM activities [5]. For the last years, the importance of risk management has grown, due to several reasons, such as (1) customer requirements; (2) regulatory pressure; (3) public image; and (4) management attitudes that are becoming more professional in integrating risks in their strategies, planning, and operations [6]. Furthermore, risk-based thinking is also a priority for modern quality management standards like ISO 9001, suggesting a process approach to management. Therefore, incorporating risks in business process models is crucial.

The new BPM logic is also extensible to the supply chain. On the one hand, creating a technological infrastructure to decentralize production provides visibility to product flows since the early stages of sourcing raw materials for product use. On the other hand, requiring more "*effectiveness of communication between actors and favoring data collection and sharing*" [7]. As a result, processes are becoming increasingly "inter-organizational," distributed, and agile, but also more challenging to manage with traditional modeling languages, such as Business Process Modeling and Notation (BPMN) [8]. For example, BPMN cannot represent all the details of Inter-Organizational Business Processes (IOBP) [8] since it lacks the semantics to describe the dependencies of the global control flow of the message exchange [9]. Additional problems are the absence of formal specification of process interfaces and support for alignment with multiple partners. Furthermore, capturing all the information required to audit risks [10] is more difficult in decentralized manufacturing contexts. However, the original BPMN cannot represent potential points of error, formal specification of risks, risk categories, risk likelihood, and impact on the process [11].

Aiming to advance the new BPM logic [1] in Industry 4.0, we conducted a design science research project in cooperation with companies in technical coatings (e.g., thermal spraying, plasma, or electrodeposition of advanced materials) and paper pulp production (e.g., eucalyptus pulp production, bioelectric energy production, forest management). This paper details the second design science research (DSR) cycle in a leading European producer in the pulp sector, being one of the most efficient producers in

Europe of bleached eucalyptus pulp. Additionally, the company produces electricity from forest biomass, having several power plants. Our overall research objective at this stage was to create a BPMN extension to model inter-organizational business processes for Industry 4.0 adoption (IOBP 4.0), incorporating risk-based thinking in the process models.

The remainder of this paper is structured as follows. Section 2 presents foundational literature in Industry 4.0, IOBP, BPMN, risks and other related work. We detail the research approach in Section 3, and the results follow in Section 4. Subsequently, we demonstrate (Section 5) and evaluate (Section 6) the adoption of IOBP 4.0 in a real-world setting. The paper closes by stating conclusions, the main limitations, and future work opportunities.

2 Background

2.1 Industry 4.0

Industry 4.0 started a new digital transformation era by adopting cyber-physical systems (CPS) [12]. This global change is supported by cloud technologies and the Internet [2], integrating physical assets (e.g., machines, components) and "cyber" capabilities to improve real-time monitoring and control of advanced production processes [13].

Industry 4.0 enables companies to have more flexible manufacturing processes and analyze data in real-time, improving operational decision-making and strategic planning [2]. However, instead of being restricted to internal operations, Industry 4.0 is a boundary-spanning phenomenon that needs external information and more complex relationships with business partners. Digital transformation also extends to the redesign, coordination, and improvement of supply chains, from early manufacturing to after-sales [14].

The decentralization of manufacturing comes with an associated challenge: horizontal integration, establishing collaboration networks between companies in the supply chain, sharing resources, and exchanging increasing amounts of data [2]. In addition, moving from single to multi-site manufacturing raises the need to support decentralized decisions and orchestrate technological components (e.g., machines, enterprise systems) that can interact with each other and with workers in real-time, generating more complex data flows and activities [3].

More complex business processes in Industry 4.0 are mobilizing academia to propose process modeling approaches [15]. One of the main goals is to assist managers in moving beyond organizational borders and understand process-centric work practices that expand to different elements of supply chains [7] while keeping the process compliant, traceable, and resilient.

2.2 Inter-Organizational Business Processes

IOBP are sequential activities executed in collaboration by two or more trading entities to achieve a business objective of shared value[16]. Implementing IOBP requires a minimum level of trust between the participating organizations, guaranteed through legal contracts, which specify the responsibilities and obligations agreed by all the participating parties [17].

Currently, IOBP models are usually created independently by each partner organization, using disconnected documentation and procedures. This approach enables each business partner to focus on its internal activities. Aiming to improve this disjointed approach, [18] proposes a way to merge different process models supporting collaboration in producing components and products by creating a unified perspective of the business process. However, the design of IOBP is problematic:

- The interaction between internal business processes and IOBP requires transparency between partners [19];
- The coordination of IOBP interdependencies is challenging (e.g., equipment shared by different partners) [9];
- Partner's responsibilities across the different activities in the IOBP flow must be defined [20];
- Semantic gaps may occur, caused by each business partner having its specific internal process language and terminology [8];
- Autonomy may be required by each business partner to design, execute and improve their internal business processes and strategies, eventually leading to different paces of digital transformation. Mechanisms are needed to synchronize and reduce the degree of coupling between the external and internal interfaces of the business partners in the IOBP [9];
- Business partners may be distributed across different geographical locations, each subject to distinct compliance requirements and laws [21];
- Monitoring decentralized activities and decisions in IOBP requires deploying policies that allow traceability of metrics of the several elements (e.g., state of process execution, inventory count in each partner) [22].

The contributions for modeling IOBP are significant, but the resulting process models are often incomplete [8, 9] and difficult to share within the organizations. Therefore, new or extended notations (e.g., using BPMN) can be created to promote the design and execution of IOBP more wholly and effectively.

2.3 Risk-Based Thinking and Business Process Models

ISACA [23] defines risk management as the process of identifying the vulnerabilities and threats to the information resources used by an organization in achieving their business objectives and deciding what countermeasures, if any, to take in reducing the risks to an acceptable level, based on the value of the information resource to the organization. According to [24], a definition for risk comprehends (1) the probability that the actual outcome of an event will differ from the expected outcome and (2) the impact associated with that outcome. A report of the World Economic Forum [25] defines five essential risk categories: economic, environmental, geopolitical, societal, and technological risk.

In the context of BPM, risk management can contribute to assessing the process regarding the existing risks, adopting risk mitigation strategies, and serve as a tool to support the revision and design of the business process, at design time and at execution time.

Several risk models have been proposed in the IS field. The proposal of [26] introduces a three-level hierarchy of risks. The third level is the most exhaustive and consists of the compliance and operational risks that emerge from business processes (e.g., information security, privacy and, regulatory issues). Kaplan [26] suggests that level 3 risks can be more predictable and related to operational procedures. The second level includes strategy risks, such as environmental, human resources, and IT-related risks [26]. Finally, at level 1, global enterprise risks may occur due to the most unlikely events, usually called "black swan", which reveal the most adverse consequences for the organization's survival [26]. Nevertheless, studies incorporating risks in business process models for Industry 4.0 adoption are still nascent in the literature.

2.4 BPMN and BPMN Extension Mechanisms

Business process models are used to document business processes, enabling their understanding and analysis by domain experts with different backgrounds [27], playing a pivotal role in management activities [22].

Business Process Modeling and Notation is a popular industry standard for business process modeling. It provides an intuitive and simple notation that is readily understandable by business users [28]. It also has a well-defined language meta-model that simplifies tool integration and model exchangeability [29].

BPMN provides an "*extension by addition*" mechanism that enables the definition and integration of domain-specific concepts [30]. Moreover, BPMN allows to create extensions, while ensuring BPMN core elements' validity [31]. Finally, the development of BPMN extensions is usually less costly than developing an entirely new domain-specific modeling language from scratch [29].

According to the BPMN standard [31], the mechanisms for language extension mechanisms are organized as follows:

- Extension: Binds the extension attributes to a standard BPMN model definition;
- ExtensionDefinition: Supports the incorporation of attributes in a specific element or a new element. Composed by several ExtensionAttributeDefinition (name and type);
- ExtensionAttributeDefinition: Defines new attributes as characteristics of a customized element (e.g., string, integer, Boolean);
- ExtensionAttributeValue: Incorporates the attribute value.

The study presented by [30] suggests a methodology to create BPMN extensions. However, only a few developed BPMN extensions are designed in conformance with OMG's standard [32]. Most of them are created using meta-model and XML-schema customizations, raising problems with tool integration, comprehensibility, and model exchangeability [29].

Business process models have two elements more specific to inter-organizational process descriptions: (1) pools representing entities (e.g., organizations) that perform business processes [8], and (2) message flows depicting information exchanges between organizations. However, the standard BPMN elements cannot represent all the details from the IOBP 4.0 domain, including risks more specific to the decentralized nature of Industry 4.0. Therefore, BPMN extensions emerge as a promising solution [32].

2.5 Establishing the Link: Business Process Modeling in Industry 4.0, IOBP and Risk

Numerous BPMN extensions have been proposed for Industry 4.0 contexts. PyBPMN [4] is one of the most mentioned, presenting an approach to the specification and management of the resources associated with the business processes supporting cyber-physical systems. Further studies in this field include the modeling of industrial IoT scenarios [33], analysis of business process fragments for manufacturing activities [34], and ubiquitous business process modeling [35]. The study conducted by [36] proposes a BPMN extension for manufacturing. These authors create elements for representing manufacturing operations and resources, then present different examples for using them.

BPMN extensions are also available for IOBP. For example, the pioneer contribution presented by [37] using pools and messages. The work of [38] presents the design of a BPMN extension for collaborative business processes. The proposal focuses on concepts related to the execution of collaborative tasks, activity privacy, confidentiality, state of progress of activities, and data management. In addition, the authors propose a meta-model and a set of new graphical elements for collaborative business processes.

Risk-aware business process modeling has already captured the attention of different researchers. The work of [39] presents and evaluates a BPMN extension to represent human physical risks (e.g., heavy lifting, repetitive work) in the several stages of the business process. The contribution of [11] proposes a BPMN extension for risk handling, introducing elements such as risk handlers, risk mitigation methods, and risk factors. The study of [40] defines a BPMN extension for quantitative risk assessment by including information about the likelihood and consequences of failures, in terms of business value, in different granularities of processes fragments. The framework proposed by [6] suggests that risks and workarounds should be jointly considered to model uncertainty in organizations.

Despite these essential contributions for modeling IOBP, Industry 4.0, and risk-aware process models, an integrated approach to model manufacturing in IOBP risk-aware scenarios of digital transformation is still necessary to develop, and practical examples are scarce. Therefore, this section's related work can be integrated and extended, serving as the starting point for our research, explained in the next section.

3 Research Approach

We selected design science research (DSR) as the approach to create our extension since it is a problem-solving paradigm that relies on kernel theories to produce inventive artifacts [41]. DSR evolves iteratively, starting with the "*problem identification and motivation, define objectives of a solution, design and development, demonstration, evaluation, and communication*" [42].

Our initial DSR cycle had a problem-centered initiation [42], including contacts with industry experts and a literature review on the topics of BPMN extensions and Industry 4.0. The next step was designing the IOBP 4.0 extension and demonstrating its utility [41]. The design phase follows the approach proposed by [30] using UML profiles, later improved by [43] with the analysis of the domain and its conceptualization [43]. First, we conceptualized the IOBP 4.0 domain as an ontology, revealing the main domain concepts, relationships, and properties. Then, we conducted an equivalence check to assess if the IOBP 4.0 concepts were semantically equivalent to the standard BPMN elements (e.g., tasks, gateways, data objects).

We instantiated the artifact in different companies adopting Industry 4.0 and decentralized manufacturing. Fig.1 synthesizes our DSR.

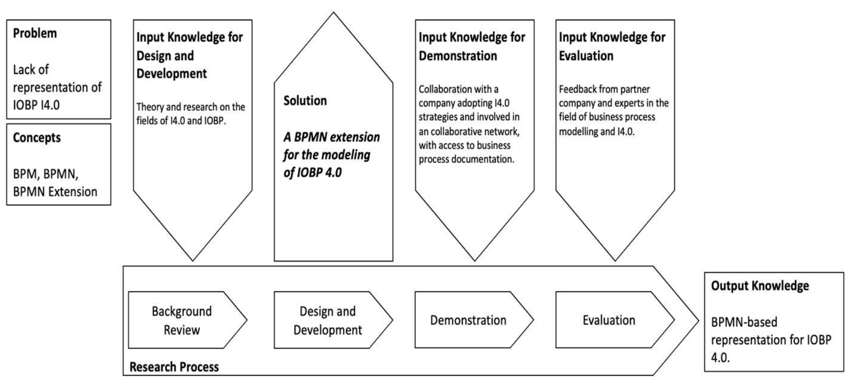


Fig. 1. DSR Grid for IOBP 4.0 (adapted from [44] and [42]).

After confirming the few contributions available for the detailed modeling of IOBP 4.0 (see left of Fig.1, problem description), we identified a BPMN extension as the most promising solution. After its design, we tested it in a real-world case in a technical metal coatings provider adopting Industry 4.0 strategies. A new cycle was necessary to incorporate risks in IOBP 4.0 process models conducted in a large paper pulp manufacturer. The case company's mission is to produce paper pulp and develop solutions for forest management and bioelectric energy production. The case company's operations require some outsourcing, and it is investing in a new system to monitor the several decentralized operations (e.g., timber cutting, pulp production, bioelectric energy production). Being ISO 9001 certified, the company found our approach interesting to model processes aligned with Industry 4.0 investments. In addition, the company provided process-related documentation, which allowed us to model the process using standard BPMN notation and IOBP 4.0. Section 4 details the artifacts created during our DSR.

4 IOBP 4.0 BPMN Extension Development

Section 4.1. presents the domain ontology for IOBP 4.0. Subsequently, we describe the extension elements.

4.1 Domain Ontology

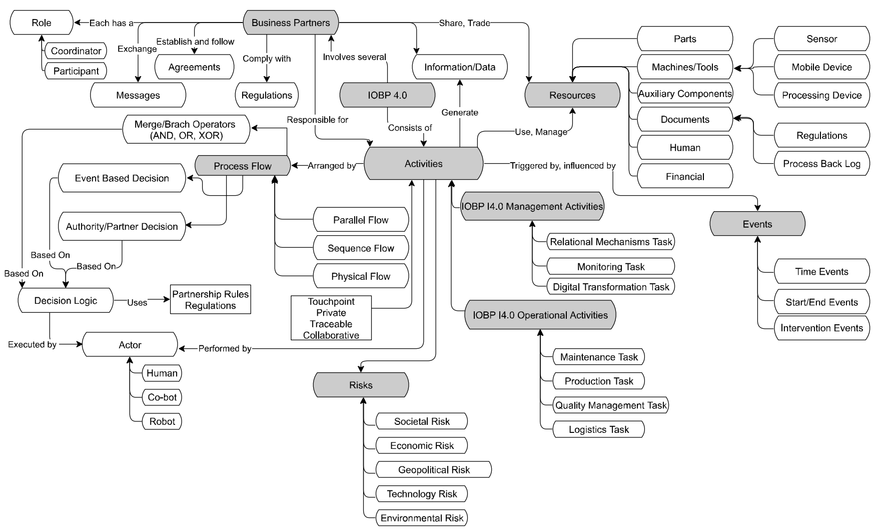


Fig. 2. Domain Ontology of IOBP 4.0.

Fig. 2 depicts the ontology we designed to understand the domain, concepts, and attributes. This domain's central concept is the business process involving two or more business partners (IOBP 4.0, on the top) and their process activities [8]. The five main risk categories [25] are represented below.

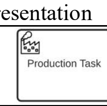
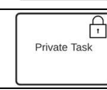
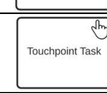
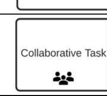
According to inter-organizational agreements, each business partner coordinates or acts in the process (coordinates or participates). Partners must comply with specific regulations (e.g., laws, procedures, standards, contract agreements) [21], exchange data (through messages and documents) [9]. In addition, they may share resources in the manufacturing network (e.g., parts, auxiliary components) [34].

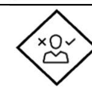
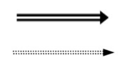
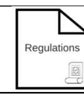
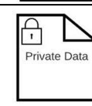
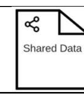
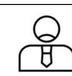
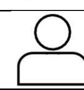
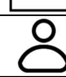
The business partners execute IOBP 4.0 management activities (e.g., relational mechanisms task, monitoring task, digital transformation task), and actors (e.g., human, co-bot, robot) perform IOBP 4.0 operational activities (e.g., maintenance task, production task, quality management task, logistics task), utilizing resources (e.g., parts, auxiliary component, machines, human, financial) [34]. There is a direct impact between activities and events (e.g., time events, start/end events, intervention events) that coexist in business processes [9]. Activities' data need to be traceable and may be public or private [22]. The activities are executed according to the process flow (e.g., parallel flow, partner flow, physical flow)- on the left side of Fig. 1. In certain parts of the flow, decisions are made (e.g., gateway, event-based decision, authority/partner decision) about the activities to be executed next, based on a decision logic (e.g., partnership rules/agreement, regulations) [9] executed by actors (e.g., human, co-bot, robot). Finally, the risks involved in process execution can be represented according to different categories.

4.2 Graphical Representation of IOBP 4.0 BPMN Extension

Table 1 introduces the BPMN elements identified in our domain ontology model. The design team's goal was to uniquely identify each new BPMN element while keeping BPMN consistent (e.g., task represented by a rectangle with rounded corners).

Table 1. Graphical Representation of IOBP 4.0.

BPMN Concept	Domain	Description	Graphical Representation
Task	Manufacturing	The production task represents a sub-type of task to execute production activities (e.g., assembly, cleaning, handcraft, heat treatment).	
Task	Manufacturing	The quality management task represents a sub-type of task executing quality management activities (e.g., product testing, check non-conformities).	
Task	Manufacturing	The logistics task represents a sub-type of task related to logistics activities' execution (e.g., packaging, handling, materials' storage).	
Task	Manufacturing	The maintenance task represents a sub- type of task related to equipment, systems, and tools maintenance (e.g., machine replacement, preventive maintenance).	
Task	IOBP	The traceable task identifies that a specific task is traceable, meaning that a set of metrics is retrieved and registered to execute that task.	
Task	IOBP	The private task represents that a specific task is private, meaning that no information on that task is shared with the partners, being kept confidential.	
Task	IOBP	The touchpoint task means that it is a region of interest for partners. Information about the task execution/state may be shared.	
Task	IOBP	The collaborative task means that a specific task is executed and managed in collaboration between several business partners.	
Task	IOBP	The relational mechanism task represents the activities related to managing relationships between the business partners, managing the responsibilities, authority, and capacities of each partner.	

BPMN Concept	Domain	Description	Graphical Representation
Task	IOBP	The digital transformation task represents the activities related to executing improvements in the business processes using digital technologies.	
Gateway	IOBP	The partner gateway represents a moment in which a specific partner decides the "path" of the activities to be executed in the following steps.	
Intermediate Event	IOBP	The partner intermediate event represents a specific partner's intervention in an activity, started by an authorized partner's decision.	
Process Flow	Manufacturing	The physical flow represents the transport/movement of materials (physical objects) between one Flow Element and the next. The transport may occur within (e.g., internal logistics) or between partners.	
Data Object	Manufacturing	The regulations represent the laws and standards that business partners must follow (e.g., ISO 9001).	
Data Object	IOBP	The private data object means that a given data object (or one of its children) is private, meaning that no information on that data is shared with the partners, being kept confidential.	
Data Object	IOBP	The shared data object means that a given data object (or one of its children) is shared: data is accessible to other partners.	
Connected to Task or Flow	Manufacturing	Parts are essential elements in industry flows (e.g., parts for assembly). They are used and exchanged between the partners and in manufacturing activities.	
Connected to Task or Flow	Manufacturing	Represents the machines/tools used in several activities (e.g., production machinery).	
Connected to Task	Cyber-Physical	Processing devices are used in process tasks to record information, manage documents, execute algorithms, or analyze data.	
Pool	IOBP	The partnership manager is the main responsible for the execution, monitoring, and management of the IOBP.	
Pool	IOBP	The partnership participant is responsible for executing activities and reporting the agreed information to the partnership manager.	
Task, Gateway	Cyber-Physical	Represents the tasks and gateways that a human actor may execute.	
Task, Gateway	Cyber-Physical	Represents the tasks and gateways that a co-bot actor may execute.	
Task, Gateway	Cyber-Physical	Represents the tasks and gateways that a robot actor may execute.	

BPMN Concept	Domain	Description	Graphical Representation
Task, Gateway	Cyber-Physical	Represents sensors used in tasks or incorporated in resources, enabling the retrieval of data and traceability of elements.	
Task	Risk	Represents a task in which there is an economic risk	
Task	Risk	Represents a task in which there is a risk for the society or the human actor.	
Task	Risk	Represents a task in which there is a risk related to geopolitical issues.	
Task	Risk	Represents a task with a risk of potential harm to the environment (e.g., gas leak, oil leak).	
Task	Risk	Represents a task with a risk for the IT infrastructure (e.g., system crash).	

Table 1 presents thirty-one elements that compose the IOBP 4.0 extension, integrating Industry 4.0, IOBP, and risk-based thinking in process models. The table adapts elements from BPMN extensions proposed for manufacturing (e.g., production task, quality management task, logistics task, maintenance task, parts, physical flow) [34, 45], IOBP (e.g., private task, traceable task, private data, shared data) [38], and critical risk categories [25]. Our contribution adds a new group of cyber-physical elements that are pillars of Industry 4.0 (e.g., robot actor, human actor, co-bot actor, processing devices, sensor, machines, tools) and IOBP elements (e.g., partnership participant pool, partnership manager pool, partner intermediate event, partner gateway, touchpoint task, digital transformation task, relational mechanism task). Additionally, new elements represent the five essential risk categories defined by [25]: technological risk, societal risk, geopolitical risk, environmental risk, and economic risk. We developed the BPMN extension elements using Lucidchart [46] and its icon library, aiming to support the representation of the IOBP 4.0 concepts. In Section 5, we demonstrate the most recent version of the IOBP 4.0 extension in the selected paper pulp company.

5 Demonstration

Fig. 3 shows a partial view of the biomass business process of the case company modeled in standard BPMN.

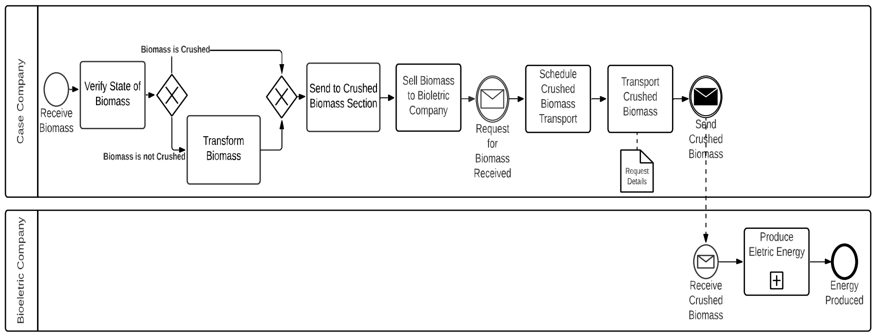


Fig. 3. Biomass Business Process Model using BPMN (excerpt).

The process is triggered when the Case Company receives the biomass from the suppliers. Then, the Case Company verifies the condition of the biomass. If the biomass is crushed, it is sent directly to the crushed biomass sections. Otherwise, the biomass is sent to the crush section and must be transformed to be in proper conditions to produce electricity. The biomass is then set for sale to bioelectric companies. When a request for biomass is received, the transport and details are scheduled. The biomass is then transported to the biomass company's facilities, along with the details of the transport and biomass. The bioelectric company receives the biomass, which is then used to produce bioelectric power.

Fig. 4 shows the same process modeled with the proposed IOBP 4.0 extension.

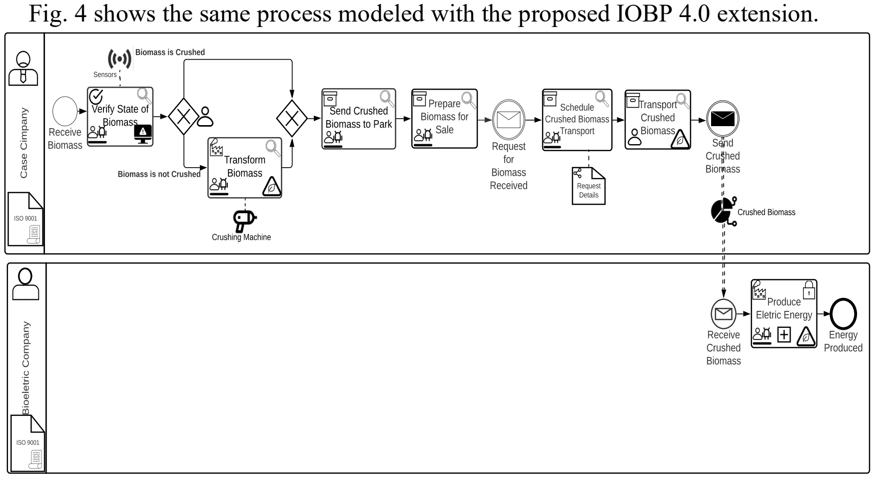


Fig. 4. Biomass Business Process Model using IOBP 4.0 extension.

The BPMN extension in Fig. 4 allows more details on the digital elements and information sharing, which cannot be represented with the standard BPMN notation used in Fig. 3. The process model built while using the extension is more accurate in representing the roles of the process participants: the Case Company is the business process coordinator and is ISO-9001 certified. The other process participants are also certified by ISO-9001. New digital elements are integrated into the model produced with the extension (e.g., the crushing machine used to transform the biomass, sensors used to verify the state of the biomass). The Bioelectric Company can monitor the transport of the crushed biomass from the Case Company to their facilities and access information on the scheduled delivery of the biomass. The Case Company also retrieves and analyses data from their tasks (e.g., verifying biomass, transforming biomass). Several documents are shared between the business partners (e.g., request details). Most of the tasks performed are classified as logistics tasks (e.g., transport crushed biomass) and production tasks (e.g., transform biomass). Robots partially automate some tasks (e.g., transform biomass, schedule delivery of biomass), while human actors perform others (e.g., transport biomass). Some tasks have an environmental risk associated (e.g., transport biomass, produce electric energy) and others a technological risk (e.g., verify the state of biomass).

6 Evaluation

The proposed IOBP 4.0 extension, now updated with risk analysis, shares the same principles of the standard BPMN and provides an answer to the need to represent inter-organizational business processes in increasingly digitalized manufacturing contexts. In addition, model intelligibility and detail are improved.

Model completeness is one of the most immediate advantages of IOBP 4.0 over the classic BPMN. First, the proposed extension introduces representative elements of the private/shared data and activities (e.g., produce electric energy is a private task, the transport details document is shared among the partners). Second, the new elements, aligned with the core BPMN standard, represent the key manufacturing stages (e.g., transform biomass is a production task, schedule delivery of biomass is a logistics task). Third, the technology strategy on Industry 4.0 becomes visible (e.g., verify state of biomass is executed by humans and robots). Fourth, the entire business process is integrated into a single model instead of disjoint models from different partners, using different notations, pointing to specific areas of risk in the model. The IOBP 4.0 process model can be used as a tool for joint innovation efforts, enabling identifying internal and external improvement opportunities by any involved organizations. Fifth, the IOBP 4.0 process models can be leveraged to train and onboard new staff (e.g., making IT experts aware of the existing infrastructure, and assisting operators in their contacts with third-party entities). Lastly, the process models can be adopted in internal audits, increasing transparency of the responsibilities, activities, internal/external interactions, and technology investments. Therefore, IOBP 4.0 contributes to an enhanced perception of each partner's contribution and risk elements requiring particular attention for monitoring activities and mitigation actions.

Although there are some similarities with UML activity diagrams, UML is an object-oriented notation primarily focused on modeling and documenting software systems (e.g., web applications, database architecture). Therefore, BPMN extensions may be more accessible to different organizational domain experts (e.g., business analysts, manufacturing technicians) interested in the design of “as-is” and “to-be” risk-aware business processes. In addition, IOBP 4.0 can be helpful in process improvement initiatives that require a descriptive notation of the domain.

Our evaluation over two DSR cycles also revealed weaknesses in our IOBP 4.0 proposal. First, the additional information increases the complexity and readability of the process models compared to the standard BPMN elements. The absence of clear guidelines regarding what to include may result in overloaded models, more challenging to understand by the practitioners. The problem is not so severe when dealing with quality experts (used to ISO 9001 process models and risk-based thinking), but other stakeholders (e.g., operators) may face increased difficulties. Second, the current version of IOBP 4.0 does not identify the state of process transformation. For example, if the specific technology (e.g., IoT infrastructure, app, machine learning model used to support decision making) used in activity X is already deployed or under development. Industry 4.0 adoption is dynamic, so it would be essential to identify the maturity of specific elements (e.g., a task executed by a human but might be executed by a robot in the future). Moreover, the risk evaluation is also inexistent in the model, restricted to disclosing the type of risk.

The team identified three main avenues that could lead to overcoming the limitations —first, inspired in the enterprise architecture field and the ArchiMate [47], separating the process model in views (e.g., digital transformation view for showing only the technology, omitting the IOBP-related data; IOBP view hiding the technology layer; risk analysis view). Testing the complete process’s visualization or only a part of its layers will be interesting. Second, the Industry 4.0 maturity level could be represented by a number (e.g., maturity stage ranging from 1-Explorer to 4-Expert) in each element of IOBP 4.0. Several maturity models could be experimented with to improve IOBP 4.0 (e.g. [48]). Finally, risks can be represented quantitatively (e.g., risk matrix result) or using colors to represent the hazardous points.

7 Conclusion

This paper reports the second DSR cycle in a paper pulp company aiming at creating and evaluating a BPMN extension to model inter-organizational business processes in the context of Industry 4.0. This cycle included reviewing relevant literature at the intersection of Industry 4.0, IOBP, and risks, and the proposal of a BPMN extension. The contributions include (1) a domain ontology of IOBP 4.0, (2) the graphical representation of the IOBP 4.0 extension concepts, and (3) a demonstration of the use of the proposed extension in practice.

IOBP 4.0 can be helpful for standards-certified companies adopting a process approach to management and risk-based thinking, like ISO 9001, to disclose their processes and third-party collaborations. IOBP 4.0 may also help coordinate distributed manufacturing processes that are at the core of Industry 4.0 transformation. In the future, the IOBP 4.0 models can be attached to contractual agreements and become a central tool to design, change, and promote shared innovation collaboratively.

There are also limitations in our DSR that we need to state. First, the artifacts produced in this cycle are essential to model IOBP 4.0, but we do not yet have evidence about the proposed approach's benefits to model IOBP 4.0 for the entire collaborative network. Second, the companies that participated in our work are not representative of the entire industry. Future DSR cycles need to integrate more companies adopting Industry 4.0. Third, the main target of this DSR cycle was manufacturing-related IOBP 4.0. However, the model can be extended or adapted to IOBP executed in other relevant sectors and other digital transformation strategies (e.g., health 4.0). Fourth, the proposed approach does not include detailed guidelines for using the IOBP 4.0 extension in modeling activities. Defining a set of design principles to model with the IOBP 4.0 BPMN extension will be important. Finally, the domain concepts and ontology were identified based on a literature review and process documentation analysis in selected companies. In the future, it would be interesting to conduct industrial surveys and assess the social implications of using IOBP 4.0 for different partners.

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Appendix A: Examples of IOBP 4.0 Use Cases

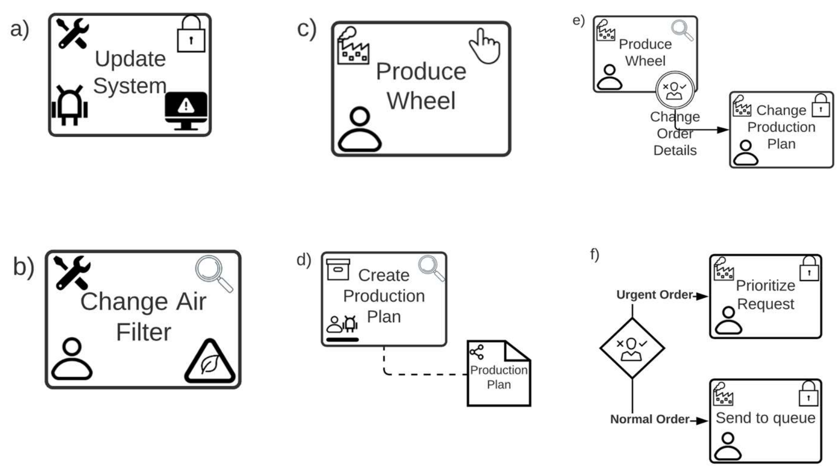

Fig. 5. Examples of IOBP 4.0 Use Cases.

The use case a) presents a private maintenance task executed by a robot with an IT risk. Use case b) shows a traceable maintenance task executed by a human with a risk for the environment. Use case c) (in the middle) presents a touchpoint production task executed entirely by hand. Use case d) introduces a traceable logistics task executed by a co-bot. The output is a shared production plan document. Use case e) illustrates a traceable logistics task executed by humans. The partnership manager may intervene during task execution by requesting the change of the order details. Therefore, the production plan is changed in a private production task performed by a worker. Finally, use case f) depicts a priority decision made by the partnership manager.