

Human-Centric Process Management

Orchestrating the Operational, Locational, and
Ethical Dimensions of Manual Work

Dissertation | Leo Poss



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Orchestrating the Operational, Locational, and Ethical Dimensions of Manual Work

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While Business Process Management (BPM) is highly effective for administrative automation, it often lacks the capacity for physical execution. Current models typically treat manual labor as a high-level abstraction, frequently overlooking the specific tools, physical environments, and values of the human actors involved. This dissertation proposes a framework to integrate physical work into the digital process across three dimensions:

1. The *Operational Perspective* ((F1)) treats tools and materials as first-class process entities rather than passive data, providing granular visibility into manual tasks.
2. The *Locational Perspective* ((F2)) conceptualizes physical space as a deterministic constraint that actively drives process logic rather than descriptive attributes.
3. The *Ethical Perspective* ((F3)) ensures the protection of the human actor. By treating ethics as a functional requirement, this perspective mitigates the risks of increased monitoring and prevents systemic rejection.

This architecture shifts the role of BPM from task routing to the comprehensive orchestration of physical work.

Contents

List of Figures	iii
List of Tables	iv
Acronyms	v

I Dissertation Outline

1	Introduction	1
2	Focus Areas and Research Questions	6
3	Related Work	10
4	Methodology	13
	4.1 Design Science Research	13
	4.2 Supporting Methodologies	16
	4.3 Research Environment	17
5	Results	18
	5.1 F1 – The Operational Perspective	20
	5.2 F2 – The Locational Perspective	26
	5.3 F3 – The Ethical Perspective	31
	5.4 Complementary Publications	35
6	Conclusion and Future Work	36
	Bibliography	43

II Research Papers

		51
P1.1	The Operational Perspective in Business Process Management: Towards Holistic Task Execution Support	52
P1.2	Formalizing the Operational Perspective in BPM: An Ontology-Based Approach for Tool Integration	87
P1.3	From Model to Execution: A Formal Foundation for Managing Materials and Tools in Executable BPMN	124
P2.1	Location-aware business process modeling and execution	153
P2.2	LABPMN: Location-Aware Business Process Modeling and Notation	185
P3.1	Navigating the Moral Maze: A Literature Review of Ethical Values in Business Process Management	205
P3.2	Measuring Moral Performance: A Framework for Ethical Business Process Management	234

List of Figures

1	Theoretical framing of human-centric BPM	2
2	Four-cycle DSR model [20]	14
3	Ontology engineering process [50]	17
4	Ontology of the operational perspective focusing on tools	22
5	Extended ontology for PRiME including tools and material	24
6	PRiME-enhanced process model	25
7	Multilayer architecture for Location-Aware BPM	28
8	Graphical representation of LABPMN elements	29
9	LABPMN process model example	30
10	Descriptive framework of ethical values	32
11	Mobile interface for moral performance assessment	34
12	The Moral Performance Dashboard	35

List of Tables

1	Overview of research gaps and contributions	13
2	Methodological overview of publications	15
3	Publications overview	19
4	Classification of process entities	21
5	Complementary publications	36

Acronyms

AI	Artificial Intelligence
AR	Augmented Reality
BLE	Bluetooth Low Energy
BPI	Business Process Improvement
BPM	Business Process Management
BPMN	Business Process Model and Notation
BPMS	Business Process Management System
BTFS	Bayerische Transformations- und Forschungsstiftung
CDME	Conceptual Domain Model Extension
CEP	Complex Event Processing
CPS	Cyber-Physical System
CRM	Customer-Relationship-Management System
CS	Computer Science
DR	Digital Responsibility
DSR	Design Science Research
EAM	Engineering Asset Management
ERP	Enterprise Resource Planning
GPS	Global Positioning System
IOT	Internet of Things
IS	Information System
IT	Information Technology
KPI	Key Performance Indicator
KVI	Key Value Indicator
LABPMN	Location-Aware Business Process Model and Notation
MES	Multidimensional Ethics Scale
ML	Machine Learning
NASA-TLX	NASA Task Load Index
OWL	Web Ontology Language
PAIS	Process-Aware Information System
PRIME	Passive Resource-integrated Modeling Extension

RAL	Resource Assignment Language
RDF	Resource Description Framework
RE	Requirements Engineering
SLR	Systematic Literature Review
SME	Small and Medium-sized Enterprise
SPARQL	SPARQL Protocol And RDF Query Language
UWB	Ultra Wide Band
WFMS	Workflow Management System

Note on AI Tools: This dissertation was edited for clarity and coherence using Grammarly and Gemini 2.5 Pro and 3 Pro. The core intellectual content and scientific findings are solely attributable to the author.

Part I

Dissertation Outline

1 Introduction

Traditional Business Process Management (BPM) has a blind spot: the physical reality of the worker. While algorithms manage control flow, the actual execution of manual work remains a “black box.” The system knows that a task occurs, but is unaware of the execution details [21, 101]. While algorithms manage the routing of work, the physical reality of the human worker, i. e., the tools they wield, the space they occupy, and the values they hold, remains invisible to the system¹.

To ground this dissertation in established theory, we adhere to the foundational definitions provided in Dumas *et al.* [21], where a *business process* is defined as “a collection of inter-related events, activities, and decision points that involve a number of actors and objects, which collectively lead to an outcome that is of value to at least one customer.” Consequently, BPM is understood as the “body of methods, techniques, and tools to identify, discover, analyze, redesign, execute, and monitor business processes to optimize their performance” [21]. In the context of automation, these methods are realized through Process-Aware Information Systems (PAISS)², which coordinate people, applications, and data based on process models [21].

Classically, these models are structured according to five fundamental perspectives [18, 31, 21]: (i) The *Functional Perspective* describes the structure of the process, determining whether an activity is atomic or composite; (ii) the *Behavioural Perspective* defines the execution order, such as sequences or parallelism; (iii) the *Organizational Perspective* governs the assignment of human participants to tasks; (iv) the *Data Perspective* manages the documents and variables used within a process; and (v) the *Operational Perspective* describes how an atomic activity is implemented—specifically, the actions required when execution reaches a certain step. To operationalize these perspectives, Business Process Model and Notation (BPMN) [53] has emerged as the de facto standard for process modeling. It provides a standardized graphical notation that links process design and implementation, allowing models to be not only visualized but also executed by Business Process Management Systems (BPMSS).

While the first four perspectives are well-supported by standard notations, this dissertation argues that the *Operational Perspective* is insufficiently formalized for manual operations, lacking the granularity to represent physical tools or environments. This leaves a critical gap in the management of physical execution, as the operational modality (the *how*) of the task remains invisible to the process system. Furthermore, while focusing on classical, stationary IT systems, the environment and the physical locations of process entities are known or restricted to a specific area [107], whereas *mobile distributed processes* and the *Locational Perspective* remain mostly unsupported, as here, locations are essential parts of the process. These processes involve multiple actors performing sequential tasks at various locations, implicitly constraining task execution to a specific location [67].

¹This limitation is inherent to the architecture of traditional Workflow Management System (WFMS). As noted in Jablonski and Bussler [31], standard workflow models view an activity as an atomic unit of work. The system manages transitions between activities but effectively suspends control during each activity. Current de facto standards like BPMN reinforce this logic: when a process token reaches a manual task, it enters a wait state, rendering the physical execution opaque to the system until completion is reported.

²Process-Aware Information System (PAIS) serve as the overarching category for systems that manage business processes, including Enterprise Resource Planning (ERP), Customer-Relationship-Management System (CRM), Workflow Management System (WFMS), and Business Process Management System (BPMS) [21]. This dissertation focuses specifically on BPMS as the subset of PAIS driven by explicit process models (e. g., modeled using Business Process Model and Notation (BPMN)), though the sociotechnical principles discussed apply to the broader class of PAIS.

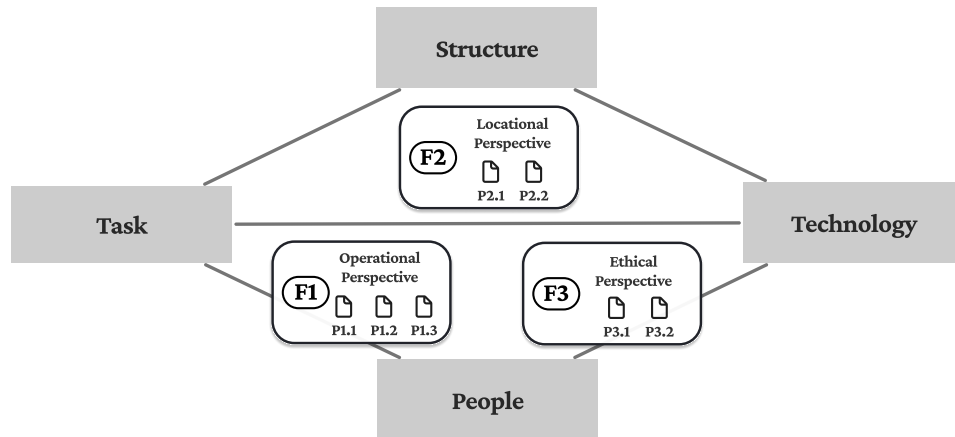


Figure 1: Theoretical framing of human-centric BPM unifying Leavitt’s Multivariate System [43] with Sociotechnical Systems Theory [49, 81]. The diagram situates the three BPM perspectives and focus areas of this dissertation at the intersections of the multivariate system variables, illustrating how **(F1)**, **(F2)**, and **(F3)** bridge the gaps between *Task*, *Structure*, *Technology*, and *People*.

Similarly, the widespread use of technology and the availability of data lead to greater awareness of the ethical implications of its use [90]. This is also the case in BPM, where the *Ethical Perspective* emphasizes interplay between human actors and technology, with an ethical process management that has been neglected in the face of the automation and standardization goals of the past [38, 77].

The exclusion of these perspectives highlights a broader structural flaw: current research indicates that truly human-centric systems must evolve from explicit manual reporting (such as logging tool usage, updating actor locations, or documenting compliance decisions) to *implicit interactions* [11]. In this paradigm, the system does not wait for input but actively “senses” the environment to understand human intent. Currently, manual tasks³ are depicted as atomic units of work executed by active resources (mostly human actors) [21, 13, 100], yet the underlying systems provide little to no support for their actual execution and the context it happens in. The system orchestrates control flow *between* tasks but does not capture the activities *within* them or the context *around* them. Thus, while BPM handles the routing of work, the human worker relies on tacit knowledge or disconnected tools for physical execution, manages spatial constraints without system awareness, and operates without structural support for ethical transparency [cf. 5, 40, 86, 85, 38, 39].

Figure 1 outlines the theoretical framing of this dissertation, which grounds itself in *Sociotechnical Systems Theory* [44] and utilizes *Leavitt’s Multivariate System* [43] for formalization. While *Technology* (PAIS) and *Structure* (defined by Leavitt as the systems of authority, communication, and workflow [43]) have been optimized for administrative control, they remain disconnected from the physical reality of

³In BPMN [cf. 54], a *Manual Task* is strictly defined as work performed without the aid of any process execution engine or application. This contrasts with a *User Task*, in which a human interacts with the system through a software interface. Throughout this dissertation, we use the term *Manual Task* to denote physical work that is currently invisible to the digital system.

the *Task* and the value-based needs of *People*. This dissertation argues that true human-centricity cannot be achieved by optimizing variables in isolation, but by re-architecting the sociotechnical relationships between them:

- *The Task-Technology Interface (F1)*: Traditional *BPM* separates the digital workflow from the physical tool. The **Operational Perspective (F1)** bridges this gap by treating tools not just as assets, but as structural constraints, i. e., ensuring the *Technical Subsystem* actively supports (or blocks) the *Task* based on physical feasibility.
- *The Structure-Environment Interface (F2)*: Standard processes follow static routing. The **Locational Perspective (F2)** internalizes the *Environment* to dynamically adapt Leavitt's *Structure* three-part structure: it reallocates *Authority* (assignment), automates *Communication* (events), and reroutes *Workflow logic* based on physical context.
- *The Social-Technical Interface (F3)*: As (F1) and (F2) increase monitoring, pressure shifts onto the human actor. The **Ethical Perspective (F3)** mediates the relationship between *People* and the *System*, establishing a governance layer that ensures the enhanced *Technology* and *Structure* do not compromise the *Social Subsystem*.

BPM frequently introduces Technology without adjusting the corresponding Task or Structure, creating a state of sociotechnical imbalance that places the responsibility for adjustment solely on People.

From a sociotechnical perspective, *PAISS* are viewed not only as software artifacts but also as complex configurations of interacting subsystems. As articulated by Sarker *et al.* [81], these systems function through the interplay of the *Technical Subsystem* (processes, software, automation) and the *Social Subsystem* (human actors, relationships, values).

BPM research has prioritized Technical Subsystem optimization (automation efficiency, system performance) [21, 61] while treating the Social Subsystem as secondary and the External Subsystem as simple limitations, neglecting the inherent interdependencies that define sociotechnical systems.

Leavitt's multivariate model [43] further decomposes this sociotechnical complexity into four interdependent variables: **Task** (the primary work objectives), **Structure** (the systems of authority and workflow), **People** (the actors who execute the work), and **Technology** (the tools and systems that facilitate performance). The core idea of Leavitt's model is that these variables exist in a dynamic *sociotechnical balance*. They are mutually determining; a change in one variable inevitably affects the others. Therefore, successful system design requires *Joint Optimization* [7], i. e., maximizing the performance of the *Technical* and *Social Subsystems* simultaneously, rather than optimizing one at the expense of the other. Failing to recognize this interdependence leads to *systemic imbalance*. Instead of treating these elements in isolation, this dissertation demonstrates their necessary interdependence: it expands **Task** definitions to include passive resources ((F1)), adapts the organizational **Structure** to be location-aware ((F2)), and

embeds ethical values to protect **People** from the increased pressure of technological transparency (**F3**). As such, this dissertation extends **BPM** across three dimensions (**Operational** (**F1**), **Spatial** (**F2**), and **Ethical** (**F3**)) to create a unified *Human-Centric Process Management* discipline that aligns the system's technical capabilities with the social needs of its users.

To address the current limitations, it is necessary to explicitly separate different process entities, laying the foundation for precise operational support. Central to this is the distinction between *active resources* and *passive resources* [56, 12, 21]. Active resources are actors capable of executing tasks, such as humans or intelligent machines [21, 32]. Passive resources, in contrast, refer to the tools, materials, and equipment required for task execution [21, 95]. Standard **BPM** typically focuses on assigning active resources (actors) to tasks [80, 75], neglecting the management and provisioning of passive resources, which are equally critical for successful task execution [73, 31].

The operational perspective has historically been marginalized, defined narrowly as “which software executes” rather than “how active resources execute with which resources.”

This marginalization extends to the *spatial context* in which work occurs. While mobile workforce management heavily relies on routing and proximity [33, 41], traditional process models abstract location away, treating it as a descriptive text attribute rather than a constraint that dictates execution feasibility [111, 85].

The locational perspective has conventionally been abstracted, defined as “where a task occurs” (passive data) rather than “how space constrains execution” (active logic).

Furthermore, neglecting these physical and spatial dimensions ultimately compromises the *social subsystem*. The resulting transparency and algorithmic control raise significant concerns regarding worker autonomy and surveillance [47, 55], yet standard **BPM** lacks the mechanisms to internalize these values, treating ethics as external to the system design [90, 108].

The ethical perspective has systematically been externalized, treated as a normative compliance checklist rather than a functional requirement essential for sociotechnical stability.

To operationalize the *implicit interaction* paradigm [11], a link is required between the digital process and the physical work environment. The emergence of the **Internet of Things** (**IoT**), mobile devices, and ubiquitous sensors provide exactly this fundamental link. By instrumenting the physical environment, these technologies enable the system to “sense” work as it happens [11], transforming manual tasks from opaque steps into core process entities. This expansion of perspectives directly impacts specific stages of the *BPM lifecycle*, which typically spans the definition, enactment, analysis, and optimization of processes [21, 106]. This dissertation focuses primarily on the *Definition* and *Enactment* phases:

- *Definition (Modeling)*: We extend the modeling phase by introducing formal notations for passive resources (¶ 1.2 and 1.3) and spatial constraints (¶ 2.2). This ensures that the physical reality of work is captured explicitly at design time rather than remaining implicit knowledge.

- *Enactment (Execution)*: We link to the execution phase by developing runtime artifacts (e. g., the *BPMS* addition in all papers except for § 3.1 and the Location-Aware execution patterns (§ 2.1)) that actively orchestrate manual work. Instead of just routing tasks, the system enforces physical constraints and allocates resources in real time.

While *Analysis* and *Optimization* are supported through data generation (e. g., the Moral Performance Dashboard in (F3)), the core contribution lies in architecting the “full support of the *BPM* lifecycle” by ensuring that manual, physical, and ethical dimensions are machine-readable and executable from the start. Addressing this requires interventions at two distinct temporal phases of the *BPMS*: *Design Time* (*Build Time*), where the physical constraints and resource requirements must be explicitly modeled as part of the process definition, as well as during *Run Time*, where the execution engine must actively monitor these constraints, moving from a passive *waiting* state to an active state of resource provisioning and context verification. This integration facilitates a shift from *automation-only BPM*, which seeks to replace human labor, to *human-augmentation BPM*, which empowers workers with context-aware support. This transition motivates the overarching research question of this dissertation:

How can process-aware information systems be architected to orchestrate the operational, spatial, and ethical dimensions of human work?

To answer this question, the research is structured into three specific focus areas, within Leavitt’s multivariate system:

- **(F1) The Operational Perspective**
This area addresses the disconnect between digital process management and physical execution. It integrates the *Technology* of *IoT* with the manual *Task*, shifting the perspective from simple *software execution* to *physical execution* and focusing on the management of passive resources (§ 1.1, § 1.2, and § 1.3).
- **(F2) The Locational Perspective**
This area reconfigures the organizational *Structure* to be responsive to physical space. It establishes location not just as data, but as a determinant that dynamically shapes process logic and resource allocation (§ 2.1 and § 2.2).
- **(F3) The Ethical Perspective**
As (F1) and (F2) increase the granularity of monitoring, this area addresses the impact on *People*. It introduces an ethical governance layer to manage the tension between system transparency and human autonomy (§ 3.1 and § 3.2).

This dissertation contributes to the field through seven peer-reviewed publications that address human aspects across these three complementary dimensions. These contributions form a coherent framework grounded in *Leavitt’s multivariate system* and sociotechnical theory. They demonstrate that true human-centricity requires an integrated approach: *Operational support* provides the necessary resources, *Spatial awareness* provides the essential context, while the technological environment, including measures to preserve trust and safeguard human well-being, is guided by *Ethical considerations*.

2 Focus Areas and Research Questions

To answer this central question, this research comprises three complementary focus areas (**F1**, **F2**, **F3**), each addressing a distinct dimension of the human aspect of BPM.

F1 Operational Perspective

This focus area bridges the *Technology* and *Task* variables. As Leavitt notes, the system's variables are interdependent; if the required *Technology* (tools) is absent, the *Structure* (workflow) cannot function [43]. Traditional BPM treats the manual task as a “black box,” ignoring this dependency. While the system manages the control flow *between* tasks (e. g., ordering, planning, invoicing), it lacks data on the physical reality *within* them. In practice, the lack of passive resources like tools and materials creates a structural bottleneck that halts process execution. **F1** formalizes these resources to prevent the “Process Breakdown” that occurs when the digital *Workflow* proceeds while the physical *Reality* is stalled. Current systems treat these physical necessities as externalities, leaving the worker to coordinate them manually.

RQ1. *How can the operational perspective be formalized and operationalized to support manual task execution with appropriate tools, materials, and contextual information?*

Contribution to RQ1. This focus area redefines the operational perspective from software orchestration to resource provisioning. The contributions span conceptual, formal, and implementation levels:

- **1.1 (Conceptual):** A mixed-methods study redefining the operational perspective. It introduces a classification scheme for process entities that distinguishes between active and passive resources and proposes a vision for IOT-enabled execution support.
- **1.2 (Formal):** An ontology-based framework that formalizes passive resources as *operational equipment* within process models. This approach integrates tool types, instances, and material properties into executable BPMN models, providing the structure necessary for automated execution [53].
- **1.3 (Implementation):** Development of *Passive Resource-integrated Modeling Extension (PRIME)*, an executable BPMN extension. It provides runtime resource management by checking resource availability to generate actor checklists and design time visualization of material flows via Sankey diagrams [82].

This focus area operationalizes the link between the *Technology* variable (using IOT sensors) and the *Task* variable (manual execution). Rather than abstracting the task, the framework ensures that the system supports the tangible context of work. Within sociotechnical systems, it connects the *Technical Subsystem* (BPMs, IOT devices) with the *Social Subsystem* (human actors performing manual work).

(F2) Locational Perspective

Active resources, particularly human actors, execute manual tasks within physical space. However, standard **BPM** typically ignores spatial context, treating tasks as location-agnostic [32, 67]. In mobile and distributed environments, e. g., field service, construction, or emergency response, location dictates process logic, as it determines worker availability, task sites, and the necessary travel time between locations [19, 111]. Without explicit location modeling, processes cannot adapt to spatial constraints, leading to inefficient resource allocation and missed optimization opportunities [85, 63].

RQ2. *How can the spatial context of process entities be integrated into process models and execution to enable location-aware process orchestration?*

Contribution to RQ2. This focus area establishes location as an active driver in **BPM** by developing patterns, notations, and execution mechanisms for location-aware processes:

- **2.1 (Conceptual + Implementation):** Presentation of location-aware patterns (location-based task allocation, automated task start/termination based on location, location-event-based dispatching) with a multilayer system architecture and prototypical implementation.
- **2.2 (Formal):** Introduces **Location-Aware Business Process Model and Notation (LABPMN)** as a formal **BPMN** extension, making location information explicit in process models through metamodel extension [cf. 94], enabling location-based process control, task allocation, and data collection.

This research validates both implementations through real-world use cases from craft businesses within the underlying research project (cf. Section 4.3). These cases demonstrate the practical applicability of the solutions, specifically regarding repair processes at customer locations, device rentals with location tracking, and monitored goods delivery between branches.

Location awareness integrates the *External Subsystem* (physical environment, spatial constraints) with the *Technical Subsystem* (Global Positioning System (GPS)/IoT tracking). This approach refines Leavitt's *Structure* variable by treating location as a primary constraint rather than a secondary data attribute, thereby enabling the system to dynamically adapt the organizational structure to the workforce's physical context.

(F3) Ethical Perspective

As **BPMSS** integrate **IoT** and other technologies, influencing human work through automation and monitoring, ethical implications become important yet remain implicit [90, 77]. Questions of fairness, transparency, autonomy, privacy, and human dignity arise: *How does location tracking affect worker autonomy [cf. 98]? Are resource allocation algorithms fair [cf. 51, 55]? Does process automation respect human values [cf. 22, 17]?* Current **BPM** research lacks systematic frameworks for identifying, measuring, and managing ethical values in process execution [38].

RQ3. *How can ethical values be made explicit, measurable, and manageable within business process execution?*

Contribution to RQ3. This focus area develops a systematic approach to operationalizing ethics in BPM, spanning descriptive and prescriptive contributions:

- **3.1 (Descriptive):** Systematic Literature Review (SLR) identifying ethical values (e. g., Fairness, Transparency, Autonomy, Privacy) [108] across BPM literature, mapped to process types (Core, Support, Management) [62] and sociotechnical perspectives (Social, Technical, External Subsystems) [44].
- **3.2 (Prescriptive):** Framework for measuring and managing ethical values during process execution, making implicit ethical considerations explicit and actionable by implementing a *Moral Performance Measurement* system. This artifact integrates standardized ethical questionnaires directly into task execution forms to capture real-time actor sentiment, which is then aggregated and visualized as *Key Value Indicators* (KVIs) to enable evidence-based ethical governance.

Ethics serves as the negotiation layer between *People* and the newly rigid *Structure*. It ensures that the algorithmic enforcement of **(F1)** and **(F2)** does not violate the social contract required for the *People* variable to function. Within sociotechnical systems, these values bridge the *Social Subsystem* (human actors' moral considerations), the *Technical Subsystem* (algorithmic fairness), and the *External Subsystem* (regulatory compliance and societal norms).

Integration Across Focus Areas

The three focus areas defined above (*Operational* (**(F1)**), *Location* (**(F2)**), and *Ethics* (**(F3)**)) are interrelated components of a single *Human-Centric BPM* framework. While traditional BPM often optimizes the process flow in the abstract, this dissertation argues that the human actor must be supported across three specific dimensions to address the *digital-physical divide* effectively:

- **The Operational Perspective (**(F1)**) asks: *What do humans need to execute tasks effectively?***
This perspective complements assigning an actorID to a task by explicitly ensuring the actor is equipped with the necessary passive resources (tools, materials) and contextual information, i. e., including the physical realities of execution. It transforms the manual task from a “black box” into a digitally supported, resource-aware activity.
- **The Locational Perspective (**(F2)**) asks: *Where are humans when executing tasks, and how does space affect processes?***
This perspective acknowledges that human actors are physical entities moving through space, not static resources. It integrates spatial context as a basic constraint for process routing, resource allocation, and timing, enabling the process engine to adapt to the physical movement of process entities.

- **The Ethical Perspective ((F3)) functions as the sociotechnical control layer.**

Empirical evidence from the TRADEmark project revealed that workers initially embraced tool tracking ((F1)) for efficiency but grew concerned when location data ((F2)) was combined with time-stamped tool usage, perceiving this as a shift from operational support to operational control. This resistance demonstrated that the technical capability ((F1)+(F2)) without ethical governance ((F3)) risks system rejection. By making the invisible visible, e. g., by tracking minute-by-minute movements and tool usage, these technologies alter the power dynamic. Without the governance framework of ((F3)), this transparency risks destabilizing the sociotechnical balance, triggering worker resistance (cf. Reactance Theory [9, 93]) and causing the technical system to fail.

Together, these areas address the human dimension in a complementary manner: ((F1)) ensures workers have the necessary *resources*, ((F2)) accounts for their *physical context*, and ((F3)) ensures their *ethical treatment* throughout. This approach reflects the interdependence within sociotechnical systems, in which the optimization of one subsystem inevitably affects the others [81].

As illustrated in Fig. 1, this interdependence shows as a mutual feedback loop between the technical and social subsystems:

1. *Technology-Induced Structural Imbalance: ((F1)/(F2)) → ((F3)):*

Leavitt argues that technological change is structurally disruptive. By introducing *IoT (Technology)* to monitor tools ((F1)) and location ((F2)), we fundamentally alter the nature of the *Task* (from autonomous to monitored). If the *Structure* (incentives, privacy rules) remains static, the *People* variable suffers (resistance, stress). Therefore, ((F3)) is more than just an “add-on”; it is a structural modification necessary to address the perceived pressure from the new technology.

2. *Ethical Values constitute Non-Functional Requirements ((F3) → ((F1)/(F2)):*

Conversely, ethical values defined in ((F3)) must not remain abstract principles; they must serve as concrete non-functional requirements that shape the architectural design of operational and location-aware mechanisms. For instance, a location-aware algorithm ((F2)) must be designed with *Privacy by Design* principles [cf. 16] (e. g., blurring data outside working hours), and algorithmic resource allocation ((F1)) must be auditable to ensure fairness in work distribution. In this way, ethics actively constrains and guides the technical implementation.

Instead of focusing on *Technology* solely to optimize the *Structure* at the expense of *People*, this framework employs ((F1)) and ((F2)) to align the *Technical System* with the physical reality of the *Task*, while employing ((F3)) to protect the human actor from structural rigidity. The integration of ((F1)), ((F2)), and ((F3)) creates a unified Human-Centric *BPM* framework where operational support ensures technical feasibility (*Technology* ↔ *Task*), location awareness dynamically adapts the organizational logic (*Structure* ↔ *Environment*), and ethical considerations mediate the resulting system pressure (*People*). This framework restores balance to Leavitt’s system by redefining *People* as empowered actors, protected by structural safeguards.

3 Related Work

This chapter situates the dissertation within the existing body of knowledge by exploring the intersection of three complementary research streams: (1) Resource Management and the Operational Perspective in BPM, (2) Location-Awareness and Ubiquitous Computing, and (3) Ethics and Value-based Information System (IS). This review synthesizes shared principles across these domains to establish a unified conceptual framework. By examining the interplay between these fields, the chapter highlights specific research gaps that form the basis of this dissertation.

The Operational Perspective and Resource Management

Resource Management in BPM Resource management is a well-established subfield of BPM, yet it exhibits a strong functional bias. The foundational work by Russell *et al.* [80] on *Workflow Resource Patterns* establishes a comprehensive taxonomy that defines how systems distribute work among resources. These patterns cover direct allocation, role-based distribution, and separation of duties. Similarly, subsequent research has sought to model resource requirements more formally. Cabanillas *et al.* [12] introduce the *Resource Assignment Language (RAL)*, a domain-specific language that enables automated design-time analysis of human resource assignments, such as detecting consistency issues and identifying critical participants. In the manufacturing domain, Braun and Esswein [8] extend standard BPMN to explicitly model machine tools, auxiliary materials, and their associated costs, thereby integrating engineering requirements into process models.

However, despite these specific advances, the broader field focuses predominantly on *active resources* (human actors or software services). A recent systematic literature review by Pufahl *et al.* [75] confirms this trend: in an analysis of 61 primary studies on resource allocation, they found that research overwhelmingly targets human and application resources, with only a few exceptions addressing consumable or passive resources. Existing approaches concentrate on *who* is responsible for a task or *when* they are available. In contrast, the management of *passive resources*, i. e., the tools, materials, and equipment required to physically execute the task, is often treated implicitly. While the discipline of *Engineering Asset Management (EAM)* specifically targets the lifecycle management of physical assets [3], existing research rarely integrates this perspective into the runtime logic of business processes. In standard BPM, tools are typically modeled as generic data objects without lifecycle semantics [56], creating a disconnect between the *process lifecycle* (the case) and the *asset lifecycle* (the tool)

IoT-Enhanced Business Processes The convergence of BPM and the IoT [32] presents mutual opportunities: BPM provides the logic to organize IoT systems, while sensor data enables the monitoring of physical execution [84]. Schönig *et al.* [83] propose a layered architecture in which sensors trigger process events, and processes control actuators. To formalize this integration, Meyer *et al.* [48] extend the standard BPMN 2.0 metamodel to treat IoT devices explicitly as *process resources*. In their approach, devices are modeled as active performers in dedicated lanes, enabling systems to allocate specific sensors or actuators based on technical attributes such as accuracy or location. Complementing this modeling view, Friedow *et al.* [25] focus on the runtime orchestration of these devices. They demonstrated a

bidirectional framework in which the process engine not only consumes aggregated sensor events via complex event processing but also actively triggers physical actuators via service tasks linked to digital twins.

Despite these advancements, a gap remains in supporting manual workers: previous approaches to supporting human execution in physical environments have focused on transforming process models into static *Process Checklists* [5]. While effective for guidance, checklists rely on human confirmation and lack real-time validation of the state. The existing Operational Perspective in the literature effectively supports the orchestration of software services [106] and the automation of machines. Still, it lacks a unified mechanism to orchestrate the interaction between *active* and *passive resources* in real time.

Location-Awareness in BPM

Context-Aware BPM Location Aware BPM is a subset of the broader field of Context-Aware BPM. In the wider Computer Science (CS) discipline, Abowd *et al.* [1] define context as “any information that can be used to characterize the situation of an entity.” Within BPM, Rosemann *et al.* [78] establish a parallel framework that distinguishes between the *immediate context* (data required for execution) and the *external context* (environmental factors). Moving beyond a static view, Brocke *et al.* [10] argue that BPM methodologies often fail due to a “one-size-fits-all” approach. They proposed a situational framework that categorizes context into four dimensions (*goals* (e. g., exploitation vs. exploration), *process characteristics*, *organizational factors*, and the *environment*) to tailor management practices to specific situations. Complementing this strategic view with an execution perspective, Yousfi *et al.* [110] introduce *Decision-Aware Business Processes*. Their approach uses “Decision Partitions” to analyze contextual parameters in real time, enabling it to dynamically select or recommend the most appropriate execution path rather than following a stagnant workflow. However, current BPM engines lack the architectural ability to treat physical context as a state-changing variable, instead of treating it as a normal process variable.

Mobile and Ubiquitous Process Modeling The integration of mobility into BPMN attempts to realize the vision of *Ubiquitous Computing* [cf. 105] within the process domain. Decker *et al.* [19] provide early concepts for modeling mobile workflows, while Zhu *et al.* [111] explore location dependencies. Yousfi *et al.* [109] introduce Ubiquitous BPMN to model business processes specifically for ubiquitous (or interconnected) environments. Furthermore, Casati *et al.* [15] propose the vision of “orchestrating the physical enterprise,” arguing that BPM should directly control physical entities like sensors and actuators.

Despite this vision, a gap remains in *execution semantics*: Most existing approaches focus on either the *user interface* (task delivery to mobile phones) or the *decision logic* (using location data at a gateway). They do not natively support concepts like *Geofencing* as a trigger for process instantiation or *Proximity* as a hard constraint for resource allocation. Sperner *et al.* [89] introduce entity-based concepts, but current literature lacks a standard-compliant, executable notation for location-aware process control (as proposed in (F2)).

Ethics in Information Systems and BPM

Ethics and Values in Information Systems Ethics has a rich tradition in IS research, evolving from privacy concerns to broader societal impacts [91, 37]. Spiekermann *et al.* [90] provides a comprehensive state-of-the-art analysis, arguing that system design should treat values as functional requirements. Winkler and Spiekermann [108] further formalize this by proposing *Value-based Engineering*, which translates abstract ethical values into concrete non-functional requirements.

Responsible and Benevolent BPM The BPM discipline is currently witnessing a normative shift, expanding its traditional focus on performance optimization to encompass the ethical implications of process execution. This trend mirrors a broader, recurring theme within IS research, where the discourse on responsibility [97] (specifically regarding responsible research practices [cf. 92]) has increasingly influenced various subdomains. Within the process-technical sphere, van der Aalst [102] introduces the concept of *Responsible Data Science*, which addresses fairness and privacy in process mining, such as the prevention of algorithmic discrimination. Extending this trajectory, Rosemann *et al.* [77] propose *Benevolent Business Processes*, arguing that BPM must move beyond transactional efficiency to proactively enhance stakeholder well-being. Aligned with these developments, Trier *et al.* [97] characterize the broader imperative of Digital Responsibility (DR) by positioning ethical considerations as fundamental quality dimensions of modern digital operations.

While the conceptual need for ethics is widely recognized, there is a significant lack of *operationalization* in the runtime environment. Existing ethical instruments, such as the *Multidimensional Ethics Scale* (MES) by Reidenbach *et al.* [76] or the refined scales by Casali [14], remain psychological tools designed for *post-hoc* human surveys. Existing research has not yet translated these values into the BPM execution lifecycle. Consequently, actors lack the technical means to monitor *Moral Performance* with the same granularity as *Time*, *Cost*, *Quality*, and *Flexibility* (cf. *Devil's Quadrangle* [21]).

Summary of Research Gaps

While specific subdisciplines exist for resource management, ubiquitous computing, and information ethics, they remain isolated from the core execution engine of BPM. Existing literature approaches the human actor from fragmented perspectives: as a schedulable resource in *Operations*, as a coordinate in *Ubiquitous Computing*, or as a moral subject in *Information Ethics*.

Table 1 synthesizes the three research gaps identified in this chapter. It connects the *administrative focus* of BPM (which excels at coordinating information and control flow) against the neglected *material* and *human* dimensions required to orchestrate manual work effectively. These gaps reflect a failure to address the full sociotechnical context of manual work. The discipline has historically prioritized optimizing *Task* flows and *Structure* for administrative efficiency, while treating the physical reality of *Technology* (tools) and the value-based needs of *People* as externalities. This administrative bias results in systems that are highly effective for document-centric workflows but structurally insufficient for orchestrating physically constrained, knowledge- and human-intensive operations.

Table 1: Overview of research gaps mapped to Leavitt’s system variables. The table contrasts the administrative focus of *BPM* against the missing sociotechnical links, showing how each Focus Area restores the relationship.

Gap	Traditional <i>BPM</i> Bias	Sociotechnical Disconnect	This Dissertation's Contribution
Gap 1: The Operational Void	Process vs. Asset: Focus on the lifecycle of the <i>case</i> (Process), ignoring the lifecycle of the <i>tool</i> (Asset).	Technology ↔ Task (Execution Feasibility)	(F1) Operational Bridges the gap by formalizing <i>Passive Resource</i> availability as a structural constraint via the <i>PRIME</i> artifact.
Gap 2: The Spatial Disconnect	Logical vs. Physical: Orchestration is limited to software services; location is treated just as passive data.	Structure ↔ Environment (Contextual Logic)	(F2) Locational Adapts the <i>Structure</i> (Authority & Routing) to the physical <i>Environment</i> by establishing location as a deterministic constraint via <i>LABPMN</i> .
Gap 3: The Ethical Gap	Design vs. Runtime: Ethics are treated as high-level principles or compliance checklists, not as measurable performance indicators.	People ↔ System (Value Alignment)	(F3) Ethical Mediates the relationship between <i>People</i> and the <i>Technical System</i> by operationalizing values as non-functional requirements via <i>Moral Performance Measurement</i> .

4 Methodology

To address the sociotechnical complexity of the research questions, this dissertation employs a multi-method research design. Given that the primary objective is to create novel solutions for human-centric *BPM*, specifically operational support, location awareness, and ethical measurement, *Design Science Research* (*DSR*) [59, 29, 35] serves as the core methodological framework. But, as creating *Information Technology* (*IT*) artifacts alone is insufficient without theoretical grounding and formal specification, two supporting methodologies complement the *DSR* process: *SLR* acts as a diagnostic tool to map the existing knowledge base [52, 57, 103, 104], and *Ontology Engineering* provides the formal semantics necessary to resolve the gap between conceptual models and technical implementation [50].

This methodological synthesis satisfies the dual mandates of *DSR* [35]: ensuring *practical relevance* through the demonstrated utility of the artifacts, while maintaining *theoretical rigor* via formal definition and systematic literature integration.

4.1 Design Science Research

DSR serves as the primary methodological framework for this dissertation. Given the objective of creating novel *IT* artifacts, specifically, extensions to the *BPMN* standard [53] and execution frameworks, *DSR* provides the necessary rigor to ensure these artifacts address relevant business problems and contribute to the scientific knowledge base.

For this, we follow the basic *DSR* process model proposed by Peffers *et al.* [59], Johannesson and Perjons [35], and Hevner *et al.* [29]. However, as the introduction of new technologies ((F1), (F2)) inevitably alters the organizational context, creating second-order effects that must be managed ((F3)), a linear application of the *DSR* methodology is insufficient. To capture this dynamic, the methodology is operationalized through the *Four-Cycle Model* of *DSR*, as conceptualized by Drechsler and Hevner [20] and illustrated in Fig. 2. This framework positions the research activities within four distinct but interacting cycles:

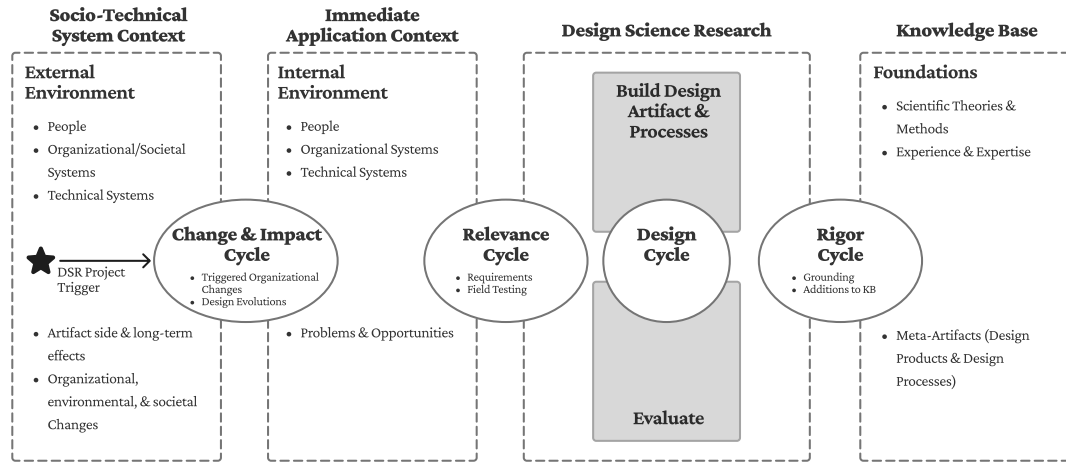


Figure 2: The Four-Cycle Model of Design Science Research, adapted from Drechsler and Hevner [20]. It illustrates the interplay between the knowledge base (*Rigor*), the immediate problem context (*Relevance*), the artifact construction (*Design*), and the broader sociotechnical impact (*Change & Impact*).

- **The Relevance Cycle (Environment):** This cycle defines the immediate problem context and provides the acceptance criteria. In this dissertation, the environment comprises the craft and field service sectors (e. g., the TRADEmark project, cf. Section 4.3), where stakeholders identified the “black box” of manual work as a key area of concern.
- **The Rigor Cycle (Knowledge Base):** This cycle provides the theoretical foundations and ensures the research contributes new knowledge. The knowledge base draws from existing BPM practices, sociotechnical systems theory, and ethics literature.
- **The Design Cycle (Artifacts):** In this stage, the theoretical perspectives are translated into tangible artifacts. This involved prototyping software extensions alongside the development of metamodel extensions [53, 54] and formal ontologies [50] to ensure structural consistency.
- **The Change & Impact Cycle (Sociotechnical System):** This cycle captures the causal link between the focus areas. The successful implementation of artifacts in **(F1)** (e. g., PRIME) and **(F2)** (e. g., LABPMN) resolved the issue around the physical-digital divide, but in doing so, triggered the *Change & Impact Cycle*. The technical realization of operational and spatial support revealed a critical sociotechnical challenge: the reduction of physical work to algorithmic metrics. Field evaluation indicated that technical feasibility alone (**(F1)/(F2)**) was insufficient for adoption without ethical governance. Thus, the technical outputs of **(F1)** and **(F2)** became the problem inputs for **(F3)**, requiring a distinct artifact to manage the resulting transparency.

Table 2 maps each publication to specific DSR cycles and supporting methodologies.

Table 2: Overview of the primary research methods, DSR cycles, supporting techniques, and validation approaches used in each publication (□ 1.1–□ 3.2), showing how the dissertation combines conceptual work, formalization, and implementation across the three focus areas.

Pub.	Primary Method	DSR Cycle	Supporting Methods	Validation Approach
□ 1.1	DSR (Conceptual)	Relevance → Design	SLR, Abductive Reasoning [96]	Field observations (TRADEmark)
□ 1.2	Ontology Engineering	Rigor → Design	7-step method following [50]	Competency questions, SPARQL queries
□ 1.3	DSR (Implementation)	Design → Change	Prototyping	Cyber-physical demonstration
□ 2.1	DSR (Patterns)	Relevance → Design	Pattern mining	Multi-layer architecture
□ 2.2	DSR (Formal)	Rigor → Design	BPMN extension mechanism [94, 8]	Feature comparison, Use cases
□ 3.1	SLR	Rigor	PRISMA [57], Inductive coding	82 publications analyzed
□ 3.2	DSR (Prescriptive)	Change + Impact	NASA-TLX [28]	Usability testing

DSR Application Across Focus Areas

The application of DSR was tailored to the specific maturity and requirements of each focus area, progressing from conceptual exploration to formal definition and, finally, to technical implementation.

(F1) The Operational Perspective (□ 1.1–□ 1.3) In this focus area, the design cycle addressed the fundamental problem of opaqueness in manual task execution. The development cycle progressed from high-level prototypes toward formal specifications:

- **Problem Identification (Relevance Cycle):** Initial field studies in the craft sector revealed a disconnect between the digital process and physical execution. Workers lacked digital support for tool selection, leading to inefficiencies.
- **Conceptual Design (□ 1.1):** The first iteration focused on defining the *requirements*. Driven by the *Relevance Cycle* within the TRADEmark project, we observed that craftspeople bypassed existing Enterprise Resource Planning (ERP)/BPMs systems when selecting tools. Through abductive reasoning [96] applied to these field observations, we inferred that the disconnect was not behavioral but structural: the lack of a *Passive Resource* class in the process model. This inference directly shaped the classification scheme in □ 1.1.
- **Formalization and Implementation (□ 1.2, □ 1.3):** The design cycle then moved to construction. □ 1.2 formalized the domain via Ontology Engineering [50] (see Section 4.2), which served as the data structure for □ 1.3. This research implemented the final artifact, PRIME. A demonstration validated the artifact by automatically generating runtime checklists for passive resources based on IoT sensor data.

(F2) The Locational Perspective (¶ 2.1, ¶ 2.2) This area focused on extending the modeling language to include spatial context. The DSR process emphasized the formal correctness and expressiveness of the notation.

- **Problem Identification:** Standard BPMN treats processes as location-agnostic. The *Relevance Cycle* highlighted that for mobile workforce management, location is not just an arbitrary attribute but an essential constraint.
- **Pattern Discovery (¶ 2.1):** The first design iteration identified nine *Location-Aware Patterns* (e. g., geo-fencing, proximity allocation). These patterns served as the functional requirements for the process modeling extension.
- **Artifact Formalization (¶ 2.2):** The *Rigor Cycle* grounded the design in the existing knowledge base. The *LABPMN* artifact was architected using the formal BPMN extension mechanism [cf. 53]. This research evaluated the artifact by comparing its features against existing requirements and demonstrating its application in diverse field service scenarios, such as the TRADEmark craft repair process and emergency response routing [4].

(F3) The Ethical Perspective (¶ 3.1, ¶ 3.2) While ¶ 3.1 (SLR) provided the theoretical constraints from the knowledge base, ¶ 3.2 followed a DSR approach to build a *Moral Performance Measurement* framework.

- **Problem Identification:** The granular operational visibility enabled by (F1) and (F2) introduces a tension between support and control. The lack of tools to measure this ethical impact represents a critical gap that prevents the sustainable adoption of human-centric BPM.
- **Artifact Design:** The design challenge was to translate abstract ethical values (e. g., Autonomy) into measurable process indicators. The resulting framework allows designers to annotate tasks with standardized ethical questionnaires (e. g., the MES [76]).
- **Evaluation:** Validating ethics is subjective [90]. Therefore, the evaluation strategy focused on utility and usability as proxies for adoption. We employed NASA-TLX [28] to measure the cognitive load, on the premise that workers will bypass an ethical framework that interrupts the intuitive flow of labor. By demonstrating that the artifact imposes only a moderate load, we show its viability as a sustainable management tool in real-world operations [74].

4.2 Supporting Methodologies

Systematic Literature Review (SLR)

While the DSR cycles for all focus areas incorporated literature reviews, ¶ 3.1 stands out as a standalone, comprehensive SLR. Before ethical values could be operationalized (RQ3), it was necessary to establish a theoretical baseline, clarify the conceptual boundaries of *ethics* in BPM, and synthesize an overview of the field's core ethical values. Following the guidelines of Okoli [52], Page *et al.* [57], and Webster and

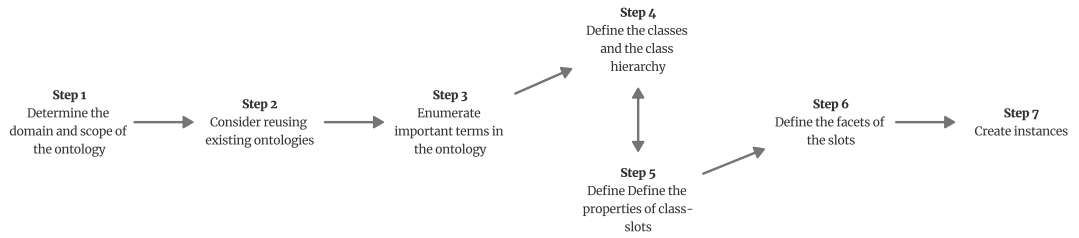


Figure 3: Seven-step ontology engineering process applied in [1.2](#), adapted from Noy [50], detailing how the passive-resource ontology for the operational perspective was defined, refined, and instantiated to enable machine-interpretable support for manual tasks.

Watson [104], this study systematically searched the list of 21 top-level *IS* journals by Lowry *et al.* [45]. By coding the results against sociotechnical subsystems, the analysis revealed a critical gap: while *Privacy* and *Security* were well covered mostly in the context of Big Data and Artificial Intelligence (*AI*), values such as *Autonomy* and *Fairness* were discussed conceptually but rarely operationalized with the growing importance of overall awareness and actionability. This synthesis provided the necessary theoretical inputs (the *values*) that subsequently informed the artifact design in [3.2](#).

Ontology Engineering

In [F1](#), conceptual definitions of *tools* and *materials* were insufficient for machine execution. To solve this, [1.2](#) employed Ontology Engineering to create a formal, machine-readable representation of passive resources. The development followed the seven-step methodology proposed by Noy [50], as illustrated in Fig. 3. This iterative process began with defining the domain scope, specifically focusing on operational equipment for manual tasks, and reusing existing resource ontologies [cf. 95, 58, 88] to avoid redundancy. This research then defined the terms, class hierarchies (distinguishing *active* vs. *passive resources*), and properties, before finalizing constraints and populating the ontology with real-world instances from the craft sector. Initial development linearly followed the seven steps in Noy [50], yet the implementation of the execution engine (*PRIME*) in the *Design Cycle* revealed semantic gaps in the initial ontology (e. g., handling quantitative parameters such as dynamic states like battery level), triggering a *Rigor Cycle* feedback loop that required iteratively refining the class hierarchy in [1.2](#) to support the runtime requirements of [1.3](#).

4.3 Research Environment

This dissertation originates from the Chair of Process-based Information Systems at the University of Regensburg⁴, building upon its established research focus on *PAISS* and the integration of *BPM* with the *IOT* [84, 32]. This enabled the concepts and artifacts presented to be developed and validated within the research project, responding directly to the current discourse in the *BPM* and general *IS* community.

⁴<http://go.ur.de/pi>

IoT-basiertes Daten- und Prozessmanagement im Handwerk (TRADEmark)

The primary research environment for this dissertation was the *TRADEmark* project (*IoT-basiertes Daten- und Prozessmanagement im Handwerk*), funded by the Bayerische Transformations- und Forschungss-tiftung (BTFS)⁵. The project aimed to digitalize and optimize business processes in the craft sector by leveraging IoT technologies. Unlike highly automated industrial manufacturing, the craft sector relies on manual labor, mobile workforces, and non-standardized processes. This specific setting provided a scientific setting for the first two focus areas:

- **Motivation for (F1) (Operational):** The observation of carpenters and technicians revealed that while their administrative processes (invoicing) were digital, their operational reality (using tools and materials) was disconnected from IT systems.
- **Motivation for (F2) (Location):** The distributed nature of craft work, spanning company premises, vehicles, and customer construction sites, required the location-aware modeling approaches developed in § 2.1 and § 2.2.

The collaboration with craft businesses within TRADEmark was essential for the *Relevance Cycle* of the DSR Methodology. The project provided access to real-world industrial data, domain experts, and physical environments for testing.

While the TRADEmark project provided the empirical context for the *Operational* ((F1)) and *Spatial* ((F2)) perspectives, the *Ethical Perspective* ((F3)) emerged as a requirement stemming from sociotechnical systems theory. As the research successfully enables handling the *digital-physical divide*, it became clear that the granular tracking of tools ((F1)) and location ((F2)) altered the power dynamics of the workplace. This technological transparency introduced a *trade-off between support and control*, placing pressure on the *People* variable. It subsequently became clear that *Human-Centric Process Management* requires structural safeguards beyond technical connectivity. The integration of human values (e. g., autonomy, fairness, and trust) acts not just as a normative constraint, but as a *non-negotiable constraint for system viability*. Without the ethical governance provided by (F3), the technical optimization of (F1) and (F2) risks triggering worker resistance, thereby destabilizing the sociotechnical system.

5 Results

As introduced in Section 2, this dissertation comprises seven publications (§ 1.1, § 1.2, § 1.3, § 2.1, § 2.2, § 3.1, and § 3.2) that address the three focus areas and their respective research questions. Table 3 gives an overview of the seven publications. For conference proceedings, this dissertation provides the CORE 2023 ranking⁶, while for journal publications, it indicates the five-year impact factor (IF) and, the CORE 2020 journal ranking⁷.

⁵<https://www.forschungsstiftung.bayern.de/>

⁶<https://portal.core.edu.au/conf-ranks/>

⁷<https://portal.core.edu.au/jnl-ranks/>

Table 3: Overview of the seven publications (□ 1.1–□ 3.2), including venue type, ranking, and impact indicators.

Publication	Type	Ranking
□ 1.1 Poss, L., Schöning, S., The Operational Perspective in Business Process Management: Towards Holistic Task Execution Support. Information Systems and e-Business Management (2026). in press. https://doi.org/10.1007/s10257-026-00735-8	Journal	4.1 IF
□ 1.2 Poss, L., Schöning, S., Formalizing the Operational Perspective in BPM: An Ontology-Based Approach for Tool Integration. Business Process Management Journal (2025). https://doi.org/10.1108/BPMJ-10-2024-0930	Journal	5.8 IF B CORE
□ 1.3 Poss, L., Schöning, S., From Model to Execution: A Formal Foundation for Managing Materials and Tools in Executable BPMN. Business Process Management Journal (2026). https://doi.org/10.1108/BPMJ-11-2025-1809 Extended Version.	Journal	5.8 IF B CORE
□ 2.1 Poss, L., Schöning, S., Location-aware business process modeling and execution. Software and Systems Modeling 24 (1), 37–67 (2024). https://doi.org/10.1007/s10270-024-01224-7 Invited Extended Version.	Journal	3.0 IF B CORE
□ 2.2 Poss, L., Dietz, L., Schöning, S., “LABPMN: Location-Aware Business Process Modeling and Notation.” In: Cooperative Information Systems. Springer Nature Switzerland, Oct. 2023, pp. 198–216. ISBN: 9783031468469. https://doi.org/10.1007/978-3-031-46846-9_11 Runner-Up Best Paper Award.	Conference	B CORE
□ 3.1 Kern, C.J., Poss, L., Kroenung, J., Schöning, S., Navigating the Moral Maze: A Literature Review of Ethical Values in Business Process Management. Business Process Management Journal 30 (8), 343–370 (2024). https://doi.org/10.1108/bpmj-06-2024-0504	Journal	5.8 IF B CORE
□ 3.2 Poss, L., Kern, C.J., Stoiber, C., Kroenung, J., Schöning, S., “Measuring Moral Performance: A Framework for Ethical Business Process Management.” In: Business Process Management: Responsible BPM Forum, Process Technology Forum, Educators Forum. Springer Nature Switzerland, Aug. 2025, pp. 117–132. ISBN: 9783032029362. https://doi.org/10.1007/978-3-032-02936-2_10	Conference	–

The seven peer-reviewed publications (□ 1.1–□ 3.2) cumulatively address the three research questions. Each publication builds on the previous one, progressing from conceptual foundations (□ 1.1) through formal specification (□ 1.2, □ 2.2) to executable implementations (□ 1.3, □ 2.1) and ethical governance (□ 3.1, □ 3.2).

Together, these papers form a cohesive *Human-Centric BPM* architecture, with each study serving as a specific component of the overall framework. Consequently, the structural progression of this chapter operationalizes the rebalancing of Leavitt’s multivariate system:

1. **Operational Feasibility (F₁):** The results demonstrate that tool availability is a structural constraint. □ 1.1, □ 1.2, and □ 1.3 show how to model passive resources as first-class entities, ensuring the *Structure* (workflow) accurately reflects the capabilities of the *Technology*.
2. **Context-Aware Structure (F₂):** Building on the task reality, the results demonstrate that *Location* determines *Authority* and *Workflow*. □ 2.1 and □ 2.2 show how spatial context fundamentally alters the execution logic, moving from static to dynamic structure.

3. **The Human Balance (F3):** Finally, the results address the sociotechnical balance between *People* and the enhanced *Structure*. As technology augments the worker’s abilities through (F1) and (F2), D 3.1 and D 3.2 provide the necessary ethical guardrails. This section presents frameworks for ensuring that human values, such as fairness and autonomy, are preserved to maintain sociotechnical balance.

5.1 (F1) The Operational Perspective

The results for this focus area fundamentally redefine the **Task** variable by replacing abstract activity modeling with concrete *resource orchestration*. While the previous section identified the “black box” nature of manual work, the contributions presented here (D 1.1–D 1.3) provide the architectural mechanisms to open it.

The central contribution is the formalization of *Passive Resources*, e. g., tools, materials, and equipment that do not autonomously initiate actions but remain essential for task execution [73]. By distinguishing these from active resources, this dissertation introduces the *Process-Resource-Integrated Management Environment* (PRIME). This distinction directly operationalizes the conceptual model proposed by Burattin *et al.* [11], who classify the environment into *Actionable Things* (actuators) and *Perceivable Things* (sensors/objects). While their work outlines the theoretical interplay between humans and IoT, PRIME provides the concrete metamodel to represent these *Perceivable Things* (tools and materials) within the BPMN standard, enabling the PAIS to *sense* the process state as they describe. As such, this framework shifts the system’s role from passively “assigning work” to actively “provisioning the work environment,” directly answering the first research question: *How can the operational perspective be formalized and operationalized to support manual task execution with appropriate tools, materials, and contextual information?*

D 1.1 – The Operational Perspective in Business Process Management: Towards Holistic Task Execution Support

Motivation. The motivation stems from treating manual work as “black boxes” in current process management. While conventional BPM defines the *Organizational Perspective* (“Who executes”) and the *Control Flow Perspective* (“When to execute”) [cf. 18, 31], it systematically omits the *Operational Perspective* (“With what”). This leaves the **Task** variable as a “black box,” ignoring the physical necessity of tools, materials, and equipment. Consequently, the successful execution of manual work currently relies entirely on the actor’s implicit knowledge to coordinate these resources.

Method. To address this gap, the study employed a mixed-methods approach. First, a structured literature review following Okoli [52] and Page *et al.* [57] was conducted to map the historical development of the operational perspective, analyzing its evolution from early WFMSS to modern BPM. Complementing this theoretical view, a targeted analysis of BPMN extensions found that current modeling standards do not sufficiently account for the nuances of physical resource management. Second, abductive reasoning [96] was applied to synthesize these findings with insights from real-world IoT projects, enabling the derivation of future operational support possibilities.

Table 4: Classification of entities participating in business processes (human actors, automated systems, operational equipment, data) along interaction type and physical characteristics, distinguishing active and passive resources for the operational perspective.

Type	Subtype	Example	Primary Citizen			Interaction Type	Secondary Citizen			Data
			trigger execution	active	passive		Physical	Location	Data	
Human			●	●	○	direct	●	○	●	n.a.
Non-Human	Self-operating systems	Autonomous robots, Drones	●	●	○	indirect	●	○	●	n.a.
Non-Human	Semi-autonomous systems	CNC machines	○	●	○	mediated	●	○	○	n.a.
Non-Human	Automated software-systems	ERPs, Automated workflows	●	●	○		○	●	n.a.	n.a.
Operational Equipment		Tools	○	○	●		●	○	○	●
Material			○	○	●		●	○	○	●
Physical Data		Documents	○	○	●		●	○	○	●
Digital Data		BPMS process variables	○	○	●		○	●	n.a.	●

Legend ● : fulfilled, ○ : not fulfilled

Results. The primary result is a comprehensive redefinition of the operational perspective, shifting from “which software executes” to “how humans execute with which physical resources.” This publication operationalizes this redefinition through:

- A classification scheme distinguishing *Active Resources* (autonomous actors) from *Passive Resources* (tools, materials) based on seven criteria: interaction type, physical character, location dependency, consumability, and reusability (see Table 4).
- Five research propositions (**RP1–RP5**) demonstrating that *IoT*-enabled passive resource management reduces execution errors by making implicit requirements explicit:
 - RP1** The integration of modeling artifacts for passive resources (e. g., tools, materials) within process models can reduce task execution errors and improve resource utilization efficiency.
 - RP2** The delivery of real-time contextual information via companion devices to human actors can increase task completion accuracy and reduce process cycle time.
 - RP3** Dynamic, *IoT*-enabled planning that leverages data on resource availability and location enables optimization of instance-spanning process execution and reduces operational overhead.
 - RP4** A refined classification scheme for manual tasks that extends beyond binary automation levels and enables granular, adaptable operational support strategies.
 - RP5** Ensuring data integration and interoperability between *IoT* systems, *ERP*, and *BPMS* is a prerequisite for achieving a overarching operational perspective.

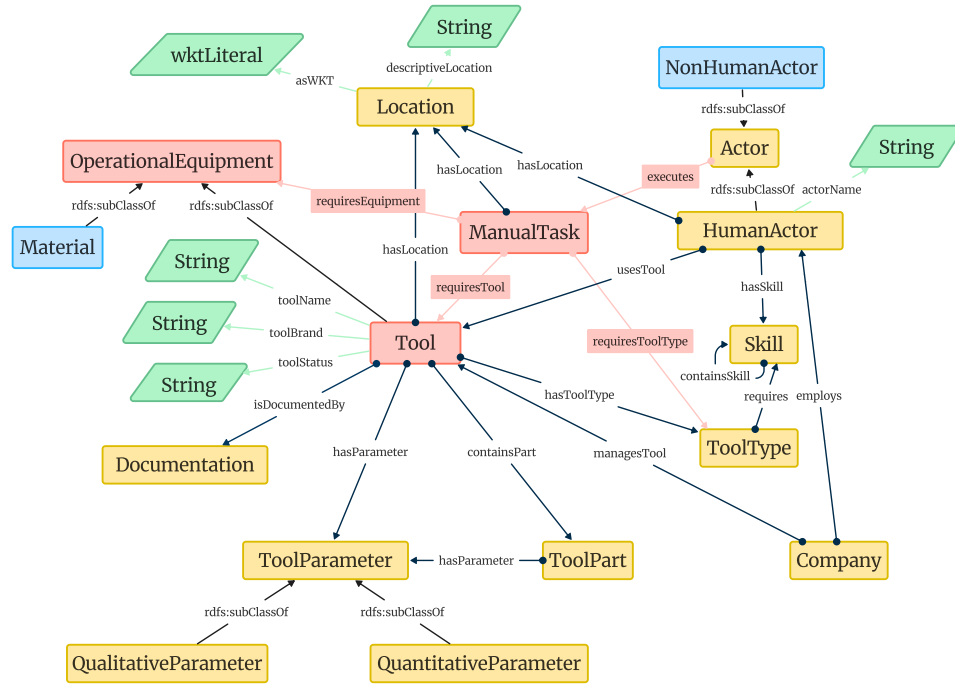


Figure 4: Ontology of the operational perspective in **BPM**, modeling relationships between manual tasks, tools, operational equipment, actors, skills, and locations. The ontology formalizes how abstract **BPMN** tasks are linked to concrete tool types and instances, enabling machine-interpretable support for manual work.

Contribution to RQ1. This publication establishes the conceptual foundation for **(F1)**. By re-defining the operational perspective and introducing the distinction between *active* and *passive resources*, it provides the theoretical basis for the formal ontology **(D 1.2)** and the executable extension **(D 1.3)**. It demonstrates that modern technologies can resolve the abstraction gap between automated functions and previously unsupported manual tasks.

D 1.2 – Formalizing the Operational Perspective in BPM: An Ontology-Based Approach for Tool Integration

Motivation. While **D 1.1** established the conceptual need for an operational perspective, these definitions alone are insufficient for software execution. Standard **BPMN** typically represents resources as generic `DataObjects` or `TextAnnotations`; however, these elements lack the semantic richness necessary for automated reasoning. A process engine cannot natively recognize that a *Drill* is a tool with a *Battery Level* that must be physically present with the *Actor*. To address the disconnect between abstract process models and the physical constraints of manual work, formal machine-readable representations are required.

Method. This study applied Ontology Engineering, following the methodology of Noy [50]. The process involved defining the domain scope (operational equipment in manual tasks), conceptualizing the class hierarchy (distinguishing between fungible materials and specific tool instances, with a focus on tools first), and formalizing relationships (e. g., `requiresTool`, `locatedAt`). The paper implemented the resulting ontology using Resource Description Framework (RDF) and Web Ontology Language (OWL) to enable SPARQL Protocol And RDF Query Language (SPARQL)-based semantic querying.

Results. The primary result is a validated *Operational Perspective Ontology*. This artifact, depicted in Fig. 4, formally defines *Operational Equipment* as a distinct class hierarchy. It captures essential properties such as tool types versus instances, dynamic states (e. g., battery level), and the relations between tasks and physical objects:

- **Tool Types vs. Instances:** Distinguishing between the requirement for a generic tool (e. g., `Any Hammer Drill`) and a specific instance (e. g., `Makita HP2071F #123`).
- **Dynamic States:** Modeling quantitative parameters (e. g., battery level, wear) and qualitative parameters (e. g., operational status) that change during execution.
- **Relations:** Formalizing the links between Tasks, Actors, and Tools, such as requirements (`requires Tool`) and ownership (`isPossessedBy`).

Furthermore, the paper presents an integration framework that connects this semantic layer to a standard **BPMs** (Camunda⁸). Using RDF4J⁹, the system can execute **SPARQL** queries during runtime, for example, checking if an assigned actor actually possesses the required tools before a task starts.

Contribution to RQ1. This publication formalizes the operational perspective, moving it from a conceptual idea to a computable data structure. Providing semantic grammar for passive resources in the form of tools enables machine reasoning about tool availability and location. This provides the necessary data foundation for the executable extensions developed in § 1.3 and the location-aware patterns in (F2).

§ 1.3 – From Model to Execution: A Formal Foundation for Managing Materials and Tools in Executable BPMN

Motivation. While § 1.2 established the semantic structure for tools, the operational perspective remains incomplete without addressing the flow of *consumable materials*. Standard **BPMN** lacks native constructs to distinguish reusable equipment from consumed resources, treating all data objects generically. This creates a representational gap that obscures the visibility of material consumption within the digital process model. To resolve this, it is necessary to expand upon abstract ontologies and technically extend the **BPMN** metamodel itself. This enables a concrete, executable implementation that orchestrates Cyber-Physical System (CPS) and cyber-physical operations (tools and materials) in real time.

⁸<https://camunda.com/>

⁹<https://rdf4j.org/>

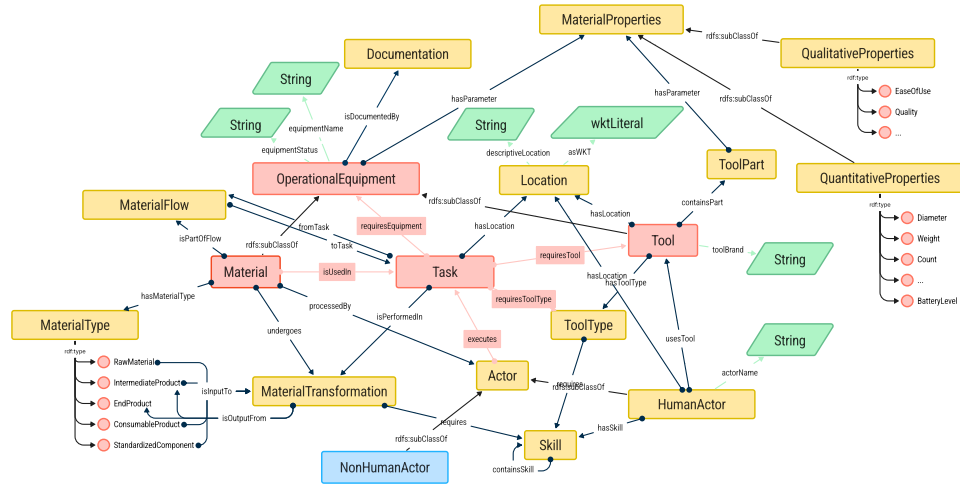


Figure 5: Extended ontology underlying the *PRIME*metamodel extension. It expands upon the tool-centric definitions of *1.2* to include *Material* classes, formalizing the relationships between tasks, tools, consumable materials, and their physical properties (e. g., quantity, weight, condition).

Method. This paper extends [70] and follows the *DSR* methodology to develop an *IT* artifact that formally extends the *BPMN* 2.0 metamodel [53]. Building on the tool-centric semantics of *1.2*, this research expanded the scope to include material-flow logic. The resulting artifact, *PRIME*, was implemented using the standard *BPMN* extension mechanism [94, 8] and instantiated in the Camunda *BPMS*. A real-world carpentry case study (building a roof truss) validates this utility. This case demonstrates the relationships between reusable tools (e. g., saws) and consumed materials (e. g., timber, screws).

Results. The primary contribution is the *PRIME* framework, which serves as a *BPMN Metamodel Extension* [53, 54] for passive resources. As illustrated in Figure 5, the underlying model distinguishes clearly between *Tools* (persistent) and *Materials* (consumable), connecting them to specific *Tasks* via flow relationships. Figure 6 demonstrates the application of this metamodel extension within the modeling environment. Specific contributions include:

- **Metamodel Extension:** The framework extends standard *BPMN* elements to support “Physical Data Objects.” This introduces distinct stereotypes for *ResourceInventory* (to track availability) and *ResourceRequirementAnnotations*, allowing process designers to define specific constraints (e. g., material: “Screw M8”, tool: “Impact Driver”) directly within the process definition.
- **Runtime Support:** The system uses these metamodel extensions to generate automatic resource checklists. By comparing the annotated requirements against the worker’s current inventory (tracked via *IoT*), the system provides real-time alerts for missing items before execution begins, similar to the approach in *1.2* but directly integrated in *BPMN* and the process model.

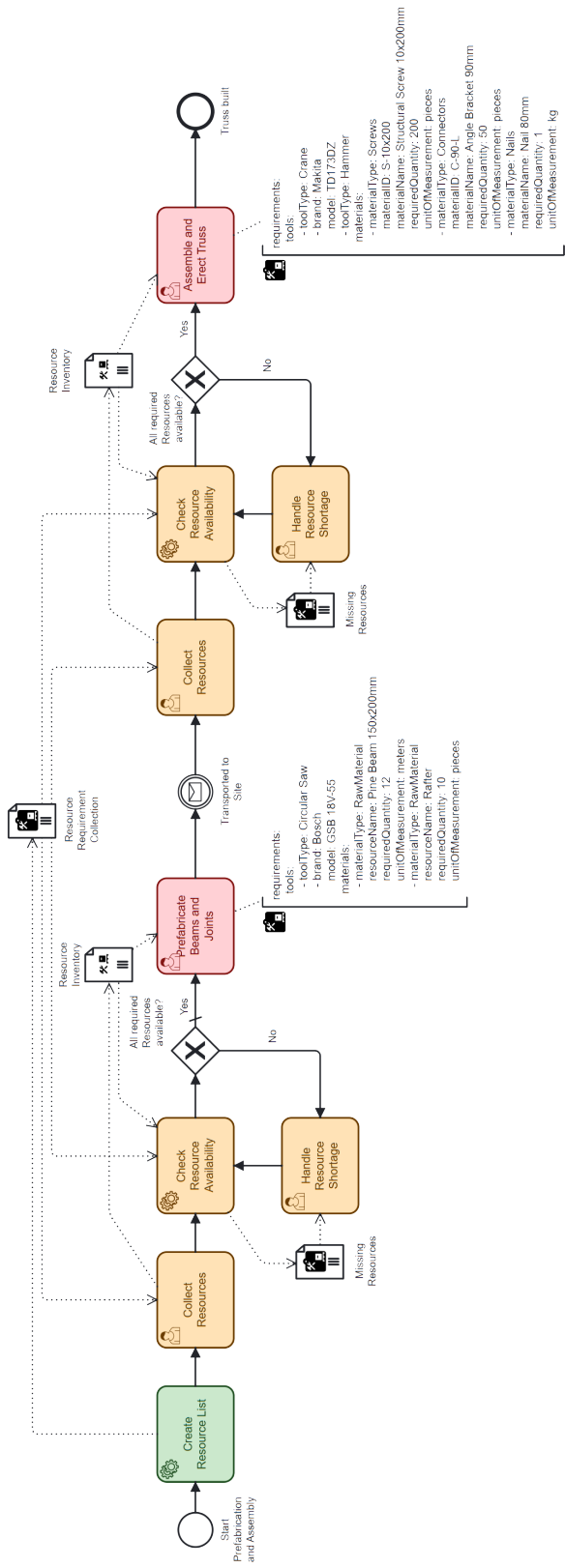


Figure 6: Process model utilizing the PRIMEMetamodel extension. The model introduces explicit ResourceInventory objects (green) and task-specific ResourceRequirementAnnotations (black boxes) that specify required tools and materials, enabling automated runtime checks for resource availability.

- **Design-Time Visualization:** The framework uses the modeled material properties to calculate material requirements and flow. This approach enables visualization of *Material Flow* (e. g., via Sankey diagrams [82]), enabling tracking the transformation of raw materials into finished products throughout the lifecycle.

The validation demonstrated that explicitly modeling these passive resources enables the **BPMS** to detect and prevent execution errors (e. g., missing materials) that established **BPM** systems would overlook.

Contribution to RQ1. This publication completes **(F1)** by providing another executable artifact. It demonstrates the technical integration of the operational perspective into the **BPMN** standard while maintaining full compatibility. By extending the metamodel to cover both tools and materials, **PRIME** elevates manual tasks from “black boxes” to fully supported, measurable process steps.

The three publications follow a logical sequence: **□ 1.1** establishes what needs to be supported (conceptual), **□ 1.2** defines how to represent it formally (ontological), and **□ 1.3** demonstrates how to implement it practically (executable). Together, they form the critical link between *Technology* and *Task*. By formalizing the operational perspective, these contributions ensure that the *Technology* (**IoT** sensors, **BPMS** extensions) actively supports the material requirements of the *Task*, thereby relieving *People* of the primary coordination burden. Within sociotechnical systems, **(F1)** bridges the *Technical* and *Social Subsystems* by providing digital visibility for manual work.

5.2 **(F2)** The Locational Perspective

The results for this focus area transform the **Structure** variable by moving from location-agnostic modeling to *Location-Aware Process Management*. While the introduction identified the lack of spatial context as a critical gap, the contributions presented here (**□ 2.1–□ 2.2**) provide the technical architecture to close it. The primary outcome is the formalization of *Location-Aware BPM* (**LABPMN**). This framework transforms physical location from a passive text attribute into an active process variable. By integrating **IoT** positioning data directly into the process engine, the artifacts allow the system to treat physical distance as a computable constraint, directly answering the second research question: *How can the locational perspective be integrated into BPM to enable spatially aware process orchestration and automation?*

□ 2.1 – Location-aware business process modeling and execution

Motivation. While the importance of location in mobile processes is recognized conceptually, existing **BPM** research has largely remained theoretical. Previous approaches have discussed location-based services, but there has been a lack of executable implementations that integrate real-time spatial data directly into the **BPMS** engine. Mobile processes in the craft and service sectors face unique challenges: workers are constantly on the move, and the “next best task” depends heavily on proximity. The motivation for this paper is to create a direct connection between conceptual location models and executable process orchestration.

Method. This paper extends [66] and follows a **DSR** approach to develop a comprehensive framework for location-aware execution. The artifact comprises location patterns for **BPM** and a multilayer system architecture that connects the physical world (**IoT** sensors, **GPS**) and the digital process engine. To demonstrate the applicability of the Location-Aware **BPM**, this research analyzes four distinct application scenarios:

- **Field Repair (Spatial Routing):** Utilizes the *real-time locations* of technicians to dynamically calculate travel distances. The system assigns urgent repair tasks to the nearest available worker to minimize reaction and transit times.
- **Device Rentals (Geofencing):** Automates billing by monitoring the asset's position within a defined *spatial polygon* (geofence). The system applies different billing rates based on whether the device is on-site (active) or in the warehouse (idle).
- **Monitored Delivery (Path Verification):** Tracks the *location history* of high-value goods between logistic nodes. The process automatically alerts managers if the delivery vehicle deviates from the predefined parameters, ensuring chain-of-custody compliance.
- **Emergency Services (Proximity Querying):** Dispatches response units based on a *nearest-neighbor query*. The system compares the incident's location against the live positions of all ambulances to identify and mobilize the unit with the shortest estimated arrival time.

Results. The primary contribution is the identification of nine *Location-Aware Patterns*:

1. **Automatic Start of Process Instances:** Triggering a new process instance when a spatial event occurs (e. g., a truck entering a warehouse geofence).
2. **Decision Making through Location-Based Data:** Utilizing spatial variables in gateways to determine control flow (e. g., "If distance > 50 km, require regional manager approval").
3. **Location-Based Task Allocation/Assignment:** Dynamically assigning work items to the nearest suitable resource.
4. **Location-Based Event Dispatching:** Routing messages, or signals to actors based on their current physical context relative to the task or influencing process flow based on an entity's location.
5. **Location-Based Monitoring of Tasks:** Visualizing the real-time geographic position and status of all active process instances on a map overlay.
6. **Location-Based Automatic Completion of Tasks:** Detecting when a worker leaves a site to automatically mark a task (e. g., "Travel") as complete.
7. **Location-Based Automation of Tasks:** Triggering automated system actions (Service Tasks) based on spatial triggers (e. g., automatically unlocking a smart gate when a vehicle arrives).

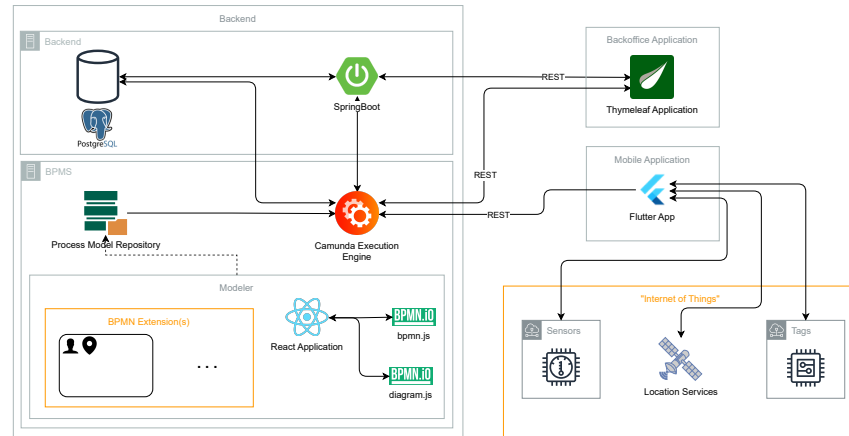


Figure 7: This multilayer system architecture for Location-Aware BPM illustrates the flow from raw sensor data in the Physical Layer to semantic location events in the Event Layer; these events, in turn, trigger and adapt process logic in the Process Layer.

8. **Location-Based Worklist Reordering:** Sorting a worker's task list dynamically based on proximity, e. g., prioritizing the closest tasks to reduce travel time.
9. **Location-Based Constraining of Execution:** Preventing a task from being started or completed unless the actor is within a specific geographic zone (e. g., requiring the worker to be on-site to sign the delivery note).

To support these patterns, the paper defines a set of spatial operators (*Geofencing*, *Distance Calculation*, *Location Updates*) and implements a multilayer architecture (Fig. 7). This architecture integrates heterogeneous location providers (GPS, Bluetooth Low Energy (BLE), WiFi) with a standard Camunda BPMS, demonstrating that location awareness is achievable without replacing the core process engine.

Contribution to RQ2. This publication establishes the comprehensive framework for (F2). By defining nine location-aware patterns and validating the multilayer architecture, this research demonstrates how to integrate spatial context into the process lifecycle.

2.2 – LABPMN: Location-Aware Business Process Modeling and Notation

Motivation. While 2.1 established the architectural feasibility and identified the necessary patterns for location-aware BPM, these patterns lacked a standardized representation. Without formal notation, location logic remains hidden in backend code or proprietary scripts, making it invisible to the process modeler. To enable adoption and tool support, this research repositions spatial context from a technical implementation detail to an explicit modeling construct by developing a formal extension to the BPMN standard that enables visual, explicit modeling of location-based constraints.

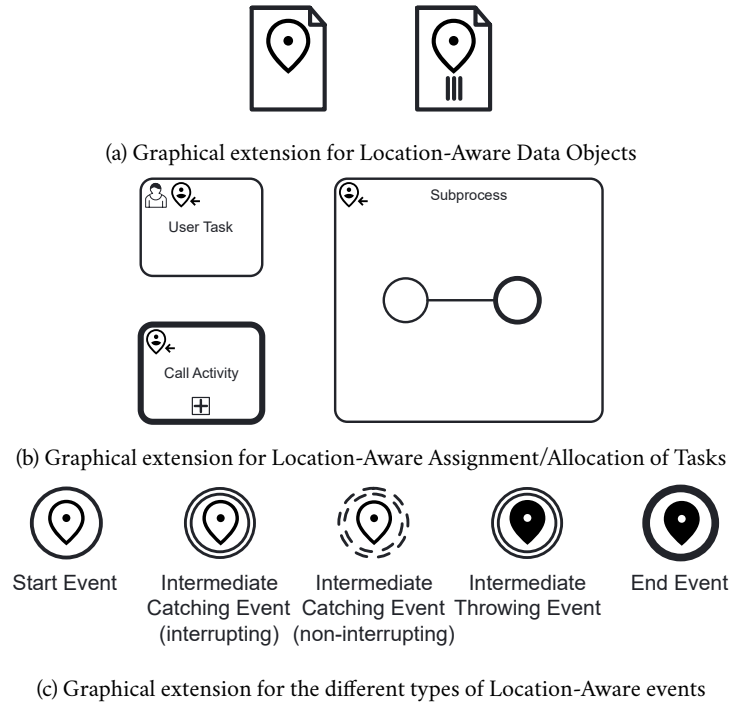


Figure 8: Graphical representation of all elements added to the **BPMN** metamodel for **LABPMN**

Method. This study used an artifact design methodology based on the **BPMN** extension framework defined by Stroppi *et al.* [94]. The development process follows three formal steps:

1. **Conceptual Domain Model Extension (CDME):** Defining the abstract concepts of the spatial domain (e. g., Geofences, Mobile Actors, Spatial Events) and their attributes.
2. **BPMN Metamodel Mapping:** Systematically mapping these domain concepts to existing **BPMN** elements (e. g., mapping a *Geofence Entry* to a **BPMN Conditional Start Event**).
3. **Stereotype Definition:** Implementing these mappings as formal stereotypes and defining their visual representation (graphical elements) to ensure the models remain intuitive for human users.

Results. The primary contribution is **LABPMN**, a formal **BPMN** 2.0 extension. Figure 9 shows a process model for replacing a broken heater using **LABPMN** with the introduced elements shown in Fig. 8. This notation augments the standard metamodel with location-specific constructs (e. g., notifying the customer before arrival or allocating tasks based on location). This makes spatial constraints explicit to the process modeler and executable by the engine:

- **Location-Based Events:** New event definitions triggered by location changes. These include *Geofence Events* (entering/leaving a polygon), *Distance Events* (relative proximity between objects), and *Location Updates*.

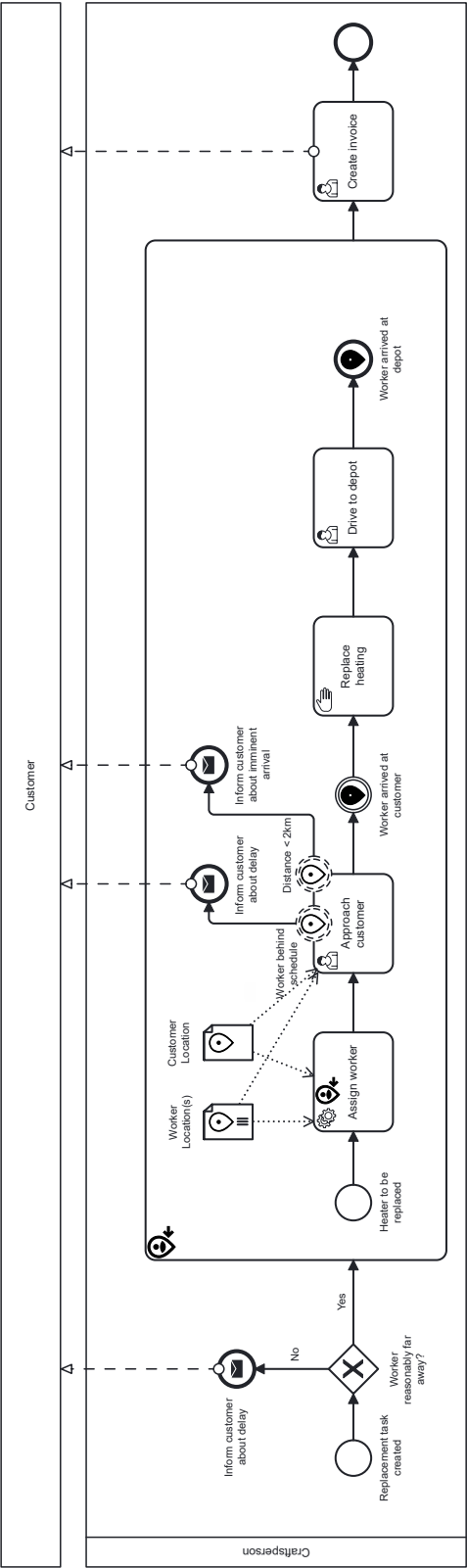


Figure 9: Simplified real-world field service process modeled with LABPMN. Explicit location markers and location events specify spatial constraints for tasks such as “Approach customer” and “Replace heating”, enabling location-based task allocation and customer notifications.

- **Location-Based Allocation:** A mechanism to dynamically allocate tasks to actors based on proximity. Visually represented by a location marker on User Tasks, this extension uses a *Location Operator* (e. g., “Shortest Distance”) to allocate the work item to the nearest qualified resource.
- **Location Data Objects:** An extension of the standard `DataObject` that represents physical locations or boundaries (e. g., a site polygon). These objects serve as input variables for spatial calculations and event triggers.

As such, the paper defines the *executable semantics* for these constructs. This means the extension enables the process engine to enforce location-based control flow at runtime, e. g., automatically starting a process when a truck enters a warehouse geofence or dynamically allocating a task to the closest active resource.

Contribution to RQ2. This publication provides the formal syntax for **(F2)**. Creating a standard-compliant extension mechanism makes spatial context explicit in the process model. This allows location patterns (**D** 2.1) to be modeled, shared, and executed using standard tools, transforming location from a hidden variable into a visible process driver.

D 2.1 and **D** 2.2 are complementary: **D** 2.1 establishes the patterns and architecture (*what* location-aware BPM looks like), while **D** 2.2 provides the formal notation (*how* to represent it in BPMN). Together, they integrate the *External Subsystem* (physical environment, spatial constraints) with the *Technical Subsystem* (GPS/IOT tracking, BPMS). This addresses the *Structure* variable in Leavitt’s model by transforming location from a passive data attribute into an execution condition that shapes the organizational workflow and resource-allocation logic.

5.3 **(F3)** The Ethical Perspective

While **(F1)** and **(F2)** successfully integrate passive resources and spatial context, they simultaneously expose the workforce to granular observability. This transparency creates a new vulnerability: without safeguards, the IOT-enabled BPMS risks shifting from a support tool into an instrument of control. This means that incorporating ethical considerations¹⁰ is essential to ensuring user acceptance and the system’s long-term sustainability. Questions of fairness, transparency, autonomy, and privacy become critical: *Does constant location tracking erode worker autonomy [cf. 47, 98]? Are resource allocation algorithms fair to all participants [cf. 55, 26]?*

Despite these risks, ethical values in BPM have historically remained implicit, often assumed rather than managed [36]. To ensure that the human-centric BPM framework enhances rather than exploits, BPM should treat these values with the same rigor as traditional time or cost metrics [21]. This focus area addresses the third research question: *How can ethical values be made explicit, measurable, and manageable within business process execution?*

¹⁰Future research could, for example, focus on hardening these considerations into embedded constraints.

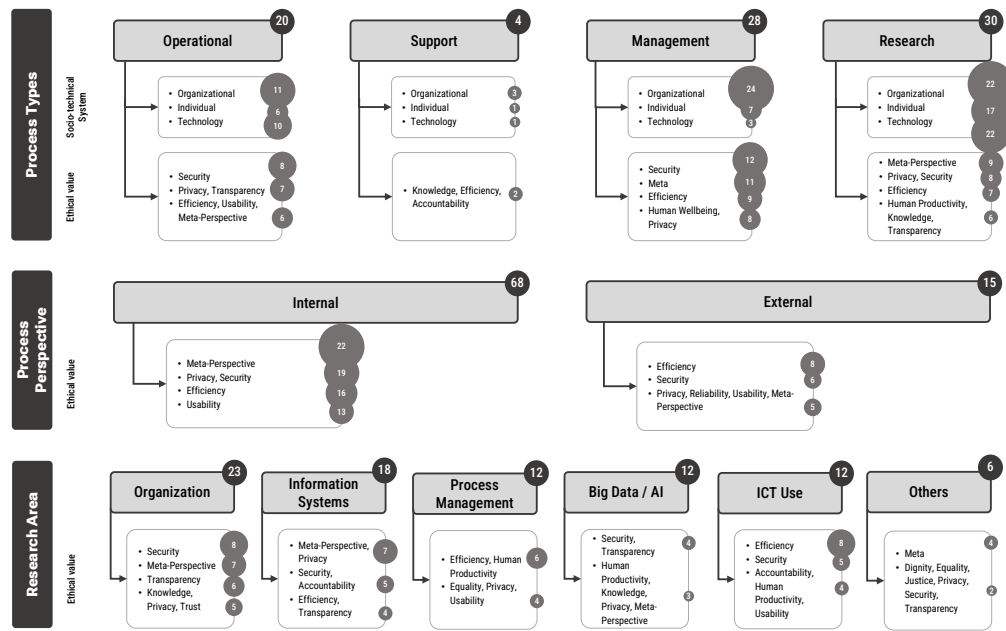


Figure 10: Descriptive framework of ethical values in process management, summarizing how frequently specific values occur across different *process types* (operational, support, management, research), *process perspectives* (internal vs. external), and *research areas*. Circle sizes indicate the number of occurrences of each value category in the final literature sample.

3.1 – Navigating the Moral Maze: A Literature Review of Ethical Values in Business Process Management

Motivation. While *Responsible AI* and *Data Ethics* are established fields [34, 27, 24], Ethics in *BPM* lacks a systematic framework for identifying and managing values. Current approaches are often ad hoc, reactive, or limited to data privacy compliance, failing to address broader human values in process execution. This research identifies and categorizes the relevant values as a necessary precursor to measuring moral performance.

Method. To establish this theoretical foundation, a *SLR* was conducted following established guidelines of Okoli [52], Page *et al.* [57], and Boell and Cecez-Kecmanovic [6]. The study analyzed publications in the top 15 journals, as identified by Lowry *et al.* [45], and mapped them to the *BPM* lifecycle as well as the Sociotechnical Subsystems [44], i. e., *Social subsystem* (e. g., autonomy, dignity), the *Technical subsystem* (e. g., algorithmic fairness, explainability), and the *External subsystem* (e. g., regulatory compliance, societal norms) and Process Types [62], i. e., Operational processes (value creation), Support processes (enabling functions), and Management processes (governance).

Results. The systematic review process initially identified $n = 5,979$ records from leading IS journals following Lowry *et al.* [45]. Following a screening of titles, abstracts, and full texts, $n = 82$ relevant studies were selected for the final synthesis. Figure 10 illustrates the resulting descriptive framework,

mapping the identified values (such as Fairness, Autonomy, and Privacy) [108] against the sociotechnical subsystems and process types. While ethical considerations are increasingly discussed in the *BPM* literature, there remains a significant disconnect between conceptual awareness and actual technical implementation. Although researchers frequently discuss values as conceptual ideals, the field still lacks the essential mechanisms to measure and manage them dynamically during process execution.

Contribution to RQ3. This publication provides the descriptive foundation for **(F3)**. By establishing a taxonomy of ethical values, it moves the discourse to specific, categorizable requirements. This theoretical mapping is the prerequisite for the prescriptive framework developed in **3.2**.

3.2 – Measuring Moral Performance: A Framework for Ethical Business Process Management

Motivation. **3.1** identified a disconnect in which ethical values exist in theory but are invisible in runtime data, meaning they cannot be managed. To move from implicit concepts to explicit management, a mechanism is needed to capture *Moral Performance* in the form of *KVIS* alongside traditional Key Performance Indicators (*KPIs*).

Method. This paper employed *DSR* to develop a modular software framework for ethical measurement. The artifact allows process designers to annotate process models with standardized ethical scales (e. g., the *MES* by Reidenbach *et al.* [76]) and binary values. This publication validated the framework’s utility and usability through expert evaluations ($n = 22$) and a cognitive load assessment using the *NASA-TLX* method [28].

Results. The primary contribution is a dual-component framework comprising a *Data Collection Client* and a *Dashboard*. First, the *Mobile Application* implemented using Compose Multiplatform¹¹ (see Fig. 11) integrates directly into the worker’s task list. It uses binary-value checks (e. g., swiping for *Equality*) and standardized ethical questionnaires to directly capture ethical sentiment at the source from the human actor during execution. Second, this data is aggregated and visualized in the *Moral Performance Dashboard* (see Fig. 12). Built on the Elastic Stack (Elasticsearch + Kibana)¹², this interface transforms raw sentiment data into actionable *KVIS*. This loop operates through four distinct stages:

1. **Real-time Capture.** During task execution, workers provide ethical sentiment data via the mobile interface (Figure 11), creating a continuous stream of moral performance indicators (*KVIS*) parallel to traditional *KPIs* (time, cost, quality).
2. **Aggregation and Pattern Detection.** The dashboard (Fig. 12) aggregates individual responses to identify systemic issues. For example, a sudden drop in *Autonomy* scores across multiple technicians in the same department may indicate excessive location tracking granularity or algorithmic micromanagement.

¹¹<https://www.jetbrains.com/compose-multiplatform/>

¹²<https://www.elastic.co/elastic-stack>

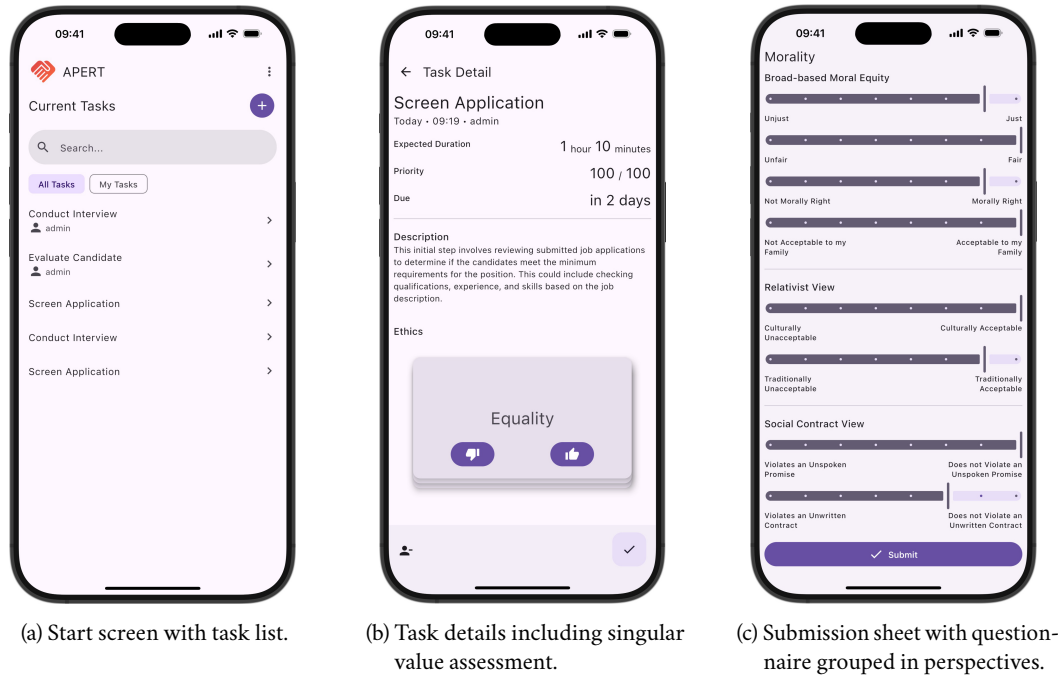


Figure 11: Mobile user interface of the Moral Performance Measurement prototype (3.2). The screens show (a) the task list, (b) task details with a single-value ethical assessment widget, and (c) the submission form where users rate the task using a questionnaire structured by ethical perspectives.

3. **Diagnostic Analysis.** Flagged issues can then be investigated using drill-down capabilities to identify root causes. If low *Fairness* scores correlate with specific resource allocation algorithms (**F1**) or location-based task assignment rules (**F2**), the technical implementation requires adjustment.
4. **Process Redesign and Validation.** In the *Business Process Improvement* (BPI) phase, *BPMN* models can then be refined based on these findings, e. g., by lowering tracking granularity or modifying allocation algorithms to prioritize workload equity and manual overrides. The modified process then re-enters the monitoring loop to validate the improvement.

This feedback mechanism transforms ethics from a compliance checklist into a dynamic governance layer. The evaluation highlights a trade-off: while experts confirm the high utility of visualizing ethical metrics, the *NASA-TLX* results reveal moderate cognitive demand. This finding suggests that designers must balance ethical monitoring against worker fatigue to prevent the system from becoming intrusive.

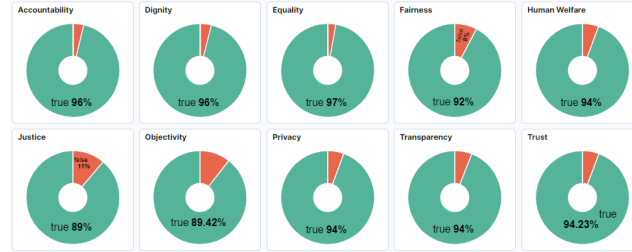
Contribution to RQ3. This publication provides the prescriptive solution for (**F3**). Technically, operationalizing ethics transforms abstract values into measurable data points. This framework ensures that the human-centric *BPM* system includes a feedback loop for the human experience, ensuring that the optimization of (**F1**) and (**F2**) does not undermine the ethical safeguards defined in (**F3**).



(a) Average assessment based on perspectives and broad views.



(b) Average perspectives per task and aggregated change of views over time.



(c) Visualization of binary fulfillment of specific ethical values

Figure 12: The Moral Performance Dashboard (3.2), implemented in Kibana. (a) Overarching principles of the used questionnaire [76] (b) Temporal trend analysis showing average ethical perspective scores per task type over time, enabling identification of declining ethical performance trends. (c) Binary fulfillment heatmap of specific ethical values (Fairness, Transparency, Autonomy, Privacy) across different process instances, with color intensity indicating violation frequency.

3.1 and 3.2 follow a descriptive-to-prescriptive progression: 3.1 describes the existing ethical values in BPM (taxonomy), while 3.2 prescribes how to measure and manage them (framework). In Leavitt's system, ethics serves as the critical link between *Structure* and *People*. It ensures that the use of *Technology* to optimize the *Task* is governed by a *Structure* that respects human values. Within sociotechnical systems, (F3) bridges the *Social Subsystem* (moral considerations), the *Technical Subsystem* (algorithmic fairness), and the *External Subsystem* (regulatory compliance).

5.4 Complementary Publications

In addition to the core publications that directly address the research questions, this dissertation yielded seven complementary publications (C1–C7). As outlined in Table 5, these works expand the scope of the dissertation by providing technical foundations, demonstrating transferability to adjacent domains, and exploring advanced extensions of the core concepts.

Table 5: Overview of complementary publications (C1–C7) that relate to, extend, or provide additional context for the core contributions of this dissertation but are not included as primary dissertation papers.

Publication	
C1	Poss, L., Schöning, S., “A Generic Approach Towards Location-Aware Business Process Execution.” In: Enterprise, Business-Process and Information Systems Modeling. Cham: Springer Nature Switzerland, 2023, pp. 103–118. ISBN: 9783031342417. https://doi.org/10.1007/978-3-031-34241-7_8
C2	Poss, L., Jasinski, R., Market, M., Schöning, S., TRADEmark - Using Location Data for Mobile Distributed Processes in BPM (Extended Abstract). In: Proceedings of the Demonstration Track at International Conference on Cooperative Information Systems 2023, CoopIS 2023, Groningen, The Netherlands, October 30 - November 3, 2023 (2023)
C3	Ackermann, L., Käppel, M., Marcus, L., Moder, L., Dunzer, S., Hornsteiner, M., Liessmann, A., Zisgen, Y., Empl, P., Herm, L.-V., Neis, N., Neuberger, J., Poss, L., Schaschek, M., Weinzierl, S., Wördehoff, N., Jablonski, S., Koschmider, A., Kratsch, W., Matzner, M., Rinderle-Ma, S., Röglinger, M., Schöning, S., Winkelmann, A., Recent Advances in Data-Driven Business Process Management. (2024). arXiv: 2406.01786 [cs.DB]
C4	Kern, C.J., Hübner, K., Poss, L., Schöning, S., Kroenung, J., “The Role of Ethics in Requirements Engineering for Developing Information Systems.” In: Research Challenges in Information Science. Springer Nature Switzerland, 2025, pp. 226–242. ISBN: 9783031924743. https://doi.org/10.1007/978-3-031-92474-3_14
C5	Poss, L., Schöning, S., One Engine to Rule Them All: Executing Declarative Processes with CEP. in: Proceedings of the Demonstration Track co-located with the International Conference on Cooperative Information Systems 2025 (2025) Best Demo Paper.
C6	Poss, L., Schöning, S., Orchestrating Cyber-Physical Operations with PRiME: A Passive Resource-integrated Modeling Extension for BPMN. in: Proceedings of the International Conference on Cooperative Information Systems (CoopIS) 2025 (2025)
C7	Poss, L., Schöning, S., A Synergistic Engine Paradigm for Real-Time, Context-Aware Decision-Making: Integrating Declarative Processes and Event Streams. Complex & Intelligent Systems (2026)

While (F1) and (F2) describe *how* to model and manage resources and location, the underlying execution logic often requires high-performance processing of sensor streams. Publications C5 [69] and C7 [71] investigate the connection between BPM and Complex Event Processing (CEP). These works provide the technical foundation for handling high-velocity IoT data streams discussed in (F1) and (F2), and for developing integrated engines that execute declarative and event-driven processes in real time. C6 provides the basis for § 1.3 and focuses on tools and materials in the operational perspective. Building on the ethical insights of (F3), C4 [36] transfers the discussion of values into the Requirements Engineering (RE) phase, arguing that ethical considerations must be uncovered and defined before process modeling even begins. The remaining publications represent specific applications and future extensions of the research. C2 [64] and C1 [66] document the practical demonstrations and early architectural prototypes developed within the TRADEmark project, serving as the empirical testbed for the core dissertation. C3 [2] places these contributions within the broader domain of *Data-Driven BPM*.

6 Conclusion and Future Work

This dissertation answers the central research question: “How can BPM be extended to holistically support human actors throughout the process lifecycle, from operational task execution and spatial context to ethical considerations?” Moving beyond the abstract goal of “holistic support,” this work establishes a concrete architectural framework for *Human-Centric Process Management*. By operationalizing Leavitt’s sociotech-

nical variables [43] (*Technology, Structure, Task, and People*), we transform the manual worker from an external variable into an integral, supported process entity. This research overcomes the limitations of traditional automation-centric BPM by formalizing the physical reality of work.

Contributions at a Glance

- **(F1) Operational Perspective:** Formalized passive resources (tools, materials) as first-class BPMN entities via PRIME extension; demonstrated real-time resource provisioning in craft business contexts.
- **(F2) Locational Perspective:** Developed LABPMN notation integrating spatial constraints (geofencing, proximity) into executable process models; validated through field service and emergency response scenarios.
- **(F3) Ethical Perspective:** Created Moral Performance Measurement framework translating abstract values (Fairness, Autonomy) into operational KVIS; established ethical feedback loop for process governance.
- **Theoretical Integration:** Unified three perspectives under Leavitt's sociotechnical framework, demonstrating that *human-centric process management* requires joint optimization of Technology–Task ((F1)), Structure–Environment ((F2)), and People–System ((F3)) relationships.

Through seven peer-reviewed publications, the contributions define a complete integration stack across three layers of abstraction:

1. **Conceptual:** Redefining the foundational perspectives of BPM [31] explicitly include the *Operational* (physical passive resources), *Locational* (spatial constraints) and *Ethical* (moral obligations) perspectives as distinct requirements.
2. **Formal:** Establishing the Ontologies and Metamodel Extensions required to model this reality.
3. **Implementation:** Delivering executable artifacts that demonstrate the technical feasibility of human augmentation.

Contribution 1: Bridging the Digital-Physical Divide ((F1)) This research fundamentally redefines the relationship between *Task* and *Technology*. It establishes that *Technology* is not just an enabler but a valid *Structural Constraint* for execution. By challenging the traditional abstraction of manual work as a “black box,” this dissertation formalized the ontology of *passive resources* (¶ 1.2) and operationalized them through the PRIME framework (¶ 1.3). This contribution demonstrates that process feasibility relies not only on the human actor but also on the precise *orchestration* of the material environment. By integrating tools and materials as core modeling elements within the BPMN metamodel, the research demonstrates that a BPMS can transition from monitoring execution to actively managing it by detecting and preventing material errors (e. g., missing equipment).

Contribution 2: Context-Aware Structural Adaptation ((F2)) This work transforms Location from passive data into an active driver of *Structure*, effectively reconfiguring *Authority* (who does it), *Communication* (when they know), and *Workflow* (how it flows) [cf. 43] based on proximity. By formalizing LABPMN (¶ 2.2), this research demonstrates that spatial context acts as a deterministic constraint on

process feasibility; specifically, it determines *whether* a task is executable and identifies *who* is best positioned to perform it. The contribution moves beyond simple tracking to implement *spatial enforcement*: by introducing native *BPMN* constructs such as Geofences and Location-Based Events, the *BPMS* can actively manage the physical distribution of work.

Contribution 3: Sociotechnical Governance for People ((F3)) This research identifies ethical governance as the essential mediator between *People* and the intensified *Structure/Technology*. The *Moral Performance Framework* (¶ 3.2) translates abstract ethical values into measurable *KVIS* via existing validated ethics questionnaires. This contribution proves that a sociotechnical balance collapses when the system optimizes only *Task* ((F1)) and *Structure* ((F2)) without accounting for their moral impact. Consequently, the artifact serves as a control mechanism, establishing a necessary feedback loop that enables the *BPMS* to detect and resolve sociotechnical imbalance before it leads to resistance or system rejection.

Collectively, these contributions substantiate the thesis that *Human-Centric BPM* represents a unified challenge of managing interdependence. This dissertation demonstrates that introducing *IoT (Technology)* to actively orchestrate the *Task* ((F1)) and spatially configure the *Structure* ((F2)) fundamentally alters the work environment: inevitably exerting pressure on the *People* variable. Consequently, the Ethical Framework ((F3)) functions as a counterbalance. By aligning these new operational capabilities with human values, this counterbalance helps preserve sociotechnical viability, ensuring the system remains viable and sustainable.

Implications

This dissertation advances *BPM* theory by resolving the structural deficit identified in the fundamental *BPM* perspectives [31]. While the *Functional*, *Behavioral*, *Organizational*, and *Data perspectives* have long been supported by standard notations, this work explicitly formalizes the *Operational Perspective*. By redefining the *Task* variable to include passive resources (tools and materials), we transform the operational view from a “black box” into a machine-readable dimension. Furthermore, the introduction of the *Locational Perspective* and the *Ethical Perspective* expands the classical framework, demonstrating that manual work requires distinct theoretical dimensions beyond simple data attributes.

Consequently, these theoretical advancements directly impact the *BPM Lifecycle*. By providing the necessary formalisms for physical resources and spatial constraints, this research bridges the long-standing disconnect between the *Process Definition (Modeling)* and *Process Enactment (Execution)* phases.

- In *Modeling*: We have demonstrated that physical constraints can be defined at design time (*PRIME*, *LABPMN*) rather than being treated as externalities.
- In *Enactment*: We have shown that a *BPMS* can actively orchestrate physical work, moving the execution phase beyond software service calls to the real-time provisioning of tools and verification of location.

This ensures that the lifecycle is no longer interrupted when a process leaves the digital realm, remaining continuous and managed across the physical-digital divide.

By explicitly grounding its contributions in *Leavitt's multivariate system*, this work demonstrates that BPM systems are not purely technical artifacts but complex sociotechnical configurations. The three focus areas demonstrate the necessity of joint optimization within the sociotechnical system: By aligning *Technology* with the *Task* (F1) and the *Structure* with the *Environment* (F2), the system gains the ability to orchestrate physical work. However, this capability introduces pressure. (F3) ensures *System Viability* by aligning the new transparency with the values of *People*. This research argues that ethical considerations (e. g., Autonomy, Fairness) act as *non-functional requirements* for system stability. Failure to meet these ethical requirements invalidates the technical efficiency gains of (F1) and (F2) by destabilizing the social subsystem (e. g., through active worker resistance, the erosion of trust, or the adoption of shadow processes). Consequently, comprehensive support requires (F3) to shield human actors from the pressures of the system's optimization logic.

The ethics framework contributes to broader IS ethics research by moving from philosophical discussions to operational implementation. While ethical concerns in technology use are well-documented [cf. 55], systematic frameworks for measuring and managing values during system execution remain scarce. This dissertation provides a template for identifying relevant values (SLR), operationalizing them through measurable indicators, and integrating them into the BPMS lifecycle. This approach is transferable beyond BPM to other IS domains where the ethical use of technology requires systematic governance.

Furthermore, this research provides practitioners with actionable tools for orchestrating human-centric processes. The PRIME framework enables the explicit modeling of passive resources, preventing resource shortages that delay execution. LABPMN enables field service managers to optimize routing using real-time location data, reducing travel time and improving responsiveness. The ethics assessment framework empowers organizations to identify processes with ethical concerns proactively (e. g., excessive monitoring, unfair allocation) before sociotechnical failure occurs.

Beyond operational efficiency, *Human-Centric BPM* contributes to organizational sustainability across three dimensions: (i) The PRIME framework ((F1)) enables precise tracking of tool lifecycles, wear patterns, and maintenance schedules. By monitoring actual usage patterns rather than time-based schedules, organizations can extend equipment lifespans through predictive maintenance or reduce electronic waste. The material flow visualization identifies opportunities for material reuse and recycling within processes, supporting circular economy principles [cf. 87]. (ii) The ethical governance layer ((F3)) addresses the "human cost" of digital transformation. By monitoring moral performance indicators such as *Autonomy* and *Fairness*, organizations can prevent the burnout and disengagement often associated with algorithmic management [46]. Location-aware process optimization ((F2)) reduces unnecessary travel and fuel consumption in mobile workforces. Dynamic task allocation based on proximity rather than rigid regions decreases carbon footprints while improving response times [cf. 23].

Additionally, this dissertation addresses broader societal concerns regarding the future of work and the ethical use of technology: Traditional BPMSs centralize process knowledge within IT departments [21]. By making passive resource requirements explicit in process models ((F1)) and providing real-time execution support via mobile interfaces, actors gain visibility into the "why" behind task assignments. This transparency supports skill development and reduces dependency on tacit knowledge [cf. 86].

Second, the Moral Performance framework ((F3)) provides a mechanism for *algorithmic auditing* [42] from the worker’s perspective. Rather than assuming that optimized algorithms (for resource allocation, routing, and scheduling) are inherently fair, the framework continuously validates them against human values. This addresses growing societal demands for explainable AI/IS and accountable automation [cf. 79]. Third, rather than pursuing full automation (which remains infeasible for complex manual tasks), the framework supports *human augmentation* using IOT and BPM to enhance human capabilities [60, 11].

Limitations

While validated through craft business and emergency service cases, several factors limit the generalizability of our findings:

- **Geographic and Cultural Constraints.** The primary empirical validation occurred within German craft businesses, which operate within specific regulatory frameworks (e. g., strict apprenticeship systems, standardized trade certifications) and cultural contexts (e. g., high trust in technical systems, strong worker protection norms). The acceptance of IOT tracking and ethical monitoring may differ significantly in cultural contexts with varying attitudes toward workplace surveillance, hierarchy, and technological adoption [30].
- **Industry-Specific Limitations.** The craft sector exhibits distinct characteristics (mobile workforces, non-standardized processes, high tool dependency) that may not translate directly to manufacturing (stationary assembly lines), healthcare (regulated clinical environments), or office-based knowledge work. For instance, the location-aware patterns ((F2)) assume physical mobility, which is irrelevant for stationary manufacturing floors, while the tool-tracking mechanisms ((F1)) extend to tangible assets rather than digital tools.
- **Organizational Size Bias.** Our evaluation focused on Small and Medium-sized Enterprises (SMEs) with approximately 20–100 employees. Large enterprises may face different scalability challenges, while micro-enterprises (fewer than 10 employees) may lack the IT infrastructure necessary for IOT integration.
- **Temporal Validity.** The rapid evolution of IOT technologies (e. g., Ultra Wide Band (UWB) indoor positioning, 5G latency improvements) may render current technical limitations (e. g., GPS accuracy, battery constraints) obsolete, potentially altering the feasibility of location-aware BPM in ways not captured by our evaluation window.

The **Operational Perspective** ((F1)), which focuses on passive resources, addresses the *material* gap but does not fully cover the *cognitive* aspects of the Task (e. g., tacit knowledge and improvisation). Similarly, the **Locational Perspective** ((F2)) emphasizes outdoor/mobile processes; however, indoor location tracking (via WiFi, BLE) introduces technical complexities, e. g., multipath interference, and floor-level accuracy, that current BPM technologies do not yet fully address. The **Ethical Perspective** ((F3)) relies on self-reported assessments, which are subject to social desirability bias; objective ethical measurement remains an open challenge [99, 90]. Furthermore, integrating IOT data poses interoperability challenges,

as diverse sensors and protocols require robust middleware. Privacy concerns around continuous location tracking demand data protection mechanisms; while technical solutions (e. g., anonymization) exist, they require careful implementation to maintain trust. Finally, successful general deployment requires organizational change management [22, 81].

Future Work

(F1) Operational Perspective Extensions Future work should extend passive resource support to include dynamic state management, tool wear tracking, and maintenance schedules. Integration with predictive analytics could enable proactive resource allocation: if a drill bit is nearing the end of its life, the system automatically schedules a replacement. Exploring Augmented Reality (AR) for real-time operational guidance offers promising directions, including overlays that display tool instructions or safety warnings directly in the worker’s field of view. Empirical validation of the research propositions (RP1–RP5) through controlled experiments could strengthen the evidence for the impact of operational support on task accuracy.

(F2) Locational Perspective Enhancements Indoor location tracking using UWB or BLE extends location-aware BPM to manufacturing floors and hospitals. Multi-modal location (indoor/outdoor transitions) and 3D positioning pose technical challenges requiring sensor fusion. Furthermore, the granular event logs generated by PRIME and LABPMN provide the ideal data foundation for *Human-Centric* and *Location-Aware Process Mining*, as defined by Burattin *et al.* [11]. Furthermore, the formal definitions lay the foundation for future conformance and model checking based on location data. While this dissertation focused on runtime orchestration (enactment), future work should apply their multidimensional discovery and conformance checking techniques to these physical execution logs. This would allow organizations not only to execute location-aware processes but also to automatically discover daily routines and behavioral deviations in manual work. While this dissertation focused on *Definition* and *Enactment*, the granular event logs generated by PRIME and LABPMN provide the necessary foundation for the *Analysis* and *Monitoring* phases of the BPM lifecycle. Future work can now apply process mining techniques to this physical data to discover behavioral deviations in manual work. Further integration with autonomous systems (robots, drones) for location-dependent task execution is a research area that integrates BPM and CPSS.

(F3) Ethics Framework Evolution Moving beyond self-reported assessments toward objective ethical indicators, e. g., analyzing event logs for fairness violations (biased allocation) or autonomy erosion, could strengthen ethical measurement. Machine Learning (ML) approaches can detect ethical anomalies, such as sudden increases in monitoring intensity. Longitudinal studies tracking moral performance over time could reveal whether interventions improve outcomes. Cross-cultural ethics research is essential as values regarding privacy and hierarchy vary globally, requiring a culturally sensitive calibration of the framework. The ultimate goal of this research is to develop *embedded ethical control mechanisms*: Future BPM engines should not just *measure* moral performance (¶ 3.2) but *actively intervene*. Just as PRIME prevents a task from starting without a tool, a future engine should prevent a task from starting if it

violates a fairness threshold, automatically rebalancing the workload to protect the human actor. This moves the field from *Human-Aware* to *Human-Protective* computing.

This dissertation demonstrates that comprehensive **BPM** requires human-centricity through concrete mechanisms that support manual task execution, acknowledge spatial reality, and ensure ethical treatment. The automation-centric paradigm that dominated **BPM**'s first decades created a systemic imbalance, optimizing the *Technology* of control flow while neglecting the *Task*, *Structure*, and *People*. By integrating the neglected dimensions into *Leavitt's multivariate system*, this research shows that modern technologies (such as **IoT** and mobile devices) enable these ignored variables to become core components of process orchestration.

The path forward is clear: **BPM** must shift focus from managing data to orchestrating reality, recognizing that the human actor is not a resource to be optimized, but the central entity the system is designed to serve.

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Part II

Research Papers

P1.1 The Operational Perspective in Business Process Management: Towards Holistic Task Execution Support

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Authors' Contributions	Leo Poss	90%
	Stefan Schöning	10%

Journal description: Nowadays, in the age of information technology and the internet, the creation and maintenance of business models has to consider the latest developments in information technology to ensure competitiveness and long-term success of the enterprise. The aim of Information Systems Management (ISM) is to integrate information technology into business models and business processes to explore its potential to meet the business goals.

Many international journals in the field of information systems (IS) or information management (IM) focus primarily on the quantitative analysis of information systems phenomena, especially through the use of empirical studies. However, research on qualitative analysis, development, and deployment of information systems is not covered sufficiently by the existing international IS journals.

Therefore, the journal Information Systems and e-Business Management (ISeB) focuses on the core tasks of Information Systems Management, the conceptual analysis, design, and deployment of information systems, as well as on all e-business related topics. (Source: <https://link.springer.com/journal/10257/aims-and-scope>)

The Operational Perspective in Business Process Management: Towards Holistic Task Execution Support

Abstract

This paper redefines the operational perspective in Business Process Management (BPM). While BPM inherently operates at the operational level, its traditional focus on automation, standardization, and software execution has historically overlooked a holistic understanding of task execution, particularly manual tasks and the tools and materials required for them. Our mixed-methods study, which combines a structured literature review and abductive reasoning, confirms this oversight, a gap also visible in modeling support. To address this, we introduce a novel classification scheme for process entities and propose a comprehensive vision for future operational support. Leveraging developments such as the Internet of Things (IoT), this vision encompasses enhanced modeling artifacts, intelligent planning, and real-time execution assistance. This paper bridges a critical abstraction gap between automated and manual tasks by redefining the operational perspective, introducing a novel classification of process entities, and proposing a framework for holistic support.

Keywords: Business Process Management, Business process execution, Operational perspective, Internet of Things, Tool support.

1 Introduction

The convergence of Business Process Management (BPM) and the Internet of Things (IoT) has unlocked new frontiers for monitoring and optimizing business operations (Janiesch et al. 2020; Cherrier and Deshpande 2018). Recent work on IoT-BPM integration highlights ongoing challenges in extracting meaningful process events from low-level sensor data (Mangler et al. 2024; Schönig et al. 2020), confirming the need to bridge physical and digital domains. While organizations leverage a diverse ecosystem of technologies to achieve a holistic view of the process (Thong 1999; Buonanno et al. 2005), a significant portion of organizational work (particularly manual tasks (cf. OMG 2011)) remains unsupported by IT, creating an analytical blind spot. This is especially critical in sectors such as construction and manufacturing (Bazan and Estevez 2021), logistics (Grefen et al. 2019), and healthcare (Braun et al. 2016), where manual labor remains a key component of value creation despite increasing digitalization. This

lack of digital visibility into manual work creates significant operational challenges. Specifically, process opacity prevents management from identifying physical bottlenecks; difficulties in quality assurance arise because the exact execution parameters of physical tasks cannot be systematically recorded and verified; and opportunities for data-driven optimization are missed because the absence of event logs for these manual activities prevents the application of advanced analytical techniques, such as process mining. The increasing ubiquity of mobile devices and sensors now offers a tangible opportunity to bridge this divide, motivating a re-evaluation of how we manage and support the full spectrum of business activities.

Traditionally, BPM has focused on modeling, automating, and optimizing IT-supported workflows (Dumas et al. 2018). This focus has cultivated a deep understanding of process perspectives, such as control flow (the *what* and *when*) and organizational structure (the *who*). However, it has historically neglected the **operational perspective** (the *how*). We define this perspective as the function of providing and supporting all resources required for a task's execution within a process model. This encompasses both the active resources that perform the work (e.g., human actors, automated services) and the passive resources they use (e.g., applications, tools, machinery). This oversight has created a critical gap: while the administrative tasks surrounding manual work (e.g., creating an order or sending an invoice) are often managed by BPM systems, the execution of the manual task itself remains unsupported and unmonitored (Muthusamy et al. 2021; Dumas et al. 2018, p. 372). The increasing automation of routine tasks raises concerns about organizational memory loss related to manual execution (Plattfaut et al. 2024), highlighting the need to maintain visibility into and support for non-automated work. Recent systematic analyses of BPM confirm that while Industry 4.0 technologies offer opportunities for process automation and innovation, significant challenges remain in scalability, interoperability, and human-centricity (Khider et al. 2025). This leaves a vast area of process reality outside the scope of traditional process management, hindering comprehensive optimization and support.

The core problem lies in the underdeveloped nature of the operational perspective within BPM theory and practice. To unlock holistic process improvement, we must integrate these non-automatable tasks as first-class citizens within our management frameworks. While recent advancements in IoT offer a promising path forward, their integration with BPM is not trivial. It presents its own set of challenges, including managing data heterogeneity and bridging the gap between low-level sensor events and high-level business process models (Janiesch et al. 2020; Schöning et al. 2020). Overcoming these hurdles is essential to enable the capture of real-time data from manual activities using sensors and wearable technology, and to address the need to manage manually executed physical processes by leveraging mobile devices and sensors during physical tasks to "perform work in a natural way" (Janiesch et al. 2020, p. 38). This technological shift prompts a fundamental re-examination of the operational perspective. Therefore, this paper is guided by the following research questions:

RQ1. *What is the current state of the operational perspective in business process management?*

RQ2. *What IoT-enabled synergistic mechanisms can be developed to facilitate the integrated support of diverse process entities for enhanced organizational value creation?*

While various technological approaches can support manual task execution, we focus specifically on IoT because of its unique capabilities to bridge the physical and digital domains through ubiquitous sensing, real-time data capture, and context-aware actuation (see [Section 2.3](#)). Unlike traditional IT systems that require manual data entry, IoT enables passive, continuous monitoring of manual work, making it particularly well-suited to addressing the operational perspective gap identified above.

Building on this technological potential to address our RQs, our research employs a two-stage approach. First, we conduct a structured literature review to trace the historical development and establish the current state of the operational perspective in BPM. Second, using abductive reasoning informed by the identified gaps and opportunities, along with real-world observations, we develop a conceptual framework that refines the definition of the operational perspective and proposes novel mechanisms for integrating manual tasks with IoT technologies.

Our analysis reveals that the operational perspective has been largely confined to simple resource allocation, lacking the rich support structures found in other process perspectives. Our key findings include a novel classification scheme for process entities that goes beyond the traditional view of resources, as well as concrete pathways for leveraging IoT. These pathways enable enhanced modeling artifacts, intelligent task planning, and real-time execution assistance for manual work. This paper makes several important contributions. *Theoretically*, we provide a clear and coherent conceptualization of the operational perspective, bridging a significant gap in BPM literature. *Practically*, we offer actionable insights for managers and system designers on how to use IoT to support and optimize previously "invisible" manual processes. By elevating the operational perspective to a first-class citizen in BPM, our work paves the way for more comprehensive and effective process management.

The remainder of the paper is structured as follows: [Section 2](#) provides the necessary background on BPM, the IoT, and their combined application in IoT-aware BPM. Following a detailed description of our methodology in [Section 3](#), [Section 4](#) offers an overview of the operational perspective in BPM, covering its historical development and current state, including its general understanding, the role of process entities, its application in the de facto standard process notation language, Business Process Model and Notation (BPMN) and future possibilities for supporting task execution, detailing enhanced modeling artifacts, intelligent planning, and real-time execution assistance. [Section 5](#) then provides an interpretation of our findings and contributions, discusses challenges and limitations, and presents explicit research propositions. Finally, [Section 6](#) concludes the paper and identifies opportunities for future work.

2 Background

To address the research gap identified in the introduction, it is essential to establish a shared understanding of the core concepts that underpin our analysis. This section provides the necessary theoretical and technological foundations. We begin by outlining the key principles of BPM, including its lifecycle and the various perspectives for analyzing processes. Subsequently, we introduce the IoT as a critical technological enabler for capturing data from the physical world. Finally, we discuss the convergence of these two fields in IoT-aware BPM, setting the stage for our detailed analysis of the operational perspective in the subsequent sections.

2.1 Business Process Management (BPM)

BPM represents a boundary-spanning discipline that harmonizes operational capabilities and technology to design, manage, and improve processes (Dumas et al. 2018; van der Aalst et al. 2016). The primary aim of businesses is to generate value through the effective execution of processes, a goal that can be facilitated by using Information Technology (IT). Business processes encompass a series of actions to achieve a specific business outcome (Weske 2007; Dumas et al. 2018). One or more business process models can represent these processes, comprising the activities and instructions, including their sequence and the decision points that govern their execution. These models serve as blueprints for real-world scenarios and cases, providing a structured representation (Weske 2007). BPM, as a research endeavor, encompasses different domains, which we will cover in the following sections. These include the BPM lifecycle that embraces the iterative nature of process improvement, BPM perspectives that are essential as they provide different views on processes (e.g., behavioral (*when?*) vs. organizational (*who?*)), the required background on participating entities in the form of resources, and the form of specific task types that separate automated from manual tasks.

To achieve its goals, BPM is conceptualized as an iterative cycle of continuous improvement, often referred to as the BPM lifecycle. While many different ways of approaching a lifecycle exist (de Morais et al. 2014), we will focus on the BPM lifecycle by Weske (2007) that can be divided into two broader phases: the first phase, where the current state is identified and modeled, and the second phase, with the use of said processes and the execution of included tasks and the goal of improving them. Any conceptual or practical approach must consider both phases, as only their combination enables the cycle to lead to the goal of business process improvement.

To analyze and manage processes comprehensively, BPM research employs several distinct *perspectives* that provide different views of a process. The main focus of research has been on the following perspectives (see Table 1): *function* (which process elements are being performed and what flows of information are relevant), *behavior* (when process elements are performed and how), *organization* (where and by whom process elements are performed), and *information* (informational entities produced or manipulated by a process) (Curtis et al. 1992). In addition to these perspectives, several others have emerged, including more focused approaches and combinations of existing ones. Among them are the *security perspective*, which describes the use

Table 1: Overview of perspectives on business processes in BPM (Curtis et al. 1992; Jablonski and Goetz 2007; Tinnilä 1995; Dumas et al. 2018)

BPM Dimension	Goal	What?
Functional	What?	Processes, Process steps, Activities
Behavioral (Control-flow)	When?	Sequence of activities, Workflow, legal regulations
Organizational	Who?	User, Responsible party, System
Information / Data	With what?	Data, Documents, Parameters
Operational	How?	Applications, Tools, Materials
Security	With which rights?	Access control patterns for processes and tasks
Data Quality	With what quality?	Quality of data used in processes
Time	With what constraints?	Temporal constraints and dependencies
Location	Where?	The physical place where activities are performed

of classical access control patterns for processes and tasks (Jablonski and Bussler 1996), the *data quality perspective*, which focuses on the quality of data used in processes (Rodríguez et al. 2012), or the *time perspective*, which extends BPM to focus on temporal constraints and dependencies far beyond the order (Gagne and Trudel 2009), the *location perspective*, which focuses on the place where activities are performed (Schönig et al. 2014; Poss et al. 2023), which can be necessary for the operational perspective, where the location specificity of tasks is one of the challenges. Finally Russell et al. (2015), which describes a *resource perspective* within its resource patterns, including both human and non-human resources, thus including parts of both the organizational and the operational perspectives)¹. While the base perspectives should be viewed as perpendicular, focusing solely on one of them as a basis for business process management is insufficient; combining them yields a holistic approach to managing business processes.

From an organizational standpoint, all participants in a process commonly can be encompassed by the term *resource* ("anyone or anything involved in the execution of a process activity" (Dumas et al. 2018, p. 96)). These resources can be further categorized into *active* and *passive resources* (Ouyang et al. 2010). *Active resources* are resources capable of independently performing an activity, such as participating human actors but also possibly machines working on their own, actively changing and influencing the real world; on the other hand, *passive resources* are all resources involved in and needed for the process, such as data, documents, tools, and used applications (these resources are also a fundamental part of business processes, but cannot act

¹Depending on the strictness and use, one could conceptually argue that all of these perspectives are part of other perspectives, e.g., the time perspective is part of the control flow perspective, if we extend the standard understanding of control flow.

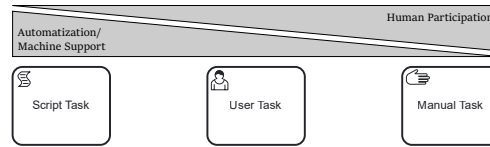


Fig. 1 BPMN tasks with human participation and their grade of automation

autonomously). Consequently, we can assert that the existing organizational perspective primarily focuses on active resources. In contrast, the operational perspective uses passive resources to support the execution of tasks through active resources². We will further specify this differentiation and provide a closer look and definition of process entities in [Section 4.2.2](#).

Finally, within a process model, individual activities (tasks) can be categorized by their execution method and degree of human involvement. BPMN provides a possible categorization and naming, which we will adapt for presentation purposes. [Figure 1](#) shows three different task types, the amount of inherent automatization or machine support, and the extent of human participation. Starting on the left, *Script Tasks* (but also, to some extent, *Service Tasks*) are tasks that are executed fully or mostly automatically by the used Business Process Management System (BPMS). Depending on the implementation or use of a BPMS, it can be programmed in any arbitrary programming language to access and work with any data. The following *User Tasks* in the center model require a human actor's attention.

Nevertheless, the BPMS can still support the creation of a specific task within the task list and a web-based user form. Different implementations also allow accessing and writing task-specific data during task execution. The last task type is *Manual Tasks*, which are used to model work not crucial to the engine or tasks with no known system or user interface³. This task type is typically used to model classic functions that are not easily automated or standardized, which we will focus on in this manuscript. Here, the automatization and machine support are low or even zero (The BPMS implementation Camunda⁴, for example, handles manual tasks as "a pass-through activity, automatically continuing the process when the process execution arrives at it" ([Camunda 2025](#)), on the other hand, the human participation is at its maximum.

2.2 Internet of Things (IoT)

The concept of ubiquitous computing, a world in which every object is connected and accessible via a network, was first proposed in the early 1990s ([Weiser 1999](#)). This vision is closely coupled with the Internet of Things (IoT), which is broadly defined as the integration of physical objects with embedded sensors, software, and other digital

²In [Russell et al. \(2015\)](#), different resource patterns are described focusing on the human resources (except for the *Additional resource* pattern where, next to the human actor, additionally the necessary resources are mentioned). In contrast, [Ouyang et al. \(2010\)](#) focuses on the difference between human and non-human resources in more detail.

³This is often also an issue with the granularity and chosen modeling approach for the specific application.

⁴<https://camunda.com/>

technologies, enabling them to connect and exchange data over a network (Gershenfeld et al. 2004). A comprehensive survey defines IoT as a paradigm in which interconnected objects collect and share data about the physical world, enabled by the convergence of technologies such as RFID, wireless sensor networks, and cloud computing (Al-Fuqaha et al. 2015).

From a business perspective, the true impact of IoT lies in its ability to create a new "organizing logic for innovation," in which the digital and physical worlds are layered and intertwined, enabling novel products, services, and business models (Yoo et al. 2010). These connected objects can be categorized into two main groups: *sensors*, which gather data from the physical world (e.g., temperature, location), and *actuators*, which actively influence the physical world (e.g., adjusting a valve, turning on a light). This capability to both sense and act on the physical environment positions IoT as a core enabler for the advanced operational support discussed in this paper.

2.3 IoT-aware BPM

The IoT fundamentally transforms how organizations approach process management by creating networks of interconnected devices that generate continuous streams of contextual data. Rather than viewing IoT simply as a set of connected objects, this paradigm represents a shift toward intelligent operational environments in which physical activities become visible and manageable through digital infrastructure (Cherrier and Deshpande 2018). BPM systems excel at orchestrating IT-supported workflows but face significant limitations when addressing manual, location-dependent, or physically executed tasks. IoT technologies directly address this gap by providing real-time visibility into previously opaque operational activities (Janiesch et al. 2020; De Luzzi et al. 2024) ("IoT can complete BPM" (Janiesch et al. 2020, p. 35)). Sensors, wearable devices, and embedded systems capture granular data about physical processes, worker activities, and environmental conditions that were historically beyond the reach of conventional BPM systems, as mentioned above. This technological convergence enables organizations to achieve comprehensive process visibility spanning both the digital and physical domains (Schönig et al. 2020). IoT-generated data streams provide contextual information that enhances process execution through real-time monitoring, predictive analytics, and adaptive workflow management (Friedow et al. 2018; Porter and Heppelmann 2015). Emerging concepts like digital twins of business processes promise affordable, comprehensive operational visibility by integrating IoT sensors with process models (Fornari et al. 2025).

A comprehensive systematic review of IoT-aware BPM reveals that most approaches focus on modeling and monitoring phases, with limited attention to operational execution support (Compagnucci et al. 2022). The architectural implications extend beyond simple data collection. Effective IoT-BPM integration requires sophisticated data processing capabilities to transform raw sensor inputs into actionable process insights. This involves developing middleware layers that aggregate data from heterogeneous sources, perform real-time analytics, and trigger appropriate process responses based on physical-world conditions. Furthermore, this integration enables new forms of process intelligence that respond dynamically to operational realities (see

the presented BPMN extensions below, which facilitate a new approach to incorporating this external data). Location-aware processes can optimize resource allocation based on real-time positioning data, while condition-monitoring systems can initiate maintenance workflows before equipment failures occur. Such capabilities represent fundamental advances in the complexity of process management, moving beyond static workflow definitions toward adaptive, context-aware operational systems (Schönig et al. 2020; Janiesch et al. 2020).

3 Methodology

Our research aims to advance the understanding and support of the operational perspective within BPM by detailing its current state and proposing IoT-enabled future possibilities. To achieve this, we use a mixed-methods approach (Venkatesh et al. 2013; Creswell 2018), integrating insights from a structured literature review with abductive reasoning informed by our ongoing research projects and real-world observations. The structured literature review (SLR) aims at mapping existing documented knowledge directly related to the topic (answering RQ1). However, to conceptualize future possibilities and organize the entities in a new way (answering RQ2), a purely deductive method is insufficient. Abductive reasoning allows us to move from observed gaps in the literature and real-world work environments to the most plausible new framework.

The foundational component of our methodology is a structured literature review conducted in accordance with the guidelines of Okoli (2015). This systematic review aimed to map the historical development and current conceptualization of the operational perspective in process management. The search strategy involved prominent digital libraries, including ACM Digital Library, IEEE Xplore, ScienceDirect, AIS eLibrary, and EBSCO. Specific search queries combined core BPM terms ("*BPM* OR *process execution* OR *process modeling* OR *workflow management* OR *WfMS*") with keywords central to the operational perspective (e.g., "*operational perspective*", "*task execution*", "*service selection*", "*execution support*")⁵. No temporal restrictions were imposed, and publications were limited to English.

Initially, our search yielded 2,978 records. After removing 83 duplicates, 2,895 unique records proceeded to the screening phase. During the screening of titles and abstracts, 2,766 records were excluded, primarily for being irrelevant based on their titles or abstracts. The majority of these exclusions stemmed from the broad nature of the term "*task execution*" in the search terms, which accounted for two-thirds of the initial search results. This left 129 records for full-text assessment. To ensure relevance, the following explicit non-exclusive exclusion criteria were applied to publications during the full-text review:

- **EC1 (Unrelated to process science):** Publications that did not focus on the core area of process management research (e.g., Ochoa et al. 2023).

⁵The search term "BPM" was used as it is the standard acronym in the field and commonly indexed in databases. A complementary search using the full term "business process management" yielded no additional relevant papers, confirming the comprehensiveness of our initial search strategy.

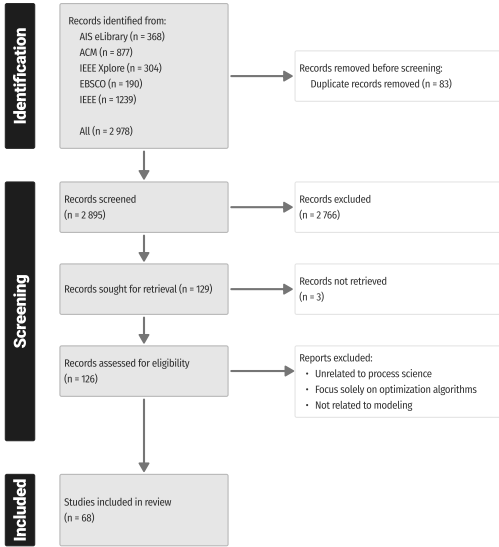


Fig. 2 PRISMA Statement following Page et al. (2021)

- **EC2 (Focused solely on task execution optimization algorithms):** Papers that only presented algorithms for scheduling or allocation without exploring the conceptualization or broader support mechanisms for task execution (e.g., Feng et al. 2005).
- **EC3 (Not related to modeling):** Articles not related to process models or modeling, which are foundational to the BPM lifecycle (e.g., Boissier et al. 2019; Song et al. 2019).

The authors jointly defined the exclusion criteria following an initial review of 20 selected papers. The first author applied these criteria systematically, documenting justifications for exclusions that were discussed within the author team.

The detailed exclusion process is documented in the PRISMA diagram shown in Fig. 2, as adapted from Page et al. (2021). The review process, including screening and data extraction, was primarily conducted by one researcher, following a protocol jointly defined by the author team. Specifically, the data extraction protocol mandated capturing the following standardized fields for each included publication: (1) general metadata (e.g., publication year, venue), (2) the specific research domain or application area (e.g., IoT, healthcare, conceptual BPM), (3) explicit or implicit definitions of the operational perspective, (4) identified process entities (active and passive resources), and (5) proposed mechanisms for supporting task execution. To

ensure reliability, unclear cases were discussed and resolved collaboratively among the researchers during the screening and eligibility phases. The extracted data were then analyzed using qualitative content analysis, following the inductive category formation approach of Mayring (2015). This method is designed to synthesize and structure material by moving from specific data to generalized, higher-order themes when a theoretical framework is emergent.

The analysis proceeded in several steps: *First*, we defined the research question guiding the analysis: "How is the operational perspective defined, conceptualized, and supported within the BPM literature?" *Second*, the 68 selected publications were analyzed to generate initial, low-inference codes directly from the text (e.g., "workflow logic," "resource allocation," "manual task," "tool support," "sensor"). In the *third* and central step of abstraction, these initial codes were iteratively refined, compared, and generalized into broader, higher-level categories (e.g., "Automated Services," "Conceptualization as Passive Resources," "Connection of Digital and Physical"). This process created a final, structured coding frame. This inductive method ensured that our analysis was grounded in the literature, allowing us to identify the evolution of the operational perspective and reveal the conceptual gaps that motivate our research.

Complementing the structured literature review, abductive reasoning (Tavory and Timmermans 2014) played a crucial role, particularly in identifying and conceptualizing future possibilities for operational support. We selected abductive reasoning over purely deductive or inductive approaches because the operational perspective lacks established theoretical frameworks for IoT integration, making pure deduction insufficient. Because our goal extends beyond describing existing phenomena (induction) to proposing novel, theoretically grounded solutions, abduction allows systematic inference from observed gaps to plausible innovations. In practice, this process was guided by insights from an ongoing research project in the logistics and manufacturing sectors, which involves observing the daily workflows of field service technicians and assembly line workers, as well as a general analysis of modern work environments where mobile device use is ubiquitous. Yet, many tasks still have to be completed manually. The abductive process involved analyzing patterns, anomalies, and unmet needs in existing practices to infer plausible and innovative solutions for operational support. Specifically, observations regarding the widespread adoption of mobile devices, the capabilities of IoT technologies (e.g., sensors, actuators, mobile devices, and personal electronics for data streams), and the evolving needs for managing non-automatable tasks guided the conceptualization of novel support mechanisms. We structured this reasoning into an iterative cycle: (i) *Observation*: Identify specific gap from SLR (e.g., lack of tool modeling); (ii) *Contextualization*: Examine this gap in real-world settings (e.g., observe how workers select tools); (iii) *Hypothesis generation*: Propose plausible explanation (e.g., tools require context-aware selection); (iv) *Mechanism design*: Develop support mechanism addressing both gap and observation (e.g., context-aware tool recommendation); and (v) *Validation*: Check consistency with both literature and practice. This cycle was repeated for each identified gap, with all authors participating in hypothesis generation and mechanism design. This iterative synthesis enabled a robust understanding of the operational perspective, moving beyond existing theoretical frameworks to propose practical, forward-looking solutions grounded in

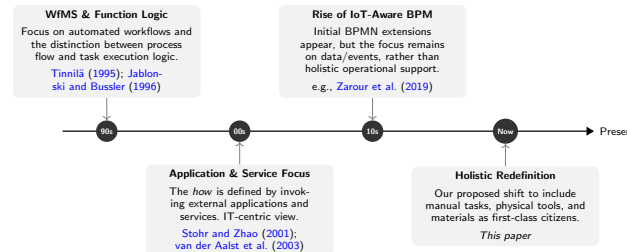


Fig. 3 Overview of the historical development of the operational perspective

contemporary technological and organizational realities. The classification of process entities (Table 2) was derived by contrasting the limited resource definitions from the SLR (inductive) with the complex reality of physical tools and materials observed in our field research (abductive), thereby necessitating new categories to bridge the two.

4 The Operational Perspective in BPM

Returning to the definition of the operational perspective already provided in the introduction, we define it as the *function of providing and supporting all resources required for a task's execution within a process model*. This generic definition includes the earlier ways of incorporating the description of how exactly a task is executed while referencing the executing active resource, on the one hand, and the used (passive) resources on the other⁶. In the following sections, we will outline the development of this definition, its current status, and future possibilities for its support within a holistic, human-centric BPM framework. This section presents our findings structured around our two research questions. **RQ1** (current state of operational perspective) is addressed through Sections 4.1 and 4.2, which present findings from our structured literature review. **RQ2** (synergistic mechanisms for integrated support) is covered by Sections 4.3 and 4.4, which combine SLR insights with abductive reasoning derived from real-world observations to propose novel support mechanisms.

4.1 The Evolving Definition of the Operational Perspective

The first mentions of the operational perspective within a process context appeared in the late 1980s, when operational and organizational perspectives on executing processes using Workflow-Management Systems (WfMS) were defined (Tinnilä 1995). During this time, the term *operational perspective* referred to a broader understanding of business processes, encompassing the tasks required to achieve a business goal. The evolution of BPM from its origins in WfMS is a significant development in the field. Consequently, perspectives on processes were adapted to focus more on the full

⁶Applications, services, machines, and even human-actors mentioned in earlier definitions can be both, passive resources, when they are used to execute a task, e.g., by a human actor or active resources, when they are fulfilling the task themselves (cf. Section 4.2.2).

BPM lifecycle (Dumas et al. 2018), extending beyond execution alone. The introduction of Business Process Reengineering (BPR) (Hammer 1990) is quoted as the first real impact of BPM (Lee and Dale 1998; Klun and Trkman 2018), which led to a shift "from a functional organization to one which is business process-based" (Armistead 1996, p. 48) and "assessing ways in which their productivity, product quality and operations can be improved" (Elzinga et al. 1995, p. 119).

Jablonski and Bussler (1996) describe the operational perspective by including it as part of a potential workflow model. Their operational perspective encompasses three key resources: tools, devices, and computers, all of which are regarded within this perspective. In a later definition, the authors define the operational perspective as "how [...] a workflow operation is implemented." (Jablonski 1995, p.119) Based on this definition, Petkov et al. (2005) provide further details, emphasizing a strict separation between the Workflow-System (i.e., the logical execution of a process within the WfMS or BPMS) and the actual execution of tasks (flow logic vs. function logic (Cardoso et al. 2004)). Additionally, Meyer-Wegener and Böhm (1999) and Stohr and Zhao (2001) focus on the tools needed for executing tasks as the main component of the operational perspective. Van der Aalst et al. (2000, 2003) and Rosa et al. (2011) all define the operational perspective as the basic steps required to complete a task, including the applications involved and the resources required in the form of business objects. Jablonski and Goetz (2007), on the other hand, focus more on the operational perspective, specifically on how services are invoked to complete a process step, without mentioning either active (executing) or passive (used) resources. Finally, Weske (2007) provides a possible operational perspective, including all the necessary information for a BPMS to efficiently utilize external applications to execute tasks, encompassing both functional and non-functional requirements. In contrast, other authors, such as Letsholo et al. (2014), include several definitions of the operational perspective, which is generally considered the organizational perspective, including active resources, the resource perspective (cf. Russell et al. 2015; Stroppi et al. 2015), and the location in their definition.

The literature review reveals a lack of a consistent, universally accepted definition of the operational perspective. Early conceptualizations, in particular, do not explicitly reference passive resources and focus primarily on the active (executing) entity. In addition, early BPM research often inferred that execution was performed by a machine, mentioning resources only as applications or generic services. Returning to the differentiation among various task types in BPMN, we note a significant gap identified at the outset. Most existing definitions and the bulk of current BPM research emphasize the standardization and support of tasks that can be automated, as well as those tasks facilitated by applications, services, and machines, which are typical user tasks within the BPMN classification.

4.2 Current State

Focusing on the current landscape of BPM research and tool support, beyond the task types discussed in Section 2, some processes involve activities that, by their nature, do not require human participation. These are distinct from the operational perspective's focus, which inherently examines how tasks are executed, often involving human actors

and their tools. Contemporary BPM research increasingly emphasizes employee-aware approaches that prioritize worker experience and empowerment (Fehrer et al. 2024). This shift recognizes that manual tasks, while not automatable, can benefit from intelligent support systems that augment rather than replace human capabilities—a principle central to the operational perspective. Among tasks that involve human participation, there is significant variation in the degree of involvement. While BPMSs frequently support user tasks by providing supplementary information, such as digital forms or other technological guidance, manual tasks (which rely exclusively on human execution) typically receive no such direct support within BPM systems. Consequently, depending on the granularity of the process models, there is often no explicit indication of how a manual task should be executed or of which specific equipment or tools are required for its successful completion.

Similar to other research areas that focus on a significant number of tasks that are standardizable, automatable, or work as expected every time, the human factor plays a crucial role in the remaining process executions by introducing various challenges and opportunities in managing business processes. To reiterate an essential distinction, the **organizational perspective** focuses on the *who* of a process, i.e., identifying the actors, their roles, and responsibilities for a task. In contrast, the **operational perspective**, which is the focus of this paper, addresses the *how* and *with what*, i.e., detailing the specific procedures, tools, and materials required for task execution.

4.2.1 Operational Perspective in General

Building on the previously established general definition of the operational perspective, this section explores various approaches to support it. We begin by examining its relevance in Enterprise Resource Planning (ERP) systems, a key starting point for understanding the specifics of task execution. Szelagowski et al. (2022, p. 326) define ERPs as systems “used to manage the organization’s resources” and BPMS to “support [...] work or document flows”. While the process is inherently embedded and explicitly implemented across various flows within ERP systems, process management provides the foundation for the process model and its associated flows. Next to two direct examples that could be transferred to BPM, Belli et al. (2019) that consider production planning and Bill of Materials in an ERP System that could be regarded as part of future application areas in BPM or Kir and Erdogan (2021) that focus on knowledge-intensive processes in supply chain management, there are additional approaches that could benefit the operational perspective that are not directly tied to ERP Systems.

Examining existing approaches from an operational perspective, we can categorize them by complexity. Starting with simple annotations of contextual information (George and Ward 2008) and using smartwatches and other mobile interfaces to track the start and end of manual tasks (Schönig et al. 2020) that do not lift the black box around manual task execution, or Ihde et al. (2022), Xiao et al. (2010) and Chang et al. (2020) that all describe resources and their use at several different application areas, the main focus lies on the optimization of allocation. Here, primarily active resources in the organizational perspective are used, and the authors assume the existence of data and knowledge about the current state of entities that were not previously made

explicit. The sole focus on improving business process and value creation (BPI) in BPM, as seen in [Johannsen and Fill \(2017\)](#), also skips the fundamentals of modeling the necessary passive resources as well as the support during execution and combined data collection, further motivating the need for a real systematic process-based support of the operational perspective.

[Haddar et al. \(2016\)](#), on the other hand, describe the collaboration between different actors on the same task, which also contains ideas that could be transferred to passive resources. Similarly, [Bocciarelli et al. \(2017, p. 601\)](#) describe modeling "non-functional properties," i.e., task resources, using a custom string-based notation and execution possibilities. Nevertheless, the authors also focus on automation, stating that the "broker defines a set of resources capable of performing the required activity." [Schmidt et al. \(2010\)](#) focus on knowledge-intensive processes, where they describe the use of software as a tool to execute, but focuses on human actors (here the authors require human resources as well as applications for the execution of a task), on the other hand, [Antunes et al. \(2013\)](#) describe different canvases to specify further human-centric tasks, end-user-focused dialog lines, and scenes with specific descriptions of what is happening. Finally, [Tietz et al. \(2013\)](#) describe an approach closest to our definition of the operational perspective by providing an overview of hierarchy-based task modeling tools that enable a more specific, focused description of tasks and the tools they include. Similarly, [Poss and Schöning \(2025a\)](#) present a formalization of tool use, supporting execution and modeling based on an ontology and facilitating the use of RDF and SPARQL for managing tools. The presented tools and approaches are far from standardized and remain only a small, unstructured part of the operational perspective.

4.2.2 Process entities and the operational perspective

After examining the historical development of the operational perspective and its current state in process models, we must also define and delineate the different entities that play a role within processes for structured development and overview. Building on the publications [Jablonski and Bussler \(1996\)](#), [Bussler et al. \(1996\)](#), [van der Aalst \(2018\)](#) and [Russell et al. \(2015\)](#) as a core, we can begin by defining basic concepts to distinguish the entities. As is universally done with the definitions and classifications of different perspectives in process management, a clear definition and selective criteria for differentiating process entities are necessary ([Dumas et al. 2018](#)). The traditional distinction between *active* and *passive* resources ([Ouyang et al. 2010](#)) is a starting point. However, it lacks the granularity necessary to model and support the complex realities of modern work, which often involves blending automated and manual tasks. Therefore, before we can meaningfully discuss how to support task execution, we must first establish robust vocabulary for what is involved and who is involved. The following classification, presented in [Table 2](#), is a core contribution of this paper. It provides a structured framework for delineating process entities based on their capabilities, interaction modes, and physical properties ([Davenport and Prusak 2010](#)). This framework is a necessary foundation for developing the enhanced modeling artifacts and support mechanisms proposed later.

Table 2: Overview of different entities participating in business processes.

Type	Subtype	Example	Primary Citizen			Interaction Type		Secondary Citizen		Data		
			trigger execution	active	passive	direct	indirect	Physical	Location	consumable/produced	reusable	transformable
Human			●	●	○	●	○	●	○	○		n.a.
Non-Human	Self-operating systems	Autonomous robots, Drones	●	●	○	●	○	●	○	○		n.a.
Non-Human	Semi-autonomous systems	CNC machines	○	●	○	●	○	●	○	○	●	n.a.
Non-Human	Automated software-systems	ERPs, Automated workflows	●	●	○	○	○	○	●	n.a.		n.a.
Operational Equipment		Tools	○	○	●	●	○	●	○	○	●	○
Material			○	○	●	○	○	●	○	○	●	○
Physical Data		Documents	○	○	●	○	○	○	○	○	●	○
Digital Data		BPMS process variables	○	○	●	○	○	○	●	n.a.	●	○

Legend ● : fulfilled, ○ : not fulfilled

Table 2 represents a key contribution of this study. This classification scheme emerged from integrating three sources: (i) traditional active/passive resource distinctions identified in our literature review (Ouyang et al. 2010; Russell et al. 2015), (ii) gaps in existing categorizations revealed by the SLR, particularly regarding physical tools and materials, and (iii) abductive reasoning based on observed entities in real-world manufacturing and logistics processes from our ongoing research projects. The framework extends beyond binary active/passive distinctions to incorporate interaction types, physical properties, and data characteristics necessary for IoT-enabled operational support.

We distinguish process entities along two primary dimensions: Primary citizens are entities that can trigger or execute process tasks autonomously (organizational perspective), while secondary citizens support task execution but cannot act independently (operational perspective). Within primary citizens, the first distinction concerns whether entities are *active* or *passive*, and whether they can *trigger the execution* of a task (organizational perspective). Active resources, including humans, robots, machines, and software systems, can execute tasks independently. In contrast, operational equipment, such as tools, materials, and data, can support task execution but cannot perform it autonomously (Dumas et al. 2018; Cabanillas et al. 2015). Next, the **interaction type** describes how an entity interacts with the process; here we have three types: *direct* interaction (active resources and operational equipment and material that directly influence the process and the entities), *mediated* interaction

(these entities have to be used by other entities to influence the process⁷) and *indirect* interaction (entities that influence the process by providing information or resources that guide or support the process rather than engaging directly with the process operations).

Finally, the secondary citizens comprise classifications on the **physical** characteristics, the **location**, and further division of each **data** entity. Here, the term *tangible* describes entities that can be perceived by the senses. In contrast, entities such as software systems and data are considered *non-tangible*, implying a lack of physical presence in the real world (Amadi-Echendu et al. 2010). However, this does not prohibit tracking and using these entities for execution support. The distinction between *dynamic* and *static* entities is based on the ability of tangible entities to move. All entities with a location can either move independently or be moved by a third party (Küpper 2005; Poss and Schönig 2024). This includes human actors and autonomous entities. Ultimately, examining whether they are *consumable/produced*, *reusable*, or *transformable* during task execution allows us to draw a final distinction. Operational equipment, such as tools, is only worn down during task execution. In contrast, material is consumed and potentially transformed (Slack and Brandon-Jones 2019; Eversheim et al. 1991; Poss and Schönig 2025b)⁸.

4.2.3 Operational Perspective in BPMN

Having established the conceptual foundation and classification of process entities, we now turn to how emerging IoT technologies can address the identified gaps in operational support. The following subsection examines current approaches to using IoT to enhance visibility and support manual tasks and their associated resources.

Leveraging BPMN as the de facto standard for process modeling and execution, we examine different existing approaches and extensions of the standard. Our primary goal is to investigate the extent to which these extensions address the operational perspective, specifically focusing on how they support the execution details of tasks, particularly manual activities, and the direct use of passive resources.

For this analysis, we drew upon BPMN extensions identified in two systematic reviews by Zarour et al. (2019) and Compagnucci et al. (2022). Table 3 illustrates the correlation between selected BPMN extensions, their corresponding perspectives, and the BPMN elements they affect. To streamline the table, we aggregated all contributions within the same extension family. We included additional relevant publications beyond the original review cutoffs, citing only the most recent publication for each extension family. The extensions are sorted by the publication year of their first appearance, followed by alphabetical order. Extended elements and affected perspectives are indicated when referenced papers explicitly expand or support the given component or perspective.

⁷This is even the case for automated software-systems, at some point, they have to be started by a human or a fully self-operating system.

⁸The classification of data depends on the definition of *transformable*, physical data like documents contain information that can be used and transformed, the documents themselves are not.

Table 3: Overview of BPMN extension families, their application areas, affected BPMN elements and perspectives.

Name of Extension(-family)	Reference(s)	Year(s)	Application Area	Executable	Extended BPMN Elements				Affected Perspectives			
					Activity	Event	Data	Pool/ Lane Group	Functional Data	Organization	Operational	Controlflow
IAPM	Cheng et al. (2018)	2011 – 2018	Generic IoT Devices	●	●	●	●	○	●	●	●	●
BPMN4WSN	Mottola et al. (2019)	2012 – 2019	Sensor Networks	●	●	○	○	○	●	●	○	●
–	Jankovic et al. (2015)	2015	Cross Organizational Processes	●	●	●	○	○	○	○	●	●
uBPMN	Yousfi et al. (2019)	2015 – 2019	Ubiquitous Computing	●	●	●	○	○	●	○	○	○
BPMN4CPS	Graja et al. (2016)	2016	Cyberphysical Systems	●	●	○	○	○	○	○	○	○
BPMN4CP	Braun et al. (2016)	2016	Healthcare	●	●	○	○	○	●	○	○	○
OutyBPMN	Rekik et al. (2016)	2016	Outsourcing	●	●	○	○	○	○	○	○	○
BPMN4V	Ben Said et al. (2017)	2017	Healthcare	●	●	●	○	○	○	○	○	○
relyBPMN	Domingos et al. (2016)	2017 –	–	○	●	○	○	○	○	○	○	○
IoT-BPO	Suri et al. (2018)	2017 – 2018	Smart Environments	○	○	○	○	○	●	●	●	●
Context4BPMN	Dörndorfer and Seel (2018)	2018	Execution Context	○	○	○	○	○	●	○	○	●
–	Dukaric and Juric (2018)	2018	Cloud Environment for Execution	●	○	○	○	○	○	○	○	○
BPMN4SGA	Vogel et al. (2018)	2018	IoT	○	○	○	○	○	○	○	○	○
BPMN-E ²	Ramos-Merino et al. (2018, 2019)	2018 – 2019	Health Care	○	○	○	○	○	●	○	○	●
–	Grefen et al. (2019)	2019	Delivery and Cross-Docking	○	○	○	○	○	○	○	○	○
BPMN-X	Ardito et al. (2020)	2020	Public Administration	○	○	○	○	○	○	○	○	○
–	Zareen et al. (2020)	2020	Security	●	○	○	○	○	○	○	○	○
–	Bazan and Estevez (2021)	2021	Industry 4.0	○	○	○	○	○	○	○	○	○
LABPMN	Poss et al. (2023)	2023	Location Information	●	●	●	○	○	●	○	○	●
RBPMN	Skouti et al. (2024)	2024	Cyberphysical Systems	●	○	○	○	○	○	○	○	○
PRIME	Poss and Schönig (2025b)	2025	Passive Resources	●	○	○	○	○	○	○	○	○

Legend ● : fully considered/fulfilled, ○ : partly considered/partly fulfilled, ○ : not considered/not fulfilled

An analysis of the results reveals that the various BPMN extensions currently used in IoT encompass elements tailored to specific application areas that span several perspectives. While the connections between use cases are discernible, their application area is quite specific, and the perspectives they address are limited. Most of the identified extensions for IoT in BPM focus on supporting basic perspectives by extending events, changing how data is handled, or influencing the process flow. From the identified and combined extensions, only three focus on the operational perspective and explicitly try to support *how* activities are executed. Ardito et al. (2020) describe a use case of a chatbot, providing a selection of types for the bot, such as *notification*, *group* or *channel*, *commands*, or *inline*, explicitly modeling how specific tasks must be executed.

On the other hand, Grefen et al. (2019) focus on co-location for collaborative business processes, which involve specific tasks requiring spatial and temporal coordination. The authors motivate this by using the example of container logistics, in which the object to be moved (the container) has a specific spatial and temporal relationship with the active resource (a crane, possibly controlled by a human). Finally, Graja et al. (2016) explicitly model the real-world environment within the BPMN Metamodel,

containing different physical entities, which are then used to support task execution. Generalizing IoT as a key enabler, other approaches also seek to extend process modeling to yield richer operational insights. For instance, [Bocciarelli et al. \(2017\)](#) outline a string-annotation-based approach that utilizes an external system to specify further task details, thereby aiming to enhance performance. In related research, [Carvalho et al. \(2018\)](#) propose breaking down end-to-end processes into smaller components and considering added artifacts that encompass both active and passive resources.

In summary, the analysis of the current state indicates that the operational perspective has been historically underexplored, a consequence of the field's dominant focus on process automation and IT support. However, active and passive resources are indispensable for effective process execution and require equal consideration. As highlighted in foundational process management literature ([Dumas et al. 2018](#); [van der Aalst 2018](#)), this oversight has created a critical gap: while the administrative tasks surrounding manual work (e.g., creating an order or sending an invoice) are efficiently managed and logged by traditional BPM systems, the physical execution of the manual task itself remains largely unsupported and unmonitored. However, the operational perspective has evolved to consider these tasks. It provides a basis for process execution, focusing on the *how* that has not yet been considered. This perspective is less about redesigning processes and more about adapting support options for existing tasks that are not fully automatable or supportable. The operational perspective has implications across all lifecycle stages, emphasizing the importance of understanding how tasks are executed, which actors participate, which applications are used, and which tools and other resources are required to complete them successfully.

4.3 Future Possibilities – New way of supporting task execution

The future possibilities presented in this section are derived through abductive reasoning, building upon the gaps identified in our SLR ([Sections 4.1 and 4.2](#)) and based on observed needs in real-world work environments. This approach allows us to move from empirical observations to plausible, innovative solutions for operational support. The evolution of organizational systems and the proliferation of IoT-enabled devices provide new opportunities for gathering and processing contextual data streams (see [Section 2.3](#)). These technological advances, combined with the widespread use of companion devices (e.g., smartphones and tablets), enable several novel mechanisms to support the operational perspective, particularly for manual tasks. The following subsections present a framework of such possibilities, aligned with the BPM lifecycle. The following sections present a non-exhaustive list of possibilities for supporting *how* process tasks are executed, aligning with the activity itself through abductive reasoning, and for synthesizing gaps identified in the literature with insights from modern work environments. These two parts, aligning artifacts along the BPM lifecycle and the perspective on the temporal ordering of a task, result in a descriptive framework that supports the operational perspective.

Enhanced Modeling Artifacts for Process Design and Configuration

To address the current limitations in supporting the operational perspective, particularly concerning manual tasks and passive resources, advancements in process design and configuration are imperative. Process modeling, analysis, and execution configuration, which make up large parts of the BPM lifecycle, offer critical junctures for introducing enhanced modeling artifacts. These artifacts aim to move beyond conventional flow-centric redesign, enabling a richer representation and management of tasks and their associated operational resources.

- **Integrated Resource Modeling:** New artifacts can be developed and incorporated for modeling resources directly within process models. As with existing data objects, necessary materials or tools can be attached and integrated into the process model.

Use Case: Imagine a furniture assembly process where BPMN models could directly specify the input (e.g., four screws, four legs, one seat plate) and output (e.g., seat plate with attached legs) materials for an Assemble Chair task, along with the required tool (e.g., small screwdriver).

- **Dynamic Resource Information:** These artifacts could include additional real-time information and parameters on (required) tools, such as their current battery level, time until next maintenance, current wear level, or maximum allowed wear for a specific task.

Use Case: For a maintenance task that requires a specific drill, the process model or task list could display its current battery status or the last calibration date, preventing delays or incorrect execution, thus supporting task execution.

- **Synergistic BPMS and ERP Integration:** Promoting the benefit and overlap between BPMS and ERP systems, passive resources like necessary materials could be included in a separate flow diagram closely connected to the process model. Adapting a Material Flow Diagram in the form of a Sankey diagram (Schmidt 2008) to BPM is one example.

Use Case: An integrated IoT-aware warehouse management system could provide real-time inventory data, eliminating the need for tasks like searching for materials or waiting for materials by informing the process model directly.

- **Granular Manual Task Classification:** Further categorization of manual tasks based on the level of human participation can significantly improve process efficiency by streamlining knowledge-intensive processes (current classifications often only present extremes, while manual tasks could be subdivided for better support).

Use Case: Differentiating between a Customer Consultation task (high human interaction, knowledge-intensive) and a Leaking Sink Repair task (manual dexterity, tool-dependent) allows for tailored operational support within the BPMN classification.

Enhanced Planning and Post-Execution Evaluation

Beyond its direct application to real-time task execution, the operational perspective yields rich data critical to improving process planning and post-execution evaluation. This holistic integration facilitates more informed decision-making and continuous process improvement.

- **Instance-Spanning Planning and Optimization:** With sufficient data on necessary and available resources, fulfillment locations, and personnel with specific skills, instance-spanning planning and optimization can be improved, influencing how tasks are executed.

Use Case: A field service management system, aware of a craftsman's location and the tools available in their company car via IoT, could prevent them from driving to a customer without the required specialized drill for a specific repair.

- **Prioritization and Organizational Improvements:** IoT data and contextual information, such as customer details or task locations, can be used for further prioritization and organizational improvements at an instance-spanning level.

Use Case: For field maintenance, real-time IoT data on the wear level of a specific drill bit (tool) or the remaining quantity of a specialized adhesive (material) in a technician's inventory could dynamically influence the daily task queue. High-priority jobs that require insufficient or worn-out resources could be automatically rescheduled or reassigned to ensure operational readiness and prevent task failure.

- **Real-time Process Monitoring for Management:** The additional information gained through operational support can provide management with a real-time overview of active and passive resources involved in processes, including their current use and location. This data is invaluable for analysis and future process improvement.

Use Case: A dashboard could display the current utilization rate of specialized equipment across all ongoing projects, enabling the identification of bottlenecks or underutilized assets and making data-driven decisions for future resource procurement or allocation.

Real-time Execution Assistance

Addressing the operational perspective's core question of *how* tasks are executed, real-time execution assistance plays a pivotal role. Moving beyond conventional machine- or application-driven approaches, this support mechanism integrates diverse contextual information to provide immediate and actionable guidance to human actors during task completion.

- **Contextual Information Delivery:** This information could include customer details, location-specific warnings about material characteristics, or information about tools needed for the task and their presence with the actor.

Use Case: A fieldworker wearing a smartwatch could receive real-time alerts about specific safety precautions for a hazardous material identified at a job site or a reminder that a specific tool required for the next step is still in their vehicle.

- **Companion Device Integration:** Companion devices (e.g., smartphones, tablets) can be easily integrated, serving as a primary source of contextual information from various sources, a communication device for data transmission, and a display for specific execution information.
Use Case: During a complex machine repair, an augmented reality (AR) overlay on a tablet can guide the technician step-by-step, highlighting components, displaying correct torque settings for bolts, or indicating parts that require replacement.
- **Adaptive Guidance for Disruptions:** If an execution deviates from the modeled task due to a disruptive event, different alternatives or guidance could be displayed to help the actor complete the task.
Use Case: If a sensor detects an unexpected reading during a medical procedure (a disruptive event), the system could immediately suggest alternative protocols or flag potential issues to the medical professional.
- **Tool-Specific Support:** Support can even extend to providing additional information on tool usages, such as required angles, temperatures, or other conditions for proper operation.
Use Case: For precise carpentry cuts, a connected saw can provide real-time feedback on the blade angle or pressure, ensuring adherence to specifications.

4.4 Research Propositions

Table 4: Research propositions for advancing the operational perspective.

Research Proposition	
P1	The implementation of integrated modeling artifacts for passive resources (e.g., tools, materials) within BPM process models will reduce task execution errors and improve resource utilization efficiency in processes involving manual tasks.
P2	During manual task execution, delivering real-time contextual information to human actors via companion devices will increase task completion accuracy and reduce process cycle time.
P3	Dynamic, IoT-enabled planning and allocation systems that leverage data on active and passive resource availability and location can significantly optimize instance-spanning process execution and reduce operational overhead for processes with mobile or distributed manual tasks.
P4	A refined classification scheme for manual tasks, extending beyond binary automation levels, can enable more granular and effective operational support strategies, leading to improved adaptability and resilience in process management.
P5	Overcoming challenges in data integration and interoperability between IoT systems, ERP, and BPMS is a prerequisite for achieving the full potential of a holistic operational perspective in Business Process Management.

Based on the gaps in supporting the operational perspective identified in our systematic literature review (Sections 4.1 and 4.2) and the future possibilities derived through abductive reasoning (Section 4.3), we synthesize our findings into an actionable research agenda consisting of five distinct propositions. As illustrated in Table 4,

these propositions aim to guide future investigations into developing and assessing a more holistic BPM approach that effectively integrates manual tasks and diverse process entities to enhance value creation. Specifically, they map directly to our proposed advancements in modeling, planning, and execution assistance:

- **P1** (Integrated Modeling Artifacts) addresses the gap identified in [Section 4.2.3](#), where current BPMN extensions lack standardized modeling for passive resources ([Ardito et al. 2020](#); [Grefen et al. 2019](#); [Graja et al. 2016](#)). Building directly on the *Enhanced Modeling Artifacts* proposed, this proposition suggests that explicitly integrating physical tools and materials into process models will reduce execution errors and improve resource utilization.
- **P2** (Real-Time Contextual Delivery) responds to the finding of [Section 4.2.1](#) that current IoT-BPM approaches do not lift the black box around manual task execution ([Schönig et al. 2020](#); [George and Ward 2008](#)). Connected to the Real-time *Execution Assistance* mechanisms outlined, we posit that leveraging companion devices to deliver contextual guidance will directly increase task accuracy and reduce cycle times.
- **P3** (Dynamic Planning) builds on the observation that current allocation approaches assume the pre-existence of explicit entity data ([Ihde et al. 2022](#); [Chang et al. 2020](#)). Rooted in the *Enhanced Planning and Post-Execution Evaluation* possibilities, this proposition asserts that instance-spanning optimization using dynamic IoT data will significantly reduce operational overhead.
- **P4** (Refined Task Classification) emerges from our entity classification framework ([Table 2](#)). Driven by the need for *Granular Manual Task Classification* identified, we propose that moving beyond binary automation levels to categorize manual tasks will enable more tailored and resilient operational support strategies.
- **P5** (Data Integration Prerequisites) acknowledges the technical challenges documented in [Section 2.3](#) ([Schönig et al. 2018](#); [Janiesch et al. 2020](#)). As a foundational requirement for successfully implementing the Synergistic BPMS and ERP Integration discussed above, overcoming these challenges is essential to realize the operational perspective fully.

5 Discussion

Our analysis revealed a critical oversight in traditional BPM: the historical emphasis on automating and IT-supporting workflows has cultivated a deep understanding of the control flow (the *what* and *when*) and organizational (the *who*) perspectives, but has largely neglected the operational perspective (the *how*). This has led to a significant abstraction gap, leaving manual and non-automatable tasks largely unaddressed and unsupported within process models and systems. This gap is particularly visible in current BPMN implementations, where manual tasks are predominantly treated as unmonitored pass-through activities. Furthermore, our review of BPMN extensions underscores this oversight, revealing that only a limited number explicitly address the execution details and operational support of physical activities.

This work contributes to the existing literature by directly addressing these modeling and analytical blind spots. Theoretically, we extend prior research by redefining the operational perspective and expanding its scope beyond the traditional IT-centric view of software-aided execution and service invocation. While previous foundational studies have differentiated between active and passive resources, our findings extend this work by introducing a novel, granular classification scheme for process entities (Table 2). This scheme addresses the limitations of binary resource classifications by explicitly integrating interaction types (direct, mediated, indirect) and physical characteristics (tangible, dynamic, consumable). The primary theoretical implication of this research is that it elevates manual tasks and physical resources to first-class citizens within BPM frameworks. By providing this structured vocabulary, our granular classification enhances the conceptual foundation of BPM. It allows researchers to theoretically model and evaluate processes beyond the digital black box, enabling a more precise and comprehensive representation of real-world, IoT-aware operations that seamlessly bridge the physical and digital domains. From a practical standpoint, we outline a concrete vision for future operational support that leverages emerging technologies, such as the IoT. We propose tangible mechanisms, including enhanced modeling artifacts for resource integration, intelligent instance-spanning planning, and real-time execution assistance delivered via companion devices. These pathways offer managers and system designers actionable insights on how to support and optimize previously 'invisible' manual processes, ultimately enabling more informed decision-making and continuous process improvement.

Despite its potential, implementing a holistic operational perspective presents several challenges. Integrating data from diverse sources, such as IoT devices, ERP systems, and manual inputs, raises significant technical hurdles related to interoperability, communication protocols, and data heterogeneity (cf. Schöning et al. 2018; Janiesch et al. 2020). Furthermore, the collection of real-time operational data, especially when involving human actors, raises critical concerns about data privacy, security, and ethics, necessitating robust anonymization and access control mechanisms (cf. Kern et al. 2024; van der Aalst 2017). The resulting systemic complexity demands sophisticated architectural designs and scalable solutions (cf. Rahmani et al. 2020; He et al. 2019). Finally, user adoption remains a key barrier; the success of these new tools hinges on their user-friendliness and the ability to overcome potential resistance to changes in established work processes (Mettler and Stepanovic 2023).

The research propositions derived in Section 4.4 outline a clear agenda for future investigation. Empirical validation is the crucial next step. Future work should focus on quantifying the impact of integrated modeling artifacts on resource utilization and error rates (P1) and measuring how real-time contextual information affects task completion accuracy and cycle time (P2). Investigating the optimization potential of dynamic, IoT-enabled planning systems for mobile and distributed tasks (P3) is another vital area. Further research is also needed to assess how a refined classification of manual tasks enables more effective and resilient support strategies (P4). Ultimately, addressing the foundational challenge of data integration and interoperability between diverse enterprise systems remains a critical prerequisite for realizing the full potential of this holistic operational perspective (P5).

6 Conclusion

This paper redefines the operational perspective in BPM, shifting the focus from automation to the full scope of organizational work, including previously unsupported manual tasks. We demonstrate that organizations can bridge the critical abstraction gap between automated functions and manual labor by integrating a deeper understanding of how work is done, supported by a novel classification of process entities and a clear vision for leveraging the IoT.

Our structured literature review of 68 publications reveals that while BPM has developed sophisticated support for control flow, organizational, and information perspectives, the operational perspective has remained underdeveloped, confined primarily to service invocation and simple resource allocation. This gap is particularly noticeable in current BPMN implementations, where manual tasks are treated as pass-through activities without explicit representation of required tools, materials, or execution procedures. To address this, we propose a novel classification scheme for process entities (Table 2) that extends beyond traditional active/passive distinctions to encompass interaction types, physical characteristics, and resource properties, which are essential for comprehensive operational support.

From a practical standpoint, we propose concrete mechanisms across the BPM lifecycle: enhanced modeling artifacts for integrated resource representation, intelligent instance-spanning planning based on real-time IoT data, and context-aware execution assistance via companion devices. These pathways are particularly relevant for sectors such as construction, logistics, and healthcare, where manual labor accounts for a significant share of value creation yet remains largely invisible to traditional process management systems. The five research propositions presented in Table 4 establish a clear agenda for empirical validation, addressing critical questions about modeling impact (P1), real-time support effectiveness (P2), dynamic planning optimization (P3), the benefits of refined task classification (P4), and the prerequisites for general data integration (P5).

We argue that the future of BPM depends not only on automation but also on creating a comprehensive support ecosystem for all tasks, regardless of who performs them. This approach enhances overall process efficiency and effectiveness. By elevating the operational perspective, we establish a more comprehensive, adaptable, and effective foundation for process management that reflects the true complexity of modern work environments.

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P1.2 Formalizing the Operational Perspective in BPM: An Ontology-Based Approach for Tool Integration

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Business Process Management Journal (BPMJ) examines how a variety of business processes intrinsic to organizational efficiency and effectiveness are integrated and managed for competitive success. (Source: <https://www.emeraldgroupublishing.com/journal/bpmj>)

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Formalizing the Operational Perspective in BPM: An Ontology-Based Approach for Tool Integration

Abstract.

Purpose This study aims to formalize the operational perspective in Business Process Management (BPM) by developing an ontology-based approach to integrating passive resources, mainly operational equipment, into process modeling and execution. The research addresses the current gap in BPM techniques for comprehensively modeling and tracking passive resources essential to real-world processes and manual tasks.

Methodology The study employs the Design Science Research Methodology (DSRM) (Peppers *et al.*, 2007) to create an artifact that addresses the identified problem. For this, we develop a meta-model and ontology for the operational perspective following established ontology creation guidelines (Noy, 2001). Based on a systematic literature review, we identify existing approaches and gaps to create a prototypical implementation based on the ontology using Resource Description Framework (RDF) to showcase the practical application in a craft business context.

Findings This research presents a novel ontology-based framework that formalizes the operational perspective in process management, specifically focusing on the role of passive resources. The developed meta-model and ontology facilitate the structured integration of operational equipment into BPM, improving transparency, resource allocation, and process execution. A prototypical implementation using IoT technologies showcases the framework's feasibility in supporting passive resource management within craft business contexts, including tool allocation and real-time process adaptation.

Research implications This research bridges a critical gap between BPM and asset management, offering a foundational framework for integrating passive resources into process management. The ontology-based approach facilitates the explicit modeling of operational equipment and materials, paving the way for enhanced BPMN extensions. Future research directions include expanding the ontology's scope, developing AI-driven resource allocation, and investigating applications in human-centric and knowledge-intensive processes. This work underscores the significance of incorporating operational equipment management within BPM to achieve greater process efficiency and adaptability.

Keywords: Business Process Management · Business process execution · Operational perspective · Internet of Things · Tool support.

2

1 Introduction

Business Process Management (BPM) is an established discipline concerned with the design, execution, and optimization of organizational processes to achieve strategic goals (Weske, 2019). However, the increasing complexity of modern business environments, characterized by integrating cyber-physical systems and the rise of Industry 4.0 (Janiesch *et al.*, 2020), presents significant challenges for traditional BPM approaches and non-automatable tasks that require human execution. Specifically, the effective management of passive resources, such as raw materials, equipment, and tools, within process execution remains a critical concern. From a scientific point of view, this is already conceptually well defined in the operational perspective in BPM, which describes “how and with the help of which tools tasks are executed” (Jablonski and Bussler, 1996).

Existing research on explicit resource management within BPM has primarily focused on active resources, i.e., human resource allocation (e.g., Arena *et al.*, 2018; Arias *et al.*, 2018) and optimization (e.g., Djedovic *et al.*, 2018; Ihde *et al.*, 2022). While these studies provide valuable insights into task assignment and scheduling, they often neglect the explicit modeling and dynamic management of passive resources within the operational perspective. For instance, consider a maintenance process where a technician needs specific tools to complete a repair task – the availability and allocation of these tools directly impact the technician’s ability to perform the task and, consequently, the overall process efficiency. However, traditional BPM approaches often lack the mechanisms to formally represent and track these tool requirements within the process model. This omission creates a significant gap in BPM literature, hindering the development of comprehensive and holistic process models and execution support systems that accurately reflect the operational reality.

This study aims to bridge this gap by proposing an ontology-based approach to integrating passive resources into the operational perspective of BPM. Motivated by the challenges identified by Janiesch *et al.*, (2020) regarding the *monitoring of manual activities* (C2), *concretizing abstract process models* (C11), *improving resource monitoring and quality of task execution* (C16), with the inherent future goal of *optimizing resource utilization* (C15), this research addresses the following research questions:

RQ1. How can we formally define required passive resources as operational equipment for the operational perspective in process management?

RQ2. How can we foster the Internet of Things to support passive resources in process modeling and execution?

Drawing upon the Design Science Research Methodology (DSRM) (Peffer *et al.*, 2007) and established ontology creation guidelines (Noy, 2001) (cf. section 3), we develop an ontology that formally defines and

Business Process Management Journal

An Ontology-Based Approach for Tool Integration 3

represents passive resources, their properties, and their relationships with other process elements, such as tasks and actors. This ontology enables a granular and accurate representation of process requirements within the operational perspective, facilitating automated reasoning about resource availability and allocation.

Our findings demonstrate the feasibility and benefits of using an ontology-based approach to managing passive resources in BPM and its operational perspective. The developed ontology provides a structured framework for incorporating passive resources into process models, enabling improved transparency, resource allocation, and process execution support. This contribution extends existing knowledge by providing a formalized and operationalizable framework that goes beyond the current “black box” approach to manual tasks and passive resource management. The ontology-based approach addresses a critical gap in BPM literature by enabling the explicit modeling and dynamic management of passive resources, particularly operational equipment, within the operational perspective. This formalization allows for more comprehensive and holistic process models that accurately reflect the operational reality, including the representation and tracking of tool requirements within process execution. By bridging asset management and BPM, this research lays the groundwork for enhanced process transparency, resource allocation, and execution support in real-world scenarios where passive resources are essential for task completion.

The paper is structured as follows: We provide an overview of BPM, its perspectives, and resources and entities, followed by an introduction to Asset Management and the IoT. We review related work on passive resources in process management in section 2. After shortly describing the methodology for this artifact following DSRM (Peffer *et al.*, 2007) and the ontology creation (Noy, 2001) in section 3, we present our formalization of the operational perspective in a meta-model and ontology, and our support for passive resources in section 4. Finally, we present two use cases for the ontology with real-world processes from our research project, including an architecture for multi-perspective process management in section 5. The evaluation approach spans multiple sections, with formative evaluations integrated throughout section 4 and section 5. In contrast, summative evaluation results are primarily presented in section 5 and section 8. This progressive evaluation strategy aligns with the FEDS framework (Venable *et al.*, 2012), ensuring comprehensive validation of our contribution’s technical and practical aspects. Finally, the paper closes with a discussion of the artifact, including its limitations in section 7, and the conclusion with recommendations for future research in section 8.

4

2 Background and Related Work

2.1 Business Process Management

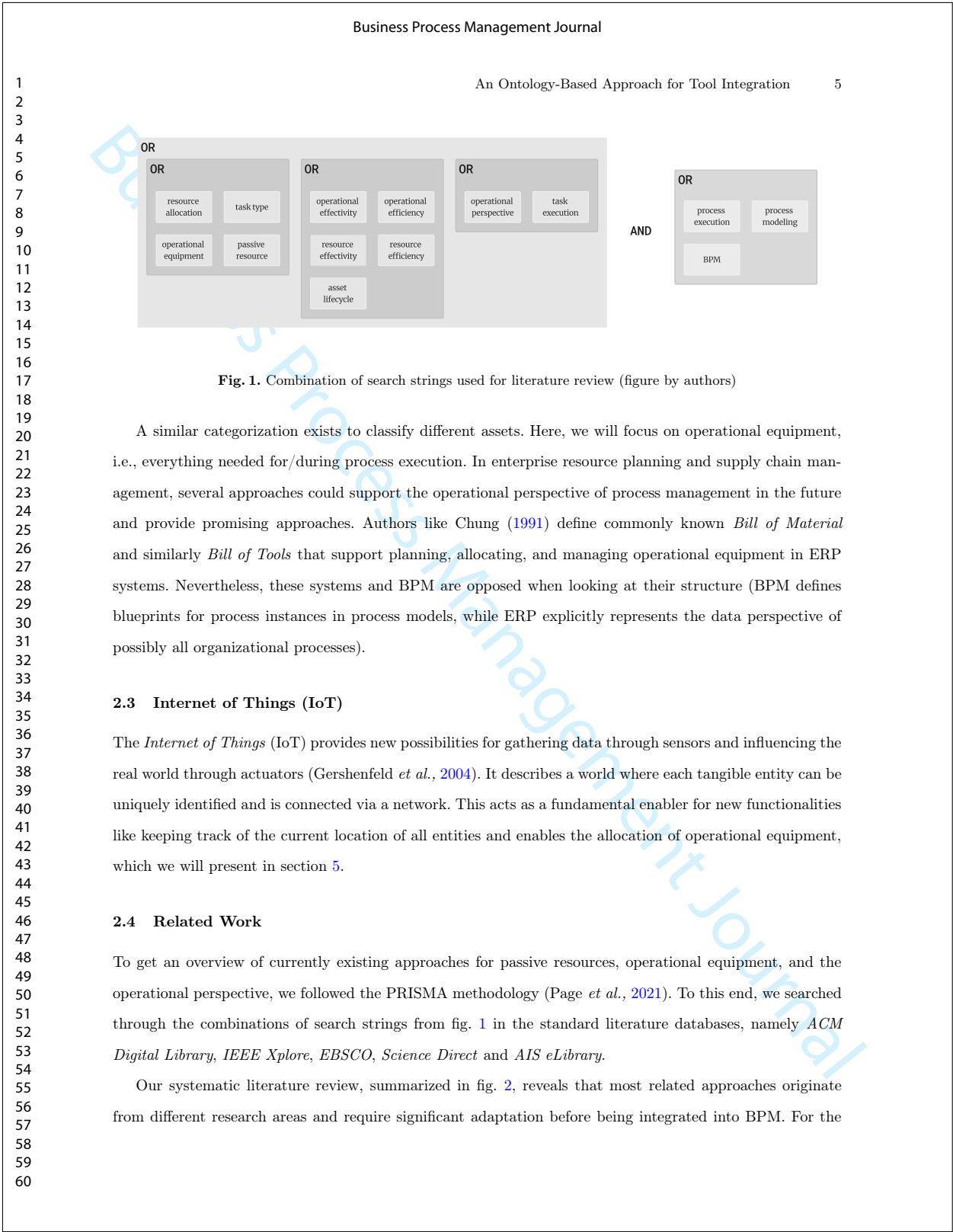
BPM is an organizational endeavor to improve organizational processes and value creation (Weske, 2019). For this, processes in an organization are discovered, modeled, and executed using information technology. These process models provide a structured blueprint for the execution and can contain different amounts of additional information depending on the modeling paradigm or language (Weske, 2019).

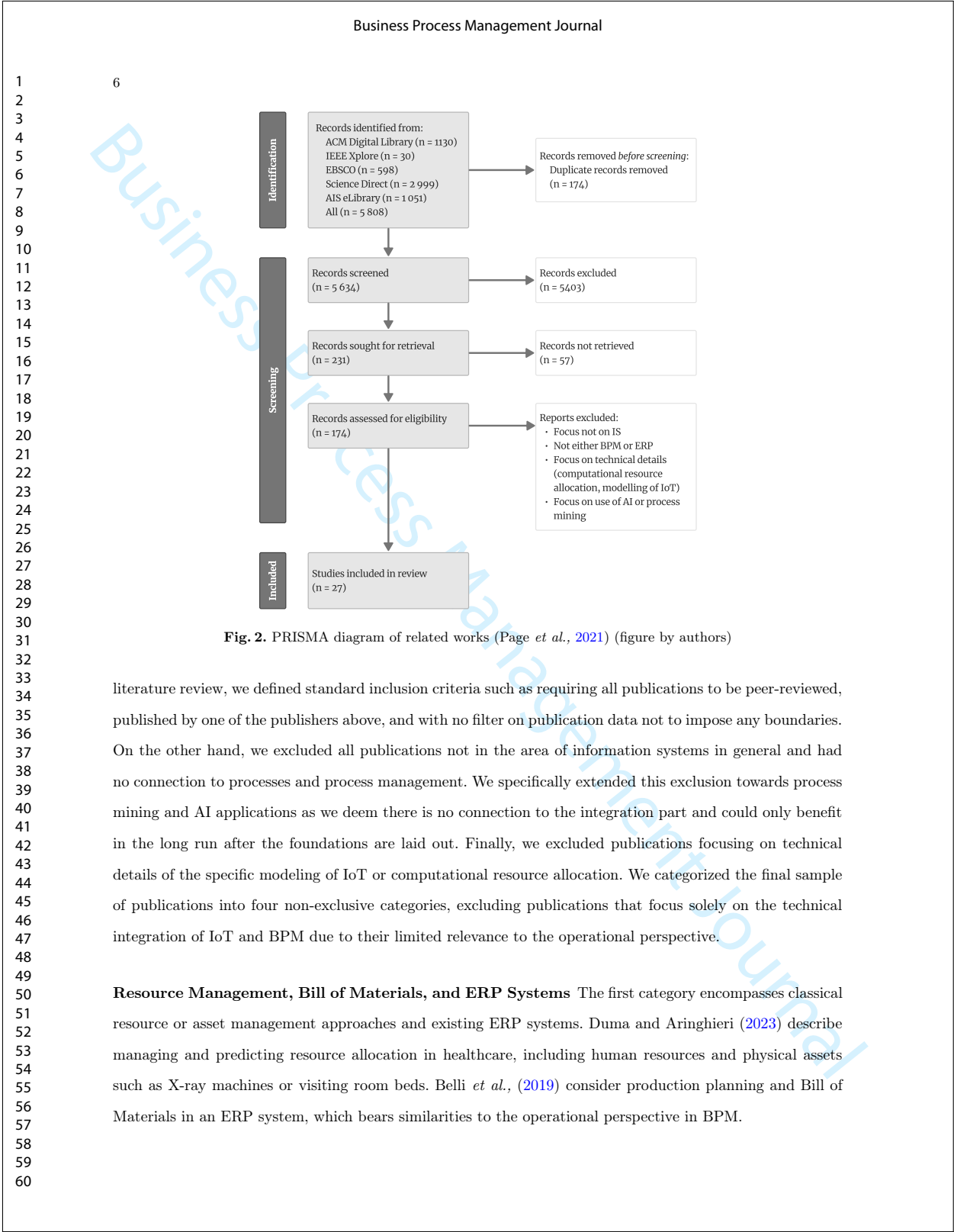
Perspectives Next to the commonly known BPM lifecycle that divides process management along a managerial axis, research defines several perspectives within BPM. Curtis *et al.*, (1992) and Jablonski and Bussler (1996) define the base for a perspectival view on BPM as a whole. These perspectives include the *data perspective*, which encompasses input and output data for an object, as well as the utilization of data within the process itself, or the *control flow perspective*, which describes the sequence of process steps and the general flow and dependencies of the model. In addition, we can look at the *resource/organizational perspective*, which specifies process execution based on the organizational structure, considering active resources that can perform tasks on their own (see next section), and the *operational perspective*, which is at the core of this contribution: how and with the help of which tools tasks are executed. These definitions of perspectives might differ historically and are not always identical, yet we will strictly follow these definitions.

Resources and Process entities Finally, another important aspect of BPM and process models are all entities involved within processes. Generally, we can divide these entities into categories based on several attributes: *active/passive* if an entity can execute and perform tasks on their own, *tangible/non-tangible* that separates data and software from entities in the real world that have a location that can be either *dynamic* or *static* if entities can move on their own or have to be moved by another entity. Moreover, the categories *consumable*, *reusable* or *transformable* for all passive entities enable the distinction between operational equipment such as tools and material and physical and digital data used for a specific task.

2.2 Asset Management

Apart from BPM, several other research directions consider passive resources or operational equipment in organizations. Many of these approaches can be summarized within the term *asset management*, defined in ISO 55000 as “the coordinated activity of an organization to realize value from assets” (ISO, 2016). Assets are “anything with actual or potential value to an organization.” (The Institute of Asset Management, 2024).





Optimization of Resource Allocation A significant proportion of the literature addresses the issue of optimizing resource allocation, with a particular focus on the organizational perspective and active resources. Arena *et al.*, (2018) employs an ontological approach for human actors, incorporating factors such as worker groups, experience levels, and skills to optimize task allocation. Djedovic *et al.*, (2018) propose a combined approach for human resource allocation that integrates process mining techniques.

Direct Execution Support Under direct execution support, we classify all approaches that could support resources during process execution with a specific process model. Gallik *et al.*, (2022), for example, explicitly model IoT devices within process models, which could be one possible way to model operational equipment in the future – even though these IoT devices currently have to be considered active rather than passive resources. Bocciarelli and D'Ambrogio (2011) and Bocciarelli *et al.*, (2023) introduce *Performability-enabled BPMN (PyBPMN)*, extending the BPMN meta-model to attach arbitrary data to most elements of a BPMN diagram. Similarly, Wagner (2022) focuses on process simulation, attaching additional descriptions of queueing distributions to tasks while explicitly modeling both active and passive resources.

Formalization through Meta-models or Taxonomies Several approaches to formalizing process management were proposed in recent decades, specifically smaller parts or specific perspectives and application areas. In their 1998 book, Bußler (1998) introduce a meta-model of the organizational perspective, which Oberweis (2010) subsequently expanded upon. This model defines various resources with states within their *resource meta-model (RMM)*, categorizing them as material, organizational, and human resources. However, its primary focus remains on the organizational perspective and active resources. According to Haddar *et al.*, (2016), used data can be formalized within process models, which could also refer to passive resources in data-driven workflows. B. Schmidt *et al.*, (2010) described ontologies for unstructured task execution processes, including a resource ontology encompassing “all the data needed by an individual to perform knowledge work,” which aligns with the operational perspective but focuses primarily on applications and data for knowledge work.

The *Role-Activity Diagrams (RAD)* theory presented in Wilson and Ould (1995) provides another formal perspective on resources and their roles. It underscores the importance of clearly defining roles and their interactions with process elements, including tools and equipment, which aligns with our explicit modeling of actor-task-operational equipment relationships. Zur Muehlen (2004) offers a comprehensive taxonomy of resource allocation mechanisms in workflows. While its primary focus is on human resources, many of its patterns can possibly easily get adapted to passive resources, which undermines the adaptability of our approach. For instance, the *Direct Allocation* pattern could be applied to assigning specific tools to tasks. In

	Approach	Key Features	Advantages	Limitations	Comparison to Our Approach
Resource Management Systems ERP and ERP Systems	Healthcare Resource Management (Duma and Aringhieri, 2023)	Resource allocation prediction Human and physical asset management	Comprehensive resource tracking Predictive capabilities	Limited to healthcare domain Focuses mainly on active resources	Our approach extends beyond single-domain applications Incorporates passive resource states
	ERP-based Production Planning (Belli et al., 2019)	Bill of Materials integration Production planning focus	Established integration patterns Structured resource hierarchies	Limited to manufacturing context Static resource relationships	Our model provides dynamic resource state tracking More flexible relationship modeling
Resource Allocation, Optimization	Ontological HR Approach (Arena et al., 2018)	Worker groups modeling Skill-based allocation	Rich semantic modeling Experience level integration	Human resources only Complex ontology maintenance	Our approach handles both active and passive resources Simpler modeling paradigm
	Process Mining Integration (Djedovic et al., 2018)	Data-driven allocation Historical pattern analysis	Evidence-based optimization Continuous improvement	Requires extensive historical data Limited to existing patterns	Our model works with both historical and real-time data Supports novel resource configurations
Direct Execution Support	IoT Device Modeling (Gallik et al., 2022)	IoT integration Device state tracking	Real-time monitoring Direct device interaction	Limited to active IoT devices Complex implementation	Our approach handles passive resources Simpler resource state modeling
	PyBPMN (Bocciarelli et al., 2023)	BPMN extension Arbitrary data attachment	Standard compatibility Flexible data modeling	Complex metamodel Limited resource semantics	Our model provides specific resource semantics More focused on resource states
Metamodels and Taxonomies	Resource Meta-model (Oberweis, 2010)	Resource categorization State modeling	Comprehensive taxonomy Formal foundations	Focus on active resources Limited operational perspective	Our approach balances active and passive resources Strong operational integration
	Workflow Resource Patterns (Russell et al., 2015)	Push/pull patterns Resource allocation patterns	Well-established patterns Implementation flexibility	Abstract patterns Limited state handling	Our model provides concrete implementations Enhanced state management

Table 1. Comparative Analysis of Resource Management Approaches (table by authors)

conclusion, the well-known workflow resource patterns Russell *et al.*, (2015) provide an additional pertinent framework. Their differentiation between *push* and *pull* patterns in resource allocation can be applied, thereby informing how our system determines whether to assign tools (*push*) automatically or to permit actors to select from available tools (*pull*).

Our analysis of existing approaches reveals several key differentiators of our proposed solution. While previous work has made significant contributions in specific domains, our approach addresses several critical gaps:

1. *Resource State Integration*: Unlike ERP-based approaches (e.g., Belli *et al.*, 2019) focusing on static resource relationships, our solution provides dynamic state tracking for active and passive resources. This extends beyond the IoT device modeling proposed by Gallik *et al.*, (2022), used to model IoT devices, yet their use is limited to acting as active resources.
2. *Implementation Complexity*: While PyBPMN (Bocciarelli *et al.*, 2023) offers flexible data modeling, it focuses on simulation and requires a specific syntax and parsing system to be used. Our approach simplifies resource state modeling while maintaining comprehensive resource semantics, making it more accessible for practical implementation.
3. *Resource Classification Balance*: Previous meta-models like RMM (Oberweis, 2010) primarily focus on active resources within the organizational perspective. Our approach better balances active and passive resources while maintaining strong operational integration, addressing a significant gap in existing frameworks, and focusing on the left-out passive resources in process modeling and execution.

4. *Pattern Adaptability*: While established workflow resource patterns (Russell *et al.*, 2015) provide abstract frameworks, our solution offers concrete implementations with enhanced state management capabilities. We extend workflow patterns to enable active and passive resource allocation scenarios by laying a foundation with the ontology.

This comparative analysis highlights how our approach builds upon existing frameworks while addressing their limitations through innovative solutions in resource state management and pattern implementation.

Since we tackle the issue of the influence of physical equipment in value-adding *processes*, we first look at process modeling notations. No current process modeling notation supports physical equipment. Neither the standard BPMN nor other notations such as Petri nets, YAWL, and Declare support it. Moving beyond, we looked at other languages standardized by the OMG and beyond process modeling; only business models and their respective languages contain the possibility of modeling operational equipment and resources: SysML (OMG, 2019), for example, is a “general-purpose modeling language for systems engineering,” but it is not process-centric, comes with significant overhead, and greatly contrasts the ontological and formal definitions of our approach.

While existing research offers valuable insights into resource management within BPM, a notable gap exists in comprehensively integrating passive resources, mainly operational equipment, into the operational perspective. Although studies like Belli *et al.*, (2019) and Duma and Aringhieri (2023) address resource allocation and optimization aspects, they focus on active resources and lack the detailed modeling of tool-task-actor relationships necessary for practical execution support. This research aims to bridge this gap by proposing an ontology that explicitly formalizes these relationships, drawing inspiration from existing resource ontologies Arena *et al.*, (2018) and B. Schmidt *et al.*, (2010) but extending them to specifically address the unique needs of passive resources within the operational perspective of BPM. The goal of providing an ontological definition for the operational perspective and integrating this into process management is at a higher abstraction level, as it is necessary to enable all the approaches based on them.

3 Methodology

This manuscript follows the Design Science Research Methodology (DSRM) (Peffers *et al.*, 2007), enhanced with more recent developments in DSR approaches (Gregor and Hevner, 2013; Johannesson and Perjons, 2021; Sein *et al.*, 2011). This combined framework provides a comprehensive structure for creating and evaluating artifacts while considering their organizational context and long-term impact.

The methodology integrates the traditional DSRM steps with the multi-cycle view of Drechsler and Hevner (2018), ensuring rigorous connections to the knowledge base and practical environment. This integration helps

Business Process Management Journal

10

continuous evaluation throughout the design process, enabling the recognition of emergent requirements. It also ensures explicit consideration of the organizational context and positions knowledge contributions. Additionally, we follow Veit *et al.*, (2017) that provide an additional framework for research in business processes where they use the differentiation between the production of traditional knowledge (Mode 1) and academic problem-solving with focusing on its practical applicability (Mode 2) based on Baber *et al.*, (1995). The authors provide 24 problem classes for these two modes in BPM research and help define methodological boundaries.

Our research uses a hybrid approach, combining deductive and inductive reasoning to address the research questions comprehensively. The deductive component begins with existing theories on Business Process Management and asset management, from which we derive our initial hypotheses and ontological framework. This top-down approach guides our formulation of the meta-model and initial ontology structure. Concurrently, we use an inductive approach by analyzing real-world processes and operational equipment usage in craft businesses and beyond. This bottom-up method allows us to identify patterns and relationships not initially apparent in existing theories, enriching our ontology and meta-model. By iteratively applying both approaches, we ensure that our framework is both theoretically grounded and practically relevant.

Problem Identification and Motivation The core problem addressed in this paper is the gap in BPM techniques for modeling and tracking passive resources, especially operational equipment such as the handicraft tools needed for a specific task. The motivation is to enhance process transparency, resource allocation, and execution, particularly in contexts requiring specific tools for task completion. The current definition of the operational perspective already motivates and conceptually describes operational equipment used to carry out process tasks. This definition has fallen short in research over the last few decades (Jablonski and Bussler, 1996). Until now, there are no concepts and implementations for modeling and supporting them during process execution. The most similar approach is data objects in BPMN, used to model the “items (physical or information items) that are created, manipulated, and used during the execution of a Process” (OMG, 2011)). Nevertheless, these *information items* fall far behind the actual need for physical, operational equipment in real-world processes as these items are not tangible, are simple references, and have no physical representation. They have no hierarchical order and do not include additional parameters and specifications.

Objectives of the Solution Based on the identified problem, we define the following design objectives:

1. **Formalization:** Develop a formal ontological definition for passive resources in process management.
2. **Integration:** Create a meta-model and ontology that incorporates passive resources, especially operational equipment, into existing BPM frameworks.

3. **Practicality:** Ensure real-world applicability (for the prototypical implementation, particularly in craft business contexts).

4. **Extensibility:** Design an ontology that can be easily extended for various operational equipment and industry needs.

5. **Interoperability:** Ensure compatibility with existing BPM systems and IoT technologies.

Design and Development We develop a meta-model and ontology for the operational perspective in BPM, following the ontology creation process by Noy (2001), which includes steps such as defining classes, properties, and instances (cf. fig. 3). We integrate these steps deeply into the broader DSRM processes as a fundamental methodological adaptation.

Demonstration A prototypical implementation based on ontology demonstrates the practical application of our approach, addressing tool allocation and real-time process adaptation in a craft business context.

Evaluation The artifact is evaluated through a case study in the craft business domain, showing its applicability with two different process models and quantitatively evaluating the implementation to assess how well it meets the design objectives and addresses the identified problem. This also aligns with Mode 2 research (cf. Baber *et al.*, 1995) that focuses on heterogeneous solutions that focus on the results of organizations beyond academic needs that overlook practical application.

Communication This manuscript serves as the primary medium for communicating the problem, artifact, and its effectiveness to researchers and relevant audiences.

Alignment with Paper Structure The following sections of this paper directly address the steps outlined in this methodology: section 4 corresponds to the Design and Development phase, detailing the creation of the meta-model and ontology. section 5 covers both the Demonstration and part of the Evaluation phases, describing the prototypical implementation and its application. section 8 completes the Evaluation phase and contributes to the Communication step by summarizing findings and suggesting future research directions.

Adhering to DSRM is a first step in addressing the gap in BPM techniques for modeling passive resources. It also provides a framework for evaluating our proposed solution.

4 Concept

BPM contains different steps along the lifecycle to ensure value creation. For this, different entities are involved, either actively executing tasks or being used during process execution. The organizational perspective

Business Process Management Journal

12

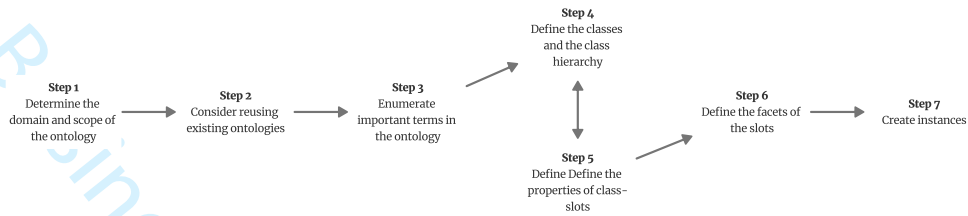


Fig. 3. Process for the creation of an ontology following Noy (2001) (figure by authors)

considering active resources (mostly human actors, autonomous robots, or software services) has long been a focus of IS research. It provides many different approaches for modeling and execution support, yet passive resources are as crucial for the process.

As previously stated, the operational perspective for active resources is analogous to the organizational perspective, which emphasizes the manner and means by which operational equipment tasks are executed. Until now, the interconnections and interactions between different entities in the operational perspective of BPM have remained opaque. This overview offers a structured understanding of the entities involved in a task, facilitating the use and monitoring of organizational assets and supporting employees during task execution.

This also completes the first step of the process given in fig. 3, where we define the domain and the scope. Section 2.4 describes different approaches for the inclusion and execution of the operational perspective and passive resources in process management. Suárez-Figueroa *et al.*, (2011) describe different abstraction levels for the ontological resource re-engineering process that we can transfer to our creation. The specification within the meta-model describes the highest form of abstraction, followed by the conceptualization and formalization in the ontology that defines structure and components by already providing a formal and semi-computable model. Bußler (1998) defines different meta-models for the perspectives to show the interrelation between different parts of business processes and to define them systematically. Similar to this approach, the goal is to define a systematic base for the operational perspective.

By systematically and ontologically defining the connections between different process entities, we can improve transparency, ease task execution, enable better process and necessary entity planning, and gain a better overview of process management. Using the ontology, we can implement cross-system functionality that enables the following functionality: All assets of a company, from the operational perspective, mainly operational equipment, are finite and, compared to digital assets, cannot be duplicated or scaled as efficiently. We can formally model the requirements for tasks and operational equipment for this. Examples include a specific number of trucks at a logistics company, different assets like machines or beds in a hospital, or tools

needed for a specific task at a craft business. For each example, the operational equipment has to be assigned to an actor, which is the basis and strict requirement for executing a task.

Existing approaches for asset management are often solely location-based (e.g., asset management in a hospital). In contrast, allocating operational equipment and assets like tools or trucks for executing a task lies at the core of the task itself. The ownership relationship between the operational equipment and the actor goes far beyond simple knowledge of the current use but enables the execution of a task (a delivery driver cannot deliver without a truck; similarly, if the repair of a broken heater at a customer requires a specific tool, the craftsman cannot complete the task if the craftsman does not carry the tool).

4.1 Meta-model Formulation: A Structural Framework for Operational Asset Integration

?? shows the meta-model of the operational perspective of process management. We have to start from top to bottom and from left to right, logically, from the *process model* itself and its elements like *lanes*, *gateways*, or *tasks*, independent of the actual modeling language. Now, taking the task classification of BPMN as the de-facto standard and the only implementation of the operational equipment, we could be looking at specific task types: *script tasks* that are entirely automated, on the one hand, *user tasks* where a human actor has to do something but the task is supported by a non-human entity, and *manual tasks* at the other extreme. As explained above, the operational perspective considers how and with which tools and equipment tasks are executed. Furthermore, script tasks are already included in a BPMS within the context of BPMN. These tasks are explicitly used to invoke well-defined external scripts concerning inputs and outputs. Consequently, our attention can be directed towards manual tasks.

In BPMN, manual tasks do not carry any content and get modeled as a black box, which is one of the primary motivations for this approach, as mentioned in the motivation. In current BPMSs, these tasks are simply skipped and not included, meaning we cannot easily rely on standard BPMN and BPMS features to support the execution (cf. Camunda, 2024; Flowable, 2024).

Looking at a *manual task* directly, it can contain *instructions* that further specify the task; manual tasks have a specific *location* of fulfillment, where they have to be executed (imagine the craft business that repairs a broken heater here the task can evidently only be executed and finished at the location of the heater), for a specific task we can need zero, one or multiple *specific tools* and/or zero, one or multiple *tools of a specific tool type* (cf. section 5). The tools can all have *documentation* for the specific use. A tool can contain multiple smaller *parts*, each with a parameter (imagine a drilling machine with a drill with a diameter of 5 mm). These parameters can be *quantitative* (e.g., 5 mm) or *qualitative* (e.g., ease of use of a specific tool, see fig. 6). Because tools are physical equipment, they also inherently have a *location* in the real world.

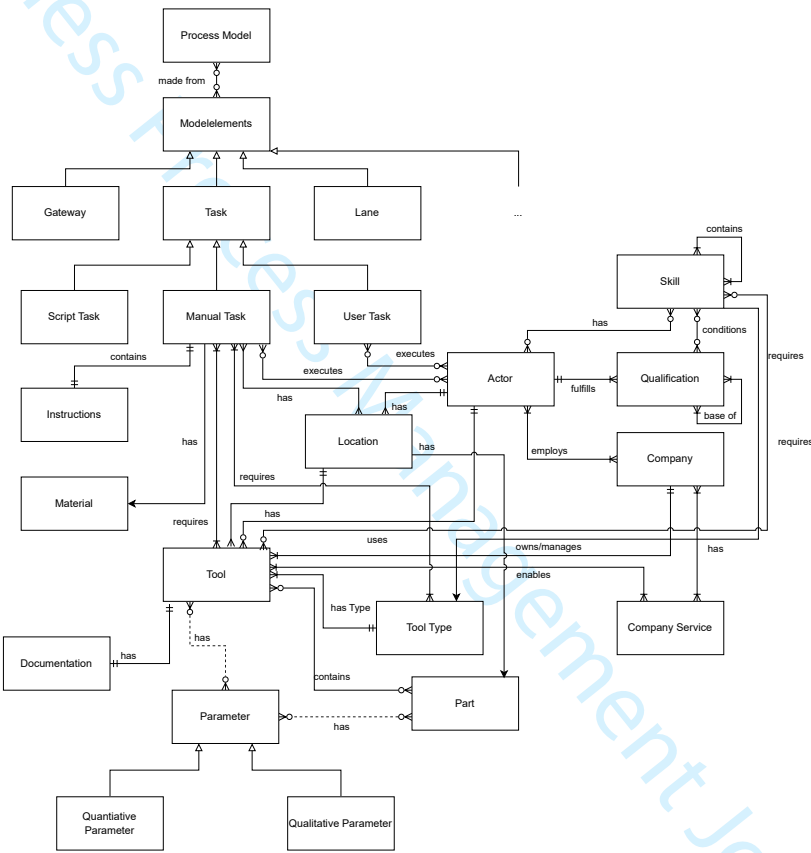


Fig. 4. Meta-model of the operational perspective in BPM focusing on operational equipment (figure by authors)

Depending on the exact needs, the operational perspective also concerns all human actors who have a location and execute manual or user tasks (in the BPMN context). These *actors* use tools to perform *tasks* and are employed by a *business*. This part of the organizational perspective is included as it aids in bringing together a holistic view of business process modeling and execution. The actor might need specific *skills* to use a *tool type* or *tool* based on possible owned *qualifications* that also restrict the possible allocation of tools and tasks to a specific actor.

Finally, taking a holistic view of operational equipment and, even more generally, assets, we also included the *company* that owns and manages the tools, employs actors, and provides specific services to customers enabled by their employees' tools and qualifications, concluding step 4 creating the ontology (fig. 3).

4.2 Ontological Specification: Formalizing Semantic Relationships in the Operational Perspective

Based on the meta-model, we further formalize the link between the different entities and remove parts that do not have to be explicitly included to build our ontology. Ontologically defining the previous preliminary meta-model enables the automated processing of the included information. We will use this in our implementation to automatically query and use well-defined data structures that contain all relevant information from an operational perspective in BPM.

Looking closer at fig. 5, we again have the operational equipment, tools, and manual tasks at the center as well as the relations from the actor executing the task to the requirements either directly to one or multiple tools or one or multiple tools of a specific type (marked in red). Similar to this, we also model the tool, including different parts, parameters, and documentation. Conversely, we increase the granularity and distinguish between human and non-human actors. Focusing on human actors, we explicitly model the current ownership of a specific tool^a and the dependency of an actor having a particular skill that might be required to use a specific tool. We did not explicitly focus on non-human actors that can further be divided into dynamic (autonomous entities) and static (e.g., machines) actors.

We did not further specify material explicitly as it differs fundamentally from tools. While material is consumed and/or transformed during task execution, tools only might be worn down. Finally, to complete a tool's lifecycle, we retain the company as an explicit type that employs the actors and manages and owns all the tools. All tangible types have a location for which we used the spatial representation of *GeoSPARQL* (Battle and Kolas, 2012), and we added parameters like the name or type designation and the brand to tools and an actor name to our actors (steps 5 and 6 following Noy (2001)).

^a We called this relation *usesTool*, which in reality could also imply *currently allocated to*, *within the car of the actor* or more generally *with the actor*.

Business Process Management Journal

16

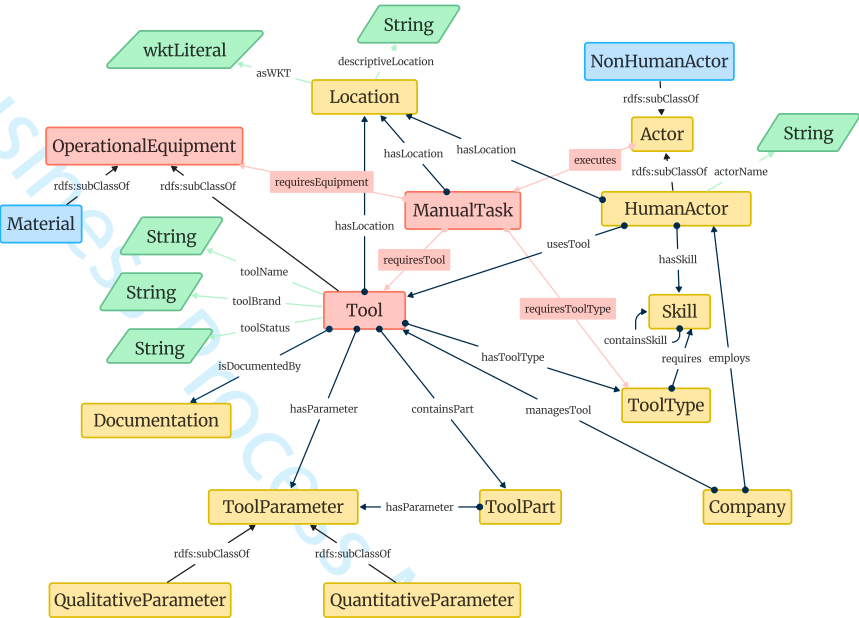


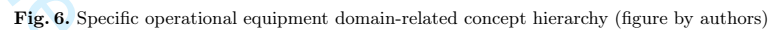
Fig. 5. Core concepts and relationships for the operational perspective (figure by authors)

We provide exemplary entity types for the area of craft businesses in fig. 6 to specify different abstract types further (step 7 for the creation of an ontology, cf. fig. 3). Quantitative parameters include things like the *diameter of a drill* or the *current battery level* of a tool. In contrast, qualitative parameters include the *ease of use* of a specific tool or the *power source* (e.g., corded, cordless, pneumatic). Each tool can contain different parts, like a *drilling machine* containing a *battery pack* and a *drill*, and is of a specific type, like a *hammer drill*. Using this ontological approach, we enable the future extension of entity types by additional parameters and new or more specific tool types that might be required for a specific task.

4.3 Operationalizing the Ontology: Integration of Operational Assets in Process Execution

Our developed ontology formalizes the relationships between tools, actors, and task types explicitly modeled in business processes and executed using BPMS. This structured approach to data representation enables significant improvements in asset allocation, process planning, and task execution by explicitly modeling the tools used in the process model.

We can use IoT devices and technology to gather real-time information on the current mapping between tools and actors. By combining which actor currently possesses which tool with our knowledge of task-specific



The implementation of this system, which we will detail in section 5, demonstrates how we can adapt a standard process from our research project to automatically trigger specific tasks if an actor does not have the necessary tools. This practical application illustrates the tangible benefits of our approach in improving process execution efficiency and effectiveness.

```
18
SELECT ?tool ?toolName ?toolBrand ?toolDescription ?toolStatus ?toolType
WHERE { ?tool a oe:Tool .
  OPTIONAL { ?tool oe:toolName ?toolName . }
  OPTIONAL { ?tool oe:toolBrand ?toolBrand . }
  OPTIONAL { ?tool oe:toolDescription ?toolDescription . }
  OPTIONAL { ?tool oe:toolStatus ?toolStatus . }
  OPTIONAL { ?tool oe:hasToolType ?toolType . }
}
```

Listing 1: Query all current tools, including their specification and tool type

5 Implementation

5.1 Ontology

After conceptually defining the ontology, it is necessary to practically implement it to provide a real-world solution and show its applicability. We can do so by using different libraries available for all large programming languages that provide an access layer for handling ontological data structures. For this, we first will offer a full-fledged implementation that enhances a real-world process model containing different tasks with specific tool requirements and another use case in which operational equipment in the form of mobile heating units is used as an example of ontologically selecting the correct unit based on external parameters.

By adopting the Resource Description Framework (RDF), we can imagine the ontology as a structured and formalized graph database where we can insert and query necessary information using SPARQL Protocol And RDF Query Language (SPARQL)^b. This leverages the formal definition and enables easy access to adding, querying, and updating data in an organized manner (cf. Pérez *et al.*, 2009). Using the defined schema allows us to easily determine relationships between entities and efficiently use SPARQL queries to retrieve relevant information from our knowledge base. The easiest way to use an ontology is by using standalone tools like *Apache Jena Fuseki*^c that also contain a SPARQL endpoint and user interface, or integrating it into an existing web application using *RDF4J*^d for Java or *RdfLib*^e for python or similar packages and libraries.

A simple first query in SPARQL is shown in listing 1. It is used to query all current tools, i.e., all entities of type `oe:Tool` and all their respective variables defined in the ontology above (namely name, brand, description, and current status). We also query the tool type, a unique identifier of the entity within the ontology (IRI). Like ontologies work, the RDF data model represents data in triples, allowing the work with structured and semi-structured data. This is visible in the query, where we query all elements with type tool (`a oe:Tool`) with optional parameters. We can read this as “if the tools’ description is available/it has a description, return it” (`OPTIONAL {?tool oe:toolDescription ?toolDescription .}`)^f. Based on this,

^b <https://www.w3.org/TR/sparql11-query/>

^c <https://jena.apache.org/documentation/fuseki2/>

^d <https://rdf4j.org/>

^e <https://rdflib.readthedocs.io/en/stable/>

^f For additional information on SPARQL and RDF, see DuCharme (2013)

Business Process Management Journal

An Ontology-Based Approach for Tool Integration 19

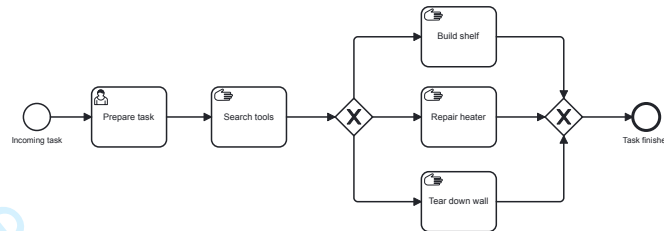


Fig. 7. Process model for craftsperson with three different tasks without tool tracking (figure by authors)

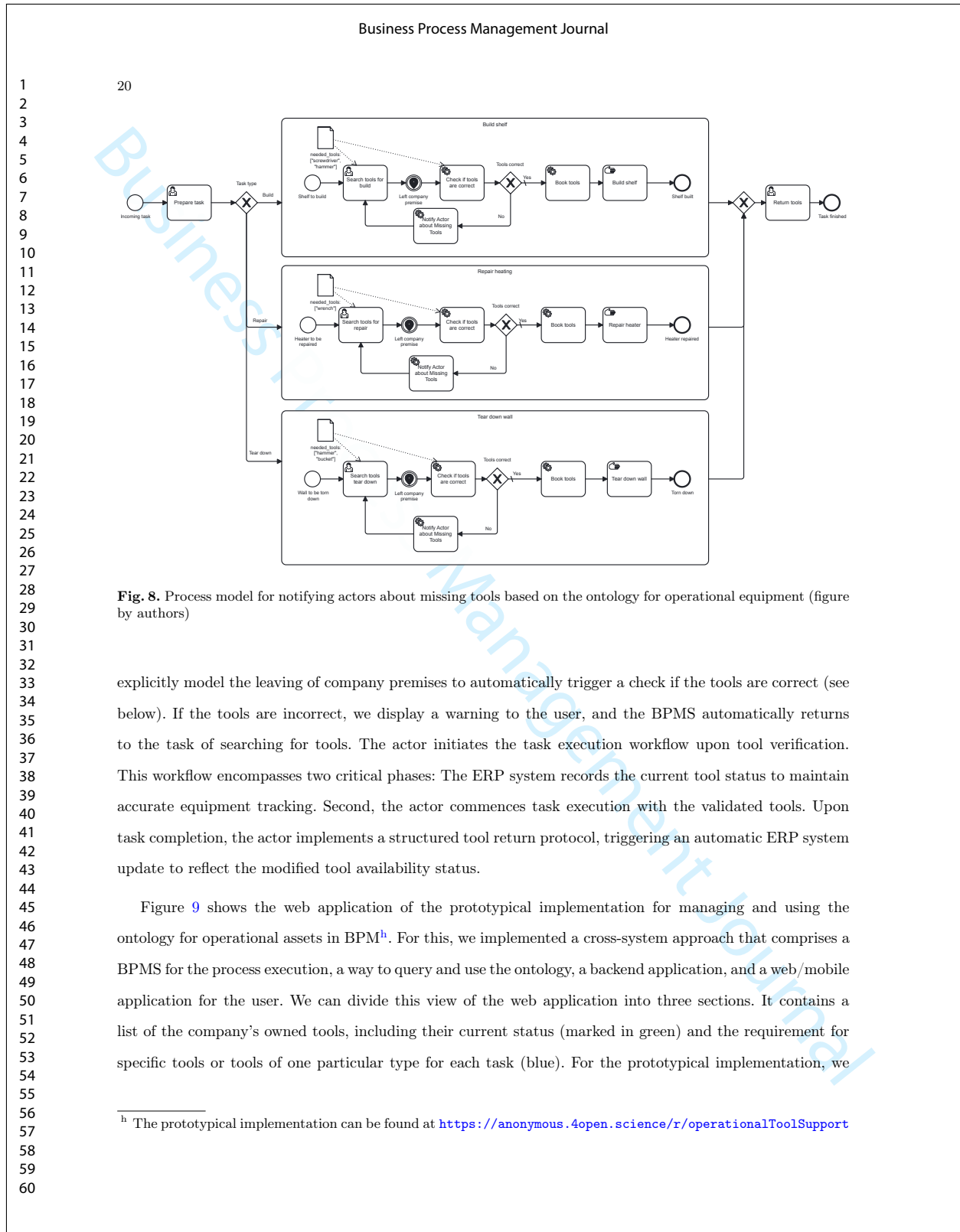
we can look deeper at the integration of the ontology and process management, where tasks normally require some passive resource for their execution (the operational perspective of BPM). We will do this by presenting two different use cases: the first for tracking tools needed for specific tasks, which we will also use in the evaluation, and the second one, where we use the ontology for automated decision-making in selecting the best heating unit to rent out to a customer.

5.2 Use Case I – Task requirements and tracking tools in crafts businesses

To showcase the integration of the ontology with business processes, we will use a simplified extract of a process model from a research project at a craft business shown in fig. 7. The company provides three services for simplicity: building, repairing, and tearing down things. All three tasks require specific tools for their execution, where the main focus and value creation lies in the manual activity of an actor. Before an actor can start working on a task, they must collect all the necessary tools. This process model completely hides real-world interactions with operational equipment from the process-management system and lacks supportability. Process designers must model even straightforward requirements like tool usage separately⁸. The operational perspective omits descriptions of “how and with which tools” performers execute tasks. The process model thus needs several modifications before it can effectively integrate with our ontology.

The trimmed-down and adapted process for including operational equipment starts with an incoming task of a specific type (fig. 8). This task type directly influences several things from the beginning; the organizational perspective that describes the relationship between actors and tasks is widely known and supported in BPMS, where we could attach a specific group of users based on their qualifications or skills to the subprocess as candidates, on the other hand, there has been no possibility to do the same with operational equipment. Depending on the task type, the actor gets the task to collect the correct tools as soon as the task is prepared. Then, using location-aware events defined in Poss *et al.*, (2023), we can

⁸ BPMN offers data objects for modeling such requirements (OMG, 2011), which display them in the process model but lack a standardized method for accessing and working with them during execution





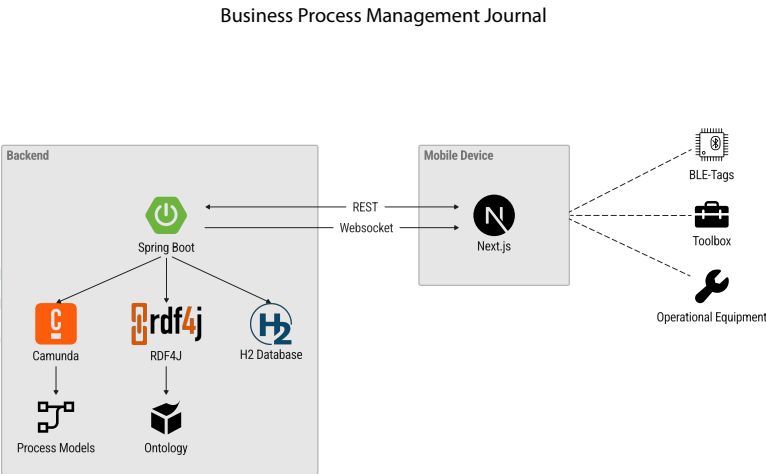


Fig. 10. Architecture of the prototypical implementation (figure by authors)

```
1 SELECT ?requiredTool (EXISTS { oe:<ACTOR> oe:usesTool ?requiredTool } AS ?hasToolTotal)
2 WHERE {
3   oe:<TASKTYPE> oe:requiresTool ?requiredTool .
4 }
```

Listing 2: Query for all needed tools and if the actor currently uses them

that are currently in use by the actor (<ACTOR>). This query gets executed in the script task *Check if tools are correct*, which, in turn, gets triggered automatically after the actor leaves the company premises. Depending on the exact query, we can either query for a simple boolean value if the actor has all the necessary tools (listing 3) or, more specifically, which tools are currently missing and set the corresponding process variable within the instance (listing 2). The other possibility is that we specify that a specific task, e.g., tearing down a wall, requires any jackhammer, but we do not care which type precisely. Listing 4 shows the SPARQL query to get the necessary tool type for a specific task type (<TASKTYPE>) as well as the number of matching tools the actor (<ACTOR>) currently has in their possession.

5.3 Use Case II – Selecting operational equipment based on external requirements

In addition to the first use case for automatically tracking tools used by an actor and providing necessary information for tools, we can also use the ontology for more classical operational equipment like external heating containers. For this, we enhanced another business process from our research project where the company rents out different-sized mobile heating containers depending on the specific needs of a customer’s property.

Figure 11 shows an extract of the process, the first few steps of renting out a mobile heating unit. This includes selecting the appropriate unit, which internally uses the ontological definition and thus benefits from being queryable using SparQL. After that, the unit is prepared by an actor and transported by the customer,

```

1 SELECT (COUNT(?requiredTool) = COUNT(DISTINCT ?usedTool)) AS ?hasAllTools)
2 WHERE {
3   oe:<TASKTYPE> oe:requiresTool ?requiredTool .
4   OPTIONAL {
5     oe:<ACTOR> oe:usesTool ?usedTool .
6     FILTER(?usedTool = ?requiredTool)
7   }
8 }

```

Listing 3: Query if the actor currently has all required tools as a single boolean value

```

1 ASK {
2   oe:<TASKTYPE> oe:requiresToolType ?requiredToolType .
3   oe:<ACTOR> oe:usesTool ?tool .
4   ?tool oe:hasToolType ?requiredToolType .
5 }

```

Listing 4: Query for correct tool types following the ontology

or the delivery is planned and delivered by an employee. Here, we model the mobile heating unit as a tool with a specific tool type `HeatingContainer` and a Task (here: Subprocess) that requires the particular equipment. Additionally, we model different parameters like this unit's physical size and capacity (here, we define the necessary capacity based on the floor area of the structure: rooms up to 125 cubic meters (approx. 4.400 cubic feet, 50 square meters with a standard ceiling height of 2.5 meters) need at least five kW, rooms up to 250 cubic meters require 10 kW, larger up to 500 cubic meters (200 square meters) ones require at least 20 kW). This can then be used to select the most suitable unit within the task *Select unit*. For this, we can use two approaches: directly querying the ontology for available units matching the criteria or extending the ontology axiomatically based on requirements.

Listing 5 demonstrates a query methodology for identifying available rental units that satisfy specific room size parameters. The initial implementation explicitly models all possible combinations, requiring direct query modifications when requirements change. Listing 6 introduces an enhanced architectural approach: we augment the ontology with dimensional parameters and axiomatically define unit selection criteria^m. This methodology diverges from the previous approach by leveraging SparQL `CONSTRUCT` statements that emulate OWL reasoning rules, enabling dynamic requirement evaluation and constraint validation (listing 7). The framework's extensibility accommodates additional constraints through ontological enrichment via supplementary classes, objects, or constraints.

Compared to the first use case, this use case could, in a minimalist way, provide similar functionality using standard BPMN features depending on the specific needs by explicitly defining all potential outcomes. This solution is only viable for a few possibilities and selections and would behave functionally similarly to an event-based gateway in BPMN.

^m This framework facilitates future integration of customer-specific contextual parameters

Business Process Management Journal

24

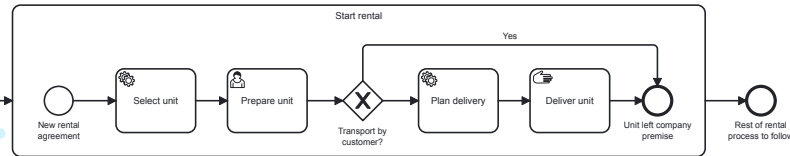


Fig. 11. Extract of rental process of mobile heating unit (figure by authors)

```

1 SELECT ?heater WHERE {
2   ?heater a oe:HeatingContainer;
3   oe:hasCapacity ?capacity .
4   ?capacity oe:hasValue ?capacityValue .
5   FILTER (
6     (<ROOMVOLUME> < 20 && ?capacityValue >= 5) ||
7     (<ROOMVOLUME> >= 20 && <ROOMVOLUME> < 50 && ?capacityValue >= 10) ||
8     (<ROOMVOLUME> >= 50 && ?capacityValue >= 20)
9   )
10 }

```

Listing 5: Query for all possible heating units that can be used for the explicit room

Using RDF4J, we can transform the query results into Java objects for further processing. This approach allows us to bridge the semantic knowledge represented in our ontology with the runtime execution environment of the BPMS. Combining both systems in Spring Boot enables us to perform ontology-based reasoning about tool requirements and availability, directly influencing process execution by setting variables or triggering events in Camunda. This tight integration between the semantic layer and the process execution layer forms the core of our implementation, allowing for dynamic, context-aware management of operational equipment within business processes.

6 Evaluation

Our evaluation follows the FEDS framework (Venable *et al.*, 2012), employing a Human Risk & Effectiveness strategy to assess the sociotechnical impact of integrating passive resources into BPM. This approach ensures user acceptance, practical utility, and real-world effectiveness, aligning with the four-cycle view of Drechsler and Hevner (2016) and Gregor and Hevner's contribution framework (Gregor and Hevner, 2013). We conduct a two-tiered evaluation:

1. **Naturalistic Formative Evaluation:** Focus group with stakeholders, pilot implementation, iterative feedback, and assessment of BPM integration.
2. **Summative Evaluation:** Comprehensive case study assessing technical usefulness, user experience, organizational impact, and generalizability.

The problem statement stems from an ongoing research project within our group that explores the integration of the Internet of Things and business process management in craft businesses. A significant issue

```

1  oe:Room a owl:Class .
2
3  oe:hasRoomVolume a owl:DatatypeProperty;
4      rdfs:domain oe:Room;
5      rdfs:range xsd:float .
6
7  oe:hasRequiredCapacity a owl:FunctionalProperty, owl:DatatypeProperty;
8      rdfs:domain oe:Room;
9      rdfs:range xsd:float .

```

Listing 6: Extend the ontology to include rooms with different sizes and their requirements

```

1  CONSTRUCT { ?room oe:hasRequiredCapacity 5.0 }
2  WHERE { ?room a oe:Room ; oe:hasRoomVolume ?volume .
3          FILTER (?volume <= 125.0)
4  }
5
6  CONSTRUCT { ?room oe:hasRequiredCapacity 10.0 }
7  WHERE { ?room a oe:Room; oe:hasRoomVolume ?volume .
8          FILTER (?volume > 125.0 && ?volume <= 250.0)
9  }
10
11 CONSTRUCT { ?room oe:hasRequiredCapacity 20.0 }
12 WHERE { ?room a oe:Room; oe:hasRoomVolume ?volume .
13         FILTER (?volume > 250.0)
14 }
15
16 SELECT ?heater WHERE {
17     ?heater a oe:HeatingContainer ;
18         oe:hasCapacity ?heaterCapacity .
19     ?room a oe:Room ;
20         oe:hasRequiredCapacity ?requiredCapacity .
21     FILTER (?heaterCapacity >= ?requiredCapacity)
22 }
23

```

Listing 7: Query for all suitable units directly from the ontology without defining the requirements in the query

is the lack of up-to-date information regarding the location of tools and devices needed for various tasks and their limited availability. Both use cases discussed in this paper are grounded in real-world examples and are being implemented in normal-sized settings with limited tools and process instances. In January 2025, we held a focus group to discuss the implementation status and the underlying concept, which included software developers and stakeholders from the handicraft industry. Over a discussion period of 60 minutes, participants received the core idea positively, with one noting that the current process for retrieving the tools and materials necessary for a workday is often frustrating, time-consuming, and inefficient due to the absence of reliable data on tool locations or availability. Sometimes, “tools that should be in stock are not brought back and are still at a construction site,” which prevents the execution of specific tasks requiring those tools – large tools that only exist once or twice in the company.

In this regard, having an overview of necessary resources improved efficiency and reduced errors in necessary but non-value-adding tasks. Another positive aspect mentioned is the integration with the BPMS and the future extendability, which allows flexibility and future scalability based on the standardized formulation of tool information. Finally, during the focus group, the participants raised concerns about the integration cost

of existing data and the initial effort required to fill the ontology database from scratch. The observed limitations primarily stem from implementation-specific constraints rather than inherent conceptual deficiencies. Our empirical investigation, conducted through stakeholder consultations, established operationally relevant parameters for the following analysis: The craft enterprise operates with a workforce of approximately 20 employees and maintains an active inventory of 100 specialized tools, excluding standard vehicle-equipped implements. These parameters inform the scope and scalability considerations in our later analysis.

One limitation often encountered during our literature review is scalability and access/retrieval times for real-world usage, which we will tackle in the next paragraphs – none of them is an issue here. For this, we will demonstrate its usability in the context of the first use case by scaling the implementation used and testing throughput times, including the overhead of the backend layer, using the REST-API. Here, we will scale several things, such as the number of existing tools in the ontology (tools owned by the business), required tools, and currently carried tools. Additionally, for an overall overview, we will include raw file size, the RAM used for the ontology running in SpringBoot with Camunda, and the time needed to load the ontology into memory. Here, for the integration, the library includes two possibilities to access the ontology: loading it directly to memory or storing it and accessing it on the file system.

For testing, we added different numbers of tools to the ontology at design time. Then, we queried them using the REST endpoints, enabling a close-to-real-world experience using the approach presented above. We started with only one tool available but then increased it to one million tools handled within the ontologyⁿ. As most integrations provide caching by default, we wait for the application to be fully started and then send all requests twice; the first triggers the initial hit, while the second gets loaded from the cache. We repeated this process five times for each specification and will use the mean values collected during these runs. All tests were run on a machine with an *i7-12700K processor* and *32 GB RAM* with default JVM and Spring Boot settings.

Figure 12 shows on a logarithmic scale that scaling up the ontology by adding tools increases the time needed to read data from disk into memory and the amount of RAM used during runtime. Conversely, using an ontology of a realistic scale comprising 100,000 elements augments RAM usage by approximately 160 MB and a 4-second delay during startup. This outcome appears reasonable; even scaling it to one million elements would require an additional 2 GB of RAM or a flatter increase when using the file system. Understandably, initial setup times for the file system are larger, and predictably, access times will be slower than direct in-memory access.

ⁿ This is around twenty times more than needed for our research project and leaves enough room for additional entities and adaptations of the ontology.

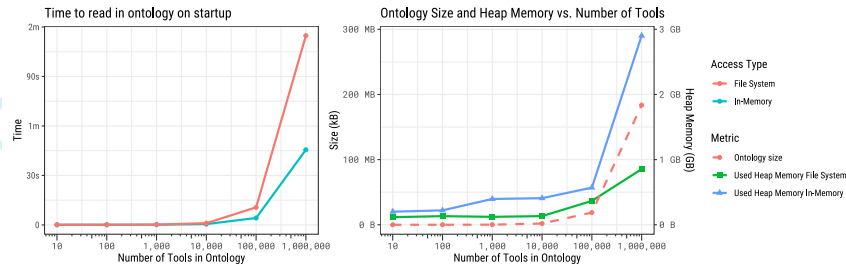


Fig. 12. Scaling of ontology – Reading memory on startup and ontology size vs. required RAM (figure by authors)

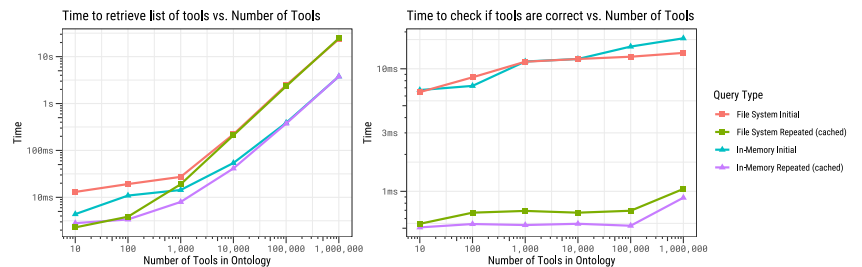


Fig. 13. Scaling of ontology – Querying all tools available at different total tool counts and checking if tools are correct (figure by authors)

More interestingly, we can see in fig. 13 that the times to get a list of available tools also scale exponentially when accessing them all at once. Here, for a million items, we would need 4 seconds to query them all from memory, which could easily be avoided by paginating the query with `OFFSET` and `LIMIT`. Even using the slower file-based approach, an ontology with 100,000 elements and no optimization would take around 2,4 seconds. We can also see that the system caches the results of queries up to 10,000 elements for the current system configuration, which leads to significant performance gains between 6x and 1.5x. Checking whether an actor has the correct tools is much faster than querying the tools and remains negligible at 10 milliseconds for the query independent of the ontology integration. Before proceeding, we also tested the approach on a standard Raspberry Pi 4 with 4 GB RAM. For an ontology including 100 plain tools, we saw access times of 75 ms initial and 22 ms cached for querying all tools and 32 ms initial and 3 ms cached for checking if they have the right tools. This matches the requirements of the research project and undermines the usability of widespread low-powered IoT devices like a Raspberry Pi.

In addition to scaling the total number, we added more requirements in the form of required tools to the task. We also add these randomly before runtime. Access at runtime is then done again using the REST

Business Process Management Journal

28

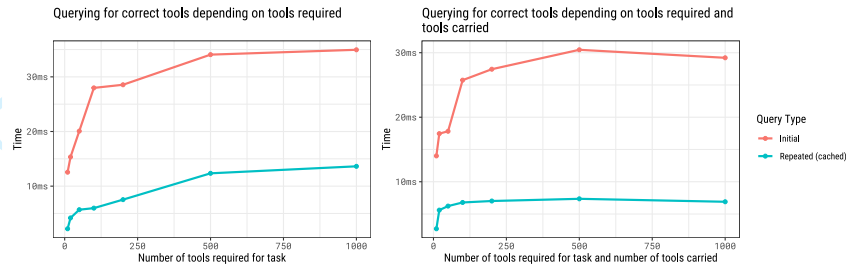


Fig. 14. Scaling of ontology – Check if tools are correct at different required and carried tools with 10,000 tools in ontology (figure by authors)

endpoints. For this, we added more requirements to a specific task until repairing the heater required 1,000 different tools. Again, we check if the actor has all the necessary tools while carrying only one and then scale up the currently carried tools. On continuous axes, fig. 14 shows that the access and query times are again negligible, remaining in the low double-digit millisecond range and even less if the result is already cached.

Overall, this shows that expanding the ontology and scaling it for real-world use will not negatively impact performance or usability and will enable many benefits by providing additional information about resources available at runtime. It is important to note that all results here are also based on many other factors, from the used queries and optimizing them (cf. M. Schmidt *et al.*, 2010) to the libraries, raw computing performance, and package versions. Therefore, these figures are more of an understatement that scalability is no real issue for usability in modern systems when dealing with real-world data and reasonable ontology sizes.

7 Discussion and Limitations

This approach is usable for different processes and operational equipment because of the blueprint character and the formal definition of both BPMN and, even more, the ontology. As we showed with the second use case, like the process model, the ontology can be directly extended to include new objects but also towards new classes and axioms depending on the specific needs of an application. A future extension of the first use case could consist of automatically checking if all necessary tools have at least a certain amount of battery left before leaving for a day of work. Some professional tools already include the possibility of periodically checking the current status and parameters of the tool. Combined with a full-fledged process planning, we could imagine a future use case where we precisely know how long a specific task takes and how much battery is needed for each of the planned tasks for the day. This would mean optimizing resource usage and supporting human actors during task execution.

Business Process Management Journal

An Ontology-Based Approach for Tool Integration 29

The proposed architectural paradigm demonstrates significant potential for deployment across domains characterized by resource-intensive operations, real-time data integration requirements, and complex allocation optimization challenges. Healthcare delivery systems and logistics operations exemplify ideal implementation contexts. In emergency medical services, the framework could orchestrate the dynamic allocation and tracking of specialized medical equipment, similar to our initial tool management use case. Similarly, hospital resource management could leverage this approach for department-specific medical device allocation based on patient requirements, facilitating temporal optimization of resource utilization patterns. Moving toward logistic applications, we can think about modeling different types of packaging resources (e.g., reusable pallets, disposable crates, or specialized containers), each with specific parameters. Here, we could use the ontological approach to automatically identify and allocate available resources that meet particular shipment requirements. We could also suggest repositioning idle packaging materials from overstocked warehouses to areas in need, further improving resource utilization and material waste. Similar to the widespread research on allocating human and non-human active resources, enabling operational equipment modeling and efficient management can significantly impact process efficiency and value creation.

A key limitation in integrating the ontology with BPM systems is the lack of standardized modeling patterns for ontological representations within process models. The current approach of explicitly modeling ontological requirements and process paths introduces unnecessary complexity and reduces model clarity. Future development should focus on enabling direct modeling of semantic relationships between process entities, thereby streamlining the integration of ontological concepts in BPM implementations.

Integrating real-time resource state tracking and dynamic allocation mechanisms using IoT sensors and advanced analytics can enhance organizational efficiency and operational excellence by enabling robust data integration architectures. This technological capability optimizes resource utilization and addresses societal concerns such as environmental sustainability through reduced energy consumption and material waste while improving worker safety via structured process controls. Additionally, incorporating operational equipment as a first-class citizen in Business Process Management (BPM) systems can enhance these benefits by monitoring tool usage to prevent unqualified employees from operating equipment, thereby conserving resources and promoting sustainable practices. By extending optimization efforts through supporting equipment management in BPM, organizations can achieve even greater environmental and societal impact, aligning with the push toward responsible resource management.

Our evaluation demonstrates that the developed solution successfully achieves the defined objectives.

1. Formalization: We provide a comprehensive and formally defined ontology for passive resources, capturing their essential properties and relationships within a process management context.

30

2. Integration: The meta-model and ontology seamlessly integrate passive resources, particularly operational equipment, into established BPM methods, enabling their inclusion in process models and execution.
3. Practicality: The pilot implementation in a craft business context and the positive feedback from stakeholders confirm the real-world applicability of our approach.
4. Extensibility: The ontology's modular design and use of established standards ensure its extensibility to accommodate diverse types of operational equipment and industry-specific needs.
5. Interoperability: The successful integration with existing BPM systems and the consideration of IoT technologies demonstrate the solution's interoperability and potential for wider adoption.

This achievement underscores our approach's value and potential to enhance process management by explicitly including passive resources.

8 Conclusion and Future Work

This research presents a novel ontology-based asset management framework that advances theoretical understanding and practical implementation. The framework provides methodological innovations for asset identification and tracking through formal ontological representations, establishing precise relationships between domain knowledge and operational assets. By implementing a structured representation model, our approach enables enhanced decision-making processes through systematic asset classification and relationship mapping. Its applicability extends beyond its initial validation in craft businesses, demonstrating the potential for broader implementation across manufacturing and supply chain management. We have validated our approach's theoretical soundness, practical utility, and real-world usability through rigorous empirical evaluation involving domain experts and iterative testing. The framework's capacity to capture and represent complex asset relationships while maintaining operational flexibility suggests its viability as a foundation for future asset management research.

Our study makes several key contributions to BPM and asset management. First, we address a critical gap in BPM techniques by formalizing the operational perspective, particularly focusing on integrating passive resources such as operational equipment into process modeling and execution. Second, our comprehensive meta-model and ontology enable the structured integration of tools and equipment into process models, enhancing transparency, resource allocation, and execution support. Third, through our prototypical implementation using process models from craft business contexts, we demonstrate the practical applicability of our approach, showcasing real-world benefits in tool management and process optimization (cf. Veit *et al.*, 2017).

The developed ontology-based framework extends existing BPM theory and offers practical solutions for organizations seeking to improve their operational efficiency and resource management. By bridging asset management and BPM, we lay the groundwork for future advancements in holistic process models that accurately reflect operational realities. Our approach’s scalability and flexibility, as demonstrated through rigorous testing and evaluation, underscore its potential for wide-scale adoption across various industries and operational contexts.

This study suggests several directions for future research. Expanding the scope of pragmatic validation across diverse industrial contexts will further test the framework’s adaptability and scalability. Comparative analyses with existing asset management methodologies will provide quantitative metrics for assessing our approach’s efficiency and effectiveness in modeling complex asset relationships. Some limitations identified during our research require additional investigation. The implementation reveals increased model complexity due to the discrete handling of tools, reducing model intuitiveness for end-users. These challenges motivate several key areas for future development:

1. *BPMN Enhancement*: Conceptual development of BPMN extensions to support explicit modeling of operational equipment and passive resources within process models. Current BPMN limitations in modeling seemingly simple tasks, such as furniture assembly instructions with specific tools and materials, highlight the need for enhanced modeling capabilities.
2. *Ontological Expansion*: Extension of the ontology’s scope to encompass comprehensive material and tool relationships, particularly drawing from assembly process paradigms. This expansion would enable a more precise representation of resource interdependencies and process requirements.
3. *Advanced Tool Planning*: Development of sophisticated tool planning capabilities that build upon our current documentation and attachment framework based on existing research identified in the literature review. This includes the integration of predictive tool management systems, the implementation of AI-driven resource allocation algorithms, and the optimization of process execution through intelligent tool scheduling.
4. *Implementation Refinement*: Enhancement of the system implementation to incorporate detailed parametrization of both passive and active resources, the specification of operational constraints (e.g., minimum battery levels), and skill-based task-matching capabilities.

While our use cases focused on craft businesses, the ontology’s fundamental principles, implementation, and integration with BPM demonstrate broader applicability. Enhancements would address current limitations while expanding the framework’s utility across diverse operational contexts. Developing these capabilities would significantly advance asset management while maintaining the theoretical foundations in formal ontology and process management.

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P1.3 From Model to Execution: A Formal Foundation for Managing Materials and Tools in Executable BPMN

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From model to execution: a formal foundation for managing materials and tools in executable BPMN

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Business Process
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Abstract

Purpose – Standard Business Process Model and Notation (BPMN) lacks native constructs to manage the physical tools and materials involved in manual work, creating a *digital-physical divide*. This research proposes the Passive Resource-integrated Modeling Extension (PRiME), a framework extending BPMN to formally model, execute, and monitor the lifecycles of passive resources in cyber-physical systems.

Design/methodology/approach – Following the Design Science Research Methodology we developed a formal ontology for passive resources, distinguishing between consumable materials and reusable tools. The resulting artifact of mapping the ontology to the BPMN 2.0 metamodel is a standard-compliant, executable extension validated through a prototype implementation and demonstrated in two scenarios.

Findings – PRiME provides a machine-readable mechanism to execute resource checks directly within the process engine. The framework enables (1) runtime support by generating real-time resource checklists and shortage alerts to prevent operational delays, and (2) design-time analysis via a Sankey-based visualization of material flows. Performance benchmarks confirm that the extension imposes negligible overhead, with sub-second processing of the analysis pipeline.

Research limitations/implications – This research establishes a foundation for *Physical Business Process Management* by elevating physical assets to first-class citizens within process orchestration. By enforcing algorithmic availability checks and visualizing material consumption, the framework addresses nonproductive time and supports sustainability (SDG) goals through precise waste tracking. Furthermore, it shifts the cognitive burden of resource management from the worker to the system, augmenting skilled labor and aligning operational efficiency with responsible consumption standards.

Originality/value – Unlike previous conceptual proposals or architectural frameworks, this research provides a fully executable BPMN extension for passive resources. It combines a formal ontological foundation with a practical, standard-compliant implementation that bridges the gap between theoretical process modeling and physical execution.

Keywords Business process management, Operational perspective, Resource Management, Cyber-physical systems

Paper type Research article

1. Introduction

Using technology of the Internet of Things (IoT) in combination with Business Process Management (BPM) represents a paradigm shift in how organizations orchestrate cyber-physical operations (Schöning *et al.*, 2020; Dumas *et al.*, 2018). While IoT enables different entities to form complex systems, BPM provides the foundation for discovering, implementing, executing, monitoring, and evolving collaborative business processes within and across organizations. However, as BPM extends into cyber-physical environments across manufacturing, construction, and logistics domains, organizations face a fundamental challenge in managing operational resources (Janiesch *et al.*, 2020; Goel and Lin, 2022). Traditional BPM focuses on modeling and optimizing IT-supported processes; however, it often overlooks the crucial “*how*” of manual work: the physical tools and materials involved. For instance, in construction, while digital systems handle ordering and invoicing, the actual

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BPMJ

work of a craftsperson and their use of physical tools are largely digitally unsupported by Business Process Management Systems (BPMS) (Vasilecas *et al.*, 2014; Ouyang *et al.*, 2010). This creates a critical gap, particularly in organizations where manual labor is central to their operations. Addressing this gap is a key challenge for *Business Process Technology* (BPT), as effective digital transformation requires technologies that can seamlessly integrate and support both digital and physical aspects of work.

Despite the recognized potential for IoT-enhanced business processes, current BPM standards, including BPMN 2.0, primarily focus on active resources and control flows. The absence of native constructs for passive resource allocation, availability checking, and release mechanisms (cf. Albach *et al.*, 2000) prevents organizations from achieving the operational transparency that cyber-physical integration promises. This limitation manifests as the *digital-physical divide* (Poss and Schöning, 2025): a disconnect between digital process models and the complex reality of managing physical resources. Solving this requires a theoretical shift in BPM: moving beyond active resources to formally conceptualize the lifecycles of passive resources (consumable materials and reusable tools) within standard process orchestration. This is visible in manufacturing and craft business environments, where the gap between digital design and physical manufacturing operations significantly affects operational efficiency. This leads to the following research question: *How can IoT-enhanced BPM systems effectively model, execute, and monitor the distinct lifecycles of passive resources within integrated cyber-physical business processes?*

To address this challenge, we present the Passive Resource-integrated Modeling Extension (PRiME). Unlike previous conceptual proposals, this work provides a fully executable artifact grounded in a robust theoretical foundation. Our specific contributions are threefold.

- (1) **Theoretical Advancement via Formal Ontology:** We advance the theoretical discourse on the operational perspective of BPM by formally conceptualizing physical assets as first-class citizens. By deriving a strict distinction between consumable materials (repetitive factors) and reusable tools (potential factors) rooted in production theory (cf. Allen and Alting, 1994), we provide a theoretical foundation for bridging the digital-physical divide, validated against the BPMN 2.0 metamodel (OMG, 2011).
- (2) **Executable BPMN Extension:** We translate this theoretical foundation into a standard-compliant extension that introduces `ResourceRequirement` and `ResourceInventory` elements, enabling process engines to natively execute availability checks.
- (3) **Dual Validation and Artifacts:** We validate the framework through two distinct applications: (i) a real-world, IoT-integrated runtime demonstration for shortage detection, and (ii) a standalone, reproducible design-time visualization for material flow analysis.

This research extends our earlier work in Poss and Schöning (2026). The core framework is enhanced in several key ways:

- (1) *Extended Methodology:* We introduce a formal equivalence check that compares domain concepts against existing BPMN elements to motivate the ontology.
- (2) *Structured Literature Review:* The related work section has been expanded into a PRISMA-based systematic review to better position the contribution.
- (3) *Improved Evaluation and Discussion:* Next to evaluating scalability and processing times for different scenarios with the prototypical implementation, we explicitly analyze the economic impact and incorporate sustainability indicators (ESG), and discuss the framework's alignment with the UN SDGs (United Nations, 2015) (specifically 4, 8, 9, and 12).

The paper is structured as follows: After a short presentation of our chosen research approach in [Section 2](#), we introduce the required background on BPM, its perspectives, the de facto modeling standard Business Process Model and Notation (BPMN), and its extension mechanism, as well as the IoT in [Section 3](#). Following this introduction, an overview of related work is presented in [Section 4](#). This is followed by the conceptualization and development of our BPMN extension for passive resources ([Section 5](#)), which is subsequently demonstrated and evaluated using a real-world process from an ongoing research project ([Section 6](#)). After a short discussion of the results in [Section 7](#), including an analysis of the framework's potential economic impact and its alignment with ESG criteria and SDGs ([United Nations, 2015](#)), the paper concludes with a conclusion and future work in [Section 8](#).

2. Research approach

This research employs the Design Science Research Methodology (DSRM) ([Johannesson and Perjons, 2021](#); [Peffer et al., 2007](#)) to develop and evaluate the BPMN extension artifact addressing the digital-physical divide of BPM and including passive resources in BPMN. The DSRM framework structures our approach into five core phases: *problem identification*, *solution design*, *development*, *demonstration*, and *evaluation*. As illustrated in [Figure 1](#), the development of PRiME integrates the BPMN extension methodologies of [Braun and Esswein \(2014a\)](#) and [Stroppi et al. \(2011\)](#) into this broader DSRM lifecycle. Specifically, we prepend a formal domain analysis and ontology development to this process. This allows us to conduct an equivalence check, i.e. comparing domain concepts against existing BPMN elements ([Braun and Esswein, 2014a](#)), before executing the standard technical extension steps outlined by [Stroppi et al. \(2011\)](#). To ensure methodological rigor, [Table 1](#) details the specific validation methods and evaluation metrics used in each phase.

3. Background

This section outlines the foundational concepts of the operational perspective in BPM, the extension mechanisms of BPMN 2.0, and the role of the IoT in bridging the digital-physical divide.

3.1 The operational perspective and BPMN extension mechanisms

While Business Process Management (BPM) traditionally focuses on the control flow and organizational aspects of work, the *operational perspective* represents a critical but underexplored dimension. [Poss and Schöning \(2025\)](#) formally define this perspective as “supporting and providing all resources needed to execute a task”. While earlier definitions focused strictly on the *what* and the *who*, this operational perspective explicitly addresses the *how* of manual work by modeling the physical tools and materials required ([Curtis et al., 1992](#)).

To model the specific requirements for tools and materials, *Business Process Model and Notation* (BPMN) has emerged as the de facto standard. BPMN 2.0 supports domain-specific adaptation through a formal extension mechanism ([OMG, 2011](#)). This mechanism facilitates *extension by addition*, in which new XML attributes and elements are appended to existing standard elements. This strategy contrasts with *extension by specialization* (common in UML), allowing the core metamodel to remain unaltered ([Stroppi et al., 2011](#)). Consequently, process models utilizing PRiME remain interoperable; standard-compliant tools can still open and execute the core logic, simply ignoring the extended attributes they do not recognize ([Braun and Esswein, 2014b](#)).

3.2 Internet of Things (IoT) as an enabler

The Internet of Things (IoT) provides the technological infrastructure needed to implement these extensions. By integrating network-connected sensors and actuators, IoT enables

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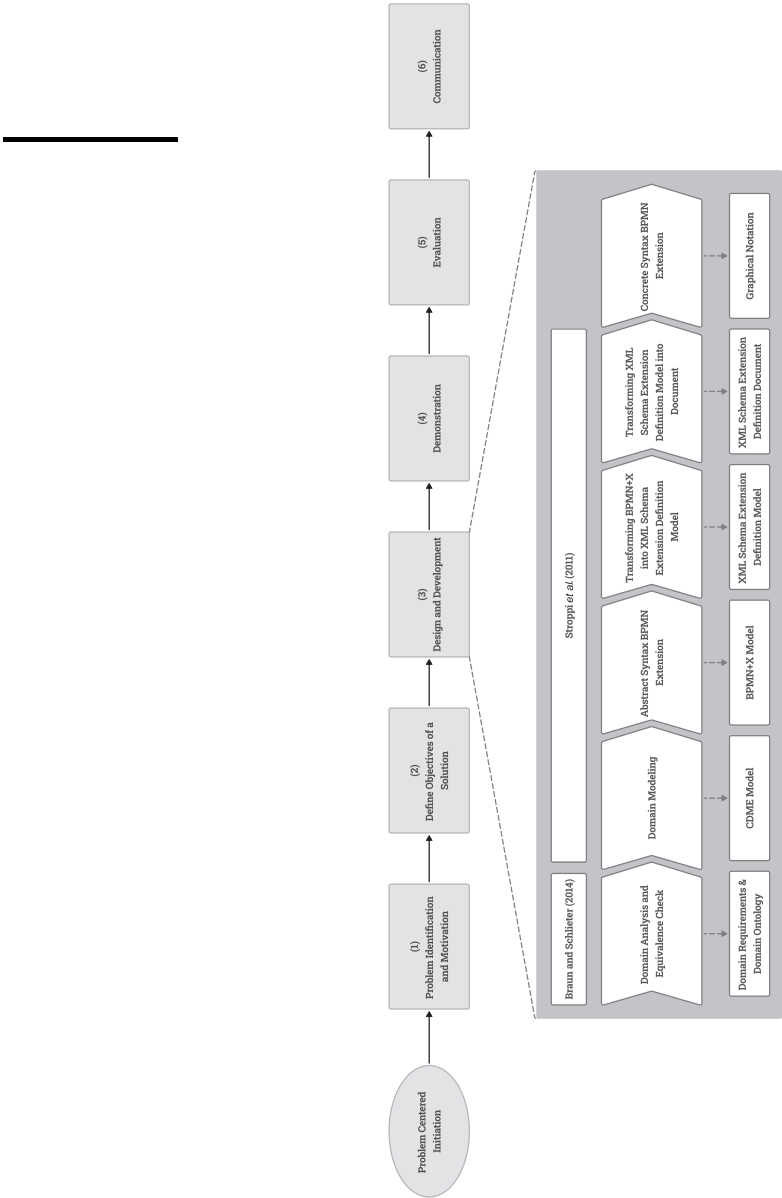


Figure 1. Embedding of BPMN extension development following (Stroppi et al., 2011; Braun and Esswein, 2014a) into DSR. Figure by authors

Table 1. Validation criteria and evaluation indicators per DSR phase

DSR phase	Outcome	Validation method	Evaluation indicator
1. Problem Identification	Gap Analysis	Structured Literature Review (PRISMA)	– Coverage of 1,769 records – Identification of <i>digital-physical divide</i>
2. Objectives Definition	Design Requirements	Logical Derivation	– Alignment with identified gaps – Explicit mapping to four design objectives
3. Design and Development	PRiME Artifact (Ontology and BPMN + X)	Formal Equivalence Check	– Syntactic correctness – Compliance with BPMN 2.0 metamodel extension mechanism
4. Demonstration	Runtime and Design-Time Prototypes	Functional Testing	– Successful orchestration of physical resources in craftspeople scenarios – End-to-end coverage of the resource lifecycle
5. Evaluation	Performance and Utility Analysis	Quantitative Experiment and Reproducibility Check	– Pipeline latency < 500 ms for real-time modeling overlays – Correct identification of resource shortages and automated updates to inventory variables

Business Process
Management
Journal

continuous monitoring of physical assets and transmits data to the process engine in real time (Janiesch *et al.*, 2020; Schönig *et al.*, 2020). This capability is essential for bridging the *digital-physical divide* (Poss and Schönig, 2025), enabling the process management system to dynamically validate the availability of physical resources before authorizing task execution.

4. Related work

We approached identifying and evaluating existing research on extending BPMN for passive resources by following the PRISMA guidelines (Page *et al.*, 2021) shown in Figure 2. Based on the three thematic pillars (1) BPMN model enhancement, (2) passive resources/inventory in process contexts, and (3) operational/production/execution dynamics in BPM, we developed the following search strings: (“*business process*” OR “*BPM*” OR “*Workflow*”) combined with each of the following (*Operation** OR *production** OR *execution**), (*material* OR “*passive resource*” OR *inventory*) and (“*operational equipment*” OR “*bill of tools*” OR “*bill of material*”) and used them with IEEE Xplore, ScienceDirect, AIS eLibrary, EBSCO, and ACM Digital Library.

In total, the initial search yielded 1 769 records across all sources. Of these, 690 were retrieved from IEEE Xplore, 364 from ScienceDirect, 199 from the ACM Digital Library, 12 from AIS eLibrary, and 476 from EBSCO. An additional 28 records were identified through backward and forward citation searches. After removing 91 duplicate records, a dataset of 1 678 unique entries was screened. During the screening phase, titles and abstracts were reviewed against predefined inclusion criteria, including a clear focus on BPMN extensions and resource modeling. This led to the selection of 178 studies for full-text review. Of these, two articles could not be accessed, leaving 176 for detailed analysis. In the final stage, 158 studies were excluded for reasons including a lack of connection to BPMN, a focus on general optimization without notation extensions, or the absence of passive resource modeling.

In total, 18 studies met all inclusion criteria and were included in our systematic literature review. These works form the foundation for our analysis of existing approaches and are summarized in the concept matrix (Webster and Watson, 2002) in Table 2 that details the goals,

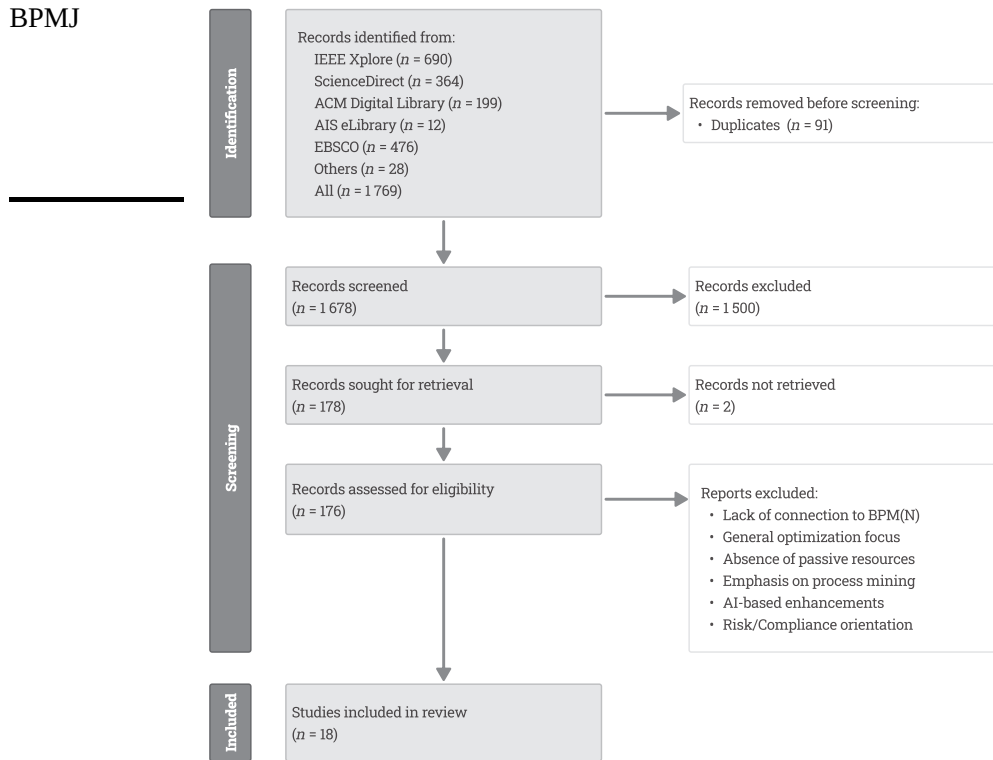


Figure 2. PRISMA statement (Page et al., 2021) of the literature review. Figure by authors

approaches, outcomes, and drawbacks of each publication. To provide a comprehensive overview, we organize these approaches into four conceptual categories based on their primary contribution to resource modeling.

- (1) *Graphical*: Introducing new visual elements, icons, or shapes to BPMN.
- (2) *Conceptual*: Proposing theoretical frameworks, metamodels, or taxonomies for resource interactions.
- (3) *Architectural*: Extending system architectures at the BPMS level (e.g. adding resource managers or databases).
- (4) *Executable*: Providing actual runtime executability that goes beyond visual or theoretical support.

4.1 Graphical extensions

Several studies propose enhancing BPMN with new visual elements to make the passive resource requirements explicit. For example, Zor et al. (2010) adapt standard BPMN for manufacturing by mapping Value Stream Mapping (VSM) concepts to existing constructs, later formalizing these ideas into dedicated graphical elements like Material Gateways (Zor

Table 2. Concept matrix of related work

Reference	Goal	Approach	Outcome	Drawbacks	Exec	Graph	Concept	Arch
Bocciarelli <i>et al.</i> (2016), Bocciarelli <i>et al.</i> (2022), and Bocciarelli <i>et al.</i> (2017)	Enhance BPMN to model resource allocation and performance for simulation	Extends BPMN/PyBPMN metamodel for resources (atomic, dynamic, composite) using text annotations	Metamodel extension enabling detailed resource simulation (availability, NFPs, groups, alternatives)	Lacks runtime execution support; focused on simulation and modeling via text annotations	○	●	●	○
Braun and Esswein (2014a)	Extend BPMN for machines and auxiliary materials in engineering	Extends BPMN metamodel for physical and temporal resource dependencies	New graphical elements: a “Material” element for consumables and an “Auxiliary” element for support materials	Not executable, lacks runtime validation or BPMS integration; limited detail on tools	○	●	●	○
Braun <i>et al.</i> (2015), Braun <i>et al.</i> (2014), and Braun and Schlieter (2014)	Adapt BPMN for resource modeling in healthcare treatment paths	Creates a “resource perspective” via metamodel extension, distinguishing resource types and bundles	New modeling elements for resource types/bundles, detailed via separate resource diagrams	Healthcare-specific, not a general solution. Lacks tooling/execution support. Requires extra diagrams for detail	○	●	●	○
Goel and Lin (2022) and Goel (2022)	Framework for executable resource lifecycle management in BPMN.	Introduces new activity types: “Request,” “Release,” and “Resource” activities	Domain-independent activity types for runtime execution and optimization of resource allocation via subprocesses	Lacks detailed tool specification; direct assignment of resources to tasks in the model is unclear	●	●	○	●
Hess and Meis (2011)	Healthcare-specific resource modeling with a custom language	Extends the MEMO ResML language with healthcare-specific resource types and a graphical syntax	Metamodel for physical healthcare resources, including concepts like telemedical devices	Domain-specific (not a general solution), not based on BPMN, and requires standalone tooling	○	●	●	○
Ilde <i>et al.</i> (2019)	Real-time optimization with a dedicated Resource Manager	Extends a BPMS with a “Resource Manager” component, integrated via special tasks in the process	Executable architecture with a Resource Manager for defining resources and allocation algorithms; shows cost reduction	No visual modeling of required resources in the process; task-resource links are unclear. Limited to specific domains	●	○	●	●

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BPMJ

Table 2. Continued

Reference	Goal	Approach	Outcome	Drawbacks	Exec	Graph	Concept	Arch
Jung (2007)	Design a language (MEMO ResML) for modeling resources	Defined a conceptual metamodel that includes resource states, roles, and structures	A conceptually rigorous metamodel that serves as a foundation for other domain-specific languages	No graphical notation or executable integration with BPMN.	○	○	●	○
Liu et al. (2011)	Model resources as entities within an SOA to integrate them with business processes	Develops a service-oriented “Resource Manager” to handle resource allocation patterns and rules	A service-integratable Resource Manager enabling monitoring and optimization of resource usage	Lacks visual modeling elements for resources within the process model; focuses on backend logic	●	○	●	●
Ouvang et al. (2010)	Develop a conceptual data model for complex resource constraints	Uses Object Role Modeling (ORM) to create a data model for resources, integrated via task annotations	A conceptual data model for resources/constraints, allows simple definition by name/quantity in models	Purely conceptual and not executable; does not allow for detailed tool specification	○	○	●	○
Vasilecas et al. (2014)	Enable dynamic, rule-based simulation of resource allocation	Develops a resource database model; uses background scripts triggered by tasks for DB queries	A database model providing a scriptable foundation for simulating resource management	Simulation only, no graphical extension. Script-based approach lacks model transparency	●	○	●	●
Zor et al. (2010) and Zor et al. (2011)	Integrate material and equipment flows into BPMN for manufacturing	Extends BPMN with new modeling elements for manufacturing, mapping concepts from Value Stream Mapping (VSM)	New elements, such as a “Machines and Tools Container,” to visualize material handling and task dependencies	Not executable and lacks formal standardization; new elements can increase model complexity	○	●	○	○

Source(s): Following Webster and Watson (2002)

et al., 2011). Similarly, [Braun and Esswein \(2014a\)](#) introduce new graphical elements for “Material” and “Auxiliary” items to model consumables and support materials in engineering processes. Taking a different approach, [Goel \(2022\)](#) propose new activity types (“Request”, “Release”, and “Resource”) to manage the resource lifecycle directly within the process model. While these graphical extensions improve model clarity, a common drawback is their limited generalizability and lack of executable semantics without further architectural support.

4.2 Conceptual extensions

The most common category of contribution involves conceptual extensions, primarily through enhancements to the metamodel. [Jung \(2007\)](#) laid early groundwork by defining a metamodel for resource states, roles, and structures, providing a foundation for other works. Building on this, [Braun *et al.* \(2015\)](#) offer an extensive framework for healthcare, extending the BPMN metamodel to classify resources (active vs. passive) and define resource bundles. Other approaches focus on simulation, such as [Bocciarelli *et al.* \(2016\)](#), who extend the metamodel to detail resource properties like availability and non-functional characteristics using text annotations. [Ouyang *et al.* \(2010\)](#) use Object Role Modeling (ORM) to create a data model for defining complex resource constraints. A key limitation of these purely conceptual works is that they often lack machine-readability and the executable logic required for real-time process execution, focusing instead on analysis and simulation.

4.3 Architectural extensions

To bridge the gap between modeling and execution, some researchers propose architectural extensions to BPMS's. [Ihde *et al.* \(2019\)](#) exemplify this with a Resource-Aware BPMS featuring a “Resource Manager” component for dynamic resource allocation and optimization. This pattern of a central manager is also seen in [Liu *et al.* \(2011\)](#), who developed a service-oriented “Resource Manager” to handle allocation patterns and rules. These approaches are powerful because they are often executable. For instance, [Goel and Lin \(2022\)](#) present a framework for executable resource lifecycle management, and [Vasilecas *et al.* \(2014\)](#) use a script-based method to query a resource database for dynamic simulation. However, a common challenge with architectural extensions, as seen in [Ihde *et al.* \(2019\)](#) and [Liu *et al.* \(2011\)](#), is the lack of intuitive visual modeling, which makes it difficult for process designers to discern resource dependencies directly within the BPMN diagram.

In summary, this evaluation highlights the importance of integrating passive resources into process models. While many approaches conceptually integrate material-related aspects into BPMN, most focus on simulation or domain-specific modeling. Executable solutions exist, but often compromise visual clarity at the modeling level. This reveals a significant gap between comprehensive conceptual modeling and actionable, visually integrated execution support, which our work aims to address.

5. Design and development

This section outlines the design and development of the PRiME framework, based on the methodologies outlined in our research approach. The process is structured into two main phases. First, we establish the conceptual foundation for the extension. This involves a domain analysis, the creation of a formal ontology, an equivalence check against the BPMN standard, and the derivation of explicit design objectives. Second, we translate these concepts into a formal, standard-compliant BPMN extension, including the creation of a Conceptual Domain Model (CDME) and a corresponding graphical notation.

5.1 Concept

5.1.1 Domain analysis. To extend BPMN to include materials and tools as passive resources, following the combined approach of [Stroppi *et al.* \(2011\)](#) and [Braun and Esswein \(2014a\)](#), we

BPMJ

need to analyze the domain of each component. This phase formalizes the core concepts, relationships, and material transformation activities within a process, establishing the foundation for a comprehensive resource ontology. The classification of materials and tools is rooted in Gutenberg's production factor model (cf. [Albach et al., 2000](#)), which distinguishes between *Elementary Factors* directly involved in production and *Dispositive Factors* related to managerial and organizational coordination. *Elementary Factors* further subdivide into *Repetitive Factors* (consumed during production, e.g. raw materials, auxiliary materials, operating materials) and *Potential Factors* (used repeatedly without consumption, e.g. machinery, tools) [1]. To address the limitations of the classical model, which homogenizes materials across repetitive factors, a more granular classification is introduced that differentiates materials based on their process integration, transformation stages, and usage characteristics. This includes *raw materials*, *intermediate products*, *end products*, *consumables*, and *standardized components*. Similarly, material operating resources (tools) classified as *potential factors* are detailed by their characteristics and uses. These include tool parts with specific quantitative and qualitative parameters that define the instance of the object.

To formalize these concepts, we developed a material and tool ontology ([Figure 3](#)) that extends the prior work of [Poss and Schöning \(2025\)](#). This ontology defines core classes (e.g. tools, raw materials), taxonomic hierarchies, and object relationships. Furthermore, it introduces specific datatype properties to capture quantitative and qualitative attributes, such as weight, dimensions, and battery levels. Based on this extended ontology, we can now examine the properties of each resource and compare them with those defined in the BPMN standard. This is the *Equivalence Check*, which precedes the domain modeling step to ensure a good fit and to motivate the specific process elements required (cf. [Braun and Esswein, 2014a](#)). The equivalence check is detailed in [Table 3](#). It is organized into three sections: (1) passive resources in general; (2) specific material handling concepts, such as flow, storage, and transformation; and (3) other domain concepts, including resource location and the active resource (human or machine) executing the task. The equivalence check reveals current limitations of BPMN in representing passive resource requirements, inventory handling, and flows. To address this, explicit extensions are introduced: `ResourceObject` for classifying materials and tools, `ResourceInventory` for tracking availability, and `MaterialFlow` to distinguish between physical and informational flows.

This analysis of existing approaches and the following modeling of the requirements and the domain of passive resources itself, followed by a comparison to already existing elements and possibilities in the BPMN standard, leads to establishing the following design objectives for PRiME.

- (1) **DO1 – Explicit modeling of passive resources:** Introduce structured annotation mechanisms within BPMN to define material requirements (e.g. quantity, unit, type) at the task level. This enables clear differentiation between active and passive resources, establishing a foundation for runtime material management.
- (2) **DO2 – Representation of resource availability, dependencies, and material flows:** Enable the modeling of material inputs and outputs for process tasks, along with mechanisms to track material availability and resolve dependencies. This includes detecting material shortages, triggering exception handling, and dynamically updating inventory to ensure process execution aligns with material constraints.
- (3) **DO3 – Conformance with BPMN Standards and Modeling Tools:** Maintain strict compliance with the BPMN 2.0 standard by using its provided extension mechanisms (e.g. extending existing `TextAnnotation` or `DataObjectReference`) to embed resource metadata.
- (4) **DO4 – Executability in a Real-Time Runtime Environment:** Ensure the extended BPMN model is executable within a real-time process management system. This

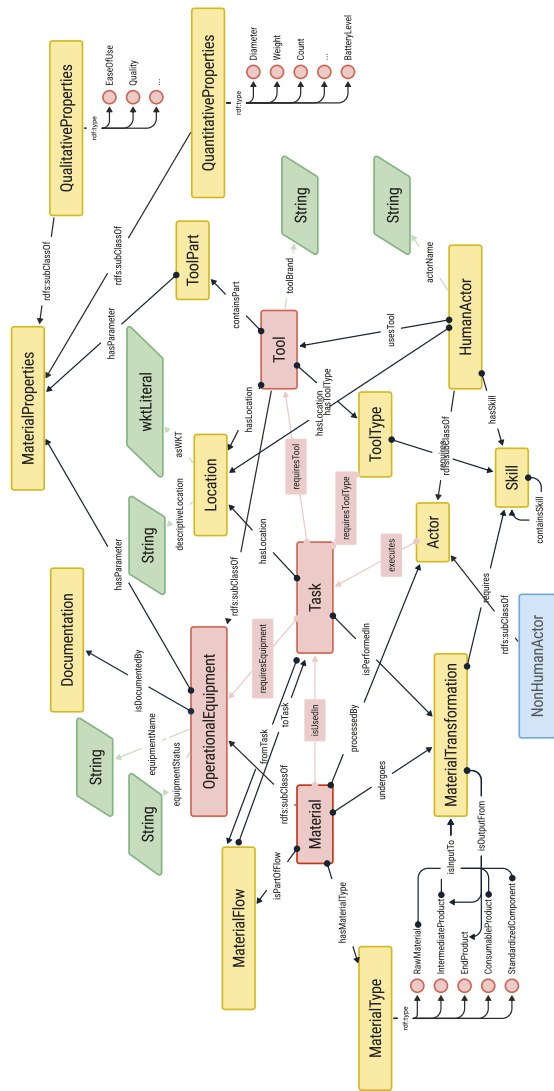


Figure 3. Extended ontology (Poss and Schöning, 2025) for passive resources in BPMN. Figure by authors

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Table 3. Equivalence check for BPMN extension

	Domain concept	Current BPMN representation	Limitations/Gaps in BPMN	Proposed BPMN extension
<i>Passive Resource Entity</i>	<i>Passive Resource</i> Core representation	No direct equivalent	No native tangible entity modeling	Extend BPMN with <i>Passive Resource Object</i>
	<i>Passive Resource Type</i> Categorization of resources for material and tools	No direct equivalent	Lacks explicit categorization	Extend BPMN with <i>Resource Type Attribute</i>
<i>Resource Handling</i>	<i>Passive Resource Properties</i> Quantitative and qualitative properties	No direct equivalent	No structured property modeling	Extend with <i>structured data attributes</i>
	<i>Transportation</i> Movement/Transfer of Resource	Sequence Flow (generic)	No differentiation between flows in BPMN (cf. (Zor et al., 2011))	Introduce <i>Resource Flow Connector</i>
	<i>Storing</i> Temporary or long-term placement of resources	No direct equivalent	Lack of integration with process flow	Extend BPMN with <i>Resource Repository/Collection</i>
	<i>Packaging</i> Wrapping/Enclosure for Transport/Storage	User/Service Task	–	
	<i>Inspection</i> Quality control	User/Service Task	–	
	<i>Assembly, Forming, Joining, Finishing</i> (Allen and Altung, 1994) Combine, shape, connect or enhance materials	User Task	Lacks explicit resource <i>state transition</i> modeling	Explicitly model state transitions of material
<i>Others</i>	<i>Location</i> Physical space where passive resources are stored	Lanes/Pools/existing extensions like (Poss et al., 2023)	–	
	<i>Active resource</i> Actor performing the task	Manual/User/Script Task	–	

involves providing the required logic for material availability checks, inventory deductions, and visualization updates as a prototypical implementation.

5.2 BPMN extension development

The goal is to develop the PRiME framework, which models passive resources, i.e. consumable materials and reusable tools. Following the methodology (Stroppi et al. (2011), as shown in Figure 1), we achieve this by developing the corresponding BPMN elements based on the identified requirements. This requires formally defining domain-specific concepts and their relationships within a Conceptual Domain Model (CDME) before transforming them into a compliant BPMN+X model, which extends the BPMN metamodel. This model is then transformed into a standard XML document.

The Conceptual Domain Model of the Extension (CDME) (Appendix, Figure A1) introduces a dual-structure approach to integrate resource management without breaking BPMN semantics.

- (1) **Design-Time Specifications (Annotations):** We introduce the `Resource RequirementAnnotation` as an extension of the standard `TextAnnotation`. This allows modelers to attach static, structured requirements (e.g. “Requires: Circular Saw”) to tasks. We distinguish between `MaterialRequirement` (fungible) and `ToolRequirement`, which can further specify a generic `ToolType` or a specific `ToolObject` (e.g. for calibrated equipment).
- (2) **Runtime Management (Data Objects):** To enable execution, these requirements are instantiated into `ResourceObjects` managed within a `ResourceInventory` collection. This distinction ensures that the *process definition* remains clean (annotations), while the *process instance* carries the necessary state data (inventory objects).
- (3) **Physical Flow (Associations):** We extend the standard `DataAssociation` to create a `MaterialFlow`. Unlike data associations, which model information read/write access, this explicitly represents the physical transport of a quantity from a source (Inventory) to a target (Task), carrying a structured payload (Material ID, Quantity).

The transformation to the BPMN + X model (Appendix, Figure A2) follows standard extension rules (Stroppi et al., 2011): new data structures are defined as `<< ExtensionElement >>`, while their integration points (e.g. attaching requirements to tasks) are formalized via `<< ExtensionDefinition >>`.

Finally, as a last step, we introduce additional icons, following the rules provided in OMG (2011), to visually distinguish the newly introduced elements shown in Figure 4. Again, distinguishing between tangible, real-world objects and resources, and the list of requirements and the corresponding annotations for tools and material requirements.

6. Demonstration and evaluation

To demonstrate and evaluate the new elements, we present two distinct examples based on real-world requirements identified in collaboration with actors from the craft business sector. Before detailing the use cases, Table 4 provides a clear mapping from the core PRiME constructs, as defined in our conceptual model (Section 5.2), to their concrete implementation artifacts within our prototype. This table bridges the conceptual framework and its practical realization.

One example is similar to the approach in Poss and Schöning (2025), in which additional information about requirements is directly attached to tasks within the process model. This example focuses on runtime support, enabling the automatic provision of information on required and potentially missing tools and materials during process execution (Section 6.1). The second example (Section 6.2) takes a further step by introducing a novel method for statically parsing and presenting relevant information on resource requirements as a Sankey

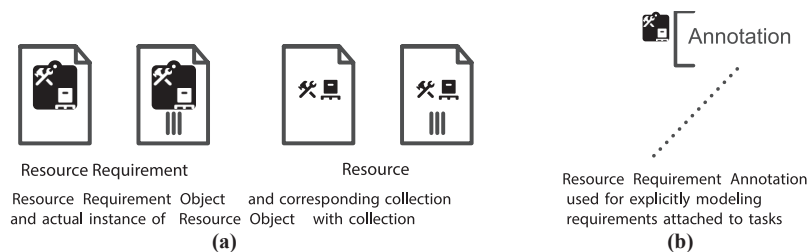


Figure 4. Graphical representation of introduced elements. Figure by authors

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Table 4. Mapping of PRiME constructs to prototype implementation artifacts

PRiME construct	Implementation in demonstration	Purpose
<code>ResourceRequirementAnnotation</code>	JSON object within a BPMN <code>TextAnnotation</code> element	To attach human- and machine-readable resource needs directly to a task in the model
<code>ResourceRequirementCollection</code>	A Camunda process variable (JSON object) generated by a service task	To create a comprehensive “Bill of Resources” for a process instance, used as a checklist for validation
<code>ResourceInventory</code>	A Camunda process variable (JSON Array) updated via IoT events	To track the tangible, available resources (tools and materials) carried by a process participant
Material Flow Visualization	A Sankey diagram overlay rendered using d3.js as a plugin for the Camunda Cockpit	To provide design-time analysis by visualizing the complete flow of materials through the process tasks

diagram (Riehmman *et al.*, 2005). This serves as an overlay on the process model, displaying the flow of materials through each step for design-time optimization. To ensure the technical reproducibility of these results, the complete evaluation setup is available at https://github.com/LeoPoss/PRiME_MaterialFlow/tree/processRequirements. The repository contains.

- (1) **Executable Artifacts:** The BPMN 2.0 XML models for all evaluated scenarios.
- (2) **Backend Services:** The Java/Spring Boot source code for the prototype, including mock IoT REST APIs to simulate physical sensor events.
- (3) **Evaluation Suite:** An automated JUnit test suite that programmatically validates the quantitative performance and latency metrics presented in Section 6.3.

6.1 Runtime support: monitoring required and carried resources during process execution

To demonstrate the practical utility of our approach, we apply the concept from Poss and Schönig (2025) to provide runtime support for monitoring the tools and materials required for manual tasks. Figure 5 displays an excerpt of a real-world process model from an ongoing research project, adapted for publication purposes, where the functionality is integrated into the workflow management system and an external application within the research project. For this publication, we present a simplified version that displays formatted requirements within a basic Camunda form [2]. The model comprises a set of tasks, with their resource requirements specified via JSON-based annotations. The process depicts a carpenter’s role in building a wooden roof truss. It involves two distinct tasks: *Prefabricate Beams and Joints* and *Assemble and Erect Truss* (highlighted in red). These tasks are separated by a waiting period for transportation. Crucially, each task requires a different set of materials and tools. For better understanding, we explicitly model service tasks to indicate whether the correct resources are carried. Then, we verify the requirements and explicitly address material shortages highlighted in yellow, as well as requirements specified through the extended elements and those annotated to each task.

The technical implementation follows the process flow, beginning with the *Create Resource List* service task. This task executes a Java delegate that parses all `ResourceRequirementAnnotations` from the process model’s XML definition. It aggregates these individual requirements into a single `ResourceRequirementCollection` object, which is then stored as a process variable. This variable serves as a comprehensive “Bill of Resources” for the entire process instance. Next, in the *Collect Resources* user task, the actor is presented with a list of required items for the current phase, as illustrated in Figure 6a. For the prefabrication phase, tools include a Circular Saw (Bosch), and

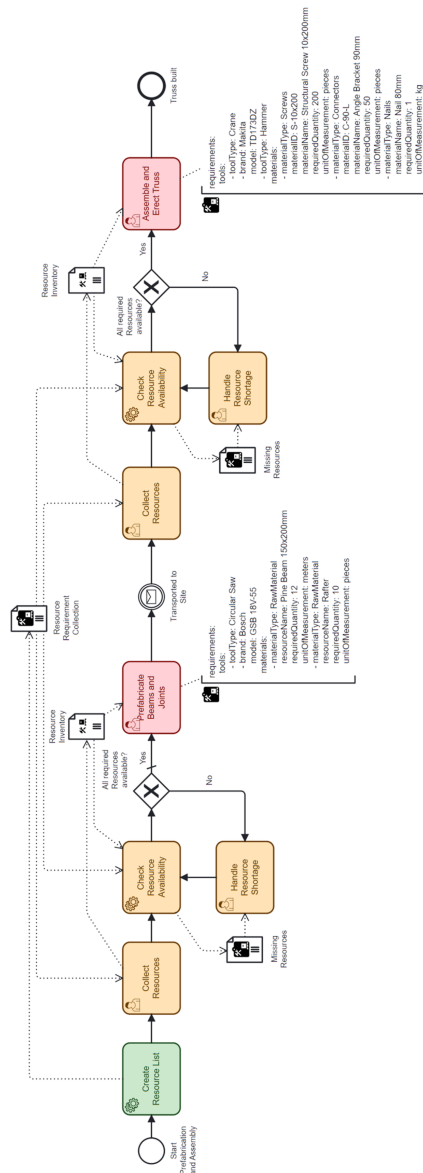


Figure 5. Process model from an ongoing research project enhanced with PRIME elements. Figure by authors

BPMJ

Collect Resources

Truss Prefabrication (Requirements) (v. 1.0)

Set follow-up date Set due date Add groups Admin Admin

Form History Diagram Description

Collect Resources

Please collect the following resources from the inventory before proceeding

Resources

Tools

- 1 x Circular Saw
- 1 x Cordless Drill
- 1 x Crane
- 1 x Impact Driver
- 1 x Hammer

Materials

- 12 meters Pine Beam 150x200mm
- 10 x Rafters
- 200 x Structural Stone 150x200mm (S-15x200)
- 50 x Angle Brackets 100mm (G-50x1)
- 1 kg Nail 80mm

Total: 10 Items

Save Complete

A list of resources to be collected

(a)

Handle Resource Shortage

Truss Prefabrication (Requirements) (v. 1.0)

Set follow-up date Set due date Add groups Admin Admin

Form History Diagram Description

Missing Resources

The following resources are not available in sufficient quantity

Missing Resources

- Pine Beam 150x200mm
- Missing: 12 meters
- Type: RawMaterial

Total missing: 1 Items

Save Complete

Verification of carried resources showing a list of missing items

(b)

Figure 6. Runtime information displayed on the task list. Figure by authors

materials include Pine Beam and Rafters. In our project, IoT sensors automatically track the collected items, populating the `ResourceInventory` process variable with a digital manifest of the resources the actor is actually carrying. In the physical deployment, IoT sensors (e.g. RFID, Bluetooth Low Energy (BLE), and smart shelves) automatically track collected items. However, to ensure the artifact's technical reproducibility without requiring specific hardware, we developed a standalone version of the prototype. In this reproducible implementation, the physical hardware layer is mocked via two REST endpoints (`/api/resources/inventory` and `/api/resources/inventory/update`). The *Create Resource List* task initializes the process with mock inventory data and simulates sensor events via direct API calls. This abstraction enables the core logic of the PRiME extension (inventory tracking, shortage detection, and variable aggregation) to be validated in a standard software environment without requiring physical dependencies.

The following *Check Resource Availability* service task then performs a critical validation by comparing the required items in the `ResourceRequirementCollection` against the actual items in the `ResourceInventory`. If this check detects a mismatch, an exclusive gateway directs the process flow to the *Handle Resource Shortage* user task. Here, the actor is shown a list of the specific missing items (Figure 6b), allowing them to correct the error. Once the user confirms the issue is resolved, an execution listener updates the `ResourceInventory`, and the process returns to the verification step to ensure the inventory is correct before proceeding with the main workflow. Internally, this mechanism relies on the native process (instance) variables of the Camunda engine. As illustrated in Figure 7, the execution listener attached to the availability check calculates the difference between the required and available resources. It then serializes this delta into specific process variables, such as `materialAvailable` (Boolean) to drive the exclusive gateway, and `formattedMissingMaterials` (String/JSON) to store the specific list of shortages. These variables are directly bound to the input fields of the *Handle Resource Shortage* Camunda Form. Consequently, the user interface is dynamically populated with the live data, presenting the worker with a precise, human-readable checklist of the missing items required to proceed (Figure 6b).

Upon successful completion of the *Prefabricate Beams and Joints* task, the framework manages the material transformation. The consumed raw materials (Pine Beams, Rafters) are decremented from the inventory, and new intermediate resources (Prefabricated Truss Components) are added. After the transport phase, a second resource check is performed before the final *Assemble and Erect Truss* task. This check validates the on-site availability of

Add criteria				
Name	Type	Value	Scope	Actions
MaterialInventory	String	{ "materials": { "materialName..."	Table Mounting (Requirements)	 
MissingMaterialObject	String	{ "materialName": "Screw MB..."	Table Mounting (Requirements)	 
attachingTableLegs_Material...	String	{ "taskId": "attachingTableLeg..."	Table Mounting (Requirements)	 
formattedMaterialList	String	Corner Connector (EV-001): ...	Table Mounting (Requirements)	 
formattedMissingMaterials	String	Screw MB: 4.0 pieces missing	Table Mounting (Requirements)	 
insertingCornerConnectors_...	String	{ "taskId": "insertingCornerCo..."	Table Mounting (Requirements)	 
materialAvailable	Boolean	false	Table Mounting (Requirements)	 
materialRequirementCollection	String	{ "requirements": { "material..."	Table Mounting (Requirements)	 
mountWoodenSlatsToTableTo...	String	{ "taskId": "mountWoodenSlat..."	Table Mounting (Requirements)	 

Figure 7. Exemplary overview of process variables with missing resources. Figure by authors

various resources and consumables. This two-phase validation demonstrates how the system can manage resource logistics across different locations and stages of a complex project. Finally, the system distinguishes between resource types: consumables, such as screws, are decremented from inventory upon use, whereas tools, such as the crane, are simply marked as available again, ready for use in other processes.

Finally, the utility extends beyond real-time operational support to post-process analytics. The granular data captured during execution, including resource usage times (derived by correlating inventory updates with task start/end timestamps) and material consumption quantities per task, is persisted in Camunda’s history database. By analyzing historical data, process owners can calculate a project’s true resource cost, identify recurring patterns of tool shortages or material waste, and optimize inventory planning for future projects.

6.2 Design-time visualization: displaying material flow on a process model

Beyond execution support, the extracted material requirements can be used to visualize the material flow directly on the process model at design time. The frontend visualization is realized as a client-side plugin for the Camunda Cockpit. This architectural approach enables the direct integration of a material flow overlay into the standard process monitoring interface without altering the core Camunda application. The plugin registers itself using the `cockpit.processDefinition.diagram.plugin` extension point, allowing it to programmatically interact with and augment the rendered BPMN diagram.

The plugin’s operation follows a two-stage pipeline. First, upon loading the diagram, it initiates an asynchronous fetch request to a dedicated API endpoint to retrieve the material flow data for the current process definition. This data is pre-processed by the backend into a graph structure, consisting of nodes (representing tasks and materials) and links (representing the directed flow of materials). The second stage is the rendering process, which leverages the `d3.js` library [3]. The core functionality of this stage involves geometrically aligning the Sankey diagram with the BPMN model. A standard Sankey layout would arrange nodes algorithmically, breaking the correspondence with the user-created BPMN layout. To solve this, our plugin first leverages Camunda’s frontend API to query the `elementRegistry` service, extracting the coordinates and dimensions of each task shape in the underlying diagram. After the `d3-sankey` library [4] computes the initial flow geometry, the plugin manually overrides the positions of the task nodes, ensuring they align with their corresponding graphical elements in the process model. Finally, the plugin renders the visual components.

- (1) *Links*: Each material flow is drawn as an SVG `<path>` element. A custom path generator creates smooth curves between source and target nodes. The stroke-width of

BPMJ

each path is calculated to be proportional to the value of the link (i.e. the material quantity).

- (2) *Labels*: To provide context, an SVG `<textPath>` element is appended to each link's path. This element renders the material name and quantity along the curve of the flow.

The resulting visualization, shown in [Figure 8](#), illustrates the material flow involved in assembling a wooden table. The process model comprises three key tasks: *Mount Wooden Slats to Tabletop*, *Inserting Corner Connectors*, and *Attaching Table Legs*. Each task is annotated with its specific material requirements using `RequirementAnnotations`. The nodes on the left-hand side list all required raw materials for a single process instance. Flow lines represent the movement of materials from the initial supply to the tasks where they are consumed. For instance, *Screw M10*, *Screw M8*, *Table Leg*, and *Side Rail* are consumed at various stages, with intermediate products such as the *Partially Assembled Table* and *Table Frame* being produced and subsequently utilized in downstream tasks. The final task, *Attaching Table Legs*, results in the *Finished Good*, which represents the fully assembled table. While the current implementation primarily supports linear process flows, this foundational approach demonstrates the potential to communicate complex material dependencies transparently within a process model.

6.3 Performance and scalability analysis

It is important to note that PRiME relies on standard BPMS capabilities; specifically, the parsing of XML extension elements and the comparison of JSON or YAML-based data sets. Consequently, the extension does not introduce computationally intensive algorithms; the complexity is effectively linear $O(n)$ relative to the number of resource items. To evaluate the practical efficiency and scalability of our approach, we established an automated testing suite to measure the execution time of the design-time material-flow visualization pipeline. To ensure statistical robustness and reflect true runtime performance, the testing suite utilizes a JVM warm-up phase to resolve initial class-loading overhead, followed by 10 independent measured executions for each scenario. The results in [Table 5](#) report the mean and standard deviation for each operation. In addition to the real-world “Table Assembly” and “Truss Prefabrication” processes, we introduced a “Synthetic Scaling” scenario to address broader, enterprise-level testing requirements. We manually significantly increased the structural complexity of the process model, which comprises 115 process tasks, 24 of which are annotated with 120 resource requirements. As shown in [Table 5](#), the framework efficiently processes high-density models. The total pipeline latency for the synthetic stress test averaged just 21.13 ± 2.10 ms, demonstrating that the system completes its parsing and transformation virtually instantaneously with highly stable variance. These results conclusively confirm that PRiME imposes negligible computational overhead and scales predictably without bottlenecking the process engine, even when managing extensive resource dependencies.

To empirically validate our claim of linear complexity, we additionally generated a series of process models programmatically, with 10–500 tasks, each containing up to 300 concurrent resource requirements [5]. As before, we utilized a JVM warm-up phase followed by 10 measured iterations for each scale point to capture true runtime variance. As illustrated in [Figure 9](#), the total pipeline latency exhibits a strict linear correlation to the model size. Scaling the process complexity by a factor of 50 (from 10 to 500 tasks) increases the total execution time by less than 15 ms (from 7.77 ms to 22.26 ms). Furthermore, the standard deviation remains exceptionally tight across all scales ($SD < 3$ ms). This explicitly confirms that the underlying parsing and transformation algorithms process massive, enterprise-scale models with near-constant time overhead, ensuring the BPMS remains highly responsive regardless of model density.

In contrast to other BPM paradigms for passive resource handling, which focus primarily on high-level conceptual frameworks (e.g. [Jung, 2007](#)), or process simulation (e.g. [Bocciarelli](#)

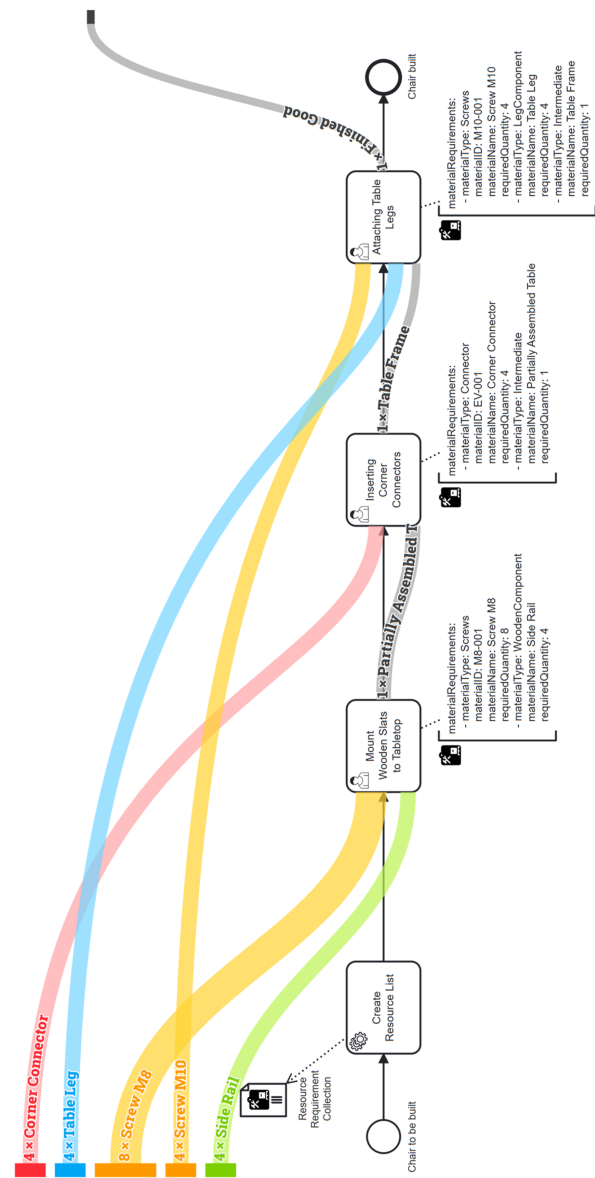


Figure 8. Visualization of material flow added to process model. Figure by authors

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Table 5. Performance latency of design-time visualization pipeline

Operation	Truss prefabrication	Table Building	Synthetic scaling
Number of process tasks	11	4	115
Annotated tasks	2	3	19
Resource requirements	10	7	88
Annotation format	JSON	YAML	JSON
Task order extraction	2.35 ± 0.71 ms	1.50 ± 0.33 ms	7.20 ± 0.84 ms
Material annotation parsing	1.43 ± 0.29 ms	1.40 ± 0.27 ms	3.08 ± 0.47 ms
Sankey transformation	3.72 ± 0.56 ms	2.70 ± 0.28 ms	10.86 ± 1.30 ms
Total Pipeline Latency	7.50 ± 0.79 ms	5.60 ± 0.47 ms	21.13 ± 2.10 ms

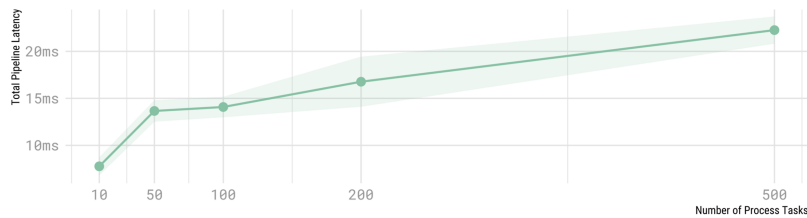


Figure 9. Total pipeline latency scaling linearly across programmatically generated synthetic models (10–500 tasks). Figure by authors

et al., 2022; Vasilecas *et al.*, 2014), PRiME provides a concrete, executable implementation. Because these related works target different research objectives, such as abstract resource-allocation logic rather than the formal, standard-compliant execution of resource lifecycles, their use cases and technical artifacts are not directly comparable to a runtime benchmark. To confirm the practical efficiency of our approach, we measured the execution time of the design-time material-flow visualization. Measurements were taken for the “Table Assembly” and “Truss Prefabrication” processes. As shown in Table 5, the total pipeline latency averages far below half a second.

These results confirm that the extension imposes no significant overhead. The visualization is rendered in real time during modeling, and the runtime logic (restricted to simple variable comparisons) executes virtually instantaneously within the service tasks. Notably, the observed variance in material annotation parsing times is primarily driven by the underlying serialization libraries rather than the extension’s architectural logic. The JSON-based scenarios use `kotlinx.serialization` [6], while the YAML-based scenarios rely on the Jackson [7] library. Consequently, optimizing raw parsing speed remains an external dependency, independent of the PRiME framework.

7. Discussion

This work aimed to address the digital-physical divide in cyber-physical systems by developing and demonstrating PRiME, a framework for integrating passive resources into executable BPMN models. The research systematically achieved the four design objectives established at the outset. *First*, the explicit modeling of passive resources (DO1) was realized through a dual-artifact approach: the `ResourceRequirementAnnotation` provides a structured, human- and machine-readable format for defining needs at the task level, while the

underlying ontology formally classifies resources, distinguishing between consumable materials and reusable tools. *Second*, the representation of resource availability and dependencies (**DO2**) was implemented by defining `ResourceInventory` as a dynamic process variable to track carried resources, and by coupling it with Java delegates that perform availability checks and handle shortage exceptions. The material flow visualization further enhances this by providing direct visual feedback on resource consumption. *Third*, conformance with BPMN standards (**DO3**) was a central design principle, ensured by the exclusive use of the official BPMN 2.0 extension mechanism. By embedding definitions within standard `TextAnnotation` elements, the models remain fully compliant and interchangeable with standard-compliant tools. *Finally*, the crucial aim of executability in a real-time environment (**DO4**) was validated through the Camunda-based prototype. This implementation proved the framework's practical applicability by providing runtime logic for availability checks, user notifications, and dynamic inventory updates within a live process engine. By successfully meeting these goals, PRiME provides an executable solution that overcomes the primary limitation of many conceptual or simulation-focused approaches, which often neglect direct operational applicability.

The use of DSRM, integrated with the extension development process of [Stroppi et al. \(2011\)](#) and [Braun and Esswein \(2014a\)](#), ensures the artifact is well-founded and systematically designed. The `ResourceRequirementAnnotation` serves a dual purpose: it provides human-readable clarity for process modelers at design time, while delivering machine-readable structured data to the process engine for runtime automation. This is demonstrated through two separate use cases: providing real-time resource checklists and shortage alerts to operational workers, and offering a design-time visualization of material flows for process analysts. Because PRiME relies on standard BPMN metamodel extensions, resource requirements can be modeled using any arbitrary format or Domain-Specific Language (DSL), provided the implementation serializes them into a machine-readable format. Future extensions could further integrate formal ontologies to enforce strict, machine-verifiable requirements (cf. [Poss and Schöning, 2025](#)).

Furthermore, PRiME aligns strongly with emerging paradigms in IoT-enabled process execution, particularly the development of the Digital Twins ([Fornari et al., 2025](#)) and the shift towards Object-Centric Process Mining (OCPM, [Aalst \(2023\)](#)). While current Digital Twins often struggle to synchronize with the physical reality of the shop floor, PRiME's executable tracking of passive resources provides the real-time, physical state data required to construct high-fidelity process digital twins. Additionally, the execution logs generated by PRiME that explicitly track the distinct lifecycles, locations, and interactions of multiple tools and consumables, provide a rich, multi-dimensional event log. This natively supports OCPM by allowing organizations to analyze complex, intersecting material flows and resource bottlenecks that traditional, single-case-ID process mining cannot capture.

Despite these contributions, the current work has limitations that offer clear avenues for future research. First and foremost, the framework's accuracy fundamentally depends on the quality of manual annotations and the ability to track actual resource inventory. While the system validates availability against these requirements, it cannot verify the requirements themselves, thereby introducing a risk of human error.

Beyond its technical contributions, PRiME can also be viewed from a sociotechnical perspective as a tool for cognitive augmentation in skilled craftwork. Rather than deskilling or replacing the craftsman, the framework offloads the significant cognitive load associated with managing a complex, dynamic resource inventory. In the assembly use case, the system automates tracking of components and tools, freeing the master craftsman to focus on high-value activities that require their tacit knowledge and experience. Furthermore, the creation of `ResourceRequirementAnnotations` serves as a means of knowledge formalization. It makes the task's implicit resource needs explicit, thereby creating a digital, reusable knowledge base. This formalized knowledge can serve as a scaffold for training apprentices,

BPMJ

guiding them in establishing appropriate resources for a given task and in effectively preserving and transferring valuable craftsmanship knowledge.

The deployment of PRiME offers tangible economic benefits by systematically eliminating the “hidden factory” of non-productive time. In manual and cyber-physical operations, a significant portion of labor cost is wasted on searching for tools, waiting for materials, or halting work due to incomplete setups. By enforcing an algorithmic Availability Check before a task begins, the framework flags shortages in advance. For instance, preventing a worker from arriving at a construction site without a critical tool not only saves hours of round-trip travel time but also prevents cascading delays that idle subsequent trades. Commercially, this translates into direct efficiency gains through maximized wrench time. Furthermore, by generating precise Bills of Resources and visualizing material flows, organizations can shift toward just-in-time procurement, thereby reducing inventory holding costs, minimizing material shrinkage, and lowering the capital tied up in excess stock.

Furthermore, the framework provides the necessary data infrastructure to support Environmental, Social, and Governance (ESG) criteria, specifically aligning with the *UN SDGs* (United Nations, 2015).

- (1) **SDG 4 (Quality Education):** The explicit modeling of resource requirements transforms tacit craftsmanship knowledge into a digital, reusable asset (Target 4.4). By formalizing the tools and materials required for complex tasks, PRiME creates an educational scaffold that guides apprentices in proper operational setups, thereby facilitating the preservation and transfer of valuable vocational skills to the next generation.
- (2) **SDG 8 (Decent Work and Economic Growth):** By automating the cognitive load of resource management, PRiME supports Target 8.2 (technological upgrading). Crucially, it promotes *decent work* by augmenting rather than replacing the skilled craftsman. It removes the non-productive frustration of searching for missing tools, allowing workers to focus on high-value, skill-based tasks.
- (3) **SDG 9 (Industry, Innovation, and Infrastructure):** By integrating IoT-based resource tracking into standard BPMN, PRiME facilitates the retrofit of legacy manual industries with smart capabilities (Target 9.4). It bridges the digital-physical divide, allowing traditional sectors to adopt resilient, cyber-physical infrastructure without replacing their core workforce.
- (4) **SDG 12 (Responsible Consumption and Production):** The explicit modeling of material flows directly supports Target 12.2 (Sustainable management of natural resources). The visualization of material consumption (Figure 8) transforms abstract inventory data into visible consumption patterns, allowing managers to identify usage hotspots. Additionally, the distinction between *consumable* and *reusable* resources supports Target 12.5 (Waste reduction). By tracking the exact lifecycle of a tool versus the consumption of a material, organizations can shift from wasteful “bulk provisioning” to precise “just-in-time” resource allocation, minimizing material waste and avoiding emissions from excess inventory production.

The operational logic of PRiME targets specific inefficiencies inherent in manual work. By enforcing a digital availability check before executing physical/manual tasks, the framework addresses the “search time” often required to locate tools and materials. In distributed environments, such as construction sites, preventing a worker from starting a task without the necessary equipment logically reduces non-productive travel time and execution delays. Additionally, the material flow visualization enables comparison of planned and actual resource consumption, providing the transparency needed to identify inventory waste. Regarding transferability, the core contribution and distinguishing between consumable and reusable passive resources are applicable beyond the craft sector. The requirement to

synchronize materials (consumables) with specific equipment (reusables) is equally critical in domains such as healthcare (e.g. matching surgical instruments with medical supplies) and industrial maintenance (e.g. routing spare parts and diagnostic tools to a repair site).

Finally, the practical relevance of this artifact is grounded in its development context. The requirements were gathered directly from Small and Medium-sized Enterprises (SMEs) in the skilled crafts sector, who identified the lack of digital resource tracking as a specific barrier to process management. The prototype demonstrates that standard-compliant BPMN can address these operational needs without requiring complex, proprietary software solutions.

7.1 Handling complex process scenarios and visualization scalability

A key limitation identified is that our material flow visualization was demonstrated on a linear process, which may face scalability challenges in models with complex branching or loops (Dumas *et al.*, 2018). For instance, consider a quality control loop in the table assembly process (Figure 8), where the *Attaching Table Legs* task might be repeated if a subsequent inspection fails. In such a scenario, the material requirements for that task would be consumed with each iteration. Our current design-time parsing mechanism aggregates all resource requirements for the entire process instance. While this approach effectively generates a total Bill of Resources, a standard Sankey diagram of aggregated data obscures iterative or conditional material flows. This can potentially misrepresent true resource consumption patterns—a known challenge in complex flow visualizations (Riehm *et al.*, 2005). To address this, the visualization could be adapted in two ways. First, it could aggregate flows separately for distinct execution paths (e.g. rendering rework loops with dashed lines or lower opacity). Alternatively, the static overlay could be transformed into an interactive element, allowing users to expand specific loops to analyze per-iteration consumption. An aggregated flow representing a loop can be clicked to “expand,” revealing per-iteration consumption or statistical information (e.g. expected consumption based on historical loop counts). Implementing these adaptations would transform the visualization from a static design-time overview into a more powerful analytical tool, demonstrating foresight and a deeper engagement with real-world process complexity.

7.2 Threats to validity

A systematic reflection on the validity of our research is crucial for any Design Science artifact (Peppers *et al.*, 2007; Johannesson and Perjons, 2021). We structure this analysis into three categories: internal, construct, and external validity.

- (1) *Internal Validity*: This concerns factors that could have influenced our results, primarily related to the specific design of our prototype. The demonstration was implemented using the Camunda process engine and a custom parsing script. The construction of an artifact, such as our prototype, is a core activity in Design Science Research (Peppers *et al.*, 2007). While this setup successfully demonstrates the executability of PRiME, the observed performance characteristics are specific to this technical environment and may differ from those of other process engines or implementation strategies.
- (2) *Construct Validity*: This threat relates to how well our conceptual constructs, such as `ResourceObject` and `ResourceRequirement`, accurately map to the real-world concepts they represent. We systematically addressed this threat by grounding our extension’s core concepts in established production theory, specifically Gutenberg’s production factor model (Albach *et al.*, 2000), to classify resources as consumable (*Repetitive Factors*) or reusable (*Potential Factors*). Furthermore, by strictly adhering to the official BPMN 2.0 extension mechanism (OMG, 2011; Stroppi *et al.*, 2011) and following a formal development process from ontology to CDME and

BPMJ	BPMN + X models, we ensure that our constructs are well-defined and integrated in a standard-compliant manner, accurately representing the intended domain concepts. (3) <i>External Validity</i>: This concerns the generalizability of our findings (Johannesson and Perjons, 2021). The requirements, process models, and evaluation scenarios for PRiME were derived primarily from collaborations with actors in the craft business sector. Consequently, the external validity of our framework is currently strongest within this domain. While the fundamental concepts of materials and tools are universal, further studies are necessary to evaluate their applicability and potential need for adaptation in other domains, such as large-scale manufacturing, healthcare, and logistics, which may present distinct resource-management complexities and constraints. (4) <i>Conclusion Validity</i>: This concerns the validity of direct inferences drawn from the data. A primary limitation of this study is the absence of longitudinal, empirical data quantifying the direct economic impact, such as specific cost reductions or measured efficiency gains, in a comparable live industrial deployment. Because PRiME introduces a novel, executable paradigm for passive resources, direct comparative benchmarking with equivalent frameworks is currently infeasible, as prior work largely focuses on conceptual modeling or non-executable simulations. Consequently, we cannot rely on pre-post measurements with a common instrumentation baseline; any “before” values would necessarily be based on retrospective estimates rather than systematically collected observations. As a result, while the logical derivations of saved travel time and reduced inventory costs are operationally sound and grounded in established business process analysis techniques, they must be interpreted as theoretically informed projections rather than statistically validated outcomes. Nevertheless, the successful runtime availability checks and the quantitative measurements of parsing overhead (cf. Table 5) provide robust evidence that the artifact is technically feasible and highly performant within its defined scope, thereby validating an early-stage evaluation that focuses on technical validity and utility rather than a full economic impact assessment.
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8. Conclusion

This paper addresses the critical gap between digital process models and physical reality in cyber-physical systems, where standard BPMN fails to adequately represent the operational lifecycles of materials and tools. To address this, we introduce the Passive Resource-integrated Modeling Extension (PRiME), a formally defined and executable framework that bridges the digital-physical divide. The primary contributions of this work are threefold. First, we developed a formal BPMN extension grounded in a detailed ontology that distinguishes between consumable materials and reusable tools. Second, we validated the framework through two perspectives: real-time runtime support for workers (checklists and alerts) and strategic design-time analysis (Sankey flow visualization). Third, we presented a systematic design methodology that ensures the extension remains standard-compliant and robust.

The implications of this research are significant. For practitioners, PRiME enables process models to serve as more faithful and executable blueprints, thereby enhancing operational transparency. More importantly, it functions as a tool for cognitive augmentation. By offloading the mental load of resource tracking, the system enables skilled craftspeople to focus on high-value tasks that require their tacit knowledge and experience, thereby augmenting skilled manual labor rather than replacing it. For researchers, this work provides a validated foundation for orchestrating cyber-physical systems and formally integrates the operational perspective into executable BPM. Furthermore, the granular tracking enabled by PRiME provides a direct link to sustainability and circular economic initiatives. The

framework’s ability to precisely monitor material consumption creates opportunities for waste reduction analysis, while its underlying logic can be inverted to support product disassembly and recovery of reusable components. These positions process management not just as a tool for efficiency but also as a mechanism for promoting sustainable industrial practices.

Building upon this foundation, which serves as a first step towards a process-centric digital twin, future work will focus on three key areas. First, to address the current limitations in empirical benchmarking, we aim to conduct longitudinal case studies in active cyber-physical environments to capture direct ROI measurements and quantitatively validate the projected economic benefits. Second, to further strengthen the framework’s theoretical rigor, future research will explore formalizing PRiME’s resource constraints using languages such as the Object Constraint Language (OCL) or Alloy. This will enable automated formal verification and model checking, ensuring that complex resource dependencies in extended BPMN models are logically consistent and conflict-free prior to execution. Finally, we will advance from passive monitoring to active automation and dynamic resource optimization. Currently, PRiME detects shortages but relies on human intervention to resolve them. Future iterations could integrate with planning algorithms to automatically resolve contention for shared tools and trigger automated procurement workflows when consumable inventory thresholds are breached.

Integrating the operational perspective directly into executable models is a critical step toward a holistic BPM, where the orchestration of physical assets is no longer an afterthought but a first-class citizen alongside control flow, enabling the support of the execution of physical operations.

Business Process
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Appendix
CDME and BPMN + X

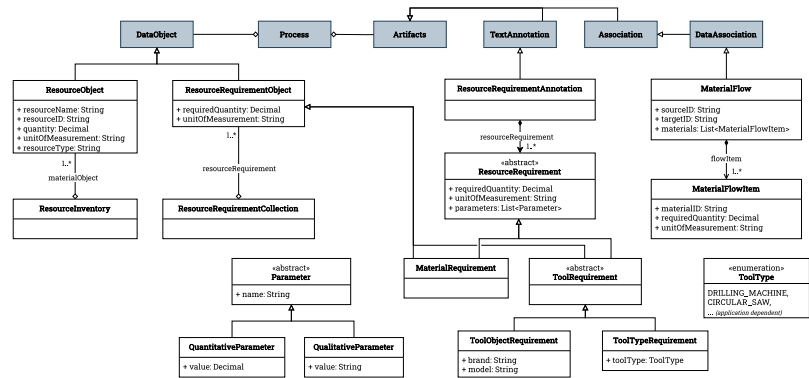


Figure A1. CDME passive resource domain

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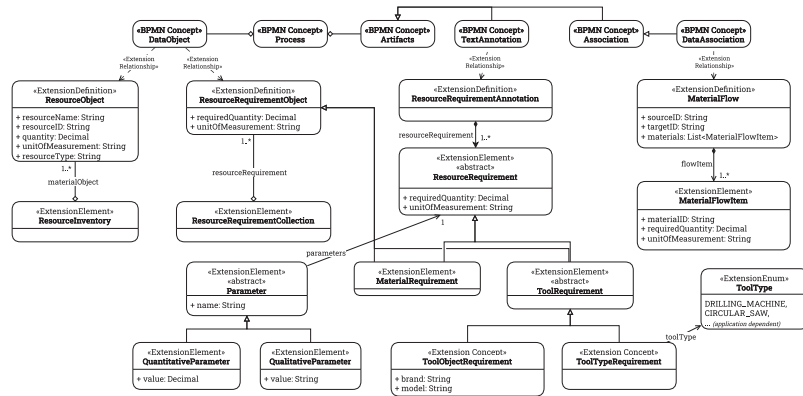


Figure A2. BPMN + X passive resource domain

Notes

1. This does not align perfectly with the standard definitions in BPM, in which machinery can be seen as an active resource, i.e. one that can autonomously perform an activity (Dumas *et al.*, 2018).
2. <https://camunda.com/>
3. <https://d3js.org/>
4. <https://github.com/ricklupton/d3-sankey-diagram>
5. See the attached repository for the code.
6. <https://github.com/Kotlin/kotlinx.serialization>
7. <https://github.com/FasterXML/jackson>

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Journal description: *Software and Systems Modeling (SoSyM)* is a bi-monthly international journal (published in English) that focuses on theoretical and practical issues pertaining to the development and application of modeling languages and techniques for software, as well as engineered and natural systems and processes. The aim of the journal is to publish high-quality works that (1) further understanding of the theoretical and foundational underpinnings of modeling languages and techniques, (2) present rigorous analyses of modeling experiences, and (3) introduce scalable modeling techniques and processes that facilitate rigorous and efficient development and understanding of software and systems. SoSyM encompasses several communities involving modeling languages and techniques, such as Model-Driven Engineering, Modeling and Simulation, or Data Engineering.

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SPECIAL SECTION PAPER



Location-aware business process modeling and execution

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Abstract

Locally distributed processes include several process participants working on tasks at different locations, e.g., craftspeople working on construction sites. Compared to classical IT environments, new challenges emerge due to the spatial context of a process. Real-time location data from Internet of Things (IoT) devices can help businesses implement more efficient and effective processes through business process management (BPM). However, only small parts of existing research have touched on those advantages, while the architecture and implementation of actual executable location-aware processes area has only been vaguely considered. Therefore, we introduce and present a non-exhaustive list of patterns for using location data in BPM while also including an actual implementation of a location-aware approach using a multilayer system architecture based on standard BPM technology. These can be used to leverage the location perspective of process entities as contextual data in BPM.

Keywords Process execution · Location-awareness · Distributed processes

1 Introduction

Business process management (BPM) is a management approach to goal-driven design and the optimization of diverse and cross-organizational business processes, providing methods and tools to support the design, execution, management, and analysis of processes [1].

Different new areas, such as digital marketing, where the location of the customer can be used (e.g., location-dependent pricing or digital nudging—e.g., ads based on the current location or other data based on this), or the use of locations of customers and employees by large e-commerce companies and package deliverers (utilizing location for routing optimization as well as for customer benefits, such as knowing when a package will arrive), or their use in crisis response/paramedics (where the current location of the rescue team in comparison with the victim's location is crucial) could benefit from an integrated approach providing support

and easing the use of location data. However, on the other hand, established areas not directly tied to the classical use of business processes in production sites or factories but in service-provisioning could benefit from using location data within business processes and value creation (e.g., craftspeople relying on mobile and locally distributed processes, where several process participants work on subsequent tasks at different locations).

All those processes come with different challenges compared to other business processes, where the spatial context is often disregarded due to negligible distances between fulfillment locations [2]. Looking back at already existing approaches, location information can be used to adapt the price or change the content of an ad space, where the location of a user is part of a more extensive set of decision variables and can either be used to improve the user experience or improve the value generation on the companies side. On the other hand, with crisis response and craftspeople at a construction site, the location of the target entity is the core of the process.

Historically, BPM focuses on classical IT processes with little to no spatial context, mainly on the automation and support of tasks through machines and their standardization. The Internet of Things (IoT) describes a world where every object can connect to a data network with its own identity [3], enabling electronic hardware to communicate remotely with

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physical objects. The data obtained from the IoT devices representing the locations of different entities involved describe their conditions and circumstances [4, 5].

As previously outlined, the prevailing solutions are predominantly rigidly programmed, provided by specific companies, and customized for particular use cases. BPM and its toolchain offer a solution to conceptualize such location-aware functionality by providing a generic toolkit for implementing and leveraging location data in any mobile and distributed business process open for any process-aware system and organization. Despite those practical applications, existing research in BPM has mainly focused on different facets of location awareness, such as process adaptation, modeling, and mining [6, 7], or managerial considerations in the realm of context-aware processes [8, 9].

The description and implementation of an executable system to capture and process location data for business processes are either neglected, only vaguely contained, or described for a closed environment scenario, such as a smart factory [10]. In particular, to the best of the authors' knowledge, the allocation of concrete actors to tasks based on location data within BPM¹ and reordering the task lists of multiple process instances based on distance is still an open research issue. The described research gap poses the following research questions:

RQ1. What potential patterns exist for utilizing the location context of actors and entities in BPM?

RQ2. How can these identified patterns be effectively employed during the modeling and execution phases of the business process?

We fill this gap in the following sections by introducing different patterns for the use of IoT-based location information in BPM (and the needed operators) as well as an implementation of an executable and well-defined location-aware approach for process modeling and execution (see Fig. 1). Specifically, we outline a multilayer system architecture grounded in standard BPM technology. We implement a comprehensive suite of location-aware patterns applicable to different real-world application areas that enhance mobile distributed processes. These patterns include: (i) location-based task allocation, (ii) location-based automated start and termination of tasks and process instances as well as location-event-based dispatching of tasks and restricting the

execution based on location, and (iii) location-based reordering of tasks.² The different patterns have been implemented and evaluated using common real-life distributed processes from crafts businesses, including a repair process at a customer location, the rental of devices like heating units, or the delivery of monitored goods between different branches, each combining the potential of the use of location data with an executable implementation to adapt to other real-life processes.

This article is an extension of the conference publication [13]. It extends the original article in various ways:

- (i) The presented patterns have been extended in different directions.
- (ii) The background on location has been extended, and a formal description of used operators has been added.
- (iii) The prototypical implementation changed fundamentally and is presented in more detail.
- (iv) The related work section has been extended and discussed more thoroughly.
- (v) The evaluation section has been extended and includes presenting and discussing three implemented real-life use cases from our research project.

The remainder of this paper is organized as follows. In Sect. 2, we present the background and related work w.r.t. location-aware BPM, as well as our research methodology after that Sect. 3 is dedicated to establishing the foundations for information generation and processing from location data. After that, we present the different patterns for the use of location in BPM in Sect. 4.

To augment the understanding of our contributions, Sects. 5 and 6 give a brief overview of the BPMN extension LABPMN from [12] that enables the use of the presented patterns for BPMN as the de facto standard for process modeling and provides one possible implementation, and classify the patterns within the well-established data patterns of [14]. The prototypical implementation details, supporting the integration of location data in process modeling and execution, are explicated in Sect. 7.

Furthermore, Sect. 8 provides insights into real-world applications, illustrating the application of these patterns in three distinct processes from partners of a research project within crafts businesses—namely repair processes at customer locations, device rentals, and monitored goods delivery between different branches and one process from emergency services also inherently dependent on location information adapted from [15] showcasing the use of the patterns in another application area. Finally, the paper concludes with a summary and outlook in Sect. 9.

¹ The algorithmic optimization of an allocation problem and other optimization problems, e.g., for process planning, are existent and can be used for the actual implementation. [11], for example, describes the classic house allocation problem with an example of allocating three agents to three different tasks, which could be used for the allocation pattern presented below. Here, the focus is on the different patterns and how they can be used, independently of actual algorithms and implementation choices

² For LABPMN, the matching BPMN extension extending the meta-model for the inclusion of location, see [12]

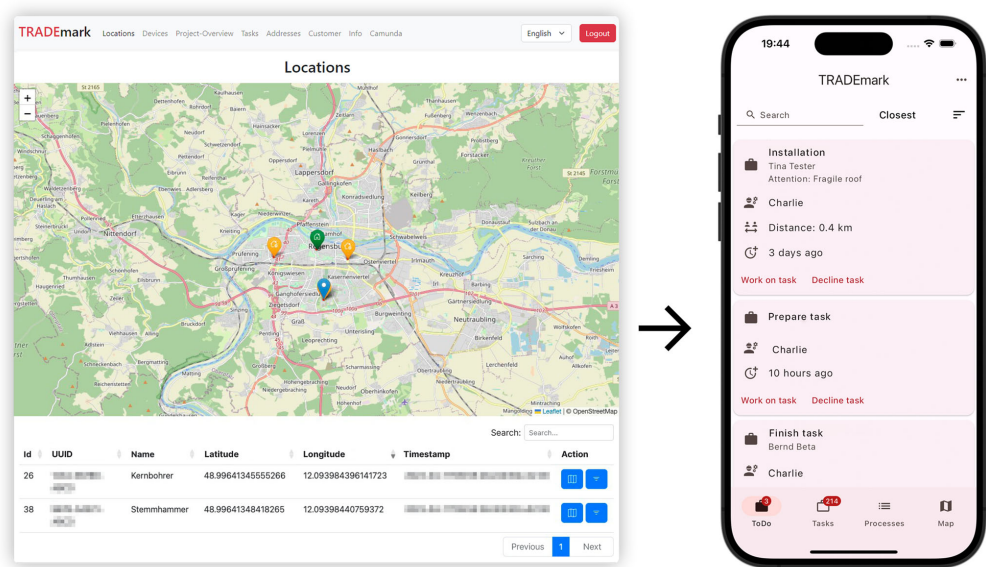


Fig. 1 Using location information to dynamically adapt mobile applications in business process execution (prototypical implementation presented in Sect. 7)

2 Theoretical background and related work

We commence with foundational knowledge regarding business processes, process context, and location awareness and proceed to present related work. This review aims to highlight the existing research gap concerning the integration of location data from IoT devices and BPM.

2.1 Background on context- and location-aware business processes

Based on the research field of business process management (BPM), the following sections will explain the connection to the Internet of Things (IoT), the use of contextual information during the execution of business processes, and location data as a considerable part of context information and its connection to BPM.

Business Process Management A *business process* is a series of activities to achieve a specific business outcome [1]. *Business Process Management (BPM)*, on the other hand, is a management approach aimed at designing, optimizing, and overseeing diverse cross-organizational business processes. This is achieved by using methods and tools that support the design, execution, management, and analysis of these processes. By leveraging BPM, organizations can iden-

tify opportunities for improvement and align their processes with the needs of both clients and their objectives. While standardization may seem advantageous initially, excessive standardization can impede the management of external influences. While this approach may work well for a production line, it hinders the optimization of mobile work processes. As stated in [16], "the management of processes should fit the process nature." In the case of a production line, external data may be less relevant from a process perspective and, therefore, disregarded, while mobile processes are heavily dependent on various locations.

Business processes can be represented by one or more *business process models*, consisting of activity models and instructions detailing how the processes should be executed. These models serve as a blueprint for real-world scenarios and cases, providing a structured representation [17].

Several modeling languages exist for this purpose, with *business process model and notation (BPMN)* [18] being the widely accepted current standard. BPMN incorporates various standardized elements that enhance both human and machine readability, enabling machine-supported execution of business processes. Furthermore, BPMN allows for the extension of the meta-model to introduce new functionality that is not part of the standard's core features. This extension capability can be employed to directly reintroduce logic

necessary for the following patterns into the models, visually representing the actions during execution.

Over the years, the extension mechanism introduced in BPMN in 2011 [19, 20] has facilitated the development of numerous specialized extensions tailored to various application domains. These extensions enhance BPMN's functionality and adaptability to meet the specific requirements of diverse real-world scenarios (as discussed in [2, 19]). The reuse and enhancement of standard BPMN elements offer advantages such as standardization and widespread tool support. The BPMN extension mechanism is closely tied to the Meta Object Facility (MOF) meta-model [21], which separates the meta-model, process model, and process instances. This separation provides enhanced flexibility through interchangeable model properties and parts. In other words, extending individual elements of the BPMN meta-model does not strictly necessitate the modification of standard BPMN elements.

Finally, it is essential to emphasize that business process management (BPM) is not a one-time activity; rather, it constitutes an ongoing cycle with various versions documented in the literature, as elucidated in [22]. This work adopts the *BPM life cycle* framework delineated in [1], which is derived from Deming's PDCA cycle (Plan-Do-Check-Act). The patterns presented in this context emphasize the use of location information during process execution, as opposed to focusing on the incorporation of contextual information such as sociocultural surroundings and organizational resources during process modeling (cf. [8, 16]).

IoT-aware BPM

The *Internet of Things (IoT)* concept envisions a world where every object can connect to a data network and possesses its unique digital identity [3]. This digital infrastructure allows electronic hardware to communicate remotely with physical objects. Bridging the gap between human actors and electronic devices is made possible by tightly integrated systems that leverage data from IoT devices to enhance efficiency and effectiveness and enable data-driven work. IoT data are a foundational technology that provides context information and data that can be seamlessly integrated into business process management systems (BPMS). Using IoT data for process execution, monitoring, and analysis can offer a more comprehensive perspective on business processes. Incorporating real-time data from devices and sensors into BPM technology provides businesses with added value by reducing costs and improving efficiency.

The Internet of Things encompasses the use of sensors, devices, and networks to collect, transmit, and process real-time data from the physical world. This capability facilitates the creation of intelligent environments capable of adapting to the needs of users and organizations. The data collected through IoT can be leveraged to establish

intelligent environments that respond to both user and organizational requirements, thereby enhancing process efficiency and effectiveness [23, 24]. In essence, the Internet of Things fundamentally enables the development of new functionalities that would otherwise be unattainable.

Context-aware BPM

Data acquired from IoT devices, representing various locations of the entities involved, provide information on the conditions and circumstances of these entities, making it an integral component of the *process context* [4]. In the field of *Human-Computer Interaction (HCI)*, the concept of context has been a focal point of research for numerous years, resulting in various definitions, the distinguishing factor being the relationship involved. In HCI, the relationship between an actor and a system becomes contextualized, whereas, in the context of a *business process management system (BPMS)*, we contextualize the entity incorporated within a process instance's execution. Schilit et al. (1994) define a *context-aware system* as a system capable of detecting and responding to environmental changes, while [5] define *context-awareness* as an application's ability to adapt to user context, with the *user's context* denoting the circumstances or situations in which a computing task occurs.

[25] describes *location-based services*, predating their connection to business processes and the practical use of the IoT. These services are a subset of context-aware services based on two context levels. The *primary context* encompasses factors such as time, location, identity, and activity, which are derived from sensors. In contrast, the *secondary context* level includes personal, technical, social, physical, and spatial contexts, which can be deduced or filtered from the primary context data [25].

Location-aware BPM

[25] define *spatial locations* as based on well-defined reference systems that subdivide a geographical area into units of a common shape and size, most commonly specified as a numerical explicit representation in a coordinate system (e.g., latitude and longitude), while in the real world, we commonly use street names and numbers (addresses) for defining a location of an entity. With a possible loss in precision, both formats can be converted into each other using geocoding. While addresses are more human-readable, they often need to be more accurate, considering both timeliness and accuracy and preventing numerical calculations on location information (cf. Section 3). Following the earlier differentiation of primary and secondary context, in this work *IoT-data* will refer to all data obtained from IoT devices, which can be *location data* (data to represent a location, primary context), while *spatial data* include the location of an entity, as well as other information based on the location of an entity (secondary context, e.g., the distance between two entities).

In the context of *complex event processing* (CEP), [26] distinguishes between different types of context: temporal, state-oriented, segmentation-oriented, and spatial. For this research, only the spatial classification is essential, which gets further divided into three different parts, where spatial information can be used as part of the generation of events [26]: (i) *Fixed location*: Describes a fixed location, such as the position of a customer or the company office, (ii) *Entity distance location*: Represents locations within a certain radius of an entity, for example, geofencing, (iii) *Event distance location*: Similar to entity distance location, but describes the radius drawn around an event happening (e.g., an accident) as the basis to include subsequent events. Another differentiation that must be made for the location information of the entities is the primary difference between *dynamic* and *static locations*. At the same time, the latter remains the same, and the first can change over time.

Although the concepts and goals of CEP and BPM have been focused on different application areas, within the context of IoT, they share various similarities, and both approaches can be combined [27].

Finally, we define the term *mobile distributed process* as a process involving multiple actors operating on sequential tasks at various locations, *implicitly constraining* the task's execution to a specific location, e.g., a craft business employing multiple workers working on different construction sites. This leads to a distinct set of problems compared to classical (IT) environments of business processes, where the spatial context of a process is less critical, or the distances between places of fulfillment are pretty small and might be negligible.

2.2 Related work

The following section describes currently existing approaches for combining BPM and IoT and using location data or parts of a possible future approach.

For the literature review, we formulate and apply the following search string, which encompasses the primary areas of interest, business processes, and location. The search string had to be present in at least one of the three components: title, abstract, or keywords:

(BPM OR "business process" OR "workflow*") AND (location* OR spatial OR geographic* OR context*)*³

Deliberately absent from the search string were terms directly associated with the Internet of Things (IoT) and related terms, such as sensor networks or cyber-physical systems. This omission accounts for discrepancies in terminology usage over time, which could result in older publications using the terms differently or including publica-

tions primarily focusing on hardware-related research. In a previous attempt to retrieve related works, we experimented with incorporating all combinations of context with IoT, but this approach failed to include several relevant publications.

The selected digital libraries for our search comprised widely used repositories in the fields of Computer Science and Information Systems, including the ACM Digital Library, IEEE Xplore, EBSCO, Science Direct, AIS eLibrary, as well as other publications identified through forward and backward searches to lower the possible miss rate on relevant articles. Different existing SLRs and meta-publications on the topic, such as [19, 29, 30] were used to add possibly missing publications. Additionally, we limited our review to articles published in English and German and, following the methodology of [29], we filtered the data to only include publications after 1999. This timeframe was chosen to encompass possible approaches predating the standardization of BPM in 2007 but postdating the initial use of the term Internet of Things around that year.

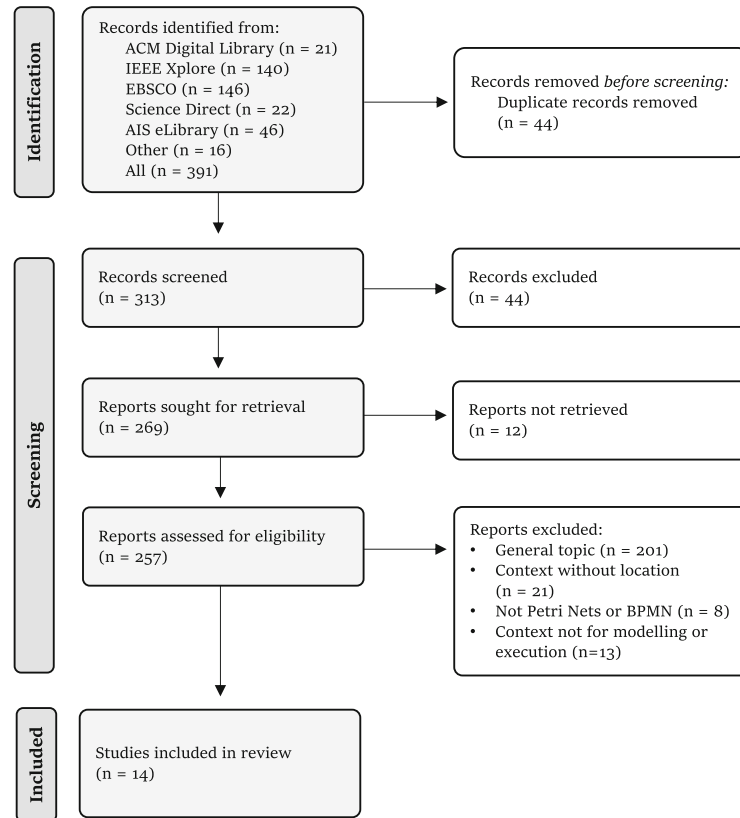
The PRISMA Statement with the different steps and selections, criteria, and results can be found in Fig. 2. The contents of the identified relevant literature are listed in the concept matrix in Table 1, giving an overview of the definition of the corresponding problem, as well as the goal, the chosen approach, and the result—independent of their original application domain [31]. Individual approaches can be classified into four non-exclusive categories, namely: *graphical modeling extensions* where the spatial perspective aims to explicitly model locations in business processes, *conceptual modeling extensions* where new use cases are presented (mainly the location-based restriction of the execution of tasks, e.g., in [32, 33] as well as research considering the *architecture of BPMSs* and the *use of spatial information to derive new functionality*, e.g., the use of location data from event logs to get an overview of task locations [7] or the visualization of work items and resources [34]. Note that even if the approach of [32] is conceptually defined and executable, the author and others like [33] and [35] only consider location constraints as use for spatial information during process modeling or execution. [2], on the other hand, gives an overview of related work for combining IoT and BPM, but not specifically for location data or the use of context information. They determine that most extensions avoid handling data, thus disregarding the core of the connection between location and their use for business processes.

Graphical Modeling for Location-Aware BPM

In reality, many business processes are location-dependent and should be executed differently based on the specific locations of the entities involved. However, current business process modeling languages do not inherently support incorporating location information into business processes. As a

³ The asterisk notation, utilized with supporting libraries, ensured the inclusion of all results beginning with the respective search term

Fig. 2 PRISMA statement [28] of our literature review



result, the processes modeled using these languages often do not accurately reflect real-world business processes [36].

[37] focus on extending BPMN events to better capture events in IoT scenarios. Their extension is not limited solely to location events but more generally reuses data objects mapped explicitly to IoT resources. They maintain the basic structure of events, including the three different types of events (start, intermediate, and end) and the two flavors (catching and throwing). The given event definition in BPMN determines the nature of the event, whether it is a message event, a timer event, or a different type. Next to reusing existing elements, they also introduce a new type of event, the location event, marked with a pin icon that can describe either the current position or the movement of devices or physical entities. Based on IoT-A [38], they extend the event definition to include sections related to fault tolerance, specifying the maximum number of retries allowed to receive requested data and information quality, which restricts the data to be used. However, no information was provided on

the extension of the BPMN meta-model (which is one of the requirements of the standard [18]), as well as an overview of the actual concepts for the actual use of location.

Conceptual Modeling Extension for Location-Aware BPM

Extending existing business process modeling notations with graphical elements alone is insufficient to make business processes truly location-aware. Business processes need both visual representation and machine-readability for their execution. Additionally, new concepts must be developed and integrated into these notations to respond to location information effectively.

One such concept is *Location Constraints* (LCs), utilized by [33] among others. An LC can be associated with an activity and defines where the activity must be performed or where it is prohibited. The former is termed a positive constraint, while the latter is a negative constraint. Within the publication, a two-dimensional location model is introduced that describes the spatial attributes required for defining loca-

Table 1 Related work concept matrix following [31]

Goal	Approach/procedure	Outcome	Drawback	Notation	Executable?	Graphical	Conceptual	Architectural	New functionality
[39] Develop a system to effectively handle constraints of network connectivity and mobility of workflow resources	Two-level approach: Global level: Dynamic assignment of activities based on, e.g., resource location. Local level: Additional resource attributes to prioritize activities for participants	Resource management by custom work list handler, supporting late and dynamic binding to location-dependent activities. Integration of map view	Dated approach focusing on constraints in mobile connectivity, only workflow reordering	–	●	○	○	●	●
[40] Modeling location-aware business processes based on architectural primitives	Business-rule driven architecture with semantic coordination and location primitives. Process flow: Business rules restricting the execution of an activity	Influence of location laws on activities based on predefined location	Not executable, handles only location constraints	–	○	○	●	○	○
[33] Include location constraints in BPM	Location constraints on activities at design time and dynamic constraints during run time. Graphical symbols and extension of the BPMN meta-model	Extension of the BPMN meta-model	Not executable, handles only location constraints	B	○	●	●	○	○
[41] System architecture for location information in process optimization within a factory of things	Focus on the provision of location information to location-aware client applications. Externalize location rules from the source code into a knowledge base. System architecture handling aggregation, mappings, and allocation of location information	Conceptual idea to location-aware application architecture	Not executable, processes event logs to gain insights of execution locations	–	○	○	○	●	○
[42] Comparison of business process notations regarding location aspects	Comparison of adaptations of notations, attempt to create notation for mobile information systems from scratch	Suggestion on the visual appearance (color-fill, icon, etc.) of location aspects of existing notations	Not executable, graphical representations only	B/P	○	●	○	○	○

Table 1 continued

Goal	Approach/procedure	Outcome	Drawback	Notation	Executable?	Graphical	Conceptual	Architectural	New functionality
[34] Decision support for choosing next work task	Map metaphor and distance notions to visualize work items and resources. Distance notions for priority of work items based on different factors, e.g., location. Visualization is split into work items and resource layers	Work list visualization framework based on maps and distance notions implemented as YAWL component	Decision support system for – worklist reordering, location only	–	●	○	○	○	●
[35] Shorten wait times in the cardiac care process	Combination of location system and BPM by complex event processing (CEP)	Abstract location-aware BPM system architecture. Implementation prototype of architecture	Different application area, CEP for process improvement, fixed process	B	●	○	○	●	●
[36] Modeling location-aware business processes. Location-aware extension of process execution system	Declarative language for modeling business processes. Provision of additional modeling elements for location dependencies in DPIL. Description of how elements could be executed by business process execution engine	Concept and prototype of declarative location-aware process execution engine. Location-dependent task assignment and process progression	Only declarative modeling, no implementation, worklist reordering	B	⊙	○	●	○	○
[43] Identify and conceptualize location-dependencies in process modeling	Pattern-based approach to identify location-dependency in process models	Location dependent task symbol, location dependent condition	Only graphical, influence control flow with location data	B	○	○	●	○	○
[37] BPMN event extension for IoT	Create new BPMN events with an extended event definition (includes location event)	Start, intermediate, and end event and extended event definition for location, fault tolerance, and quality of information	Retrospective event processing based on location (and other IoT) data	B	○	●	○	○	○
[44] Constrain control flow and process behavior based on location	Petri net modeling extension, mapping to colored Petri nets. Usage of location constraints using geospatial relationships	Modeling technique can specify how location impacts the basic control flow	Only Location constraints	P	●	○	●	○	○

Goal	Approach/procedure	Outcome	Drawback	Notation	Executable?	Graphical	Conceptual	Architectural	New functionality
[6] Extend BPMN to enable the modeling of mobile context-aware business processes	Sensor modeling for the dependencies of context information. Context marker; context event, and context expression language by extending the BPMN meta-model	Context4BPMN extension with context-aware BPMN elements and a modeling guideline	Focus on general modeling general context events, no implementation	B	○	●	○	○	○
[32] Integration of an executable location constraint annotation into business process modeling languages	Integration of an executable location annotation in Petri nets and BPMN. Petri nets: Introduction of new constructs. BPMN: Usage of artifacts and associations	Extension of graphical and formal representation of Petri nets and BPMN by location constraints	Only location constraints during modeling	B/P	⊙	●	●	○	○
[7] Include location in process modeling and process mining	Geospatial information in event logs. Geo-enabled process modeling: Nodes represent geographic locations, and transitions represent the activities. Process model is visualized on a map	Location aspects of business processes are treated as "first-class" modeling entities. Activity flow is secondary	Location data for process mining; process model from enhanced event logs	-	⊙	○	●	○	●

Notation: **B**: BPMN, **P**: (colored) Petri nets, **-**: other/not specified; Categories: ○: only conceptual, ⊙: description of implementation, ●: actual implementation

tion constraints, including two types of location that can be referenced: cycle locations and polygon locations. Additionally, there is a reference area within which all locations must be included. The authors differentiate between location classes and location instances, where location classes are used to conceptually group related location instances. The authors introduce several non-BPMN-conform visual elements, such as double-edged parallelograms for location classes or hexagons with equal signs for positive location constraints. Although the concepts were new in this regard, there is no need for specific non-BPMN elements, as all concepts can be expressed by combining existing and more basic patterns.

On the other hand, [33] also differentiates between direct constraints (defined at design time) and indirect constraints, which are derived during runtime and further divided into internal and external LCs based on the source of the location data (location of another activity vs. external system or manually entered). The BPMN meta-model must also be extended to fully incorporate the logical structure of the defined LCs into BPMN. To achieve this, [33] integrated the classes of the corresponding graphical symbols into the BPMN meta-model by inheriting from existing classes.

Despite the location constraints (LCs) described in [33], the authors do not address the issue of ensuring that activities are performed in the intended locations. Moreover, the focus on only LCs leaves behind a significant part of the possible uses of location data in BPM. [32] also deals with LCs in BPMN. BPMN artifacts are used to model the LCs, allowing the modelers to provide additional information about the process that is not directly related to the sequence flows or the message flows of the process [18]. As a result, the artifacts do not alter the behavior of the process. [32] extends the class diagram of the BPMN meta-model and the corresponding XML schema to include LCs in BPMN. LCs have the same constructs and functionality as introduced in [33], with the representation in the model being the main difference.

In contrast to [32, 33] also extends Petri nets with LCs.⁴ For this purpose, [32] introduces new constructs to Petri nets: the constructs needed to represent LCs and a new connection type to link the new constructs with each other and with the existing transitions. The functionality and graphical representation of the LCs in Petri nets are the same as in BPMN. The authors also provide new sets and formulas for the formal representation of the extension of Petri nets.

[44] take a step further by not only restricting where an activity can be performed, as in [33] and [32] but also influencing the control flow of the process-based on location information. To achieve this, they introduced location-

dependent transitions and geospatial relationships in colored Petri nets in addition to LCs. Location-dependent transitions are assigned a location after execution. Location constraints are expressions used to limit the locations that can be bound to a location-dependent transition. The expression evaluates to a Boolean result and involves exactly one output transition—the constrained transition. Note that a transition is only enabled if a token exists in all input places and all LCs are satisfied. The LCs can be viewed as location-dependent guard functions within Petri nets.

To make location-aware workflow nets (LAWF-nets) executable, [44] propose a mapping to Colored Petri Nets (CPNs), which can be executed using CPN tools. The location-based expressions used in location constraints are implemented by an extension integrating a geographic information system (GIS). Location constraints imposed by the GIS constrain the control flow. The execution of location-dependent transitions, in turn, triggers changes in the GIS.

So far, all the concepts presented are based on extending imperative process modeling languages such as BPMN and Petri nets. [36] take a different approach and focus on extending a declarative process modeling language. Declarative process modeling is particularly well-suited for scenarios with many unforeseen paths because it describes the desired result rather than the exact path to achieve it. The specific path to the result is derived from constraints that limit the activation of the following possible steps. This paper uses the declarative process intermediate language (DPIL) to model the process. In order to make DPIL location-aware, its meta-model must be extended to include location entities, such as resources and locational constraints. Two distance patterns are introduced to formulate locational constraints: (i) The extreme distance pattern, that determines the nearest or furthest entity from a given location, and (ii) the exact distance pattern, that determines the distance between two locations of entities, enabling the control of activity execution based on location information.

[40] also describes a declarative approach, where the constraints that connect and restrict activities are called business rules. The paper focuses explicitly on coordination and location laws, which are specific business rules related to coordination and location aspects. Business rules are specified in the event-condition-action form, whereas a coordination law is a business rule that regulates and combines services or activities. A location law models location-dependent aspects of business rules. Therefore, the positions of all location-dependent entities are recorded, meaning that location aspects are externalized from the source code into location laws, simplifying code adjustments and maintenance while also adding complexity by adding another part to the system.

⁴ Even though BPMN is the de facto standard for modeling business processes, we include different approaches, as the underlying concepts might also apply

Architecture of Location-Aware BPMS

To effectively and efficiently use location data during the execution of business processes, an intelligent combination of different components in the form of a system architecture is required. The following section presents an exemplary system architecture, as well as an abstract system architecture for the integration of location in BPMS. [41] presents an architecture for location-aware process optimization within a factory of things. The authors focus on providing location information to the location-aware client application, which is not further detailed.

The location preparation is divided into a provision layer, which contains the various sources and technologies for location information; a mapping layer that is responsible for converting the location data into a consistent data format; and a Distribution Layer with a context broker to allocate the location data to its consumers. The interpretation layer consists of a server with a knowledge base, which can be queried via an Application Programming Interface (API) to separate the interpretation of location raw data from the location-aware client application. The client application is located in the application layer and could be, for example, a location-aware BPMS. This architecture provides a centralized location provision and interpretation infrastructure, from which location-aware client applications can benefit from reusability and separation of concerns.

In [39], the Workflow enHancements for Mobility (WHAM) system is introduced. The system focuses on dynamic activity assignments in mobile environments. For this purpose, a two-level resource management approach is used. At the global level, dynamic assignment of activities is based on resource location and types, activity priority, and load balancing. Additional resource attributes filter and prioritize the assigned location-dependent activities at the local level. According to the understanding of [39], these activities are tied to a specific location. To ensure dynamic and location-dependent assignment of activities, a location status for mobile resources has to be maintained. Furthermore, the late assignment of mobile resources to activities is crucial, as they frequently undergo spatial relocation (i.e., they move) over time.

To implement dynamic and late assignment of mobile resources to activities within workflows, [39] employs a workflow server in conjunction with a mobile resource management component on the server side. The resource's location is determined on the client side and stored within their respective resource profiles. When the client establishes a connection with the server, the worklist handler conveys the current location to the server, generating an appropriate worklist tailored to the client's location. The workflow proxy and the work item data cache are vital in ensuring that activities can be executed, even when mobile participants are temporarily disconnected from the workflow server's net-

work. Furthermore, a map view, integrated into the worklist handler, displays the locations of activities within a participant's worklist, assisting mobile participants in planning their work.

Use of Location for New Functionality

Finally, using location in BPM also fosters new applications, such as including geospatial information in event logs for process mining [7]. Consequently, location aspects become the primary modeling entities, while activity flow becomes secondary. Moreover, while the presented approach differs from earlier ones, at least from a lifecycle standpoint (modeling and execution vs. process monitoring), representing geographic locations and using event logs of transitions of entities between them also incorporates location information into the process analysis.

Detached from any specific modeling language, [45] proposes that location enhances human task assignment in business processes. They suggest using location and user availability status to efficiently assign tasks and prevent tasks from becoming idle.

Finally, another use of location in *augmented process modeling*, similar to the approaches presented above, is visualizing processes and tasks in actual spaces. [34], for example, focuses on visual support for work assignments in mobile environments. They achieve this by visualizing the location of tasks on a map while also employing distance metrics to suggest the next task based on various factors. This approach lifts the use of location away from the process model itself and implies implementing a complementary task list.

On the other hand, [46] also uses the location as part of contextual process information to use augmented reality to display process specifics at the actual location of the task (e.g., live sensor data at the specific machine or a task list next to a workspace with tasks specific to the workspace instead of the actor). These approaches differ fundamentally from the patterns presented in the following sections. While they use the location of a process entity, they are not directly tied to the process model as a way of visualizing and providing the needed logic for process execution.

2.3 Research methodology

The following sections follow the introductory course of the well-established *design science research methodology* (DSRM), which has the fundamental goal of creating valuable artifacts within the information systems discipline [47]. Methodologically, the current procedure model of [48] and [49] divides the research process into six iterative phases: (i) *explicate problem*, (ii) *define requirements*, (iii) *design and develop artifact*, (iv) *demonstrate artifact*, and finally, (vi) *evaluate artifact*. However, the problem and the requirements

for a solution have already been outlined in Sects. 1 and 2, Sects. 3 to 5 explain the basics of generation and processing of location information and different patterns of the use of spatial information with BPM and an attached BPMN extension, and Sects. 6 to 8 form the last step by providing a prototypical implementation for the previously presented patterns, combining the demonstration and evaluation in terms of currently running real-world application examples for the patterns.

We have also met the requirements of DSR as an iterative process [49]. In addition to conducting rapid system prototyping, we actively engaged with our industry partners by presenting intermediate results. Their valuable input and expertise were fundamental in refining our objectives and enhancing the system architecture's design and functionality.

3 Location information generation and processing

The context of a process describes the conditions and circumstances involving the entities [4]. This information can be used during the execution of a process to enhance and support its realization. One common aspect of context frequently used is the location of entities, which includes both spatial and temporal information to be used during process execution.

To employ an entity's location as contextual information during the execution of a business process, we first need to acquire current location data. Fortunately, the Internet of Things (IoT) and other advancements in networking and technology have led to various techniques for object localization.

These physical locations can be categorized into three distinct types [25]. For real-world BPM applications focusing on distributed mobile processes, we can primarily focus on the first two⁵:

- *Descriptive Location*: These locations are characterized by descriptive names or numbers and are typically associated with well-defined natural or human-made geographical objects.
- *Spatial Location*: These locations are explicitly represented within a coordinate system, commonly either two-dimensional (latitude and longitude) or three-dimensional (latitude, longitude, and altitude).

Upon acquiring location data, processing it to extract meaningful insights from the various data points becomes

⁵ The third category pertains to a location within a communication network (*network location*), which is less relevant for real-world appliances

necessary. Depending on the type of location data, an initial transformation is required to enable mathematical calculations. Geocoding serves as a tool to facilitate the conversion between spatial and descriptive representations. This process relies on lookup tables that contain mappings between addresses and numerical representations. It is important to note that the transformation from spatial to descriptive representation inherently involves a loss of precision, especially in large company premises with multiple buildings sharing the same official address but having significantly different spatial coordinates. Depending on the specific needs, there are also descriptive location descriptions available that do not rely on regular addresses and can overcome shortcomings for large premises or unserved land or forests, such as *What3Words*⁶ or *FixPhrase*.⁷ Both of these services rely on the same fundamental concept: the division of the surface of the earth into fixed small areas that are uniquely identifiable (3×3 meters for What3Words or approximately 10×20 meters for FixPhrase) and the subsequent provision of a service to geocode the addresses of these alternative address systems back to latitude and longitude. This transformation enables comparability between values, using mathematical formulas and calculating distances, making it more suitable for computational purposes. On the contrary, descriptive locations are human-readable, straightforward to remember, and comprehensible.

This duality of representation should be considered when utilizing location data with human actors. Depending on the specific requirements, any application must be capable of supporting both descriptive and spatial representations to accommodate the data consumer's needs.

Even after transformation, a single numerical data point alone is insufficient for direct utilization within a business process. The meaningful analysis typically requires at least two data points containing a combination of two distinct entities, locations, or timestamps. Combining these data points allows us to derive meaningful insights and understand the context of the entity's actions. The subsequent section will formally describe various location operators, assuming the availability of two data points for analysis.

3.1 Location data collection

There exists a multitude of various methods for technologically locating objects, extensively described in [25, 50–52]. Three distinct methods for localization can be distinguished:

1. *Presence*: This is the simplest and least accurate method to determine whether an object is present.

⁶ <https://what3words.com/>

⁷ <https://fixphrase.com/>

2. *Positioning*: This method aims to identify and locate objects accurately.
3. *Proximity*: This method falls between the other two, aiming to determine presence and location, which depend on each other.

In Table 2, a non-exhaustive compilation of existing location technologies is provided, along with associated techniques and parameters, including range, accuracy, cost, and energy consumption. Notably, many currently available technologies and techniques exhibit drawbacks, encompassing challenges related to cost and energy consumption, as well as complexities and scalability issues.

These techniques are accompanied by several additional developments and specificities, meaning this list should be regarded as an overview of possibilities. Further comprehensive descriptions and explanations can be found in the above sources and other sources for those seeking more detailed insights into the inner workings of different technological approaches and techniques.

Depending on the technology chosen, subsequent steps must be taken to access the collected location data in a machine-readable format, which can then be processed in the next step.

3.2 Location data processing

After collecting and storing the locations of relevant entities, our focus now shifts to determining how to utilize these different locations effectively. The first step in CEP would be to process the incoming data and generate events from them, which can be used in a different system. However, because location information is needed, other challenges of IoT data, like a sub-second frequency or overwhelming data, are less relevant when dealing with location data. Depending on the used source for the data, we can already filter, thereby only updating the location if it changes. For our application and the use of location, we can directly use currently available data without preprocessing it.

Drawing from the patterns presented in [13] and related literature, as exemplified by [53], which will be elaborated upon in Sect. 4, we have identified various operators essential for incorporating location in BPM. We introduce spatial and temporal operators to form a foundation for these patterns. The spatial operators bear a resemblance to those introduced in [36], which contains concepts for two explicit distance patterns, an *extreme distance pattern* (where one entity is either the nearest or farthest from another entity) and an *exact distance pattern* (which binds the current distance to a variable).

For the following patterns, we need different operators that we can use for each of them. They can be mainly split into two categories: *temporal-independent spatial operators*, where we select one entity from a list of entities based on their

Table 2 Comparison of different techniques for localization

Technology	Technique	Positioning	Application area	Range	Accuracy	Cost		Terminal/tag	Operation	Energy-usage	Scalability	Complexity
						Base-station						
Barcode	PS	R	I	10 m	1 cm – 10 m	●		○	○	○	●	○
Infrared	PS	R	I	5 m	1 cm – 5 m	○		○	○	○	●	○
RFID	PS	R	I	0.5 – 10 m	1 – 5 m	●		○	○	○	○	○
NFC	PS	R	I	10 cm	1 – 5 m	○		○	○	○	○	○
WiFi	PM	R	I	on the network (< 100 m)	1 m	○		●	○	○	●	○
BLE	PS	R	I	10 m	0.5 – 2 m	○		○	○	○	●	○
UWB	A	R	I	50 m	0.5 m	○		●	○	○	○	○
LPWAN	PM	R	I/O	on the network (< 40 km)	1 m	●		○	○	○	○	○
Radar	A	R	O	1000 km	15 m	●		●	○	○	○	○
cellular	PS	A	O	worldwide	50 m – 1 km	–		○	○	○	○	○
sensor-based	PM	A	I/O	on the network	10 cm – 1 m	●		○	○	○	○	○
visually	PM	A	I/O	–	1 cm – 1 m	○		○	○	○	○	○
GPS/GSM	PS	A	I/O	worldwide	6 – 10 m	–		○	○	○	○	○

Rating: ○ : low, ● : medium, ◎ : high, ● : very high

Techniques: A: Angulation, PS: Proximity Sensing, PM: Pattern Matching

Positioning: R: Relative, A: Absolute

Application area: I: Indoor, O: Outdoor

current location, and *temporal-dependent spatial operators*, where we examine one single entity and check for noteworthy events and its movement over time.

Consider the following sets: $\mathcal{E}$ representing the positions of all possible entities involved in a process, divided into static ($\mathcal{S}$) and dynamic positions ($\mathcal{D}$) with $\mathcal{E} = \mathcal{S} \cup \mathcal{D}$ and the set $\mathcal{A} \subset \mathcal{D}$ representing the positions of actors and let $f_d(x, y)$ be any distance function that returns a distance⁸ between locations x and y .

Temporal-independent Spatial Operators

- To find the *minimum distance* between the location of any one entity and the location of another entity $e_1, e_2 \in \mathcal{E}$ with $e_1 \neq e_2$, you can use the following expression:

$$\min f_d(e_1, e_2) \quad (1)$$

- Similarly, to find the *maximum (longest) distance* between an entity's location and all other entities from $e_1, e_2 \in \mathcal{E}$ with $e_1 \neq e_2$, you can use:

$$\max f_d(e_1, e_2) \quad (2)$$

These expressions represent the minimum and maximum distances, denoted as $d_{\min}$ and $d_{\max}$, respectively, between all current locations entities $\mathcal{E}$ and the location of exactly one entity $e \in \mathcal{E}$.

Temporal-dependent Spatial Operators The calculation of whether an entity is inside or outside of a geofence is independent of the actual distance function here (this is mainly the case for geofencing, where we draw a circle or polygon around a location and want to check if an entity moves inside or leaves the area). We can either use the distance around a specific location as a threshold, leading to $i(x, y)$ being the result of the location update (making the geofence a circle), or more proficiently use the ray-casting algorithm that can be used for arbitrary polygon geofences, and returns whether or not a point is located within a polygon.

$$i(x, y) := f_d(x, y) \text{ op } d_{\min}$$

$$i(x, y) := \text{boolean interrelation between } x \text{ and } y$$

where

$$\text{op} \in \{<, \leq, =, \geq, >\}$$

The *location update* describes the fact that the location of an dynamic entity $d \in \mathcal{D}$ changed at least/exactly/at most

⁸ Different distance metrics can be calculated or queried (e.g., as-the-crow-flies, driving distance)

$d_{\min}$ between $t - 1$ and t .

$$f_d(d_{t-1}, d_t) \text{ op } d_{\min} \quad (3)$$

To accurately detect an *entity entering a geofenced area*, both of the following conditions must be satisfied:

- The first condition ($i(d_{t-1}, e_{t-1}) = \text{false}$, with op being $<$) ensures that the entity a was initially located outside the geofenced area just before the time interval t . This condition is necessary to prevent false positives where the entity is already inside the geofence at the beginning of the interval.⁹
- The second condition ($i(d_t, e_t) = \text{true}$) confirms that the event has indeed entered the geofenced area at time t . This condition is essential to validate that the event has crossed the geofence boundary during the specified interval.

Thus, we can define the enter geofence operator as follows:

$$i(d_{t-1}, e_{t-1}) = \text{false} \wedge i(d_t, e_t) = \text{true} \quad (4)$$

Similarly, to detect an *entity leaving a certain area*, we reverse the truth values. a is inside the geofence at time $t - 1$ and outside of it at t . Meaning:

$$i(d_{t-1}, e_{t-1}) = \text{true} \wedge i(d_t, e_t) = \text{false} \quad (5)$$

Using those operators, we can concisely express different operations using the location of entities. For example, the specific elements referenced in [53] can also be expressed using these operators. The operator *position achieved* is the inequality $f_d(x, y) \leq \varepsilon$ (with ε being a small positive number, optimally zero), *position update* can be expressed using the operator above, and the *conditional position* is entering or leaving a geofence each for $a \in \mathcal{A}$ and $s \in \mathcal{S}$.

4 Patterns for location-aware business process execution

The following sections present different possibilities for using spatial information within executed business processes and how it can influence the execution of mobile distributed processes. These patterns generally describe the use of location in business processes. To facilitate comprehension and to make the abstract patterns more accessible, we align the patterns directly along commonly known elements and

⁹ While it may not be practical to define a geofence around a moving entity (d), we do not impose restrictions on the operator solely using static or non-changing locations (s)

Table 3 Patterns for the use of location-based information in executed processes

Conceptual use	Task	Involved BPMN concept			
		Gateway	Boundary event	Single-instance	Multi-instance
Automatic start of process instances	○	○	○	●	○
Decision making through location-based data	○	●	○	●	○
Location-based task allocation	●	○	○	●	●
Location-based monitoring of tasks	●	○	●	●	●
Location-based event dispatching	●	○	●	●	○
Location-based automatic completion of tasks	●	○	●	●	○
Location-based automation of tasks	●	○	○	●	●
Location-based worklist reordering	●	○	○	●	●
Location-based constraining of execution	●	○	○	●	●

paradigms of BPMN [18] (for a short introduction on the basics of BPMN, see Section A). Nevertheless, the patterns are agnostic to the process modeling standard or paradigm and even more so to the implementation of the execution engine.

Using a BPMS, the task's execution can be automated and supported by IT. At the same time, a business process model describes the schema of a process; typically, different instances of any process run concurrently. While most of the focus of research and implementation support is on executing and optimizing single instances ("the process model as it is"), looking at multiple concurrently running processes leads to a completely different set of restrictions, and the interplay leads to other possible synergies that are not depictable in standard process models.

Table 3 shows a non-exhaustive list of the identified conceptual uses for location-aware business processes together with a classification of BPMN patterns that we will explain in more detail in the following sections. The following table also differentiates between single-instance and multi-instance, the first including patterns that can be used on a single execution instance of a process. In contrast, the latter implies the existence of at least two process instances (multi-instance), as described above. Utilizing or integrating location data within a task or facilitating its execution constitutes another use of such data. However, it is essential to note that location is just one component within a more extensive collection of necessary or utilized data points compared to the other patterns, which will be mentioned in Sect. 4.10.

4.1 Location-based automatic start of process instances

Location data can be used to start process instances automatically, e.g., starting an externally modeled process for a specific task when an actor arrives at a specific location. As explained above, primary context information, i.e., the sin-

gle location of an entity alone, is insufficient to start a new process instance. Only when the location of at least one other entity or a different location for the same entity is available can metrics be calculated to initiate a process instance, e.g., the event distance location with the place of fulfillment for the job being the event, meaning, we need at least two different data points to use our operators. Fundamental to that is the availability of location data outside the bounds of the process instance for all involved entities.

Depending on the calculation of the used metric, logic is required to be included within an event start (in BPMN: a conditional start event), meaning that the calculation has to happen "outside" of the process instance's lifecycle, implying that the start of the process instance is not bound to the BPMS but has to be triggered externally. The triggering event of a process could also be modeled as part of a message start event, relying on the viewpoint and the modeling choice, thus losing semantic information during the modeling. Coming back to the presented context levels of [25]: spatial information of the involved entities are primary data, as they are gained from sensors (or more specifically mobile IoT devices) and cannot be used by themselves, whereas the distance between two entities is derived, thus secondary context, and can be used to start a process instance.

4.2 Decision making through location-based data

Decisions are a fundamental aspect of any modeling language and enable the structuring of the process by influencing the process flow [1]. Decisions can be implemented in all parts of the system architecture depending on the frequency and availability of required location data. These decisions range from using an expression that gets evaluated directly within the BPMS to employing lifecycle hooks and execution listeners attached to the BPMS. Alternatively, decisions can be deferred to the middleware or processed as a stream using CEP, thus closing the abstraction gap between IoT data and

human-executable processes while incorporating all three spatial context classes.

As the most basic concept, decision-making based on location information is the most general application. Every conceivable data point can be included in a business process decision. Depending on the level of sophistication, decisions can be made at a basic level using the operators above for simple decisions or incorporated into larger decision tables where the location of an involved entity is just a tiny part.

4.3 Location-based task allocation/assignment

Another noteworthy pattern involves allocating or assigning one or multiple actors to an activity or subprocess. While the terms *Allocation* and *Assignment* may initially appear synonymous, their usage has been distinguished in the previous literature. Various authors have coined their definitions for these terms, sometimes exhibiting overlaps or contradictions. For this discussion, we will employ the term "allocation" to signify assigning a specific task to a single actor during the process execution. Conversely, "assignment" encompasses a broader scope, encompassing candidate users and groups during process modeling and programmatically filtering and modifying them during process execution.

It is important to note that allocation establishes a direct connection between a single actor and a given activity or subprocess. At the same time, an assignment can result in none, one, or multiple candidates being associated, independent of the current process status. However, both activities address the interaction between actors and activities and will be jointly explained.

A task allocation to a process participant specifies the responsibility for a single task or a group of tasks to a concrete user. During process modeling, tasks can get assigned to a particular user group whose members are candidates for execution, meaning the allocation happens deferred during the process execution [1, 54]. Although earlier approaches considered the use of location data for process models (cf. Section 2.2), the research gap of allocating concrete users to tasks based on location data has been neglected.

The realization of a location-based task allocation is primarily a task of a smart cross-system implementation. Let us explain this directly using a small application scenario: Imagine a crafts business where exactly one actor is working at one customer location for one specific process instance; this subprocess of concrete manual work starts with the allocation of the current process instance to exactly one worker. The start of the tasks triggers either the calculation or querying of distances and the allocation itself. Because the BPMS itself does not store real-time data and because of the separation of the backend and the data-handling middleware, the BPMS has to either actively get the information or delegate the task to the middleware. Depending on the actual need,

both possibilities are feasible. Even more, we can either try to get the current location of all possible entities by directly querying the sensor and using the most current stored data as a fallback or solely rely on the most current known location. After calculation, a list of distances with unique identifiers for the corresponding actors is returned, which needs to be sorted and then used for the allocation. All possible logical expressions/operators can be applied to the data based on the locations and the application area.

One significant issue must be addressed is the allocation or assignment span, also known as the allocation lifecycle. Depending on the process and the modelers' needs, this pattern has to include a possibility of involving more than just one task visually and in the implementation. For this reason, both a single task and a subprocess, including multiple tasks, can be used for allocation and assignment. After the task or subprocess is finished, the used actor is available again, and all relations are removed.

Ultimately, the allocation gets sent to the BPMS, including the current distance to the target location, which can then be used further to support the actors and increase the transparency of the allocation process. Depending on the actual implementation and the BPMS choice, we can either explicitly model the allocation/assignment as a script task or append it to the lifecycle of a complete subprocess (again, for BPMN, cf. [12]). As in decision model and notation (DMN), where the goal is a decision between multiple process flows [55], the allocation of a single actor to a task based on location data can be understood as a Boolean decision for one and against all other actors, whereas the assignment filters the candidate users for a task or list of tasks.

4.4 Location-based event dispatching

Following the classification of spatial context data from [26], we can divide all events that occur during the execution of processes into three classes, which then can be used during process execution to react to them and trigger additional functionality in the process. Based on the operators above, we can define different events that can occur during the execution of a task based on the locations of the involved entities. One crucial possible application is the use for notifying customers or actors based on the current location of an entity (e.g., a worker driving to a customer, where a new task is triggered when the worker enters a certain distance around the customer or automatically dispatching the refilling of resources when the supplier dropped them off at the facility).

Within BPMN, the supervision of tasks is conceptualized with the use of boundary events so that different reactions to events occurring during the execution of a single task can be modeled [1]. These events can split the process flow while executing a single task or subprocess. BPMN defines conditional non-interrupting boundary events to trigger a separate

flow based on a condition happening while one task is executed [18], which spatial data can enrich.

4.5 Monitoring process execution

The inclusion of spatial information also eases the monitoring of process execution, improving transparency by displaying all involved entities on a map and visualizing the physical environment where tasks are going to be performed, including the temporal properties of the process instance [34]. Furthermore, multiple instances running in parallel, including current and historical data, could be used to calculate the median execution time of a single task or a group of tasks or the maximum distance traveled to a customer among the most recent n jobs. In addition, the quality of task execution can be enhanced by providing the current location data of all participating entities to mobile task workers. The display of all involved entities on a map offers a visualization of the physical environment where tasks are going to be performed that includes temporal properties of the process instance [34], represented by the current position of an actor with a possible trail to show the path taken.

Conceptually, either the BPMS or the middleware has to keep calculating the distance of the allocated actor to the customer's location in the background and either push the result as a process variable to the BPMS or periodically evaluate the given expression. Depending on the company's needs, a fitting granularity of updates and data accuracy has to be chosen.

All in all, because spatial data are nothing more than contextual information, its use for monitoring the execution of processes can lead to improved transparency and show possible areas of improvement for the following improvement of the processes (business process improvement (BPI)).

4.6 Location-based automatic completion of tasks

The process flow defines the fundamental sequence of all parts within a process model, where each element (excluding the start and end events) has at least one predecessor and one successor [1]. Upon the completion of an element, all directly connected elements in the model are triggered. This process can also be automated using location-based data. The update frequency and the accuracy of the location information influence the precision of automatically completing the current task and proceeding to the following flows. It is important to note that user tasks are not automatically executable in a BPMS and, therefore, do not implement any logic [1]. However, BPMSs typically provide lifecycle hooks as listeners that can be used to execute logic when specific states of the task's lifecycle, such as *create*, *assignment*, or *complete*, are reached.

Compared to dispatching events using location data, we automatically finish one task in this approach, triggering the following tasks. When the first task splits the process flow, and the base task is not finished due to the non-interrupting nature of the boundary event, using the task's lifecycle allows us to complete tasks based on the location of involved entities. While implementing the latter approach requires decisions and calculations to be made outside of the BPMS, for the former approach, expressions can be evaluated within the BPMS itself.

4.7 Location-based automation of tasks

Location data can enhance the execution of tasks that have to be done by a human but can be supported by technology (user tasks in BPMN) and can be used to completely automate non-value-adding tasks like the documentation of work and support tasks for value-adding processes. Due to the simple fact that most BPMS typically save records of historic execution data, this information can be used on a multi-instance basis to calculate and verify metrics like start and finish time, as well as custom location-specific data of tasks like comments made by field workers for specific entity locations (Imagine a heating engineer storing location-specific information assigned to one customer). These comments can be used to support location-based information for future projects. Within our running example, the last task is creating an invoice that can be automated or supported using the execution times of the current process instance tasks split into time driving and working on-site at the customer, simplifying and automating the billing process while removing non-value-adding documentary work.

Beyond the benefits mentioned above, location-based automation can also improve workforce management. For instance, real-time tracking of field workers' locations allows for efficient dispatching, ensuring that the nearest available technician is assigned to a job, minimizing response times, and improving customer satisfaction (as already explained in Sect. 4.3). Moreover, the integration of location data can lead to predictive analytics. By analyzing historical data related to task execution times at specific locations, businesses can forecast future workloads more accurately, enabling proactive resource allocation and optimized scheduling (see Sect. 4.6). This predictive capability streamlines operations and aids in budget planning and resource allocation, ultimately contributing to cost savings and improved operational efficiency.

Furthermore, as mentioned earlier, utilizing location-specific comments can play a pivotal role in quality assurance and customer engagement. These comments can be analyzed to identify recurring issues or customer preferences associated with particular locations. This valuable information can guide process improvement initiatives and allow businesses

to tailor their services to specific customer needs, ultimately leading to higher customer satisfaction and loyalty.

4.8 Location-based worklist reordering

Taking a step back from a single executed process instance, location-based information can also be used to reorder the work list of an actor based on location information, e.g., the actual distance of a process participant to the point of interest like a customer location, i.e., entity and possibly event distance location. In contrast to the concept of work list reordering in [56], which investigates the influence of random reordering tasks on overall temporal performance based on historical data, recommender systems can be used in combination with BPM to build suggestions for the next task to be executed by a human actor. Following this approach, any metric calculated based on an actor's location or a combination with other metrics can be used to rearrange tasks within a work list of a specific user. [39] have already touched on the topic within their local resource management, adding the work preferences of human resources and application-specific resource types and states to a decision matrix while differentiating between filtering possible tasks or prioritizing them. Within the running example, imagine multiple open jobs, i.e., tasks from different process instances, at different customers yet to be allocated to a single actor. Each available actor gets a list of those tasks on their mobile user interface sorted by distance to the corresponding jobs and can then choose their next task based on this information.

Compared to allocation and assignment, this broader perspective enables organizations to dynamically allocate tasks to actors based on proximity to customers and other strategic considerations, such as optimizing resource utilization or minimizing transportation costs. Furthermore, integrating recommender systems and BPM opens avenues for intelligent task allocation. Organizations can leverage historical event logs and machine learning algorithms to provide actors with task recommendations that align with location-based metrics and individual preferences. This personalized approach can result in improved task execution times and enhanced user satisfaction.

4.9 Location-based constrained execution

One of the most common patterns in earlier research (as seen in Table 1) involves explicitly constraining the execution of specific tasks within a business process. This constraint ensures that individual activities must or must not be performed at specific locations. These constraints can be categorized as direct or indirect, as defined by [33]. Direct constraints are known and established during the modeling phase of the process, while indirect constraints are dynamically evaluated at runtime.

In practical terms, the constraint mechanism we have discussed can be a powerful tool. For example, with the right business process management system (BPMS), you can maintain a list of all entities already participating in the process instance. This list can then be used to restrict their future involvement, essentially creating a "deny list" of actors for specific activities. This approach is an extension of the earlier pattern of assigning a task to an actor based on a deny list but with the added refinement of further reducing the candidate group not only by distance but also by considering "has already worked on" criteria.

However, it is crucial to note that while the patterns introduced earlier are independent of the actual implementation and rely solely on essential BPMN elements and functionalities, back-referencing to earlier tasks is not a standard feature of BPMN. This can lead to implementation dependencies and requires careful consideration when designing location-based constraints in processes.

4.10 Other uses of location data in business processes

As explained above, location data can also be part of a bigger collection of data points within business processes. The focus of the patterns here is on the direct use of location data to influence the flow of processes, which could also result from using location data within a task.

Within single tasks, the use of location data is possibly endless, from personalizing marketing and sales campaigns where the customer's location is used in combination with their preferences and behavior to tailor more relevant and timely promotions to improving travel and tourism services by providing recommendations or enabling location-based payments and transactions for preventing fraud and enhancing security by using the customer's location and their usual location.

Comparing those approaches, we can quickly identify a difference: While the above patterns primarily focus on executing tasks, other uses focus on modeling, analyzing, and improving the structure and logic of process models.

Consider the conceptual implementation of location-based task allocation. This approach allows the process model to dynamically assign or allocate actors to tasks based on their geographical position rather than relying on static or predetermined assignments. This dynamic allocation can significantly enhance process execution flexibility and efficiency, potentially boosting actor satisfaction and motivation. This innovative use of location data in business processes can inspire new ways of thinking about process management.

As mentioned in the related works part, augmented process modeling includes spatial information combined with processes. Compared to the above patterns, this almost always implies the need for additional tools or services. Here,

for example, we can display the actual fulfillment location of tasks on a map, transforming the classic tasklist into a task map and improving the visualization of the link between multiple tasks that the same actor may execute. Another possibility could be to include virtual and augmented reality or mobile devices to provide needed information based on the current location of the actor. This information can include currently open tasks for a specific location (e.g., workspace or construction site) or specific data (e.g., all current sensor values for the machine in front of an actor or contextual information for a customer's location).

Finally, another conceptual use of location can be for personalizing marketing and sales campaigns. This approach allows the process model to incorporate location data to tailor the content and timing of the campaigns to the customer's location, preferences, and behavior. The potential benefits are significantly improved effectiveness and relevance of the process outcome and enhanced customer loyalty and retention. This use of location data in business processes offers a promising avenue for improving customer relationships.

5 Extending BPMN for location awareness

In the following section, we describe an approach for BPMN specifically as an exemplary modeling approach for the actual use of the conceptual patterns for the use of location information in business processes. For this, we introduced a BPMN extension for location-awareness in [12]. Using the guidelines in [57], we deliver the missing piece by extending the BPMN metamodel to enable a visual and understandable implementation of said patterns. The extension for location-aware BPMN (LABPMN) contains three main elements: *location data objects* (referring to the used locations), *location events* (all different standard types of event (throwing, catching, interrupting, non-interrupting) but for the explicit use with location—based on the operators described earlier), and finally an extension for *subprocesses and tasks* for dynamically assigning and allocating actors to a task based on their and the task's current location.

Using those BPMN elements, we can model all the patterns presented above to correctly represent the functionality within the process model itself. The extension of the BPMN metamodel to explicitly include location awareness and specific elements itself needs a complementary implementation based on a BPMS and a possibility to model said elements.

Providing the extension for BPM includes extending the BPMN metamodel conceptually and graphically while extending the BPMS core functionality to keep the process model executable. The Internet of Things is a pivotal enabler for new approaches to using contextual information in business process modeling and execution while relying on the de

facto standard BPMN, which enables the correct depiction, transparent execution, and use of data.

6 Visibility and interaction of location data

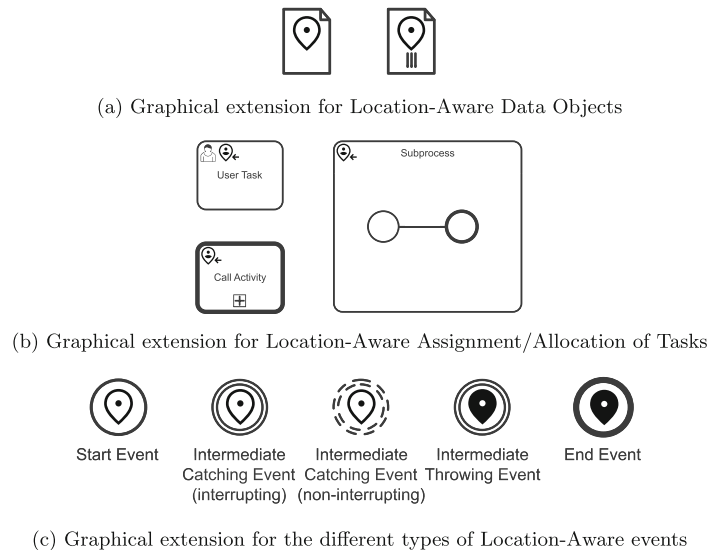
Between identifying and presenting the different patterns for the use of location data for BPM and a short introduction of the implementation, we integrate the presented patterns into the well-established data patterns defined in [14]. This integration helps explain how data can be used and exchanged, which is a fundamental step in bridging the gap between conceptual solutions and prototypical rational implementations.

Within the context of BPM, data points from various sources can be defined, stored, and utilized at different levels. Values can be made accessible within a defined part of the process or at any point for every element of the process. The precise specification of the scope and visibility of the data is crucial for addressing existing problems or adhering to best practices, such as managing limited resources, managing traffic, ensuring security, and addressing privacy aspects [58] related to IoT devices and their use while optimizing data handling within the BPMS.

The different classes described in Table 4 show the visibility of the data within the BPMS, ranging from the most specific (task data) to the most general use of the data (environment data). Minimizing network traffic and efficiently managing data requires consideration for the implementation. For instance, when creating an invoice for a customer, access to the execution time of the current process instance's tasks is essential. However, these data will no longer be needed once the invoice is created. On the other hand, customer information, such as their location, should be implemented as folder data since a single customer could require multiple repairs and thus be associated with multiple process instances; not saving these data for future tasks is not practicable in the long run. However, data utilization and handling often depend on specific implementations, system architectures, and the current process, making it challenging to provide further conceptual descriptions beyond their given definitions in [54].

Furthermore, [54] defines various patterns for external data interaction, primarily distinguishing between push and pull communication. Push communication involves variables within the processing framework (e.g., IoT middleware) that are saved and can be processed into events. These events are then pushed into the BPMS, where they must be referenced within tasks. In this scenario, the processing framework sends data to a specific task, case, or workflow without explicitly requesting it from the BPMS. To illustrate, when a task becomes active, the middleware transmits data at regular intervals or when the value changes to the BPMS. This approach can reduce processing time and latency, as the data

Fig. 3 Graphical representation of all elements added to the BPMN meta model



are immediately available for processing. However, it may result in the transmission of unnecessary data.

In contrast, *pull communication* operates vice versa; the BPMS actively requests data from the middleware when needed, such as for making decisions or using it within a service task. This approach can result in longer processing times if the middleware waits for the BPMS to request data before transmitting it. The trade-off between push and pull communication must be carefully considered for each scenario to minimize network traffic while ensuring the necessary responsiveness, especially considering the limited resources in IoT devices. It is also essential to consider the relevance of the data: not every sensor value or processed event is required for every process component.

The visibility types defined above and their use for the patterns vary greatly depending on the choices. While some exemplary location-dependent data points seem easy to categorize, many can be used differently depending on a company's needs, the available data, and the chosen method of implementation (both the implementation itself and the deployed and used BPMS).

7 Implementation

After presenting the patterns for using location and a brief overview of its potential applications with BPMN, the objective is to establish a fully executable and system-driven approach based on location data using existing standard

process management technology. This section outlines the system architecture based on Business Process Management (BPM) and the frameworks involved in a prototype implementation.

In order to make use of the different patterns, we developed a multi-level system architecture for integrating contextual location information in BPM (Fig. 4). With this approach, we can enhance process execution by utilizing location data from mobile devices used by individuals involved in the process. The implementation also provides real-time information on current tasks that need to be performed and includes a back-office application that offers contextual information about actors, customers, and other process-related resources. This tool is an initial approach to dynamically adapt mobile applications for individuals working at different locations solely based on the modeled and executed business process.

The backend employs a conventional layered model-view-controller (MVC) architecture with Spring Boot¹⁰ as its technological foundation. It offers a REST interface for the mobile application and HTML web pages for human users. These interfaces support common use cases, including storing and retrieving tools, locations, projects, and user tasks. For data storage, we use a SQL database (PostgreSQL¹¹) with a geographic data extension (PostGIS¹²). To accommodate a wide range of mobile devices (Android and iOS, with the

¹⁰ <https://spring.io/projects/spring-boot>

¹¹ <https://www.postgresql.org/>

¹² <https://postgis.net/>

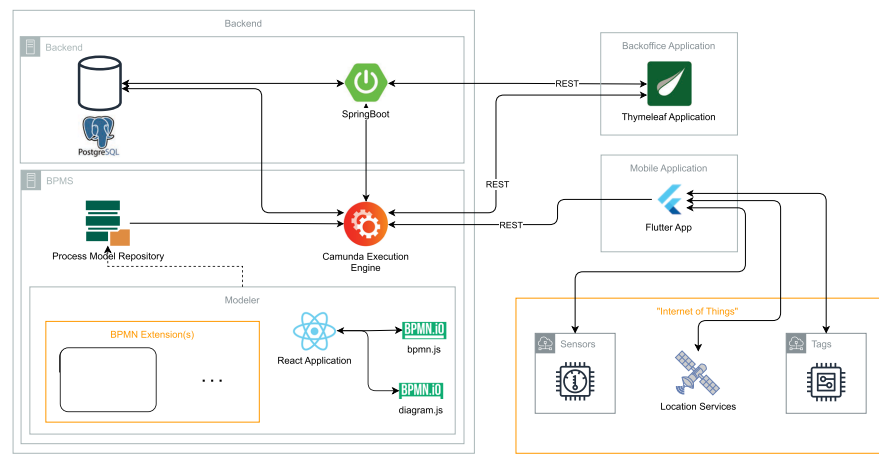


Fig. 4 Software architecture for the use of IoT data in BPM

option of deploying as a web application) and enable access to native device features such as Bluetooth communication and location services, we have opted for Flutter as the mobile development framework.

The first application is based on the BPMN extension published in [12]. The implementation of the modeling aspect of the extension is built upon the open-source implementation *bpmn.js*,¹³ which seamlessly integrates with BPMS. Camunda is responsible for executing the process model and providing the necessary logic.

The various introduced elements can be selected either directly from the context menu or after assigning a specific location-aware event type or distance type to the element within the properties panel (see Appendix Section B, Page 41).

To enhance efficiency and effectiveness in process execution, we also provide a mobile application for actors responsible for carrying out the tasks of the business process (Fig. 5). This application includes functionalities such as accessing current tasks (both assigned and unassigned), initiating and completing tasks, accessing attached forms, and working with them. It also supports initiating process instances and provides easy access to the actor's current location through the mobile device's geolocation services. Additionally, it can connect to other IoT devices, such as reading sensor values or accessing Bluetooth Low Energy (BLE) tags. Next to mobile devices like smartphones, tablets, and smartwatches, because of the standard implementation approach, all different kinds of devices could be added as

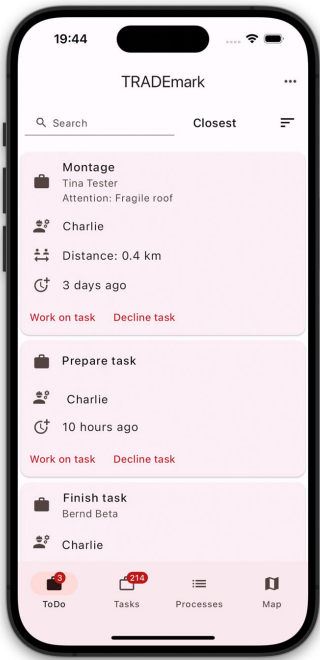


Fig. 5 Mobile application showing currently available and assigned tasks sorted by current distance, including customer-specific context information

¹³ <https://bpmn.io/toolkit/bpmn-js/>

Table 4 Data patterns defined by [14] and exemplary data depending on location

Visibility type	Definition of data visibility	Exemplary location dependent data
Task data	Within the context of individual execution instances of specific tasks	Time spent on-site for equipment maintenance at various customer locations
Block data	Within all components of corresponding subprocess	Geographic coordinates of all tasks within a field service subprocess
Scope data	By a subset of tasks in a case	–
Multiple instance data	Tasks that are executed multiple times within a single case with instance-specific data	Distance traveled for each delivery task within a logistics case
Case data	Specific to process instance (case)	Location-specific details for project milestones in a construction project
Folder data	By multiple cases selectively, accessible to all bound cases	Regional distribution centers accessible to multiple logistics cases
Workflow data	By all components in every case of the process ("process context")	Availability of on-site staff for emergency response across cases
Environment data	Data elements existing in the external operating environment	Real-time traffic conditions affecting delivery routes

data sources (e.g., single-board computers (SBCs) with SIM cards or network connection).

The backend comprises the BPMS (in this case, Camunda¹⁴), a Spring Boot application that integrates and manages all components, and the mandatory database. This component provides access to all standard BPMS features and extends its functionality with location-specific features. This includes displaying the customer locations and the current locations of items such as tools on a map (Fig. 6). It also supports the incorporation of additional contextual information for existing customers.

After modeling the location-aware process using the included modeler, we need the BPMS to access the process model. Because we extended the meta-model of BPMN in our location-aware extension, the business process model adheres to the standard XML format and could be used with a different BPMS, provided there is an implementation for the location-aware events. After providing the necessary parameters, such as event type, candidate user/group, and geofence areas (depending on the patterns used), we can use BPMS (in this case, Camunda) or mobile application to initiate a new process instance as usual.

Depending on the deployed process model, the next step involves providing access to various location information. This could involve including a database with known customer locations or accessing third-party data through a standard interface. In the implementation presented here, all expressions are evaluated within the BPMS, meaning that all operators are implemented within the BPMS itself. However, for real-world applications, additional components could be considered. For example, middleware for preprocessing and collecting data could be added, and another system could be used to outsource the required logic. This could reduce the computational load on the BPMS, especially for complex calculations.

The implementation follows the well-established data patterns described in [54], which explain the usage and exchange of data in implementing process models. These patterns are a fundamental bridge between conceptual solutions and well-reasoned prototypical implementations (see Sect. 6).

Following this basic implementation of the presented patterns, in [12], we develop a BPMN-extension for location-awareness (*LABPMN*, cf. Section 5) that substitutes the used script tasks by metamodel-conform extension elements without changing much of the application visible to the user. In [59], we provide a short overview of the updated implementation of the BPMN extension by extending the modeler and implementing support for the execution in a BPMS. Coming back to the formal description of the spatial operators (cf. Section 3.2), Fig. 11 (Page 41) shows the added parameters needed for the execution that were previously hidden from

¹⁴ <https://camunda.com>

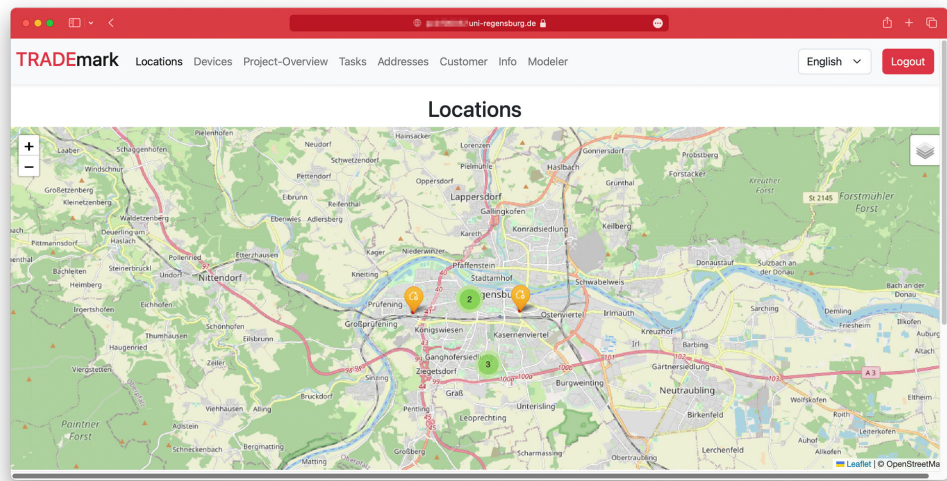


Fig. 6 Back-office application showing customer locations and the locations of current construction sites, the foundation of location handling, and deeply integrated with the BPMS

the modeler as well as process executors in the tasks getting automatically executed by the BPMS.

Besides better support and more precise visual depiction of the use of location data within the process model (a location event that is attached to a task is more expressive than a generic signal or conditional event and explicitly implies the use of location data or the allocation of a task to an actor, where the reason for the allocation is directly visible within the process model), using LABPMN as an exemplary implementation for the use of presented patterns also enables more specific handling of, for example, the allocation. Here, a sub-process element in BPMN can be used to control and depict the allocation duration.

8 Location-aware business process applications

This section thoroughly evaluates the proposed patterns by examining their applicability in four distinct real-world application domains. The first three provided use cases are actual processes from our research project currently used in operational business and are only slightly adjusted for academic publication. At the same time, the last one is adapted from [15] to show the transferability and generalizability to different application areas (here: emergency services). Our analysis encompasses the following scenarios:

1. *Conventional repair process employed by a crafts business*
The first application scenario demonstrates the effectiveness of the proposed patterns in a conventional repair process. The evaluation showcases how these patterns enhance the operational efficiency and adaptability of the repair workflow within craft businesses, where tasks are allocated based on the customer and actor's location, and additional information is provided based on historical data on the customer's location.
2. *Delivery of important objects between branches of a company*
In the second scenario, we delve into a use case involving the surveilled delivery of objects between the branch and the main office of an industry partner. Here, the incorporation of the current location of the parcel and additional sensor data into the operational framework is critical for traceability and documentation.
3. *Rental process enhancement through location information*
The third scenario demonstrates the use of location information to enhance the rental process in a crafts business. In this case, the customer can automatically obtain and return their device without requiring personnel from the company. This improvement improves customer satisfaction and ease of use by automating and supporting the complete process based on the device's location.

4. Emergency Incident Management

The last scenario uses the process for incident response management in [15]. Similar to the previous processes, the distributed character of the process, in which an ambulance gets dispatched and drives to the patient, already implies the high importance of location data. Both the decision for the type of needed service and the allocation of the emergency to one (or possibly multiple) emergency units include location data. Different regulatory requirements demand regular documentation of the current status, and depending on the location, the central call center can treat the patient accordingly.

The following cases illustrate a diverse range of industry-specific scenarios, demonstrating the versatility and effectiveness of the presented patterns. Each scenario demonstrates the patterns in action and provides a unique implementation perspective, shedding light on their architectural utility. DSRM requires knowledge to be generalizable and transferable, which we will show with these location-aware processes. We classify the different applications according to the used *technology* (cf. Section 3.1), the applied *operators* (cf. Section 3.2), and the included *patterns* (cf. Section 4).

It is important to note that the last two patterns, worklist reordering, and constrained execution, are not explicitly incorporated into the following exemplary applied processes. Worklist reordering is based on considering different parameters from multiple concurrently running instances and is thus not easily depictable within a singular process model. Similarly, constrained execution and augmented process modeling approaches, although applicable to location data, face visualization limitations within standard BPMN elements. Consequently, implementing these patterns must be separated from the business process management system (BPMS).

8.1 Location-aware repair process (P1)

Technology: BLE-Tags, Cellular, GPS

Operator: Minimum distance, geofence, location update

Pattern: Decision making, task allocation, event dispatching, process monitoring, automatic completion of tasks (implied worklist reordering¹⁵)

Driven by a real-life application from our research project, we explain the use of spatial information within a mobile distributed business process from craft businesses, where workers drive to customers to replace broken heaters. The BPMN model of the process is depicted in Fig. 7.

The process starts with an incoming job that includes the customer's location (either by entering it using the given form or by querying already known customers). Because we want

our company to act sustainably, we check if any currently working actors are reasonably far away, i.e., using all currently known locations and checking if any actor satisfies the condition of being inside a specific distance from the customer. If not, we inform the customer about a delay and finish the process instance. For this example, if we have at least one possible candidate, the process proceeds, and we use the worker's location and the customer's location again to allocate the closest available actor to the process. The location-aware subprocess is used to show and implement the lifespan of the allocation, as already explained above; all enclosed tasks are to be executed by the same actor.

Our allocated actor immediately starts driving toward the customer, periodically updating their location. Based on their current location and the expected location, we can notify the customer if the actor is behind schedule or automatically adjust following tasks from different process instances; on the other hand, we also check for the actor entering a geofence around the customer, where we automatically inform the customer about the imminent arrival. When the actor arrives at the customer, a location-aware event is thrown to update the actor's status and provide information for invoicing in another process lane. After repairing the heater at the customer's location, the actor drives back to our depot to get their stock refilled, which is again triggered using a throwing-location event, caught by a location-start event for a different business process of another department.

Looking at the process model, it becomes evident that location information is directly visible for the allocation of the actor and the triggered notifications for the customer. These notifications are initiated by entering geofences around the customer's location. Furthermore, the two intermediate location events enable the employees' current location (including assigned and used tools) to be used by other parts of the business. Finally, we can use information collected from both the BPMS, information gained by sensors, and location data to fully automate or at least support the creation of an invoice for the order.

8.2 Location-aware transport process of logistics company (P2)

Technology: Barcode, RFID, visual

Operator: Geofence, location update

Pattern: Start of processes, task assignment, event dispatching, completion of tasks

Figure 8 illustrates an enhanced process model representing a second real-world application that demands complete transparency in the delivery of goods between two distinct branches of an industry partner manufacturing orthopedic medical products. Analogously to the preceding process, integrating location information is pivotal in overseeing the

¹⁵ Not visible within the process model, as explained above

Location-aware business process modeling and execution

61

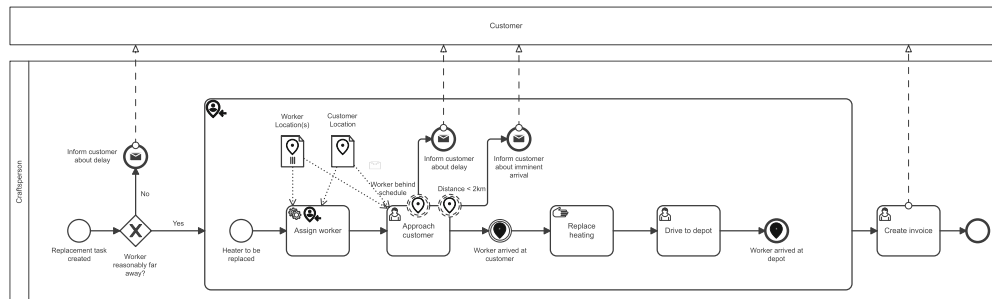


Fig. 7 Exemplary real-life process from a craft business enhanced with location data

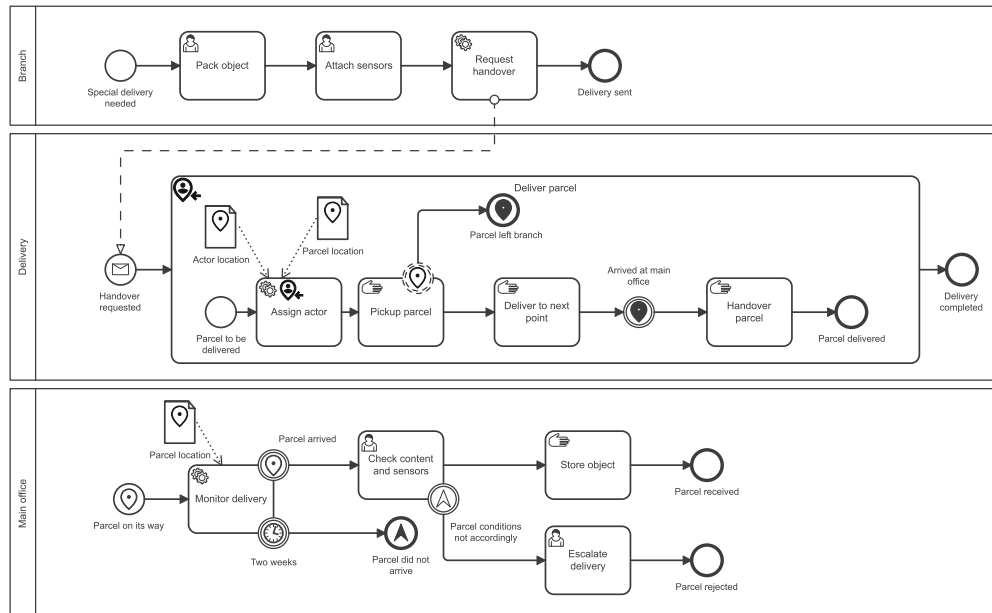


Fig. 8 Exemplary real-life process for parcel delivery between branches enhanced with location data

seamless delivery of a parcel from one of the company's branches to the central office.

The process begins at a branch of the industry partner, where an object is packed, including sensors capturing data such as humidity and temperature. Subsequently, the branch initiates a request for handover from the company's delivery department. Upon notification of the impending delivery, a selection process ensues within the delivery department, akin to the previous process. The chosen actor for delivery is determined based on contextual information encompassing their skill matrix, external specifications, and the current location,

with the latter being contingent on the nature of the object to be delivered.

Following the selection process, the designated actor retrieves the parcel, initiating monitoring at the main office. The parcel is then transported to its destination. On arrival, a handover event is modeled for the main office. At this point, the package is received, subject to examination, and its condition evaluated. If the condition is deemed satisfactory, the object is securely stored, and the process is concluded. Conversely, if an issue is identified, the delivery undergoes escalation, triggering an alternate process in the real-world

scenario. This intricate system ensures that the delivery process is transparent and equipped to handle deviations from the norm, enhancing overall operational robustness.

Similar to the previous process, the location of the parcel is the root of the process, enabling traceability through modeling elements that ease documentation tasks during execution while simultaneously increasing transparency during the modeling.

8.3 Location-aware rental process (P3)

Technology: GPS, WiFi

Operator: Geofence, location update

Pattern: Start of processes, event dispatching, monitoring execution, automation of tasks

The last process is based on a rental process (see Fig. 9). As part of its core business, a crafts company rents out mobile heaters for emergencies or during renovation/construction. The process here starts with a concluded contract that triggers the initiation of the rental process with the craftspeople. They prepare the unit and then either plan and transport it to the customer or have the customer pick it up themselves. The unit is automatically registered when it leaves the company premises and the rental period begins. During the rental period, the unit is automatically remotely monitored with access from the back office through a dashboard.

Fitting the rented objects with sensors for location can also provide additional access to information that can be used for troubleshooting or predictive maintenance. Again, directly using the location of the involved entities in the process model provides additional information that can then be used, increasing transparency in execution while making the spatial context of the process visible at first glance.

At any given point or the end of each month, the customer can decide to return the unit, triggering the return delivery (similar to the delivery to the customer but including a final examination after the return). This, in turn, automatically triggers the final invoice creation when the unit is back in the company. At the end of each month, the system automatically generates an invoice based on the current location and usage parameters.

8.4 Emergency incident management (P4)

Technology: Cellular, GPS, Emergency Services Software

Operator: geofence, location update

Pattern: Decision making, task allocation, event dispatching, process monitoring, automatic completion of tasks

Another application area that comes to mind for location services is emergency services, where the location of the victim or patient is of utmost importance. Compared to the three other processes that stem from a current research project and are running processes and business partners, the process

shown in Fig. 10 is a case study with Australian emergency services presented in [15]. Here, the authors already include location-specific events in a non-standard conform way to describe the process.

The agent begins by determining the appropriate response to the incoming emergency call. This may involve dispatching an ambulance (or, in the original example, airborne emergency services, which we excluded for better clarity). Once the dispatch request is received at the ambulance station, a unit is dispatched automatically based on its current location and other factors. Upon arrival at the scene, the unit checks for treatment. If so, the patient is approached. Each location update of the mobile unit must be recorded and saved to the record management system. During the patient's treatment, the emergency call center provides specialist medical advice based on the most recent observations. If a patient requires transportation to a hospital, they are loaded and transported to the hospital, where they are dropped off at the emergency department (ED). The arrival at the hospital is broadcast to the call center agent as a status update. Once the emergency has been completed, the computer-aided dispatch software is cleared, and the dispatch is finished for both the mobile unit and the agent in the call center. During the dispatching process, an event may occur that necessitates a recall or retasking of the unit, interrupting both subprocesses and immediately concluding the dispatching.

In addition to the various status updates that are recorded and utilized to facilitate the process at the call center, the patient's location is also employed to determine the appropriate response and necessary service and dispatch the specific unit. This process involves decision-making based on location data, the allocation of tasks, and the dispatching of events, in addition to monitoring tasks with location information and completing tasks based on an actor's location. In contrast to the process presented in [15], the process model's direct use of location patterns is evident. Assuming the external data sources and sinks provide appropriate interfaces, the process would also be directly executable if the implementation detailed above were to be used.

8.5 Potentials enabled through the presented patterns

Integrating location data into business processes offers a large number of potentials that can significantly impact real-world applications across diverse industries. One of the foremost advantages lies in the real-time optimization and execution of business processes. Companies can dynamically enhance supply chain efficiency by incorporating location data into their processes. This is achieved by adjusting routes in response to the current location of goods, tools, actors, and other involved entities that directly impact operational effectiveness (P1, P2, P3, P4).

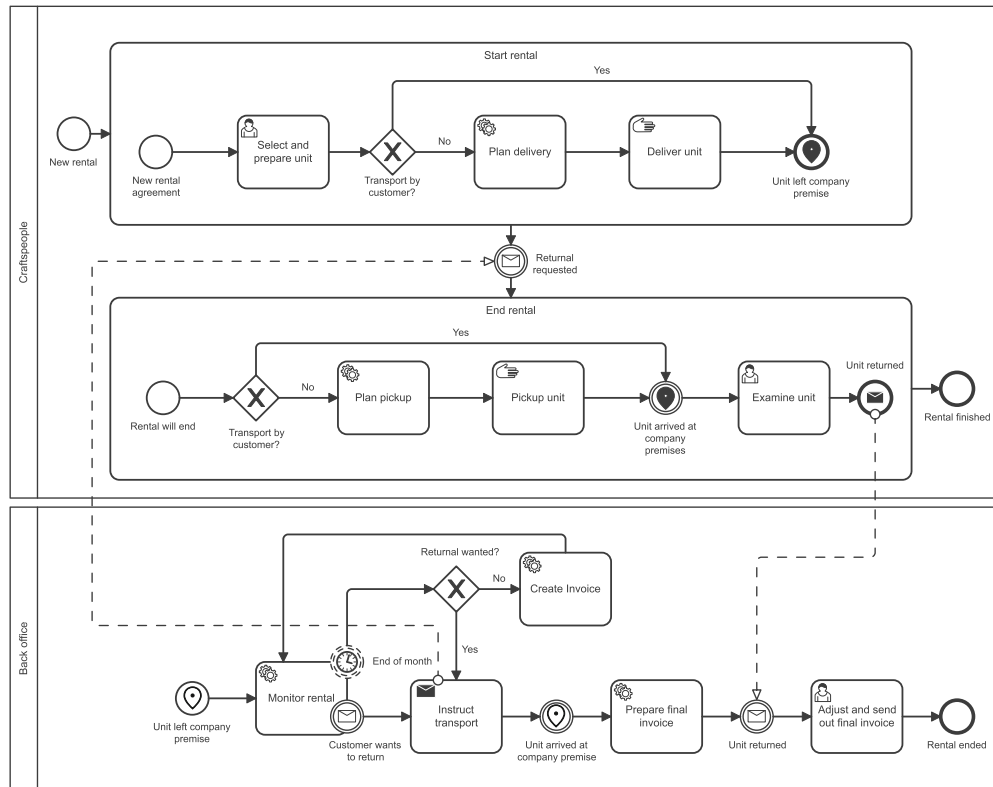


Fig. 9 Exemplary real-life process for the rental of mobile heating units enhanced by location data

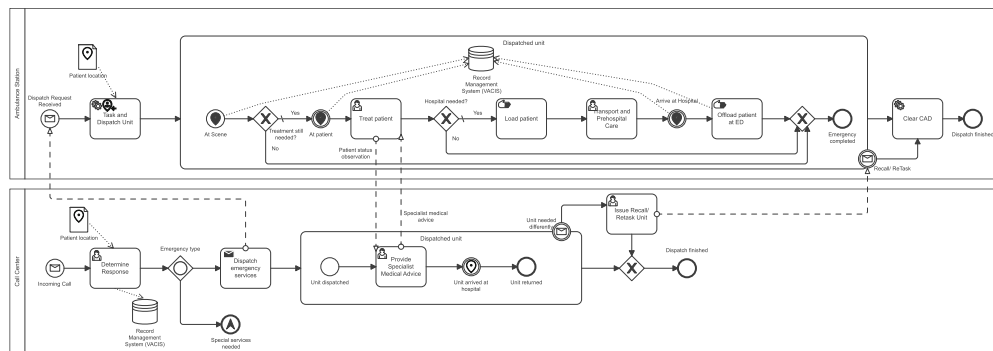


Fig. 10 Emergency services process from [15] enhanced with location-aware patterns

Automated decision-making based on location information represents a robust potential. Configuring the BPM platform to respond to specific location conditions automatically ensures streamlined processes. For instance, tasks can be automatically assigned, or processes can be triggered when an IoT device reaches a predefined location, demonstrating a sophisticated utilization of location data in optimizing workflow (*P1, P3, P4*).

In industries where risk management is critical, the integration of location data proves invaluable. Sectors such as logistics and healthcare can adapt processes in real-time to respond to unexpected events in specific locations, thus improving overall risk mitigation strategies (*P2, P4*).

The customer-centric approach is further advanced through the use of location data. Companies can tailor their services precisely to customer needs by using location information (*P1, P2, P3*).

Integrating location data allows companies to optimize resources such as personnel deployment and inventory management more effectively, improving their efficiency through resource optimization. This optimization contributes to streamlined operations and resource utilization (*P1, P2, P3*).

Real-time monitoring of assets is a critical application in manufacturing and logistics. Location data ease the continuous monitoring of assets like machines, vehicles, dispatched units, and products. This capability enables proactive maintenance, avoids bottlenecks, and enhances overall operational efficiency in these industries (*P1, P2, P4*).

Lastly, location data play a pivotal role in industries where regulatory compliance and safety standards impose strict requirements for documentation. The integration of location information (*P2, P4*) promises to facilitate the assurance that business processes adhere to required policies.

9 Conclusion and future work

As seen in the related works, using spatial information to facilitate locally distributed work within a factory hall, or even mobile work, is not new and has been part of research for nearly 20 years. Both are different from the combination of spatial information and business processes. By using IoT devices as enablers and coming from a vastly different real-world application area rooted in different executable processes at its base, this paper closes the gap between conceptual approaches for using location in BPM and the real world.

In this work, we summarize different ways of using contextual location information for the process based on the location of different entities, facilitating process execution and enabling further automation of process execution. Compared to earlier approaches, the exemplary implementation

enables efficient execution using Camunda as the BPMS. It can be easily extended because of the strict separation between the different systems (the BPMN-extension based on the patterns identified here (cf. [12]) further develops the usability by reintroducing the logic directly into the BPMS based on the BPMN meta-model).

All main parts of single processes can be enriched using the location as contextual information during execution, from simply using the distance between two locations in an expression for logic gateways or start and end events (starting and finishing a process) and tasks (allocating a task to the user closest to an entity) up to terminating tasks based on the spatial information and dispatching events based on an entities location or the distance between two entities. Considering multiple concurrently running process instances, we can use location data to intelligently reorder the task list of all actors, use multiple different actors as candidates for the allocation of tasks, or gain insights through monitoring their execution. By first presenting the different identified patterns while providing an implementation for their use during modeling and execution, we answer both research questions motivating this publication. The presented list of possibilities shows the potential of combining IoT and BPM by using contextual information in BPM to improve efficiency and the workflow of workers working within mobile distributed processes.

While the focus of the included patterns is on actively using location data for different appliances, future research could broaden this definition to include the use of location for dynamically adjusting the price of a service or to use the location as part of a more extensive set of parameters for the selection of for example an advertisement. Centering around this use of location data would vastly change the perspective on the business processes but could provide additional insights into the topic. On the other hand, for the deployment using BPMN, we already introduced an extension for depicting the location and using it within business process models, supporting the patterns presented here. Staying at BPMN as one way of implementing the patterns, different new challenges can arise by showing more interdependencies between different parts of the process models, and while these are possibly also existent in the real world, the inclusion in the model as a simplified representation could decrease readability and understandability.

Using context information in BPM is a promising approach for new ways of orchestrating company business processes. While this work focuses on location information, future endeavors could take a more comprehensive look at contextual information and its utilization in BPM. For instance, contextual information can be leveraged during the execution of otherwise unsupported manual tasks enabled through the IoT.

Redesigning and implementing new processes with research partners is time-consuming. Nevertheless, we also plan

a quantitative evaluation based on classic process metrics such as throughput and cycle times while considering improved customer satisfaction and advancements through transparency and business process improvement. The exact interaction and connections of pull- and push-communication, data patterns, and appliances are tied to specific implementations and decisions, leaving their generalizability for future assessment. The design decision regarding the level or system within which specific calculations and decisions occur is closely related.

Context information, such as the location of entities (actors, customers, and other involved entities), can be utilized in business processes to facilitate and enhance a company's value-creation process. The capacity to map relationships between locations of process entities opens up a range of new implications and possibilities for analysis and improvement. This can lead to the development of a more powerful and expressive process management.

Appendix A Business process modeling notation (BPMN)

Business process modeling notation (BPMN) provides a “standardized bridge for the gap between the business process design and process implementation” [18] by providing a graphical representation of business processes and a blueprint for the supported execution by business process management systems (BPMS). As a short introduction to the following patterns for the location-aware business process execution, which is tied to but not dependent on BPMN, different technical terms have to be introduced: The primary purpose of describing a business process is to document and standardize the sequence of tasks and decisions made to contribute to the businesses value creation [1].

BPMN describes different types of tasks, from script tasks that happen fully automated and supported by the BPMS to user tasks that are mainly executed by human actors but supported by the BPMS and connected systems to manual tasks that are entirely ignored by the BPM and completely executed by human actors. The flow between those tasks can be directed using gateways that divide, redirect, or join the process flow (the most used gateways are the “AND”-Gateway as well as the “OR”-Gateway). Next to using gateways within a flow, business process analysts can use events attached to tasks to react to specific changes during task execution (so-called boundary events).

Appendix B Location-aware parameters for modeling

(a) Location parameters for location-aware events (b) Location parameters for allocation and assignment

Fig. 11 Extension of the modeler with parameters for location-awareness

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	Stefan Schö­nig	10%

Conference description: Cooperative Information Systems (CIS) facilitate the cooperation between individuals, organisations, smart devices, and systems of systems, by providing flexible, scalable and intelligent services to enterprises, public institutions and user communities. As a result, people and smart devices can interact, share information and work together across physical barriers. The domain of CIS integrates research results from different related computing areas, such as: distributed systems, coordination technologies, collaborative decision making, enterprise architecture, business process management and conceptual modelling. In recent years, several innovative technologies have emerged: Cloud Computing, Service Oriented Computing, the Internet of Things, Linked Open Data, Semantic Systems, Collective Awareness Platforms, Block Chain, Processes as a Service, etc, that enable the next generation of CISs.

In developing the next generation CISs, research is needed towards (1) the applicability and use of the above mentioned innovative technologies, (2) approaches to develop CISs in particular catering towards the multitude of stakeholders involved in the development of socio-cyber-physical systems, and (3) associated modelling techniques to express and analyse the different aspects of these systems in cohesion.

The CoopIS conference series is an established international event for presenting and discussing scientific contributions about technical, economical, and societal aspects of distributed information systems at scale. (Source: <https://coopisconference.org/2023/>)

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LABPMN: Location-Aware Business Process Modeling and Notation

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Abstract. The combination of IoT and BPM enables new possibilities for the use of contextual information during the modeling and execution of process models. Nevertheless, many approaches for the use of location data only exist as concepts, and most existing extensions for BPMN do not fully use the potential gained through IoT.

In this paper, we introduce a novel BPMN Extension for location awareness that is, conceptually well-defined and adheres to the BPMN meta-model, and can be used both graphically, and during the execution of a process. We introduce two new main elements: The possibility of dynamically assigning or allocating actors to one or a number of tasks, and different location-based events to be able to react to location changes of active and passive resources during process execution.

Keywords: Location-awareness · Distributed processes · BPMN extension

1 Introduction

The Internet of Things (IoT) has the potential to revolutionize the way businesses operate by providing contextual information, including location data, throughout the entire lifecycle of business processes [7, 14, 20]. This can lead to significant improvements in effectiveness and efficiency in value creation, as well as the automation of non-value-adding tasks. By leveraging the power of IoT devices, businesses can gain a competitive advantage by streamlining their operations [22, 28] and aiding with everyday processes by removing non-value-adding steps and supporting actors during the execution of value-adding process steps [8].

In [20], we presented a non-exhaustive list of patterns for the utilization of location data from IoT devices in Business Process Management (BPM) based on real-world processes from three crafts businesses and established approaches from the literature. All main parts of business processes can benefit from the

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LABPMN: Location-Aware Business Process Modeling and Notation 199

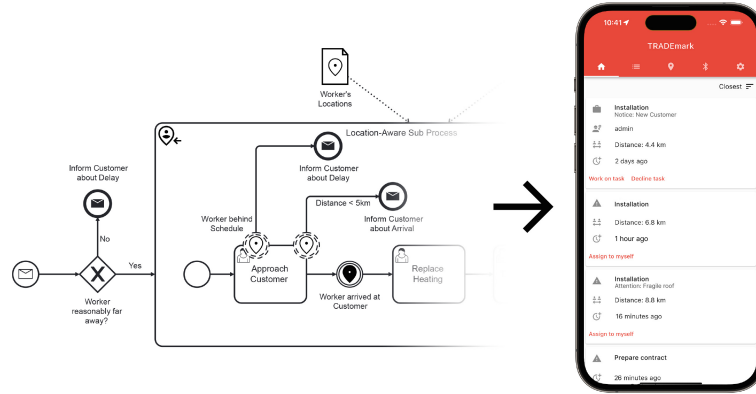


Fig. 1. LABPMN-based real-world process executed with mobile device interface

inclusion of location data, e.g., starting processes, making decisions based on location data, automatically allocating an actor to the currently closest task, monitoring the execution of a task, automatically terminating tasks or supporting in documentary and non-value-adding work. Despite including an executable and functional version for each pattern, location data is not treated as a first-class citizen in business process modeling [10], resulting in the underlying logic required for the integration of location data being obscured outside the process model itself. This contradicts the fundamental model character, which aims to serve as both a visual representation of all critical information and a foundation for supported execution using a BPMS, i.e., abstracting from the real world and conveying visual information while remaining executable [4]. The use of location information differs fundamentally from using other data coming from IoT devices, as the inherent spatial constraints within mobile distributed processes surface different problems and opportunities [13].

Using Business Process Modeling and Notation (BPMN) as the de facto standard for modeling processes enables us to extend the meta-model by introducing domain-specific concepts and appending additional information to existing standard modeling elements [23]. Trying to narrow the existing gap between the visual representation and the practical use of location within business processes leads to the following research question: *How can we comprehensively use location information for a graphical, executable notation for location-aware process modeling and execution?*

In the following sections, we address this gap by extending BPMN with location-aware elements for previously presented patterns for the use of location within BPM, providing both a visual representation for the modeling phase and an implementation for the actual execution of process models using location as a first-class citizen. Extending the BPMN meta-model can provide a foundation for further exploration of the use of location data and, more generally, context

200 L. Poss et al.

data stemming from IoT devices in BPM. While the integration into BPM has the potential to significantly improve business processes and their handling, to fully realize this potential, it is necessary to both, visually represent the functionality, while providing possibilities for execution and by supporting actual everyday use. Until now, many applications used for value creation were static and directly coupled to small parts of value creation, but the union of IoT data and BPM can lead to dynamically adapting applications supporting different involved actors and process steps. Figure 1 shows a currently running enhanced business process at a crafts business that motivated the BPMN extension and the mobile application in use showing open tasks as well as the current distance to the tasks' location. The approach has been implemented and applied to a real-life scenario and will be presented in Sect. 5. A short video explaining the main concepts can be found at <https://youtu.be/PHE6b4pQUWE>.

Starting with Sect. 2, we will explain the theoretical background of business process management, the Internet of Things, and the use of contextual data, as well as a short overview of related works. The following Sect. 3 introduces the extension for incorporating location in BPMN, by adhering to the steps provided in [23], including both, the conceptual as well as the graphical extension. Section 4 explains the actual implementation used for the exemplary real-world example provided in Sect. 5. This publication ends in Sect. 6 with the current status and future research topics based on our experience.

2 Theoretical Background and Related Work

The subsequent segment contains an introduction to BPMN and its mechanism of extension, succeeded by a brief contextual backdrop on subjects such as context, location, and the Internet of Things. This is followed by an overview of existing research efforts.

2.1 Extension Mechanism of BPMN

Business processes are a series of actions taken to achieve a specific business outcome [7]. They can be represented by one or more business process models, which consist of activity models and instructions for how the processes should be executed. These models serve as a blueprint for real-world scenarios and cases, providing a structured representation [25].

Various modeling languages exist for this purpose, with BPMN [17] being the widely accepted current standard. BPMN includes different standardized elements, that facilitate both human and machine readability while allowing the machine-supported execution of business processes. On the other hand, BPMN also enables the extension of the meta-model to introduce new functionality, that is not part of the standards' core functionality.

Over the years, the extension mechanism introduced in BPMN in 2011 [2, 27] has facilitated the development of numerous specialized extensions tailored to various application domains, enhancing the functionality and adaptability of

BPMN to meet the specific requirements of diverse real-world scenarios (cf. [5, 27]). The reuse and enhancement of standard BPMN elements offer advantages like standardization and widespread tool support. The extension mechanism of BPMN is tightly coupled to the Meta Object Facility (MOF) meta-model [18], separating the meta-model, process model, and process instances, which introduces enhanced flexibility in the form of interchangeable model properties and parts – extending single elements of the BPMN meta-model does not strictly require the modification of standard BPMN elements. [23] complement the BPMN extension interface outlined by the OMG [17] by offering methodological guidance on how to extend BPMN elements, which we will adapt to develop and introduce our new elements within this paper.

2.2 IoT, Context and Location Data

Combining BPM and the Internet of Things (IoT) enables new possibilities for enhancing and enriching business processes using contextual information like the location of active resources like actors and passive resources (e.g., tools needed for a task). The Internet of Things describes a world where every object can connect to a network with its own identity. This enables the use of sensors for business process execution, leading to improved data-driven decision-making and optimized processes [9] on the one hand and a more comprehensive view of business processes on the other [22].

The context of a process describes the involved entities' conditions and circumstances [1]. It can be used during the execution of business processes to enhance and support their realization [22]. One part of the process context is the location of different involved entities, it can be divided into two categories: First, descriptive locations, which are referenced by descriptions like names or numbers, related to either natural geographic objects or human-made geographical objects, which are well defined, and second spatial locations, which refer to an explicit numerical representation of a position in a coordinate system. Location data can further be classified as primary or secondary context [16]: Information about the location of an entity (location data) is part of the primary context, as the location of an entity can directly be sensed by sensors. Other information derived from spatial data, e.g., the distance between two entities, belongs to the secondary context [20].

Three important capabilities of location awareness in business process management are outlined in [28], including knowledge of the current status of the process in a specific location or knowledge of the location of a particular resource within a business process, awareness of relevant location-based information in real-time, and finally, the business process' ability to adapt based on location-based information.

2.3 Related Work

The subsequent section presents a review of related literature augmenting BPMN with IoT data, particularly focusing on location data (referred to as IoT-,

202 L. Poss et al.

Table 1. Related work concept matrix following Webster and Watson [24]

Affected Elements									
Name	Goal	Location integration	Illustrative example	Location Object					
				Event	Gateway	Task	Drawbacks		
<i>IoT</i>									
- [3]	Event extension for IoT	Location Event (Differentiation between cause and impact of event)	Temperature controlling process based on location of a person	E	○	○	●	○	Not executable, focus on location events, could be modeled using conditional events
BPMN4CPS [11]	Enable the modeling of CPS processes	Location information as part of sensor data	Ambulance drone case study	I	●	○	○	○	Implicit representation, separation of processes, no standard conformity
LPML [19]	Create a comprehensive BPMN extension for IoT	Location information as part of sensor data	Predictive Maintenance for conveyor belts	I	○	○	●	○	Implicit representation, not executable, "semi-formal" process model
- [9]	Enable the modeling, execution, and monitoring of IoT-aware processes	Location information as part of sensor data	Smart home, production process	I	●	○	●	○	Implicit representation, artifacts normally for "additional information" [17]
BPMN-CARX [12]	Integrate process automation, IIoT context, and AR	Location information in task context	Maintenance process	I	●	○	○	○	Implicit representation, no description of actual BPMN extension.
<i>Independent of Domain</i>									
- [6]	Constrain the location of task execution	Introduction of location constraints	Commissioning of items	E	○	○	○	○	Not executable, separate location model necessary, relies on deprecated BPMN version, does not actively influence process execution
- [15]	Include mobility aspect in BPMN events	Location Event (position achieved, position update, conditional position event)	Ordering support service	E	○	○	○	○	Not executable, focus on location events, could be modeled using conditional events
sBPMN [21]	Take special concerns into account in BPMN	Location as context and important decision variable	Crops planting on several fields	E	●	○	○	○	Separate location model necessary, assumption: only modeled processes influence the environment, notation not adjusted, few spatial functions
<i>Mobile Devices</i>									
Context4BPMN [8]	Enable modeling of influence of mobile context information on business processes	Location as part of the context	Work safety inspection process	I	○	●	○	○	Implicit representation, not executable, no decision logic, explicit model of context needed
<i>Ubiquitous Computing</i>									
uBPMN [26]	Address BPMN's deficiency in representing ubiquitous business processes	Location information as part of sensor data	Distributed sales process for specific customer	I	○	○	●	○	Implicit representation, not executable, any data can be collected

Notation: E: Explicit, I: Implicit; ●: Element is extended or considered, ○: Element is not considered

Notation: E: Explicit, I: Implicit; ● Element is extended or considered, ○ Element is not considered

Context-, and Location-Awareness in BPM). Following the methodology proposed by [24], an initial step was performed by searching significant contributions using the specified search string: “*BPMN AND (extension* OR extend* OR enhanc* OR expan* OR adapt*) AND (location* OR spatial OR geographic OR IoT OR ‘Internet of Things’ OR context*)*”. The retrieved results were then manually evaluated for relevance, employing a set of exclusion criteria established in [27].

Throughout the literature review, several similar works were identified, including those by [2, 27], and [5]. It is noteworthy that these works consist primarily of systematic reviews of the literature that refer to BPMN extensions in a broader sense. However, none of them address location-aware extensions specifically. Moreover, the systematic literature reviews mentioned above were conducted in 2014, 2019, and 2020, respectively, thereby not encompassing possible most recent publications.

The retrieved publications which will be explained in short in Table 1: Following the name of the introduced extension (if applicable), the goal and the main domain targeted by the extension are presented, followed by the way of inclusion of location information (either explicitly mentioned or implicitly as part of generic sensor data), followed by affected BPMN elements and drawbacks of each of the approaches.

Based on these publications, three different mechanisms for the incorporation of location information in BPMN could be identified: The first extends existing constructs, such as gateways and conditional sequence flows, to incorporate location information [21], enabling location-dependent decision-making and dynamic routing. The second mechanism introduces new constructs designed for handling location information in BPMN models. [6] for example proposes the concept of location constraints, which specify spatial constraints for tasks, and [15] suggests using location events to trigger process activities based on changes in the physical location. The third mechanism involves using a separate model linked to the main process model for depicting location information [21], allowing for an explicit representation of location-related data and its association with process elements. However, both, an implicit representation and the use of a separate model have disadvantages, as it lacks explicit indicators for location-aware elements, requiring additional explanation, documentation, and models. It may also result in unnecessarily large and complex process models, as affected elements are not explicitly adjusted for location-specific concerns. But, by explicitly incorporating location information into business process models, our following extension enhances the expressiveness and effectiveness of BPMN in capturing real-world scenarios where location plays a crucial role.

3 Extending BPMN for Location-Awareness

The diverse patterns outlined in [20] can be seamlessly illustrated and operationalized through the proposed extension. The core patterns are already delineated in Table 2, encompassing the start of processes, decision-making, automated actor allocation, task execution monitoring, event dispatching, and task

204 L. Poss et al.

Table 2. Patterns for the use of location in business processes [20] and their extension elements

Pattern	Extension Element
Automatic start of process instances	Location Start Event
Decision-making based on location data	Standard BPMN Gateway
Location-based allocation <i>and</i> assignment	Annotation for Task/Subprocess/Call Activity
Location-based monitoring of tasks <i>and</i> event dispatching	Location-Aware non-interrupting boundary event
Location-based automatic completion of tasks	Throwing Location Event
Location-based automation of tasks	Location Data Object and standard User Task

termination. Moreover, the extension serves to facilitate documentary and non-value-adding tasks. A comprehensive exposition of each pattern can be found in [20].

Based on the motivated goals and the identified drawbacks of existing methods, the following requirements and goals arise, that will be fulfilled by our extension for the use of location data during the execution of business processes.

R1 BPMN 2.0 conformity: The extension must adhere to the BPMN 2.0 standard to fully support existing BPMN tools. BPMN 2.0 conformity increases the acceptance of our extension within the BPMN community, as all properties and concepts of standard BPMN also apply to the extension.

R2 Explicit representation of location concerns: Location-related events and actions must be explicitly represented in business process models. This enhances the comprehensibility of process models, improves their reflection of reality, and facilitates the appropriate implementation of location concerns.

R3 Influence the process execution based on location information: This requirement is self-explaining and can be derived from conceptual modeling extensions introduced in Sect. 2.3: Both, the functional (process flow and actual execution of a single task), as well as the organizational perspective (candidate groups and task allocations) must be influenced by external data.

R4 Ability to react to internal and external changes in location: This requirement necessitates that the BPMS is aware of the location of each relevant element of a business process, as listed as one of the capabilities in [28]. It is also noteworthy that external changes in location have to be considered, including all location changes that do not explicitly result from the execution of the processes modeled in the BPMS.

[23] explain the key actions of building an extension for the BPMN meta-model with the following steps: (i) Definition of a Conceptual Domain Model of

the Extension (CDME) in Unified Modelling Language (UML), (ii) Transformation of the CDME to a BPMN plus Extensions (BPMN+X) model describing the extension, (iii) Definition of an XML Schema Extension Definition Model based on the BPMN+X model, (iv) Transformation of the XML Schema Extension Definition Model into an XML Schema Extension Definition Document.

The following sections will adhere to that schema by first describing the definition of the CDME as well as the BPMN+X model for each of the three extension elements, and, combining all parts for the XML Schema Extension Definition Model and Document, completing the conceptual BPMN extension.

3.1 Definition of CDME and BPMN+X Model

The first step for conceptualizing the BPMN extension is the development of the CDME and the BPMN+X model for each of the provided extension elements (Location Data, Location-Based Task Assignment/Allocation and different categories of Location Event).

Location Data. As already defined in our previous paper, location data can be seen as part of IoT-Data next to other data values like environment, descriptive or sensor data [20]. This location data is inherently the basic building block of all patterns, thus having to be transferred to the BPMN meta-model, which already includes different data concepts like **Data Objects**, **Properties**, **Data Inputs** and **Outputs** as well as **Messages** (see [17, p. 96]). Each process participant and other objects like used tools are seen as **Resources** within BPMN, which can be further characterized by **ResourceParameters** specified by **ItemDefinitions**, which can include their current location.

The place of fulfillment for a specific task (task location) on the other hand can be represented using the already existing **Property** concept in BPMN (see [17, p. 210]), acting as a container for data associated with certain flow elements that inherit from **ItemAwareElement**. Each **ItemAwareElement** has an **ItemDefinition** that contains the variable's value as well as other information and might refer to a **DataState** element containing the state of the data. This enables us to simply extend the already defined **DataObject** with our new **LocationObject** to elegantly introduce the foundation needed for the other concepts (see Fig. 2a). The next step is to transform newly introduced concepts following the rules presented in [23], which will lead to Fig. 2b.

Location-Based Task Assignment/Allocation. As presented in [20] as well as in [22], tasks can be allocated to actors during run time based on their current location. To implement such behavior, the executing system must be aware of the place of fulfillment of the activity as well as the locations of process participants and must implement a location-based operator. Closely coupled to that is the act of assigning a group of eligible actors, mostly during process modeling, and because both terms are not used coherently in literature, we will use the

206 L. Poss et al.

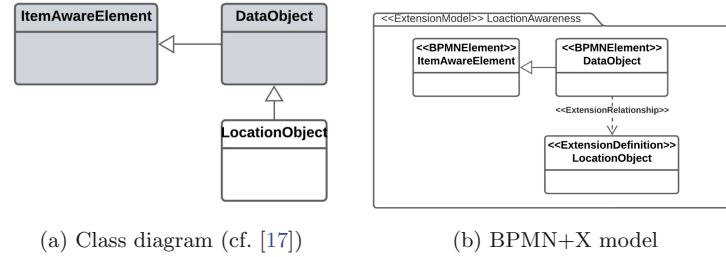


Fig. 2. Class diagram and BPMN+X model of location object

assignment as having a list of possible actors for a task or subprocess ($[0; n]$ elements) whereas allocation will be used for the 1:1-connection between an actor and a task or subprocess, independently of the lifecycle phase.

The *Conceptual Domain Model of the Extension* (CDME) for the allocation and assignment of actors based on their location is shown in Fig. 3. Base BPMN concepts are shown in gray, whereas new elements of the extension at hand are colored in white. Associated with the base class **ResourceRole**, we introduce the new class **LocationBasedAssignment**, which is responsible for the assignment of resources to an activity (i.e., the abstract superclass for tasks, subprocesses, and call activities within BPMN).

The new class needs to have access to the locations of the process participants as well as the location of the activity at hand. On one hand, the location of the activity is stored as a **Property** whereas the location of a **Resource** is stored as a **ResourceParameter**. The operator needed to compare both locations is modeled abstractly as a **LocationOperator**, which is inherited by two operators, namely **RangeOperator** and **DistanceOperator**. The first is either *greaterThan* or *lessThan* returning zero or more eligible actors for the task, whereas the latter returns exactly one process participant that is either *closest* or *farthest* from the activity's location. We also defined two different types of distances to get used within the extension, namely **linearDistance** and **travelDistance** which can also be selected for each of the extension elements.

Similar to the standard BPMN element of **ServiceTasks**, the already provided **Operation** classes from the standard are used to execute the needed logic. In combination with the already existing **ResourceAssignmentExpression**, the relevant resources can be restricted to a specific group of resources.

The next step again is to transform the CDME to a valid BPMN+X model (see Fig. 4): All existing BPMN concepts like **Activity**, **Property**, **Operation** and **ResourceAssignmentExpression** can be created as **BPMNElements**, whereas newly introduced elements are all explicitly marked as **ExtensionElements** or **ExtensionEnums**. Applying the rules presented in [23], we can transform both, generalizations as well as associations based on the concept of the class (BPMN vs. extension), its originality (original vs. new) and the concept of the property's type (BPMN concept, extension concept or simple data type).

LABPMN: Location-Aware Business Process Modeling and Notation 207

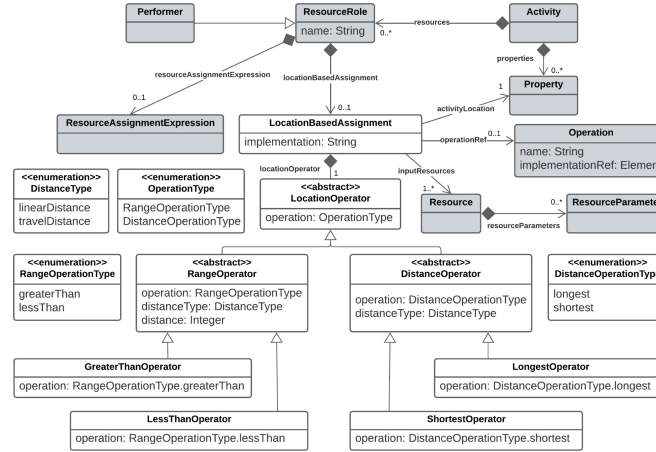


Fig. 3. CDME of location-based allocation/assignment

Table 3. Location event types and derived required inputs

Event Type	Required Inputs
entersGeofence/ leavesGeofence	[location _{t-1} , location _t , polygon, implementation]
distanceGreaterThanOr distanceLessThan	[location1, location2, distanceThreshold, distanceType, implementation]
locationUpdate	[location _{t-1} , location _t , distanceThreshold, distanceType, implementation]

Location Event Extension. The following section will explain the steps taken to introduce location-based events into BPMN. While [15] distinguished between three different types, we only introduce one explicit type of location event that is sufficient to represent any kind of location-related event.

The extension element enables the modeler to properly react to events like arriving at a location or a change in the location of a resource. By directly inheriting from the standard BPMN class `EventDefinition`, we can reuse existing concepts and automatically extend all types of events (namely: Throwing, Catching, Start, Intermediate, and End events, as well as Boundary events).

The events themselves need different parameters distinguishing between five different types seen in Table 3: One commonly found event definition based on the location of an actor could be if they or any mobile resource entered or left a specific area (*entering* and *leaving a geofence*). For that, we need two locations with different timestamps that represent a location change. Combining spatial and temporal context we can then check if a resource started outside a polygon and ends up inside the polygon (corresponds to entering the geofence) or vice versa. The plain location event introduced in [15] (*location update event*) also needs two different locations, as well as a minimum distance to trigger and the distance type. The last two identified event types (*distance greater than* and *distance less than*) both need two locations to be able to calculate or query a

208 L. Poss et al.

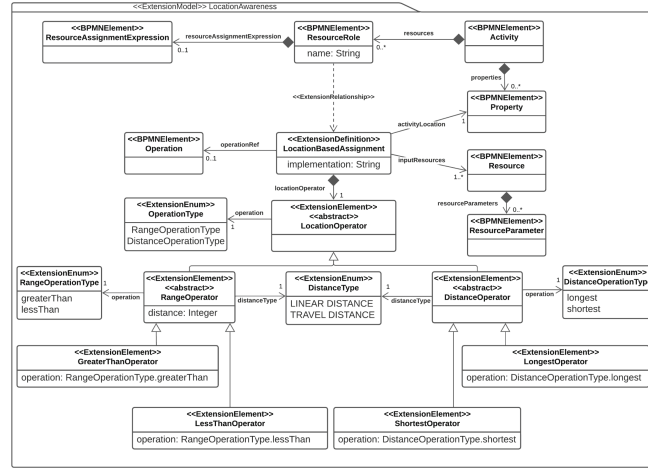


Fig. 4. BPMN+X model of location-based allocation/assignment

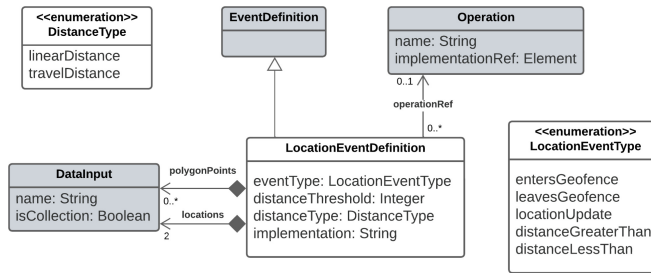


Fig. 5. CDME of location-based event

distance metric between them, the threshold to compare the metric against as well as the distance type that should be used for the comparison. Each of the needed locations is modeled as a Location Data Object introduced earlier in this section. The needed implementation is dependent on the modeler and represents the **Operation** executed with the parameters. Translating the CDME to the BPMN+X model happens analogously to the allocation and assignment extension by applying given rules and converting the concepts step-by-step (Figs. 5 and 6).

3.2 XML Schema Extension

The next step for providing a completely BPMN 2.0 conform extension is to extend the XML schema building the base of the BPMN meta-model (see Fig. 7).

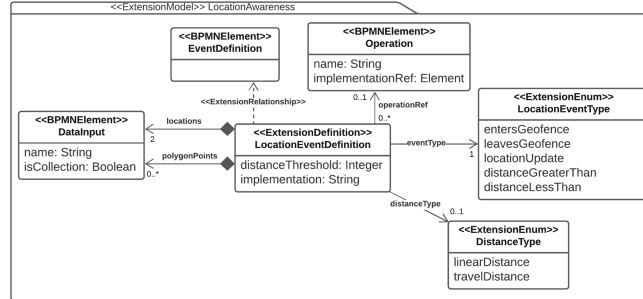


Fig. 6. BPMN+X model of location-based event

The schema `LocationAwareness` contains three `GroupDefinition` elements, one for each location-based element, we introduce (`LocationBasedAssignment`, `LocationEventDefinition` and `LocationObject`). The `LocationObject` itself contains no more information, whereas the `Assignment` contains all needed Resources as well as exactly one of the provided and already presented operators – explicitly differentiated into all options here, because both introduced operator classes are abstract, and to the best of the author’s knowledge XML does not provide any constructs to represent abstract elements. Each of the operators is then specified individually, containing all conceptually and formally needed parameters and their specifications for the decision to be made. The last `GroupDefinition` contains the element declarations for the `LocationEventDefinition`, including the type of the event as well as the needed parameters already explained above.

Because the resulting schema is specified in plain XML, the extension can be imported into different BPMN models to make use of the location-aware BPMN elements, independently of the actual realization of the BPMN meta-model.

3.3 Graphical Extension of Notation

As explained in the introduction and during the presentation of the related work, the modeling of business processes aims at two goals at the same time: supporting the execution of processes using computer systems but also helping process participants understand how a process works. For that reason, we also introduce a graphical representation for all new elements, according to the key elements and basic rules for the extension of elements described within the BPMN standard [17] (see Fig. 8).

4 Implementation for Modelling and Execution

The implementation of the modeling aspect of the extension is based on the open-source implementation `bpmn.js`¹, which provides the modeling tools needed

¹ <https://bpmn.io/toolkit/bpmn-js/>.

210 L. Poss et al.

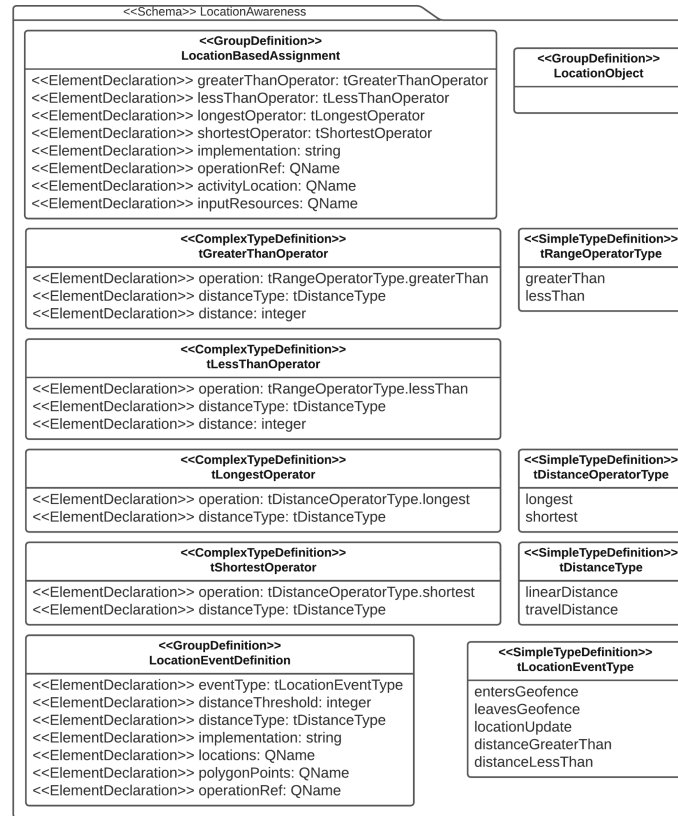


Fig. 7. XML schema

for our BPMS of choice, Camunda², that is responsible for executing the process model, providing the needed logic. Even though Camunda is widely spread and can mostly be easily extended for implementing new features, it still comes with several restrictions for an actual implementation of extensions: Some standard concepts like **ResourceRoles** are not used, but instead own attributes like **camunda:assignee**, or the use of expressions instead of **ResourceParameters** which implied removing unused properties and adjusting for implementation-specific needs amongst others. Nevertheless, the implementation includes all parts of the conceptual extension presented above. Including the needed functionality as well as the visual representation within the process model.

For the allocation/assignment, we extended the properties panel within the modeler to reflect the additionally needed attributes for the allocation task (see

² <https://camunda.com>.

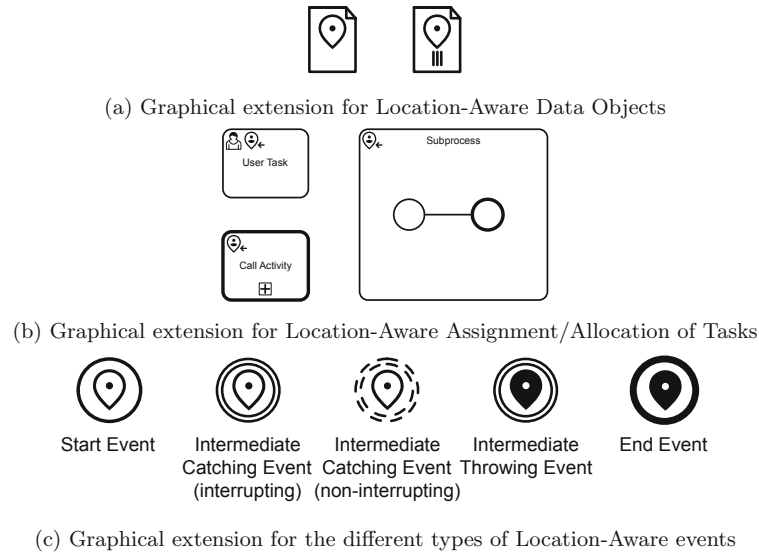


Fig. 8. Graphical representation of all elements added to the BPMN meta model

Fig. 9a). The result of the location-based allocation, either a single user in the case of the Distance operator or a list of users in the case of the Range operator, gets stored in the provided variable name and can then be used as either a slimmed-down list of candidate users or directly as the assignee for any given task or subprocess, implicitly constraining and guarding the lifetime of the allocation/assignment.

On the other hand, for implementing location-aware events we had to fall back to extending Conditional and Message Events instead of the parent class **Event** itself, to receive an executable and usable process model (see Fig. 8c and Figure 9b). The five different event types can be further get classified into two distinct categories: catching events and throwing events, where the first includes the start event, as well as both catching events (interrupting and non-interrupting), whereas the throwing event and the end event are both throwing events, pushing data that then can be used somewhere else in the process model. This enabled us to also extend the properties panel with the needed parameters for the task itself, as well as providing both, the visual representation and the functionality itself.

Compared to the assignment task and events, the actual extension of Data Objects is rather simple as they can directly be inherited to new types of objects (here: **LocationObject**). But again, both bpmn.js and Camunda differ from the BPMN specification as they do not display **bpmn:DataObjects** but rather only their references (**bpmn:DataObjectReference**), meaning the extension is visual, not directly implying a specific datatype.

212 L. Poss et al.

Location based assign...

Location operator

Shortest

Distance

Distance type

Linear distance

Activity Location

\$(customer.location)

E.g. \${task1.location}

Input Resources

\$(craftsperson)

E.g. \${craftsperson}

Assignment Variable

locationUser

E.g. locationBasedAssignee

Location

Event type

Enters geofence

Distance threshold

100

Distance type

Linear distance

Location 1

\$(task1.location)

E.g. \${task1.location}

Location 2

\$(user1.location)

E.g. \${user1.location}

Polygon Points

E.g. \${region.getPolygonPoints()}

(a) Added variables in the properties panel for task allocation/assignment (b) Implemented parameters for event extension in properties panel

Fig. 9. Extension of process modeling to include needed variables and parameters

5 Exemplary Real-World Application

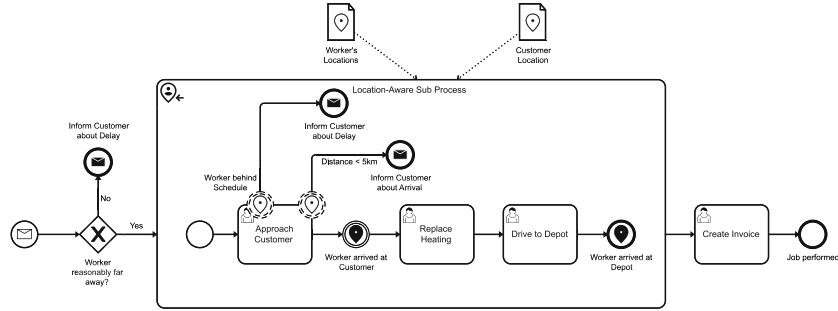
Based on a slimmed-down and simplified version of an actual process from our research project from a crafts business, we will show the currently running applied BPMN extension (see Figure 10). We already presented a version of the process in [20], where we first introduced the patterns for the use of location data during the execution of business processes. Now, as mentioned above, we are using the presented extension to reintroduce the visual aspect of the model while also proving its usability based on the real-world process.

The business process at hand describes an everyday process lived in a crafts business. The process starts with an incoming order, immediately a worker gets assigned to the task, drives to the customer, works there, and returns. After the creation of an invoice, the job, and the process instance is finished.

All user tasks within the expanded subprocess are assigned to a user or group of users based on the newly introduced location-based assignment. The location-based assignment is dependent on the location of the customer, the locations of the workers, and a location operator – in this case, the “nearest” operator. The respective locations are visualized by the two location objects, which increases the process transparency. It is also immediately evident when and for how long one actor takes over all parts of the process instance based on their location.

The two non-interrupting location boundary events facilitate monitoring of the *Approach Customer* task’s progress and enable notification of the customer regarding the worker’s arrival based on their current position. The location intermediate throw event communicates the current worker’s position to other active

LABPMN: Location-Aware Business Process Modeling and Notation 213

**Fig. 10.** Simplified real-world process using LABPMN

process instances, which can respond accordingly if necessary. Furthermore, the gained and collected information can be used to support the creation of an invoice by providing additional information about the task's execution (like an automatic way of distinguishing between time spent traveling and time spent working at the customer). The subprocess ends with a location end event, where the thrown location can also be caught by other processes e.g. to trigger a *Replenishment Process* for the worker's vehicle.

As clearly visible, all different parts of the extension are used to improve the execution of the process. Compared to our earlier approach, the visibility and the actual use of IoT-origin location data are enhanced and simplified, leading to a clearer process understanding and a more accurate representation of reality, while also supporting the actors carrying out the tasks.

When directly comparing this process model to our previous one (c.f. [20]), the inclusion of location data is evident within the model. Whereas previously, various decisions were made inconspicuously in the background, the model now displays both the assignment and the utilization of location data itself (*LocationDataObjects*). The use of throwing and catching events facilitates the interaction between different process instances as well as different processes.

6 Conclusion and Future Work

As demonstrated in the related works, the use of contextual information, especially the location of entities, within business processes is not a completely new approach, and several different attempts were made and presented over the last few years. Nevertheless, the use of IoT as an enabler for directly incorporating location data in BPM, as we presented in this paper, cuts down drawbacks of earlier approaches that were mostly only visual or executable but quite complex in their form, whereas we presented a novel approach for using location data in both, visualization and execution of business processes increasing the transparency and narrowing the gap between BPM and the actors actually executing the tasks therein.

214 L. Poss et al.

Based on a simplified process from a crafts business, we conceptualized and implemented an extension of BPMN consisting of three elements, that enabled us, in combination with standard BPMN elements, to depict all patterns presented in [20]. Based on the BPMN meta-model, we developed a concise possibility for the visual representation and provided an implementation based on standard tools like bpmn.js and Camunda that closes the abstraction gap, incorporating logic back for the use of location data in BPM into the process model itself.

Possible future work could include quantitatively evaluating the improvements gained through the extension by transferring the new notation to other real-world processes. Another possibility could be to adapt the implementation to directly extend the execution engine of the BPMS, which would lead to even more lock-in and probably pushes the extension further away from its current BPMN meta-model conformity. Most promising looks the focused extension towards different types of contextual information, further improving the support in executing manual and user tasks in business processes.

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216 L. Poss et al.

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P3.1 Navigating the Moral Maze: A Literature Review of Ethical Values in Business Process Management

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	Leo Poss	40%
	Julia Krönung	10%
	Stefan Schöning	10%

Journal description: Business processes are a fundamental building block of organizational success. Even though effectively managing business process is a key activity for business prosperity, there remain considerable gaps in understanding how to drive efficiency through a process approach. Building a clear and deep understanding of the range process, how they function, and how to manage them is the major challenge facing modern business.

Business Process Management Journal (BPMJ) examines how a variety of business processes intrinsic to organizational efficiency and effectiveness are integrated and managed for competitive success. (Source: <https://www.emeraldgrouppublishing.com/journal/bpmj>)

The current issue and full text archive of this journal is available on Emerald Insight at:
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Navigating the moral maze: a literature review of ethical values in business process management

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343

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Abstract

Purpose – Business process management (BPM), as a pillar of information systems (IS) research, has become more complex with the advent of new technologies, emphasizing the need for moral and ethical perspectives. To foster moral behavior and responsible action, including ethical values in IT systems and processes can be a solid option. By incorporating a socio-technical perspective, we are able to analyze the various aspects of BPM and organizational processes and the incorporated values. We find an overall acknowledgment of the importance of values and ethics in BPM.

Design/methodology/approach – This publication explores ethical values within BPM through a systematic literature review (SLR). The study aims to identify the ethical dimensions inherent in BPM and their practical implications in process management and task execution. The methodological approach adopted is a SLR (Boell and Cecez-Kecmanovic, 2015), adapting the PRISMA guidelines (Page *et al.*, 2021) to identify 82 articles from 21 top IS journals suggested by Lowry *et al.* (2013).

Findings – A descriptive framework is developed to explain the use and application of ethical values within business processes. This framework enables practitioners and researchers to categorize and understand the various ethical considerations involved in BPM. It provides a structured approach highlighting the interrelation between process perspectives and ethical values, demonstrating how different BPM approaches may have varying ethical implications. We compare past and future research in business processes, identifying areas for further investigation and theoretical development. A historical analysis of values and literature also helps contextualize contemporary discussions on ethics in BPM, shedding light on the evolution of ethical considerations within this domain.

Originality/value – Our study contributes to a more nuanced understanding of BPM, highlighting the importance of considering ethical values and socio-technical perspectives in designing and implementing business processes. These findings contribute to understanding the values associated with different types of processes and their employment and highlight potential areas for future research. Our study provides ethics-oriented research in IS with novel insights by examining BPM from an ethical value perspective. We contribute to the BPM literature by examining which values are applied in which process types from which perspective. In addition, our research suggestions provide food for thought for both research streams.

Keywords BPM, Ethics, Moral, Socio-technical systems, Ethical value, Literature review

Paper type Literature review

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BPMJ
30,8

344

1. Motivation

In the realm of contemporary business operations, the integration of digital technologies has revolutionized the landscape of organizational processes (Xie *et al.*, 2023; Seggie *et al.*, 2017). While these technologies aim to streamline operations and enhance efficiency, the continued involvement of human agents underscores a crucial aspect that requires close consideration from an ethical perspective. This juxtaposition of automation and human agency brings to light a discrepancy that requires a deeper exploration of the moral dimensions inherent in these processes. The moral imperative becomes increasingly important as organizations navigate new technologies, evolving labor dynamics, and novel data collection methods (Beerepoot *et al.*, 2023; Rowe and Markus, 2023; Gupta *et al.*, 2018). Scholars such as Spiekermann *et al.* (2022) and Trier *et al.* (2023) emphasize the importance of responsible development and use of digital technologies and advocate for increased focus on the ethical implications of technological advances.

Despite the progress made in business process management (BPM), which has led to significant improvements in value creation, such as transparency, efficiency, and sustainability, the ethical implications of these processes have mostly been ignored (Ko and Comuzzi, 2023). However, precisely such ethical approaches constitute responsible, socially acceptable use of information and communication technology (ICT) (Rogerson, 2011) with equal importance for business process management. The existing literature mainly concentrates on Information Systems (IS), with limited specificity regarding ethical values within business processes (Spiekermann *et al.*, 2022). Furthermore, when employing the term *values*, the emphasis tends to be on value creation rather than the ethical implications for human actors involved in these processes (Tusinski Berg, 2018). In general, the interplay of process, information system, and actor can holistically be examined through the perspective of socio-technical information systems (Cummings and Srivastva, 1977; Mumford, 2006; Beath *et al.*, 2013). Therefore, exploring the ethical implications and values in business process management is crucial, especially in digital technologies and automation. To fill this gap, we propose the following research questions:

- RQ1. Which ethical values can be found within the literature on business processes?
- RQ2. How are these identified ethical values applied and categorized within different perspectives and types of business processes?

This publication explores ethical values within Business Process Management through a systematic literature review. The study aims to identify the ethical dimensions inherent in BPM and their practical implications in process management and task execution. The methodological approach adopted is a systematic literature review (SLR) (Boell and Cecez-Kecmanovic, 2015), adapting the PRISMA guidelines (Page *et al.*, 2021) to identify 82 studies from 21 top IS journals suggested by Lowry *et al.* (2013).

The results provide valuable insights into the ethical dimensions of BPM and enhance our understanding of the relationship between technology, processes, and ethical values. A descriptive framework is developed to explain the use and application of ethical values within business processes. This framework enables practitioners and researchers to categorize and understand the various ethical considerations involved in BPM. It provides a structured approach highlighting the interrelation between process perspectives and ethical values, demonstrating how different BPM approaches may have varying ethical implications. Through gap spotting, we compare past and future research in business processes, identifying areas for further investigation and theoretical development. A historical analysis of values and literature also helps contextualize contemporary discussions on ethics in BPM, shedding light on the evolution of ethical considerations within this domain.

Since ethical values can only be adopted by individuals directly (Crane, 2016), they must be integrated into the organization while adapting the technology to them. To embody these values and virtues, great effort and careful coordination are required (Demuijnck, 2014). Especially in the context of BPM, it is crucial to consider the individual in the process steps and tasks to achieve not only a gain in efficiency but also good process acceptance on the part of those involved in the process (e.g. Kholkar *et al.*, 2013; Woliński and Bala, 2018).

2. Background

In both businesses and organizations, ethics provide a foundation for evaluating actions and shaping the climate and values within these organizations (Conrad, 2022). This goal is shared by employees and managers who want to be part of an ethical organization. Moreover, ethical principles foster credibility in public perception. Individuals are more inclined to endorse and support companies they view as honest and accountable (Crane, 2016) – when employees have confidence in the ethical principles of their organization, they hold the organization in high regard. Ethical principles cultivate shared objectives and a common language, promoting a positive work atmosphere and fostering a sense of belonging among employees (Riivari and Lämsä, 2017).

In addition, ethical considerations require management to consider economic, social, and moral factors in decision-making. This approach leads to better decisions that consider the interests of the public, employees, and the long-term goals of the organization (Sarker *et al.*, 2019). Ethical organizations can address societal concerns and engage with employees to resolve conflicts and issues, thereby contributing to societal well-being and harmony (Carroll and Buchholtz, 2008).

2.1 Ethics, morality, and values

The term *ethics* denotes the “philosophical science that deals with the rightness and wrongness of human actions” (O’Neil, 2004). Ethical theories consider the comprehensive investigation of ethical problems, concepts, principles, reasoning, judgments, interconnections, and justification (Becker, 2002). While some may use moral and ethical to mark distinctions, as using moral for traditional views of right or wrong and ethical for ideal views, most scholars use them synonymously (Garnett 1951) [1].

Ethical theories can roughly be divided into three schools of thought: teleological ethics, deontological ethics, and weak-normative and contextual approaches (Düwell *et al.*, 2011). IS researchers, however, tend to consider virtue ethics as a separate school of ethics (Gal *et al.*, 2022) – we are aware of this but will adhere to the categorization of Düwell *et al.* (2011). Deontological ethics consider actions as right or wrong, regardless of their consequences – with Kantian duty ethics (Kant, 1998) as one of the most prominent examples (Roth, 2005). Other ethical theories in this area include discourse ethics (Habermas, 1987) and justice ethics (Rawls, 1971).

Teleological theories, on the other hand, take the outcome of an action into consideration. Ethical theories of this family accept the thought that the end can justify the means. Prominent teleological ethical theories include, according to (Becker, 2002), despite them being rather different in their approach, ancient virtue ethics (Aristotle *et al.*, 2009) and the more modern utilitarianism (see for example Mill and Bentham, 2015). Value ethics (Scheler, 1973) also denote a prominent teleological ethical theory. Given the threefold classification, it is not possible to exactly categorize some theories into deontological or teleological definitions, regardless of the interpretation of their respective outcomes. Likewise, it is difficult even to classify some theories into deontological or teleological definitions, regardless of which of these definitions is applied. The classification into weak-normative

BPMJ
30,8

346

and contextual approaches allows for a more refined distinction, e.g. between ethics of prudence and narrative ethics (Düwell *et al.*, 2011).

Applied ethics take aspects of (normative) ethical theories [2] in consideration, mapping them to a domain of application. However, it is also possible to view a field of application through the lens of a (normative) ethical theory (Winkler, 2018). *Descriptive ethics*, on the other hand, are focused on the empirical compilation and description of existing moral beliefs — they involve normative and evaluative considerations as well as conceptual work (Hämäläinen, 2016).

Business ethics, as an important domain of applied ethics in regards to organizational structure, procedures, and professional life in general, deals with the ethical actions of organizations and corporations, applying ethical theories and theoretical frameworks to the context of business (Rendtorff, 2012). The advantage of applied ethics, such as business ethics, lies in their mid-level characteristic, being more abstract than a strict guideline and more concrete than fundamental principles like, for example, virtue ethics (Paulo, 2021). Within business ethics, streams such as *cosmopolitanism* suggest a global approach, finding responsible principles and values that should guide organizations and enterprises worldwide, focusing on global social responsibility (Rendtorff, 2017). Concepts such as *business legitimacy* imply that a company must consider the legitimating concepts and values to exist and prosper in a society (Rendtorff, 2020) while *sustainability*, in terms of renewable and low-impact business practices (Rendtorff, 2019), provides a different approach to foster more ethical business conduct.

Many scholars rely on values in the field of ethics because they reflect the moral concepts of a society. *Values* can be defined as conscious or unconscious orientation directives for human performance (Düwell *et al.*, 2011). Ethical values – sometimes called common values – are held in common by a specific group of people; for example, within a company or a country, their authority usually stems from standard agreements (Carr, 1998). They are not necessarily limited to the philosophical context, although certain philosophers like Windelband (1926) and Scheler (1973) have focused on defining the concept of value (Düwell *et al.*, 2011). In business ethics (Demuijnck, 2014; Agle *et al.*, 2014), scales (Schwartz *et al.*, 2012) are often used to assess personal values (Schwartz and Bilsky, 1987). For system development, value-based engineering (Spiekermann *et al.*, 2022; Spiekermann, 2023) and value-sensitive design (IEEE, 2021) provide a holistic approach to incorporating values into systems, yet the challenge of uncovering them prevails. Existing collections of values can be found for specific technologies, such as artificial intelligence (AI) (e.g. Francés-Gómez, 2023) or Big Data (e.g. Custers *et al.*, 2017; La Fors *et al.*, 2019), but rarely in integral collections of shared values. The most comprehensive collection of values known to the authors has been compiled by Winkler (2018) to foster ethical and sustainable software development.

2.2 BPM and socio-technical systems

Socio-technical systems, as defined by Cummings and Srivastva (1977), are “organized collection of [people] and technology, structured to produce a specified outcome.” These systems are integral to modern business landscapes, where the interaction between technical components and human factors facilitates the primary goal of value creation. This perspective positions information systems as socio-technical systems (Beath *et al.*, 2013), underscoring the importance of elements of technology, organization, and people and the various socio-technical systems (Sarker *et al.*, 2019).

Contemporary value creation in businesses is often supported by BPM, which enables the digitization, automation, and orchestration of business processes while integrating technical and human elements within socio-technical systems through ICT (Dumas *et al.*, 2018; Weske, 2019). As a managerial strategy, BPM is often conceptualized as a cycle of diverse tasks that require execution. Looy *et al.* (2012) delineate the standard capabilities as: (1) Modeling, (2)

Deployment, and (3) Optimization. These stages of the lifecycle are succeeded by (4) Management and encapsulated within (5) Culture and (6) Structure. This underscores the importance and impact of organizational culture and values on core business operations. The cultural component, encompassing values and beliefs, is also identified as one of the six core elements of BPM in the capability framework by Rosemann and Brocke (2014). Business process models serve as tools for articulating organizational processes, offering a simplified representation of reality (Dumas *et al.*, 2018), which are instrumental for documentation purposes and facilitate executing processes in day-to-day operations. Here, it becomes obvious that any value-based process management approach must consider the whole process lifecycle to enable a holistic view.

Based on the value chain model of Porter (1998), business processes can be categorized into three types: *core processes/functional processes*, which contain the essential value creation of an organization, *support processes/non-functional processes*, which support and enable the core processes, and *management processes*, which guide the other two types (Dumas *et al.*, 2018). On the other hand, other process characteristics can be used to categorize processes further, e.g. *external* vs *internal processes*, where the former refers to a focus primarily on external stakeholders (customers/suppliers) and the latter relates to internal stakeholders (management) (Hammer and Champy, 2001).

2.3 The importance of ethics in BPM context

In the field of BPM, the integration of ethics and values plays a pivotal role, from the general value creation and process management to influencing specific aspects such as process mining, process dashboards, and people involved in process management-related activities (Spiekermann *et al.*, 2022). Process mining, a method of analyzing event data to derive process insights, consists in handling sensitive information. The ethical considerations of maintaining privacy and confidentiality are critical, in line with the principles proposed by Aalst (2018). Process dashboards, visual representations of key performance indicators, and process metrics significantly impact organizational decision-making. Additionally, individuals actively involved in BPM activities contribute to the ethical fabric of organizational processes. Research by Ferreira and Otley (2009) underscores the role of individuals in the development of ethical organizational cultures, emphasizing the importance of shared values and ethical behavior in the execution of business processes. Workflow automation and standardization, a fundamental element of BPM, streamlines and orchestrates business processes. Ethical considerations in workflow automation extend to job displacement and potential dehumanization. Scholars like Dykman and Davis (2012) stress the need for organizations to proactively address these concerns, highlighting the ethical responsibility to mitigate conflicting impacts on the workforce through retraining and upskilling initiatives.

Introducing decision-making algorithms into BPM poses ethical challenges related to fairness and bias. As noted by Obermeyer *et al.* (2019), EFRA (2022), and Orwat (2020), algorithmic decision-making may unintentionally perpetuate discriminatory practices. Organizations must adopt ethical guidelines and fairness-based algorithms to ensure unbiased and fair outcomes and avoid reinforcing societal biases. Using business analytics in BPM requires ethical data governance to address privacy concerns and maintain data integrity. This includes transparent data practices, informed consent, and compliance with data protection regulations. When undertaking business process redesign within BPM, it is critical to engage stakeholders ethically. This is emphasized by Crane and Livesey (2017), who highlights the importance of engaging diverse stakeholders and considering their perspectives to avoid unintended negative consequences. Ethical considerations in redesign should go beyond efficiency gains to include the welfare and interests of all stakeholders involved. As BPM evolves, an ethical foundation becomes a moral obligation and a strategic

BPMJ
30,8

348

necessity. By drawing on established ethical frameworks and recognizing the ethical dimensions inherent in process-related technologies and human interactions, organizations can foster a culture of responsibility and trust in their BPM efforts.

The socio-technical approach enables us to identify correlations with the applied values and process perspectives. Some values, such as autonomy, accountability, or human health, are more critical on an individual level than global ones (cf. Burbano and Chiles, 2022). At an organizational level, security may be an essential value, while reliability may be a significant value for technology. The breakdown of these perspectives ensures that we gain insight into the various factors and can better take them into account in future projects. Depending on who is affected by a process or process technology, it is relevant to take the appropriate perspective for this group of people and take it into account.

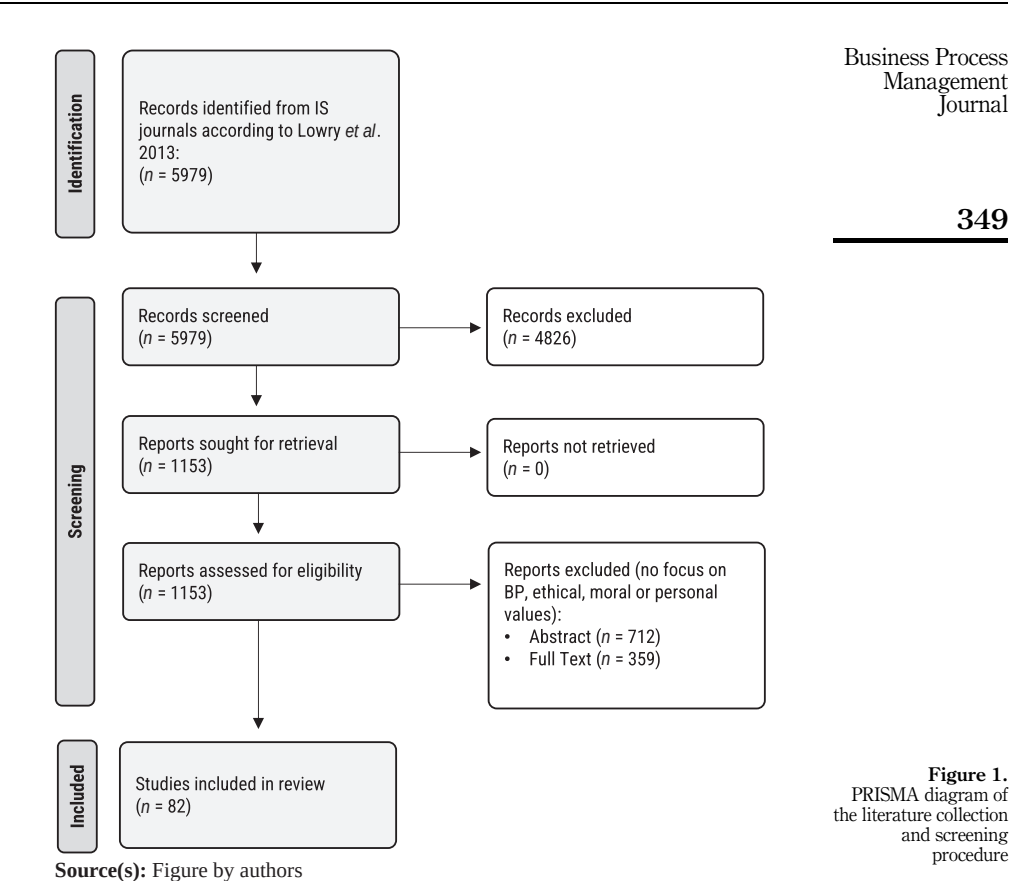
2.4 Research methodology

To address our research questions on ethical values in business process management, we conducted a systematic literature review following Boell and Cecez-Kecmanovic (2015). Our review is classified as a descriptive analysis of existing literature (Rowe, 2017). We ensured systematic exploration within the Information Systems (IS) domain by adhering to the 21 top-tier IS journals proposed by Lowry et al. (2013). Here, the authors compared expert rankings and bibliometric measures of IS journals to determine the journal quality and group them into different segments. Tier 1 is the highest, most impactful tier, consisting of three journals: Management Information Systems Quarterly, Information Systems Research, and Journal of Management Information Systems. Tier 2 likewise has a high impact on the IS community and consists of eight journals, including the Journal of the Association for Information Systems and the European Journal of IS. The third segment consists of 10 journals that are very relevant to IS, such as Management Information Systems Quarterly Executive and Business and Information Systems Engineering.

Our search strategy incorporated the following keyword combinations: (*Ethics AND "Business Process"*), (*"Ethical Value" AND "Business Process"*), (*"Ethical Value"*), (*"Moral Value" AND "Business Process"*), (*"Moral Value"*) and (*"Business Process" AND Task*). With these keywords, we aim to cover research on ethical values considering BPM as well as research on BPM, which includes ethical values, resulting in a comprehensive overview. These keywords were selected broadly to avoid excluding relevant articles with a slightly divergent scope. We examined these articles in the subsequent screening process and did not impose any temporal restrictions on our search to ensure a comprehensive overview of the existing literature. To allow a rigorous search and improve the traceability of the literature selection process, the Preferred Items for Systematic Literature Reviews and Meta-Analysis (PRISMA) have been applied (Page et al., 2021). Relevant articles were selected based on keywords and titles, followed by further refinement through abstract selection. The remaining articles underwent a full-text review and were coded using the four-eye principle.

In adherence to the PRISMA statement, we included articles that engaged with (ethical) values or ethics and offered ethical reflections on (internal and external) processes. The topics of AI and big data were solely included in our sample if they occurred in the context of business processes. We underscored the human aspect of business processes, such as challenges or prerequisites for employees or those affected by processes. We examined articles that address process-supporting elements, such as enterprise resource planning systems, for consideration of ethical and personal values. Articles that did not engage with business processes or solely delved into technical details like process performance were excluded from our sample. [3] Figure 1 presents the PRISMA flow diagram, delineating the results.

Our coding is based on inductive and deductive elements and was developed to examine processes and process tasks (cf. Table 1), illuminating the internal or external perspective.



For our inductive approach, we relied on thematic analysis (Squires, 2023). We adhered to the classification of overarching values proposed by Winkler (2018), identifying and allocating them to the respective process areas and tasks. In doing so, we allocated lower values and synonymous terms to the corresponding overarching values. Additionally, we inspected the socio-technical aspect of the study, specifically the organization, individual, or technology (Orlikowski, 2007; Leonardi, 2012), to gain a deeper comprehension of our sample's structure. One inductive category we coded for was the area of application of the values within BPM. Likewise, we identified which type of process was the publication's focus and whether it was an internal or external business process.

3. Results

3.1 Findings

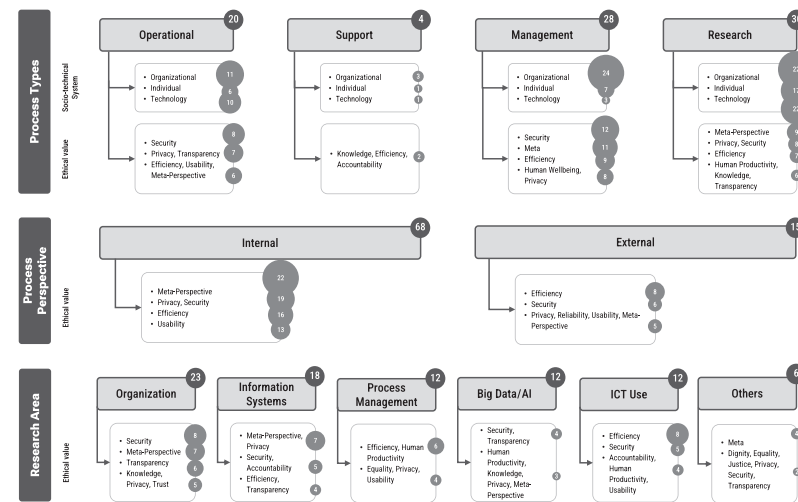
The final literature review sample identified various values classified according to different dimensions, which we combined into a descriptive framework of ethical values in business process management shown in Figure 2. Each article could only be part of one dimension but

BPMJ 30,8 350	Area	Codes	Comment	Major issue/Precision
	Field of Research	– Big Data – Business Process Management (BPM) – Information and Communication Technology (ICT) – Information Systems (IS) – Organization – Other	Inductive category	This category was created in an inductive procedure, adhering to thematic analysis (Squires, 2023)
	Process Type	– Operational Process – Support Process – Management Process – <i>Research process – added by the authors</i>	Deductive category (Porter, 1998)	This category categorizes the different types of processes. The authors added a fourth type of process, which subsumes information about research processes and a meta-perspective on BPM research
	Process Perspective	– Internal Process (I) – External Process (E)	Deductive category based on Hammer and Champy (2001)	This category was used to determine if the processes are intra-organizational or inter-organizational
	Socio-technical Systems Perspective	– Organization – Individual – Technology	Deductive category based on Orlikowski (2007) and Leonardi (2012)	This category was used to determine which socio-technical perspective was employed in the respective research paper. One paper could include several perspectives
	Ethical Values	– Accountability – Autonomy – Community – Dignity – Education – Efficiency – Equality – Freedom – Human Health – Human Capabilities – Human Productivity – Human Welfare – Human Wellbeing – Justice – Knowledge – Maintainability – Privacy – Property – Relationship – Reliability – Respect for Norms – Security – Simplicity – Transparency – Trust – Usability – Environment – <i>Meta Perspective on Values – Added by the authors</i>	Deductive category based on Winkler (2018)	This category is based on the overarching values for sustainable software development as proposed by Winkler (ibid.). These overarching values include other subordinate partial values. We have taken the liberty of adding the category of the meta-perspective on values. We have applied this when a publication discusses the significance of values for a specific application area. One paper could include several values

Table 1.

Coding methodology

Source(s): Table by authors



Business Process
Management
Journal

351

Figure 2.
Descriptive framework
of ethical values in
process management

Source(s): Figure by authors

may include one or multiple values from the catalog (cf. Winkler, 2018). The first dimension is used to classify the articles and their used values according to the different process types relying on the categorization into operational, support, and management processes (Porter, 1998; Dumas et al., 2018) while extending this to include research processes for analysis purposes. Including this additional process type allows for codifying various approaches and references to ethical values, implying the potential impact of ethical values on all other process types in the future. Here, we also matched the three categories of socio-technical systems (Beath et al., 2013) and named the central values that occur for each kind of process. As previously mentioned, processes can also be categorized as internal or external, which is the second perspective used. Internal processes are focused on the operations within an organization's boundaries (Weske, 2019), while external business processes extend beyond the confines of a single organization.

Finally, we grouped the articles according to IS research topics based on the initial content of ethical values and business processes in the final sample [4]. The title and abstract were primarily used for this purpose, followed by the contents of the articles. This covers various topics, including information systems, process management, the use of information and communication technology, recent advances in research such as big data and AI, organizational matters, and a category for articles that do not fit into any other category, such as the work of Adam et al. (2017) on gender and identity in IT or Rowe et al. (2023) on the responsibility of autonomous driving systems.

In addition to Winkler's existing overarching values, we identified the *meta-perspective*. These considerations deal with values without explicitly naming, treating, or integrating them. We included these in our sample because they often (e.g. Ghasemaghahi and Kordzadeh, 2024; Karlsson and Ågerfalk, 2009) emphasize the relevance of values and their areas of application but cannot be classified in the existing categories.

3.1.1 *Specific results.* Looking at *process types*, it can be seen that a meta-perspective predominates in research on business processes (e.g. Hassan and Mathiassen, 2017;

BPMJ
30,8

352

Mumford, 2006). This perspective refers to publications and contributions that consider and think about values and their influence without directly naming said values. In the operational processes, we identified security, privacy, and efficiency (e.g. Weinmann *et al.*, 2016; Li *et al.*, 2014) as the most frequent values, and these were also of great importance in the management processes (Córdoba, 2009; Chatterjee *et al.*, 2015). Regarding socio-technology, the operational processes mostly emphasized technological aspects, while management processes emphasized the organizational aspects and support processes focused on both. A focus on the individual can primarily be found in research, where the individual is partially examined from a metaperspective as a part of the whole (e.g. Li *et al.*, 2014; Bednar and Welch, 2019).

On the other hand, the *process perspectives* show a significant difference in the number of articles for each category. Most identified articles focus on internal processes, while only a few discuss external processes. Internal processes primarily address classical values of the Industrial IoT and the utilization of critical data within an organization, with a particular emphasis on security and privacy. Conventional management perspectives and values, such as efficiency, usability, and human productivity, are prevalent (e.g. Chang and King, 2014; Markus and Mentzer, 2014). Conversely, publications on external processes predominantly explore the meta-perspective on values, emphasizing transparency and privacy for external stakeholders (e.g. Smith and Hasnas, 1999; Hassan and Mathiassen, 2017).

Classifying all relevant articles into different *research areas* yielded promising results. Security and privacy were among the most mentioned values in each research area, except for AI and Big Data. Efficiency was also widely cited, which can be explained by the fundamental goal of value creation in businesses and its optimization. Each research area includes process management, which may explain why process management and AI articles focus on efficiency and human productivity to increase value creation. Ethical considerations would likely fall under the ICT use category, which considers the use of information and communication technology. The explicit focus of business process management includes ethical values such as security and privacy, knowledge, and usability. On an organizational level, values such as justice, human well-being, and accountability are also important, shifting the focus toward socio-technical systems' human aspect. All things considered, in comparison to the two aforementioned dimensions, the categorization into distinct domains provides a unique viewpoint by incorporating additional values beyond security, privacy, efficiency, and usability. This approach also emphasizes more sustainable values such as equality, transparency, maintainability, knowledge, human productivity, and human well-being.

3.1.2 Joint findings. *Organization* as a category encompasses the organizational-orchestrating aspect of BPM without focusing too much on the technical aspects. In this category, we find a strong reference to ethics in general (Culnan and Clark, 2009), but only a limited reference to ethical values; the focus is more on ethical codes that operationalize ethical values for a company (Benitez-Amado *et al.*, 2015).

Information Systems as a category has a strong research focus, often linked to BPM research (processes). At the research level of IS, we see a solid reference to ethics in general (Cheng *et al.*, 2014; O'Leary, 2020; Smith and Hasnas, 1999), but also a perspective on the development of IS (Agerfalk and Eriksson, 2017; Iivari *et al.*, 2015). The process perspective strongly focuses on research, occasionally adopting a management perspective – furthermore, this category is relatively balanced between an internal and external perspective. Socio-technics are viewed as a whole, with a slight trend towards the organizational perspective. In terms of values, the meta-perspective on values is dominant. Otherwise, the more substantial mention of equality and justice and the constant appearance of efficiency is of interest.

Process management subsumes all aspects of process management (and their organizational and manufacturing processes). Here, values are significant from a meta-

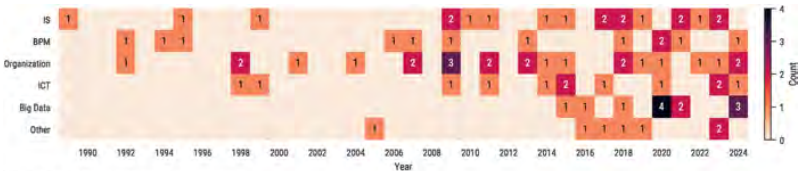
perspective (May *et al.*, 2013), and the risks of BPM, especially in privacy, are discussed (Dulipovici and Baskerville, 2007; Kummer and Mendling, 2021). The perspective in the research is mainly internal, and the processes considered are primarily operational or management-oriented. One part deals with socio-technology, considers BPM as individual cases, and strongly focuses on research (Mumford, 2006). Values like efficiency, privacy, and security are essential, while we also found an increasing interest in the value of equality, showcasing a partial area of an individual perspective.

AI and Big Data are research and application areas that involve processing large amounts of data. They are closely related and integrated into a company's value chain. The training and execution of AI methods and techniques rely on large amounts of data, which enable companies to process data from processes for value creation. Both areas are significant research drivers in IS, particularly concerning the new opportunities that this technology presents for process execution and management, as well as their primary data (Abbasi *et al.*, 2016; Gupta *et al.*, 2018), both in terms of new business models (Wiener *et al.*, 2020) and risks (Clarke, 2015). AI, on the other hand, is perceived more critically. However, the role of corporate success, including corporate processes, is certainly addressed (Enholm *et al.*, 2021), as are risks (Gupta *et al.*, 2021) and ethical issues (Siau and Wang, 2020), as well as explainability (Asatiani *et al.*, 2020). For both technologies, the internal perspective is dominant, and we find a strong focus on technology in the process types and a more minor focus on the organizational aspects. In terms of values, we observe a focus on transparency and security, as well as usability, efficiency, and privacy, with efficiency and usability being more relevant to big data and privacy and security being more applicable to AI.

ICT use involves using application and communication software to manage, design, execute, and improve business processes. This category demonstrates a focus on the ethical use of ICT, albeit from a strongly organizational perspective (Banerjee *et al.*, 1998; Chatterjee *et al.*, 2015), which is strongly associated with the responsible use of ICT (Markus and Mentzer, 2014). The elected process perspective is exclusively internal, focusing on operational and management processes. The ethical values most frequently here are efficiency, security, usability, productivity, and security.

Others as an integrative category includes e-government, healthcare, gender, and specific IT design and development processes associated with company operations. The breakdown of this process is primarily focused on operational and management aspects, with only occasional reference to the meta or support level. However, the internal perspective is again preferred, and security, privacy, and efficiency dominate regarding values. The socio-technical view, on the other hand, is very heterogeneous, with either technological focus (Begier, 2009), organizational focus (Kamal *et al.*, 2015), individual focus (Chatterjee *et al.*, 2009b) or holistic focus (Bednar and Spiekermann, 2023) all represented.

3.1.3 Historical development of research areas and value incorporation. In addition to analyzing the content, examining the number of publications that address process management and ethical values can provide valuable insights. Figure 3 illustrates the



Source(s): Figure by authors

Figure 3.
Temporal distribution
of primary research
fields

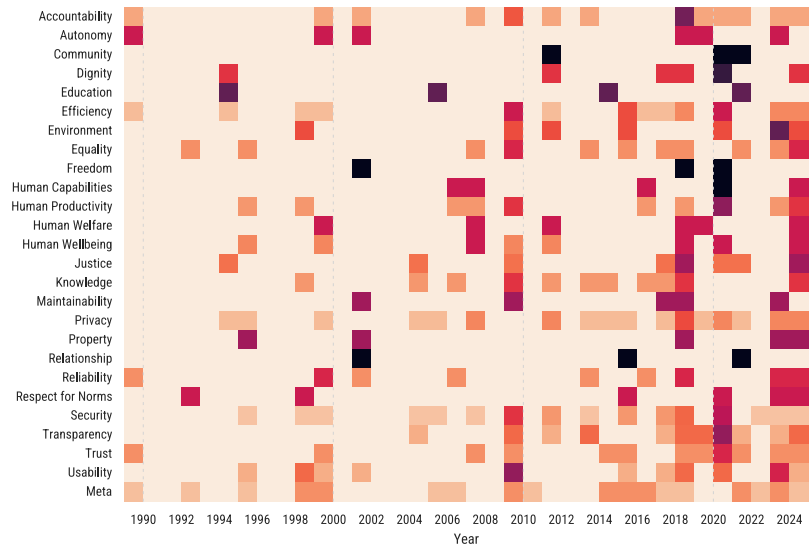
BPMJ
30,8

354

evolution of the classes covered within the final sample over the past 35 years. The graph highlights an increase in the number of publications and diversification into more specialized areas. In the early years, research focused on information systems, processes, and the comprehensive use of information and communication technology. However, research has shifted toward more specific applications in recent years, particularly emphasizing explainable and ethical AI. The advent of new technologies and applications often paves the way for novel research streams and an increasing number of publications. Despite this, these current topics have been present for more than ten years, indicating that integrating ethical values needs to catch up to the cutting edge of application and research. Interest in ethical values in AI and big data is on the rise (e.g. Wiener *et al.*, 2020; Clarke, 2015), while research on ethical values in the broader field of Information Systems (IS) (e.g. Mingers and Walsham, 2010; Iivari *et al.*, 2015) and BPM (e.g. Porra and Hirschheim, 2007) remains consistent.

Over time, interest in values has seen a marked increase. Winkler (2018) has identified 32 overarching values, each integrating different sub-values. We identified 25 values in our sample, shown in Figure 4 (we removed values only present in one article). We have also added the metaperspective on ethical values many IS researchers took (Alt *et al.*, 2021; Hassan *et al.*, 2018; Bednar and Welch, 2019). One value of constant interest over time is efficiency, a practical value contributing to organizational success (May *et al.*, 2013). Looking at the development over time, various trends can be made out: In recent years, the values of equality and justice have also become increasingly important (e.g. Chatterjee and Sarker, 2013; Adam *et al.*, 2017; Markus and Mentzer, 2014), so does transparency (e.g. Enholm *et al.*, 2021; Gupta *et al.*, 2021) and trust (e.g. Ezingard *et al.*, 2005; Heyder *et al.*, 2023) especially with the increasing emergence of AI. On the one hand, recently, there has been an increase in human-related values such as human health and human welfare (e.g. Córdoba, 2009;

Figure 4.
Temporal distribution
of identified values
(percentage of yearly
discovered
publications)



Source(s): Figure by authors

Li *et al.*, 2014; Heyder *et al.*, 2023). However, values such as efficiency or human productivity (e.g. O'Leary, 2020; Chen *et al.*, 2014) are still of interest.

As seen above, with the classification into different research areas, privacy and security are essential values mentioned in the articles. Both topics are closely tied to data collection, transformation, and use through various systems.

At the organizational level, the values of security, efficiency, and privacy can be identified from the management perspective. Personal values such as human health and well-being are scattered, partly from the individual perspective in the operational processes and partly from the technological aspect of the support processes (Dulipovici and Baskerville, 2007). In general, functional values predominate over individual humanistic values (e.g. Ixmeier *et al.*, 2024; Li *et al.*, 2014). It is noticeable in this case that we could not find individual values for either support processes or research from a personal perspective. Similarly, support processes have yet to be considered from a holistic socio-technical perspective.

3.2 Discussion

BPM and its application is a complex field consisting of a multitude of IT artifacts, processes, and individuals (Weske, 2019) who all have their personal values and beliefs (Agle *et al.*, 2014). As motivated above, value creation in businesses demands considering ethical concerns and ethical values in the design and implementation of business processes from both an organizational and technical perspective (Beverungen *et al.*, 2020). By analyzing relevant literature on business process management and ethical values, we identified relevant values for different process types (Dumas *et al.*, 2018), especially in combination with a socio-technical perspective (Beath *et al.*, 2013; Sarker *et al.*, 2019).

Analyzing the field of business processes regarding ethical values (Winkler, 2018) using a socio-technical perspective (Beath *et al.*, 2013) allows us to take a broad view of processes, their execution, and management. The individual perspective, for example, is mainly considered in operational processes (Burbano and Chiles, 2022; Chatterjee *et al.*, 2009a), where the few values found are much more centered on the individual due to freedom, human health, and justice compared to the other process types. On the other hand, management processes from an organizational perspective (Culnan and Clark, 2009; Chatterjee *et al.*, 2015; Córdoba, 2009) are dominated by values such as efficiency, productivity, and maintainability. Another significant aspect is the lack of consideration of support processes in the IS literature. In contrast, the other process types – including research processes – occur relatively evenly in the literature, whereas support processes are lacking. This could be because those processes are more challenging to identify and collect, leading to fewer results.

As illustrated in Figure 2 and described in the previous section, parts of the BPM literature recognize the importance of values without naming them specifically or going into depth. This corresponds with a large portion of the literature on values in IS in general (Spiekermann *et al.*, 2022). Research in BPM could benefit from a more sophisticated procedure for collecting and implementing values adapted to BPM and from a list of values specially adapted to BPM. The value efficiency, as depicted in Figure 4, remains a consistent focus in IS research, particularly in process management. This emphasis likely stems from the inherent objective of business processes to generate value, wherein optimizing and enhancing efficiency is fundamental (Dumas *et al.*, 2018; Begier, 2009). However, with the emergence of ethics as a research perspective, other values such as accountability, security, or transparency have gained prominence next to a slight focus on human actors in human productivity.

We have also found that from the technological perspective, the values of efficiency and safety are among the most popular (Markus and Mentzer, 2014; Dolata *et al.*, 2021).

BPMJ
30,8

356

Depending on which processes are considered, in individual cases (Heyder *et al.*, 2023; Begier, 2009), values centered on people, such as human welfare or human wellbeing, are also considered. However, this perspective still needs to be exhausted, particularly concerning cooperative interaction between individuals and the design of technologies for human-friendly and efficient collaboration. Here, the identified values of the value catalogs (Winkler, 2018; IEEE, 2018) and approaches to value-based design can provide support (Spiekermann, 2016, 2023). In other areas, values have proven to be a successful vehicle for the development and acceptance of IT solutions (Sapraz and Han (2021), and consideration of individual values can also help to support collaboration and the acceptance of specifications, as they also occur in BPM (Wickham *et al.* (2022)). Therefore, we see the values found as an essential first step in developing and implementing ethics-oriented business process management and ethical value creation in the long term.

3.2.1 Limitations. It is important to consider possible limitations of this literature review when interpreting the results. Firstly, the research was confined to the field of information systems literature, with a particular focus on journal articles. While this provides a solid foundation, relevant insights from conference proceedings were not included and may offer additional perspectives, suggesting a potential avenue for future research. As we have shown, the literature on IS is often relatively high-level, lacking the concrete views of practitioners who encounter processes, process data, and the moral conflicts they generate daily. While our paper establishes a basis for more practical future research, we must recognize that these perspectives may not be included.

In our sample of 82 articles, 12 articles focused explicitly on BPM, and 23 primarily adopted an organizational perspective, yet these studies remain relevant to BPM. Despite not all articles centering exclusively on BPM, we were still able to derive meaningful insights applicable to the field. However, it is essential to acknowledge that the varying explicitness of the focus on BPM across the sample may influence the specificity of some findings.

Additionally, our sample comprised both theoretical (e.g. Abbasi *et al.*, 2016; Alt *et al.*, 2021) and empirical studies (e.g. Adam *et al.*, 2017; Davison and Chatterjee, 2023). Many of the empirical articles relied on smaller-scale interviews, which can affect the generalizability of the findings for specific areas.

3.2.2 Research propositions. The insights on the intersection of BPM and ethical values have enabled us to formulate several research propositions. These propositions underscore the gaps and challenges identified during the literature review. These areas hold particular promise for advancing the field of BPM as a whole and ethics-oriented research in information systems (IS).

Proposition 1. Elicitation of values focused on the individual in BPM environments – especially on people performing a certain task (ethical evaluation of technological entities is widespread compared to this). This perspective needs to be improved, and although certain works such as Burbano and Chiles (2022), Chatterjee *et al.* (2009a), and Weinmann *et al.* (2016) are making an effort to contribute to this perspective, much more detailed research must be done.

Proposition 2. BPM could use tools to integrate ethical values into process environments more efficiently. Some approaches have been taken to implement values, mostly business-related, in enterprise resource planning (May *et al.*, 2013) or ICT systems in general (Bednar and Welch, 2019) but, to the best of the author's knowledge, not yet in business process modeling. Further research can build on these and implement specific tools and approaches, such as developing and improving modeling languages incorporating

ethical values at a fine-granular level, ethical value-oriented frameworks, and meta-models.

Business Process
Management
Journal

Proposition 3. IS, in general, and the BPM community, in particular, can benefit from having a specific procedure for collecting and implementing ethical values in the BP context. Currently, existing methods (e.g. [Spiekermann, 2023](#)) are not explicitly designed for the BP context with inherent sub-process steps and system specifics. Accordingly, developing a suitable procedure, possibly even at the task level, could be profitable here.

357

4. Conclusion

Our literature review aimed to obtain an overview of ethical values in business process management. We looked at values integrated into process-supported value creation in businesses to achieve this. We identified critical areas of interest, relying on a list of human values for sustainable software development ([Winkler, 2018](#)). By adopting a socio-technical-system perspective ([Beath et al., 2013](#); [Cummings and Srivastva, 1977](#); [Sarker et al., 2019](#)), we analyzed the values employed in BPM from an individual, organizational, and technical aspect. We found that operational and management processes primarily focus on efficiency and security. Research on BPM often adopts a metaperspective, discussing values and their influence without explicitly naming them. We also observed that internal processes within an organization prioritize security, efficiency, and privacy. In contrast, external processes across companies often focus on knowledge as a primary value while adopting a metaperspective on values. However, our study also revealed some gaps in the current research, notably the absence of individual values for support processes or research from a personal perspective and the need to consider support processes from a holistic perspective.

Furthermore, we discovered that the individual perspective on processes primarily concerns operational processes, strongly emphasizing values such as freedom, human health, and justice. In contrast, management processes from an organizational perspective are dominated by values such as efficiency, productivity, and maintainability, which are more focused on the company's success. This suggests that there is room for more focus on individuals and values such as human well-being or human health.

Interestingly, we found a strong focus on research in the context of processes, particularly those that adopt a metaperspective on values. This perspective often removes the focus from the individual, the design of technology, and the human in general. Many research projects that adopt this metaperspective need to be revised to assign to a single perspective, indicating a preference among IS researchers for a holistic view. This preference focuses on global values or values as a concept rather than individual ones. Our findings suggest that the discipline could benefit from a more detailed view, both at the process-task level and of the individual and their needs. This could lead to better acceptance of processes and their management or better alignment of the individual with the organization's values where the process occurs. These insights pave the way for future research to explore these aspects and their implications for the field of BPM in greater depth.

Our study thus contributes to a more nuanced understanding of BPM, highlighting the importance of considering ethical values and socio-technical perspectives in designing and implementing business processes. These findings contribute to understanding the values associated with different types of processes and their employment and highlight potential areas for future research. Our study provides ethics-oriented research in IS with novel insights by examining BPM from an ethical value perspective. We contribute to the BPM literature by examining which values are applied in which process types from which

BPMJ
30,8

perspective. In addition, our research suggestions provide food for thought for both research streams.

Although ethical values already play an essential role in research and the real world, both domains could benefit from a more refined and deliberate approach to applying ethical values in process management and overall organizational value creation.

358

Notes

1. This does not necessarily apply to their counterparts in other languages, as there can be a substantial distinction between both terms.
2. We use the term ethical theories for the remainder of this publication. We deem this to encompass normative ethics and ethical theories in general. These are distinct from descriptive ethics, meta-ethics, and applied ethics.
3. A comprehensive list of all articles in the final sample and their coding can be found in the [supplementary files](#).
4. The cross-sectional search string allowed for an *a posteriori* classification based on research focus.

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Entries denoted with * are part of the final sample of the References review that can be found in the supplementary files, including the final coding

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BPMJ
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366

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(continued)

Socio-technical System Perspective																												
Field of Research	Process Type	Process Perspective				Ethical Values																						
		Individual	Organizational	Technology	Accountability	Community	Dignity	Education	Environment	Efficiency	Equality	Freedom	Human Health	Human Wellbeing	Justice	Knowledge	Maintainability	Privacy	Property	Relationship	Respect for Norms	Security	Singleity	Transparency	Trust	Usability	Value	
Big Data	Research	I	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Other	Research	I	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
IS	Research	I	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
IS	Research	E	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
ICT	Operational	I	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Big Data	Research	I	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
HBM	Operational	I	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
ICT	Management	I	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
ICT	Management	I	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
ICT	Management	I	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
ICT	Operational	I	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
HBM	Support	I	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Big Data	Research	I	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Organizations	Management	I	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Organizations	Management	I	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
HBM	Research	E	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
HBM	Management	I	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Organizations	Management	I	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Organizations	Operational	I	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
IS	Research	E	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
ICT	Management	I	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Organizations	Research	I	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Table A1.
Detail coding of the
final sample

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368

Table A1.

Source			Process Perspective			Socio-Technical Systems Perspective												Ethical Values																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
						Individual				Organization				Technology				Accountability				Autonomy				Dignity				Education				Environment				Efficiency				Equality				Freedom				Human Health				Human Capabilities				Human Wellbeing				Justice				Knowledge				Materiality				Privacy				Property				Relationship				Reliability				Respect for Norms				Security				Simplicity				Transparency				Trust				Usability				Vitality																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
Field of Research	Process Type	Source	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E	●	I	E

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Business Process
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369

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Subsidiary Systems Perspective				Ethical Values																											
Source	Field of Research	Process Type	Process Perspective	Individual	Organization	Technology	Accountability	Autonomy	Community	Equality	Education	Environment	Efficiency	Freedom	Human Health	Human Capabilities	Human Productivity	Human Welfare	Justice	Knowledge	Integrity	Privacy	Relationship	Respect for Norms	Security	Sustainability	Transparency	Trust	Loyalty	Virtue	
Jain and Gera (2018)	Organization/Operational		I	○	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Maguire et al. (2010)	Organization/Management		I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Kamal et al. (2015)	Big Data	Research	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Kashani and Agrawal (2019)	ICT	Management	II	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Kawashita et al. (2018)	ICT	Operational	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Kim et al. (2019)	IS	Research	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Kirsch (2004)	Organization/Operational		I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Kumar and Mehlum (2021)	HBM	Management	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Lacey et al. (2024)	ICT	Management	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Lee et al. (2023)	Organization/Research		II	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Levi-Belz et al. (2018)	HBM	Operational	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Li et al. (2014)	Organization/Operational		I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Lundberg (1992)	HBM	Research	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Markus and Meuter (2014)	ICT	Operational	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
May et al. (2013)	HBM	Operational	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
McLaughlin and Cogan (2018)	Other	Operational	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
McLagan and Bryant-Gallard (2019)	IS	Operational	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Majumdar and Wadhvani (2010)	IS	Research	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Manfred (1994)	HBM	Research	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Manfred (1996)	HBM	Research	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Manfred (2000)	Organization/Management		I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
O'Leary (2020)	ICT	Research	II	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Perrault and Blochstein (2007)	HBM	Research	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
River and Markus (2023)	Other	Research	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Table A1.

(continued)

Table A1.

BPMJ
30,8

370

Table A1.

Socio-technical Systems Perspective										Ethical Values																				
Source	Field of Research	Process Type	Process Perspective			Ethical Values																								
			Individual	Organization	Technology	Accountability	Autonomy	Integrity	Education	Environment	Efficiency	Equality	Freedom	Human Health	Human Capabilities	Human Productivity	Human Welfare	Human Wellbeing	Justice	Sustainability	Privacy	Relationship	Reliability	Respect for Norms	Security	Stability	Transparency	Trust	Usability	
Saunders and Miranda (1998)	Organization	Management	I	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Siau and Tang (2017)	ICT	Operational	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Siau and Wang (2020)	Big Data	Research	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Shier et al. (1995)	IS	Management	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Smith and Hawes (1999)	IS	Management	E	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Spjeldervann et al. (2022)	IS	Research	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Strubbe et al. (2001)	Organization	Management	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Tublin et al. (2002)	Other	Operational	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Vandekerckhove and Deconinck (2013)	Organization	Management	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Weinmann et al. (2016)	Other	Operational	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Wimmer et al. (2020)	Big Data	Management	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Willmots and Smith (1995)	BPM	Management	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Zhou and Kapoor (2011)	Organization	Research	I	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Legend:
● recent,
○ not recent

Explanation: I: Internal, E: External

Legend: I: Internal, E: External, ○: present, ●: not present

P3.2 Measuring Moral Performance: A Framework for Ethical Business Process Management

Current Status	Published	
Conference	Responsible BPM Forum (2025)	
Date of Submission	June 5, 2025	
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Full Citation	Poss, L., Kern, C.J., Stoiber, C., Kroenung, J., Schöning, S., “Measuring Moral Performance: A Framework for Ethical Business Process Management.” In: Business Process Management: Responsible BPM Forum, Process Technology Forum, Educators Forum. Springer Nature Switzerland, Aug. 2025, pp. 117–132. ISBN: 9783032029362. https://doi.org/10.1007/978-3-032-02936-2_10	
Authors’ Contributions	Leo Poss	40%
	Christopher Julian Kern	30%
	Christoph Stoiber	10%
	Julia Krönung	10%
	Stefan Schöning	10%

Conference description: The Responsible BPM Forum addresses the technological, managerial, and conceptual challenges of integrating ethics into BPM. From a technological standpoint, it tackles data security, privacy, and the ethical use of AI; managerially, it focuses on aligning organizational goals with social responsibility; and conceptually, it seeks to embed ethical principles into traditional efficiency-focused frameworks. Co-located with the 23rd International Conference on Business Process Management (BPM 2025) in Sevilla, Spain (Aug 31 – Sep 5, 2025), this inaugural forum discusses responsibility across the entire BPM lifecycle (including responsible analysis, design, and performance) affecting both the computational and managerial dimensions of the field. (Source: <https://www.bpm2025seville.org/calls/responsible-forum/>)

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Measuring Moral Performance: A Framework for Ethical Business Process Management

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Abstract. This paper proposes a novel approach to integrating ethical considerations into process management. The research endeavor is timely and relevant, as ethics in Business Process Management (BPM) have been scarcely researched, and practice increasingly focuses on ethical principles. Our framework, developed based on the fundamentals of design science research (DSR), provides a structured method for integrating ethical assessments into BPM. It combines established ethical perspective questionnaires with customizable evaluations of specific ethical values, enabling both high-level and granular assessments. This framework supports the modeling phase by allowing annotation of ethical aspects, the execution phase by facilitating real-time ethical assessment by users, and the monitoring phase by visualizing collected ethical performance data. It enables customizable ethical value tracking, enhancing ethical awareness in business operations. The concept was implemented as a prototype and evaluated with domain experts, demonstrating its utility in operationalizing ethical considerations in BPM. This research contributes to ethics-aware BPM by providing a practical framework to make ethical considerations explicit, measurable, and manageable within daily business operations and expanding the scope of research on quantifying and enhancing ethical process performance.

Keywords: BPM · Ethical Values · Sociotechnical System · Benevolent BPM · Ethics-aware BPM

1 Introduction

Business Process Management (BPM) is central to how modern organizations operate, enhancing the efficiency and effectiveness of business operations [6]. While ethical considerations are often implicit in process design and execution, current BPM practices primarily focus on traditional performance metrics, overlooking explicit mechanisms for the systematic assessment and management

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118 L. Poss et al.

of ethical values [17, 26]. This gap highlights a critical need: to move beyond efficiency gains and develop methods that systematically assess, incorporate, and ensure transparency of ethical values during process execution.

The existing literature on ethical issues and organizational culture highlights gaps in broader ethical considerations, while security and privacy concerns have received some attention [3, 17]. Adopting emerging digital technologies, such as machine learning and robotic process automation, needs to be designed to avoid compromising fairness, reducing biases, or eroding trust [19]. Therefore, it is relevant to align ethics and processes to mitigate the ethical pitfalls of digital technologies while maintaining efficiency by directly focusing on the underlying socio-technical system [15]. Novel research streams, such as benevolent business process management, emphasize the importance of designing business processes that incorporate ethical, environmental, and social considerations beyond operational efficiency and transactional value [26]. The imperative for ethical considerations is further underscored by the emerging concept of Digital Responsibility [29]. This concept emphasizes promoting responsible behavior and integrating ethical considerations directly into digital technologies. While existing research articulates these crucial conceptual approaches and calls to action, a notable gap remains: practical implementations are rare, and their systematic adoption within organizations is even scarcer.

To address these gaps, we introduce a framework, theoretically developed and realized as a prototypical implementation, for making ethical considerations tangible in BPM. This framework facilitates the assessment of ethical perspectives and specific values during task execution, enabling the collection of data for monitoring and improvement, designed for integration with BPMS. Our approach aims to answer the following key research question: *How can ethical considerations be effectively integrated (from modeling through execution to monitoring) within the BPM lifecycle to enable ongoing ethical assessment and improvement?*

Our research provides a novel framework for measuring moral performance by systematically integrating ethical perspectives and values into the generic BPM lifecycle and everyday process execution. This IT artifact is designed to be system- and model-language-agnostic, providing functionalities for collecting, measuring, and visualizing ethical values associated with processes. By enabling the collection and analysis of ethical performance data, our framework provides a basis for more thorough process monitoring and data-driven discussions on ethical improvement, thereby contributing to a more sustainable and responsible digital future.

2 Theoretical Background

2.1 Business Process Management (BPM)

Business Process Management (BPM) is an important factor in driving business value creation by enabling the digitization, automation, and strategic planning of operational processes [6]. While traditional BPM research predominantly

focuses on the design and execution of processes, encompassing methodologies, languages, and tools for modeling, simulation, and execution, contemporary research has expanded this scope. This broadened perspective includes integrating business processes with critical organizational assets and resources, such as information systems, human resources, their interplay, and collaborative networks including socio-technical interplay and acting benevolent [6,26]. A business process, in its essence, is a structured set of activities designed to achieve a specific organizational objective [6,31]. These processes can be represented through one or more process models that then serve as blueprints for real-world scenarios, providing a structured and analyzable representation of the process flow [31]. In this way, a business process model serves a dual purpose: it allows for a visual representation of stakeholder communication and understanding, and acts as an executable specification for automated process execution within a BPMS.

2.2 Ethics

Ethics, often used synonymously with morality [9], is the branch of philosophy that investigates the principles guiding right and wrong human conduct [27]. It systematically examines ethical concepts, values, reasoning, and justifications [2], aiming to understand and guide human actions towards achieving a good life. This includes *normative ethical theories*, which provide frameworks for evaluating moral actions and character, *applied ethics*, which adapts these theories to specific domains [32], *descriptive ethics*, which empirically analyze existing moral beliefs [13] and *meta-ethics*, which explore the nature of ethical judgments themselves. Ethical theories, which provide systematic approaches to moral reasoning, can broadly be categorized into schools such as *teleological ethics* (focusing on outcomes or consequences, e.g., utilitarianism), *deontological ethics* (emphasizing duties, rules, and rights), and virtue ethics (focusing on moral character). While our framework does not rigidly enforce a single school, the chosen ethics scale (see below) incorporates elements reflecting both deontological (e.g., justice, contractualism) and relativistic considerations, offering a multifaceted lens for assessment.

Ethics scales are measurement instruments used in psychology, sociology, and philosophy to evaluate individuals or specific problems. In psychology, ethics scales are designed to assess ethical decision-making and behavior [5,25]. They often include dimensions such as moral equity, relativism, contractualism, and other ethical philosophies [18]. In contrast, sociology may use ethics scales to evaluate ethical behavior at different educational stages or organizational contexts [30]. Ethics scales are grounded in various ethical theories, including virtue, deontology, utilitarianism, and justice principles. The development of scales is influenced by moral philosophy, including the application of moral principles to analyze ethical issues [20]. One widely used and developed ethics scale and questionnaire is the 2013 scale developed by [25], as presented in Fig. 1. It is a more straightforward, shorter version of the scale developed in 1988 [24] and consists of three dimensions or constructs that are each evaluated on a 7-item

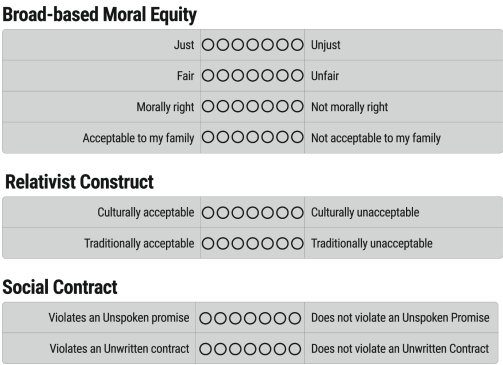


Fig. 1. Multidimensional ethics scale (MES) [25]

Likert-scale: (i) *Broad-based Moral Equity*, which describes the moral philosophy of justice (i.e., fairness and justness) with a deontological and relativistic concept for “broader-based notion of good and bad,” (ii) a *Relativistic Dimension* that includes questions on guidelines, requirements, and parameters inherent in social/cultural systems and (iii) a *Contractualism Dimension* which is a deontological construct that further evaluates the “social contract” between businesses and society. Explicitly absent are egoistic and utilitarian considerations, as they did not contribute strongly to explainability and were hard to understand. Additionally, relativism can be seen as both a source and a standard for ethical evaluation and was deemed difficult to apply (cf. [25]). This multidimensional approach enables a nuanced assessment that encompasses concepts central to deontological thought (e.g., fairness, unspoken promises inherent in social contracts) and relativistic considerations tied to cultural and traditional acceptability.

2.3 Related Work

Ethics and BPM. The integration of ethics into process management is increasingly recognized as essential for aligning technological advancements with ethical and societal values – values such as transparency, accountability, and human well-being are essential aspects in the design and execution of processes, particularly as data-driven systems become more prevalent [15, 17, 19]. [8] highlight the significance of individual contributions in the formation of ethical organizational cultures. Shared values and ethical conduct play a pivotal role in implementing business processes. Ethical considerations in workflow automation extend to the displacement of jobs and the potential dehumanization of the workforce. Organizations are expected to proactively address these concerns, as this aligns with their ethical responsibility to mitigate conflicting impacts on the workforce [7].

Business Process Evaluation and Gathering Direct Feedback During Process Execution. The BPM lifecycle includes monitoring and improvement based on fundamental metrics. These metrics are collected during process execution in addition to classical performance metrics [1]. Our work builds on the idea of expanding these metrics, similar to approaches like [12], explicitly generating additional metrics and capturing implicit feedback, such as user interactions and behavioral patterns, to enrich process understanding. Furthermore, recommender systems and personalization research rely on information collected during process execution. By analyzing user preferences, behavior, and feedback, these systems can tailor recommendations and personalize experiences, leading to increased user engagement and satisfaction (e.g., [16]).

3 Methodology

Our research endeavor aims to enhance the representation of ethical considerations within business processes, which involves the explicit articulation, systematic assessment, and visual feedback of ethical values and perspectives as integral components of process models and their execution instances. In line with existing research on this topic, we position this contribution within the *design science research (DSR)* paradigm, as it enables the development and evaluation of practical artifacts [23]. To adopt established methods and draw on specific methodological guidance, we relied on the well-established seven guidelines for DSR as defined by [11]:

- *Design as an Artifact.* This research develops an executable artifact for integrating ethical considerations into business process execution. The artifact provides functionalities for: (a) annotating process tasks with predefined ethical perspective questionnaires (e.g., [25]) and user-defined specific ethical values during the modeling phase; (b) enabling process participants to provide assessments against these during task execution; and (c) collecting this data and visualizing ethical performance indicators for monitoring and discussion.
- *Problem Relevance.* The rapid adoption of technology in business outpaces ethical integration in BPM. Existing frameworks prioritize performance, overlooking moral implications in automation. This research addresses the prevalent lack of systematic and transparent approaches for embedding and managing ethics in BPM, a gap that can impact organizational integrity, stakeholder trust, and societal well-being, especially with increasing automation.
- *Design Evaluation.* The artifact's utility and effectiveness are assessed through integration into a BPMS and user feedback. Effectiveness in supporting ethical decision-making is evaluated using empirical data and cognitive load analysis via NASA-TLX [10], following the DSRM evaluation principle.
- *Research Contributions.* This research advances ethics-aware BPM by providing a practical framework and IT artifact for explicitly embedding, assessing, and visualizing ethical values in business processes, offering a new perspective on BPMS as a system capable of actively supporting ethical process execution

122 L. Poss et al.

and monitoring, and contributing initial empirical insights into the feasibility and user perception of integrating ethics assessments in BPM.

- *Research Rigor*. The study applies rigorous methods from ethics, BPM, and IS, ensuring empirical validity. Data collection adheres to ethical guidelines, ensuring anonymity and maintaining research rigor principles in DSR.
- *Design as a Search Process*. The artifact undergoes iterative refinement based on stakeholder feedback, ensuring continuous improvement. The iterative approach aligns with DSRM's emphasis on design as an adaptive search process.
- *Communication of Research*. Findings are disseminated through conference publication, covering problem definition, design, evaluation, and demonstration. The artifact remains available for future refinements (Section Sect. 4.2).

To address our research question and the identified problem relevance, we derive the following design objectives to guide the artifact's development: ❶ *Perspective assessment* where the artifact must provide a way to assess broad-based ethical perspectives using an existing questionnaire, ❷ *Value assessment*, which requires the consideration and assessment of singular ethical values for a more granular view next to the general evaluation using a predefined, widely acknowledged measurement scale, that provide the base for the artifact, ❸ *Consider all phases of the BPM lifecycle* for a holistic approach similar to related approaches; the artifact must be supported and usable during the modeling, executing, and monitoring phases of BPM. And for general reusability and best-practices: ❹ *Independence of BPMS and modeling language* to ensure that the conceptual artifact can work independently from both the modeling language or paradigm and the chosen BPMS implementation that executes the process model, and ❺ *Modularity* which means, along the phases, the artifact must be as modular as possible to be as easily adaptable as the process modeling itself. This includes providing support for monitoring and visualizing different aspects of the data.

4 Design and Development

Based on DSR, the following sections outline the steps involved in designing and developing the artifact, including collecting, categorizing, and evaluating existing scientific questionnaires for ethical assessment, conceptualizing the framework based on these findings, and implementing this framework as a software prototype.

4.1 Concept – Ethics-Aware BPM Through Questionnaire and Ethical Values

Our framework's ability to collect ethical assessment data during task execution is designed to be independent of specific process modeling languages or BPMS. It leverages fundamental concepts of activity lifecycles common to most BPMS, specifically requiring at least an 'enabled' (task is active or being worked on) and

a ‘*completed*’ (task is finished) state [31]. The ethical assessment interface is presented to the user while the task is ‘*enabled*’ (i.e., during or immediately after completing the primary task work), and the collected assessment data is transmitted to a data store once the task instance transitions to ‘*completed*’ and thus terminates. To contextualize the results, we need to provide a means to connect the values to a specific task type or process instance, along with a timestamp for temporal ordering. Finally, to fulfill our Design Objectives, all phases and parts must be modular and easily adjustable, from the possibility of manually modeling and defining which values to ask to the final visualization and data analysis of results. The first opportunity to assess ethical aspects is by using existing questionnaires that address ethical perspectives in various contexts. We provide the possibility for comparing high-level information based on the previously introduced questionnaire by [25], while explicitly leaving room for choosing different Likert-based ethical perspective questionnaires.

Binary Assessment of Singular Ethical Values. In addition to this approach for a broader, perspectival overview, we iteratively identified the need for a more specific survey that would enable the binary evaluation of specific ethical values. Ethical values, sometimes referred to as “common values,” are shared by a particular group of people, such as those within a company or a country. The authority of these values typically originates from established agreements [4]. Several lists combine different sets of shared ethical values that can serve as a base catalog for selecting values to include for specific tasks. Two examples from related fields are [33], which describe values for sustainable information systems design, and [14], describing values for ethics in artificial intelligence. Both authors combine even more fine-grained values into overarching principles, including *Accessibility*, *Accountability*, *Efficiency*, *Environment*, *Privacy*, *Reliability*, *Transparency*, and *Trust*.

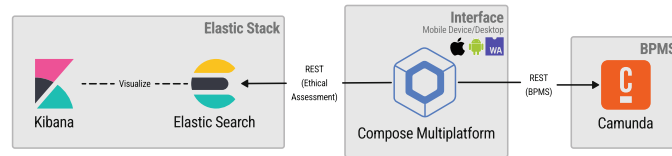
Nevertheless, using specific, singular ethical values comes with specific shortcomings: (i) their definition may be subjective and vary from person to person, and (ii) choosing one value from many may be challenging. Lastly, assessing large numbers of values requires additional effort during and after task execution (cf. Sect. 5). On the other hand, it enhances granularity, allowing for more precise monitoring and analysis.

4.2 Implementation – Evaluating Ethical Aspects in Process Execution

The following sections cover the development of a prototypical implementation for assessing ethical considerations during task execution¹. Here, we implemented the questionnaire [25] (discussed in Sect. 2.2) for assessing broad ethical perspectives, along with functionality that allows users to evaluate predefined singular ethical values relevant to specific tasks. Still, depending on the execution context

¹ Prototype source: <https://github.com/LeoPoss/assessingEthicsInBPM>, Demo server: <http://pcinf00057.ur.de/>, Visualization: <http://pcinf00057.ur.de/kibana/app/dashboards>.

124 L. Poss et al.

**Fig. 2.** Architecture of prototypical implementation

and tasks involved, the questionnaire can easily be adapted to another context if it is not relevant or applicable. The overall approach supports all phases of the BPM lifecycle, and the following sections follow this pattern, beginning with a brief introduction to the general system architecture.

The selected BPMS is *Camunda*², which is widely used within the research community. The system is readily adaptable and offers well-structured and documented access and the functionality for modeling and executing Business Process Model and Notation (BPMN) process models (cf. [21]). The interface is implemented using *Compose Multiplatform*³, which provides an abstraction layer for cross-platform native mobile applications based on *Jetpack Compose*⁴. This decision enables broad native usability on mobile devices, desktop operating systems that use the Java Virtual Machine (JVM), and browsers through Kotlin WebAssembly (WASM). Finally, we rely on the *Elastic Stack*⁵, which combines *Elasticsearch* to store information and uses *Kibana* as a tool for discovery and visualization, allowing easy adaptation based on necessary parameters and configurations.

Architecture. Figure 2 shows how the prototype for assessing values is implemented in our framework. At a high level, it consists of three main parts: Starting with the BPMS that provides the execution logic for the process model and well-defined endpoints to interact with it; second, the main application running on mobile devices, browsers, or other devices providing an interface to the BPMS and implementing the concept from above; and lastly the existing integration of Elastic Search and Kibana for data collection, monitoring, and visualization.

Functionality. For a concise overview of all functionalities, the process used for explanation and visualization represents a basic HR process modeled using BPMN with three consecutive User Tasks (cf. [21]): *Screen Application* followed by *Conduct Interview* and *Evaluate Candidate*. For simplicity, no additional steps or decisions are required; the process proceeds directly, and it concludes after evaluating the candidate.

Modeling. The first value assessment step is providing additional information during process modeling. Integration into the modeling phase is achieved by annotating User Tasks within the BPMN model. In our Camunda-based pro-

² <https://camunda.com>.

³ <https://www.jetbrains.com/compose-multiplatform>.

⁴ <https://developer.android.com/compose>.

⁵ <https://www.elastic.co/elastic-stack>.

Assessing Ethical Values in BPM 125

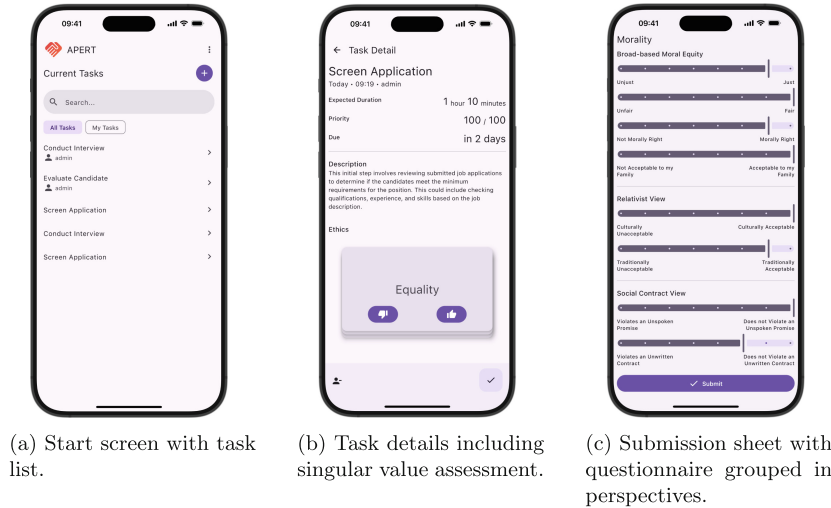


Fig. 3. Prototypical implementation running on a mobile device.

totype, this utilizes the existing capability to associate forms or metadata (via form keys) with tasks. We define a specific JSON structure for this form key, allowing process designers to specify: (a) whether the full ethical perspectives questionnaire (e.g., Reidenbach & Robin [25]) should be presented for a task (via a binary **perspectives** flag), and (b) a list of specific, singular **values** (e.g., 'Fairness', 'Transparency') to be assessed for that particular task. Our interface then queries this configuration during task execution to present the appropriate assessment options dynamically.

Task Execution and Data Collection. The application interface allows access to the BPMS and enables the user to assess value fulfillment and perspectival evaluation of tasks. The first screen in Fig. 3 displays a list of all currently available tasks and their current assignee, a search bar, and a filter for assigned tasks. Additionally, it provides the possibility to start new process instances. The following two screens include the added functionality for assessment: The detailed view for the task contains general information like the title and more detailed information like duration, due date, description, and the possibility to claim and return tasks followed by (i) a stack of swipeable cards that each contain one ethical value defined in the process model if any that can be swiped right or left based on the fulfillment during task execution, and (ii) when the task is completed and is submitted by the user, an overlay will show the questionnaire including all perspectives and sliders for assessing their satisfaction level following the seven-item scale defined in [25]. The task is finally completed after assessing binary values and perspectives. The application triggers task completion in Camunda, which advances the process and sends the data to Elasticsearch in a structured manner.

126 L. Poss et al.



Fig. 4. Exemplary visualizations based on the collected data.

Data Evaluation and Visualization. The last component collects, stores, discovers, and visualizes the data to gain deeper insights into the ethical performance of the executed process. The combination of Elasticsearch and Kibana is a widely adopted industry standard for observability, and the structured approach and format of data handling enable seamless integration with other metrics from various sources. Figure 4 shows examples of dashboards created in Kibana using data collected via the prototype. These visualizations include: The first shows the current average satisfaction for each perspective, grouped by the broader views, while the second provides a more detailed view at the task level, along with the temporal evolution of the averages for the three principal perspectives. The latter provides an overview of the binary assessment of specific ethical values, allowing for drill-down analysis to individual tasks. All parameters and visualizations are easily customizable, allowing for filtering by specific tasks and different periods, as well as visualizing changes over time using built-in functionality. This can be achieved by selecting all tasks where the value of privacy is false and then immediately displaying all visualizations for only those process

Assessing Ethical Values in BPM 127

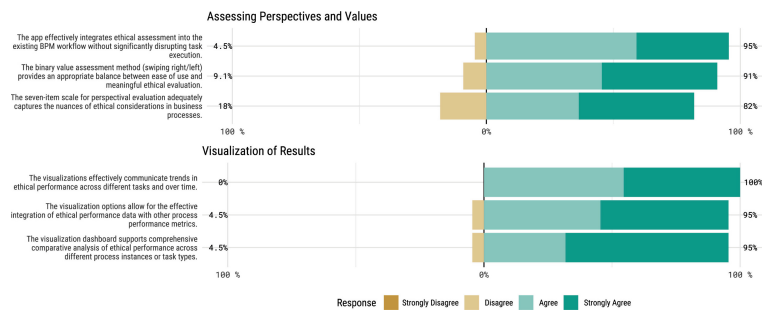


Fig. 5. Evaluation of Assessment and Visualization.

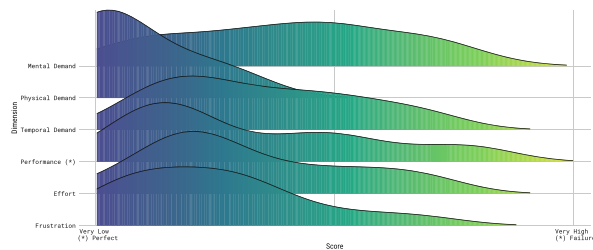


Fig. 6. Evaluation NASA-TLX Cognitive Load Assessment

instances. Another idea could be to explicitly select a single task to examine its performance further and gain insight into possible correlations between ethical values, perspectives, and other indicators. This visualization capability is crucial for the monitoring phase of the BPM lifecycle, enabling stakeholders to identify trends, potential areas of ethical concern, and facilitating discussions around ethical process improvement.

5 Evaluation

The DSR methodology encompasses a range of techniques for assessing the quality of the resulting artifact. The above approach aligns with the prototype method category. Consequently, it can be regarded as an “implementation of an artifact aimed at demonstrating the utility or suitability of the artifact” [22]. Additionally, to gather initial feedback on the artifact’s utility and usability, we conducted an evaluation with $n = 22$ process experts and practitioners. Participants were provided with a document briefly introducing the research context and the artifact’s purpose, a description of the artifact’s functionalities (modeling annotation, task execution assessment, visualization dashboard), and access to the fully functional prototypical implementation, including the mobile/web interface and the Kibana dashboard, pre-populated with sample data from the

128 L. Poss et al.

HR hiring process scenario (*Screen Application, Conduct Interview, Evaluate Candidate* – as described in Sect. 4.2). This scenario was chosen for its relatability, allowing participants to focus on the artifact's mechanics rather than complex domain-specific ethics. Participants were asked to:

- Explore the task list and complete a few instances of the predefined HR process tasks using the ethical assessment features (both singular values and the perspective questionnaire).
- Interact with the Kibana dashboard to view and filter the (sample and their own newly generated) ethical assessment data.
- Subsequently, they completed an online questionnaire comprising specific questions about the assessment interface and the monitoring dashboard (results shown in Fig. 5), as well as the NASA-TLX questionnaire to assess the cognitive load (results shown in Fig. 6).

Participants range in age from 23 to 48 (median: 32) and have, on average, 5.3 years of experience in process management and business processes. Participating companies are based in Germany and vary widely in terms of economic sectors (e.g., Manufacturing, Logistics, Automotive, Financial Services, and Technology) and size, ranging from a minimum of 5 employees to a maximum of 320,000 (median: 3,500). The positive responses shown in Fig. 5 regarding the app's effective integration of ethical perspectives (95% agree/strongly agree) and the usefulness of the seven-item scale (82%) provide initial validation for our *Perspective Assessment* and *Value Assessment* design objectives. Similarly, high agreement on the utility of the visualizations for understanding ethical performance (100% and 95%) supports the *monitoring* aspect of our framework. The artifact has been well-received overall by all participants. However, minor adjustments are still needed to facilitate its active use during everyday work (cf. Sect. 6). Finally, we evaluated the artifact using the NASA-TLX questionnaire to measure the cognitive task load (e.g., [10]), assessed ethical behavior during process execution using existing ethical questionnaires and specific ethical values, and presented the results in Fig. 6. NASA-TLX was chosen to evaluate the cognitive workload imposed by the artifact, as it provides a validated, multidimensional assessment of mental effort, frustration, and key factors in determining usability and efficiency. Given that ethical decision-making involves complex cognitive processing and high mental demand [28], this approach ensures that the artifact supports users without overburdening their cognitive capacities. The NASA-TLX results indicate that while participants were generally successful in using the artifact with moderately low frustration, the assessment process itself was perceived as having a strong mental and temporal demand, and requiring effort. This suggests that while the interface is usable, the cognitive task of ethical evaluation is inherently demanding [28]. This finding highlights the importance of features such as customizable questionnaires and sampling strategies (see Sect. 6) in managing this load in practice.

Considering the objectives defined, we can assess the evaluation of the implementation of ❶ and ❷. The other objectives ❸, ❹, and ❺ (consideration of the complete lifecycle, independence of paradigm and system, and modularity) are conceptual requirements, where the implementation of the concept provides a structural and functional evaluation, as described in [11].

6 Discussion

Based on the broader evaluation with practitioners, we can again reiterate the importance of ethical values and their support in process management. The artifact created in our paper is agnostic to business specifics and can be easily adapted to any business process and culture. To effectively integrate ethical considerations into the BPM lifecycle, our approach embeds ongoing ethical assessment as a seamless and adaptable component of BPM methodologies, thereby effectively answering our research question. While the proposed approach offers a novel method for integrating ethical considerations into business process execution, it is essential to acknowledge potential limitations identified during the evaluation. One challenge is the approach's scalability and usability for process sizes and task volumes that span a wide range. Evaluating every value and every perspective each time a task is finished can be time-consuming. However, simple sampling techniques can mitigate this issue, where only subsets of values and ethical perspectives are collected (e.g., ask to assess one value for every tenth task or one perspective every hour, depending on the number of actors and process instances), directly influencing temporal demand and effort. Another inherited concern is the potential for self-reporting bias in ethical assessments, which can be partly mitigated by using standardized and well-researched questionnaires and clear definitions of ethical values, thereby promoting consistency and comparability. Furthermore, while the adaptability of the framework is a strength, allowing for customization, it also requires careful consideration and adjustments based on specific organizational needs and cultural contexts when implementing (e.g., selecting or refining the set of ethical values or modifying questionnaires). Beyond these concept-specific limitations, it is important to recognize the inherent subjectivity in interpreting ethical values. Finally, collecting and analyzing data on individuals' ethical behavior, even if aggregated, requires careful consideration of data privacy and potential misuse. The proposed solution suggests anonymizing data where possible (e.g., not linking specific assessments to individual actors for performance review purposes unless explicitly designed for transparent coaching and with their consent) and securing storage to ensure compliance with privacy regulations, such as the GDPR.

7 Conclusion

This paper presents a novel framework and a prototypical implementation, representing the first step towards systematically integrating explicit ethical considerations into the daily execution and management of business processes. We com-

130 L. Poss et al.

binethics scales with specific value evaluations to create a multifaceted assessment in the BPM lifecycle. This customizable and agnostic approach enables the tracking of ethical values and performance monitoring from both conceptual and prototypical implementations, which we evaluated with the assistance of experts. By doing so, we also introduce mechanisms for real-time feedback on ethical performance during process execution, enabling immediate adjustments and promoting continuous ethical learning. While our current approach has its limitations, as previously outlined, it is essential to consider these limitations when formulating future strategies. To ensure the integrity of the results, it is critical to minimize self-reporting bias and subjectivity by promoting ethical processes. This includes future work in a few directions, like a quantitative study of the artifact at scale (e.g., gather quantitative data on ethical performance over a more extended period, including correlation with other process KPIs), further research on specific ethical values in process management based on interviews (e.g., interviews with stakeholders across different roles to uncover a richer understanding of the values relevant to specific process contexts), and leveraging *Value-Driven Process Improvement*, i.e., aligning business objectives with ethical considerations and foster ethics as a first-class citizen in BPM.

It is essential to reiterate the gap in BPM research regarding the explicit, manageable, and measurable integration of ethics, particularly in light of the growing role of automation and its impact on human actors [17,19]. By providing this practical framework and its prototype, we aim to stimulate further interdisciplinary research into quantifying the performance of ethical processes, developing methods for ethics-driven process improvement, and integrating ethical assessments into routine business operations.

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132 L. Poss et al.

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