

Ontology-Based Business Process Modeling: A Review

Low Kok Thai¹, Furkh Zeshan^{2*}, Nazri Kama^{3*}, Riza Sulaiman⁴, Mohammad Nazir Ahmad⁵, Uwais Qidwai⁶

Institute of Visual Informatics, Universiti Kebangsaan Malaysia (UKM), Malaysia^{1, 2, 4, 5}

Department of Computer Science, COMSATS University Islamabad (CUI), Lahore Campus²

Faculty of Artificial Intelligence, Universiti Teknologi Malaysia (UTM), Malaysia³

Department of Computer Science & Engineering, Qatar University⁶

Abstract—Business Process Modeling (BPM) has been receiving attention in recent years. Organizations operating in distributed, data, and knowledge-intensive environments need precise machine-interpretable process descriptions. Traditional business process modeling notations such as BPMN, UML Activity Diagrams, and EPCs are highly effective for visualizing workflows and supporting communication among stakeholders but do not address problems such as semantic ambiguity, inconsistent terminology, limited reuse, and poor interoperability across organizational boundaries. Since ontology-based models can enable seamless process integration, coordination, and collaboration among autonomous systems. Therefore, ontology-based descriptions are well-suited for complex enterprise systems and supply chains. Ontology-based business process modeling techniques provide a robust and theoretically grounded solution by introducing explicit semantics, formal reasoning capabilities, and shared conceptual frameworks into business process models. This semantic enrichment significantly enhances the expressive power of business process descriptions while preserving compatibility with existing modeling standards. However, ontology-based business process modeling also has its own challenges. The development and maintenance of high-quality ontologies require significant effort and domain expertise. Moreover, reasoning over large-scale ontologies may introduce computational overhead, particularly in real-time environments. Tool support is another practical concern, as seamless integration between business process modeling tools and ontology management platforms is still limited in many industrial settings. The primary objective of this study is to conduct a systematic literature review of ontology-based business process modeling approaches to provide research recommendations based on their strengths and limitations. The results indicate that there are several research gaps that should be addressed to ensure smooth process integration across organizational boundaries. Additionally, empirical validation of ontology-based BPM frameworks in real-time environments is limited. The proposed framework not capable enough to update ontologies with the evolution of the business and related processes. In this regard, an Input Process Output (IPO) BPM Framework to integrate ontologies into BPM as a three-stage transformation mechanism is proposed.

Keywords—Business Process Modeling (BPM); Ontology-based Business Process Modeling (OBPM); domain modeling; knowledge management; knowledge reasoning; knowledge engineering; knowledge modeling

*Corresponding author.

I. INTRODUCTION

Business Process Modeling (BPM) deals with discovering knowledge from information technology (IT) and management science. Organizations analyze, model, and optimize the acquired knowledge to increase the process's efficiency, reduce operational costs, and improve customer satisfaction [1 - 3].

In BPM, the processes are described as structured or semi-structured, but related activities are executed in series or parallel to ensure the proper operations are performed in an organization. Whereas the process model usually describes the temporal activities performed specifically for the creation and use of data [4]. Business processes (BP) in most cases represent complex systems where several entities are involved in their development. For example, in the case of billing a car, nine entities $\langle a, c, e, f, g, i, j, k, l \rangle$ may be involved, starting from booking a car (activity a), paying extra insurance (activity c), booking confirmation (activity e), the check-in process (activity f), car selection (activity i), checking license (activity j), charging credit card (activity k), and finally car releasing (activity l). However, the main aspects of business processes are the activity sequencing, where activities are performed in a specific order to achieve a desired result, and a workflow, in which activities are often connected in such a way that the output of one activity becomes the input of the next [4]. However, generating process models from unstructured text and implementing them in an organization is a challenging task. Although the advent and the application of Natural Language Processing (NLP) have made this process easier, natural language still presents a significant challenge due to the inherent ambiguity, semantic nuance, sentence composition, word relevance, and contextual connections between sentences [5]. Moreover, the business process modelers may misunderstand domain concepts or relationships among these concepts due to their lack of precise domain knowledge. In such cases, semantic ambiguity affects the efficiency and quality of business process modeling. To address this problem, ontology-based business process modeling techniques are the solution, which can ease semantic ambiguity by providing a means to capture rich, semantic information on complex business processes through domain-specific ontologies.

Business process modeling is a knowledge-intensive activity where modelers meet knowledge workers, business owners, and IT professionals to gain an accurate understanding of domain knowledge and process logic [6 - 9]. However, if the domain

becomes larger and more complex, then an accurate understanding of the domain can be difficult for a modeler. Particularly if the modeler does not belong to the domain, such situations may lead to semantic ambiguity (precise mapping between domain concepts will be difficult). Semantic ambiguity, as a result, may lead to high cognitive load on the modeler, resulting in over- or underspecification, thus reducing the quality of a process model [10 - 13].

A process model (conceptual model) defines how a business will conduct its operations by specifying relevant activities, events, states, and control flow logic [14, 15]. These models can be represented with Petri Nets [16, 17], Business Process Model and Notation as shown in Fig. 1 (BPMN) [18], and Event-driven Process Chain (EPC) [19] shown in Fig. 2. Although these formal methodologies to model business processes offer different perspectives on modeling, they still do not address semantic ambiguity problems directly [20].

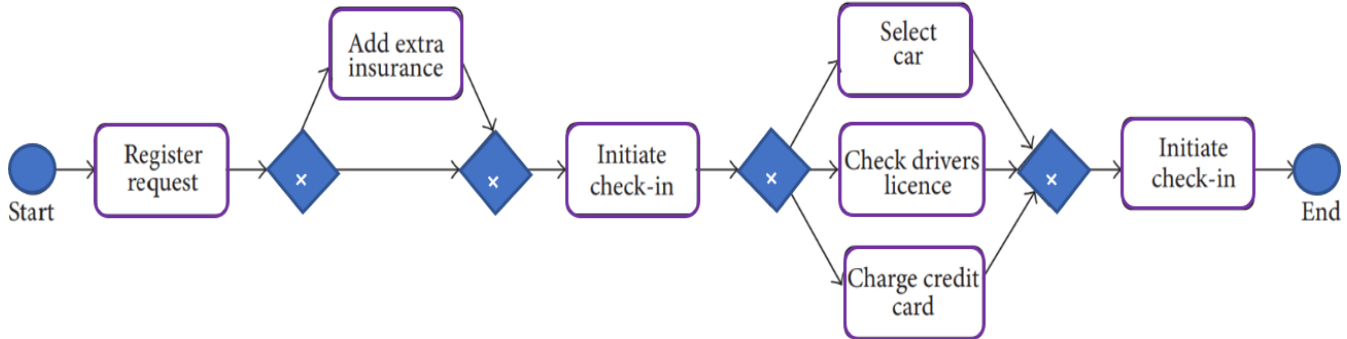


Fig. 1. Model in business process modeling notation.

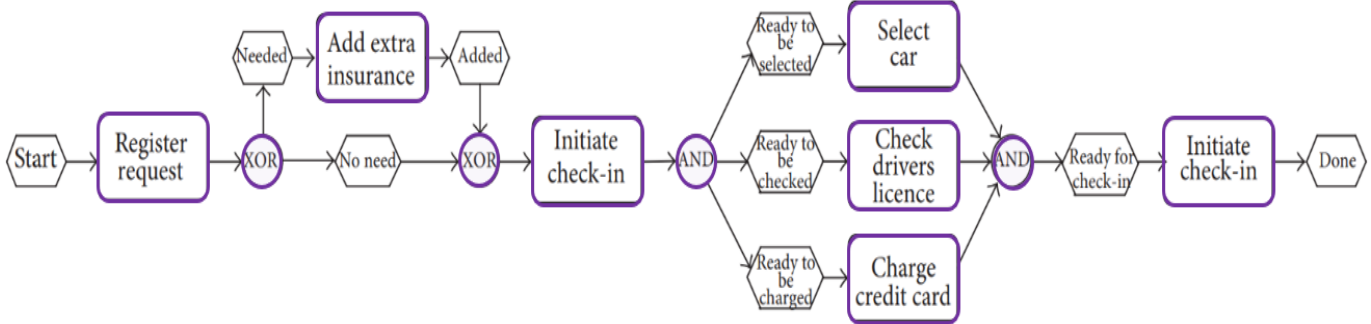


Fig. 2. Event-driven process chain model.

However, ontology-based business process modeling approaches can resolve semantic ambiguity in business process modeling through domain ontologies. Such approaches are based on cognitive load theory [21] and intended to help reduce semantic ambiguity by avoiding problems such as construct overload and construct redundancy. Construct overload deals with modeling for two or more ontologies, while construct redundancy deals with modeling constructs for a single ontology. Moreover, classes in a domain process ontology formally guide the business process modeling.

The primary objective of this study is to conduct a review of ontology-based business process modeling approaches for three main reasons:

- to establish context and understanding of the current state of the art knowledge;
- to explore the unexplored areas and to identify the research gaps that should be addressed; and
- to identify research opportunities for future research.

In this regard, a Systematic Literature Review (SLR) is performed because, according to Barbara Kitchenham [22], SLR is a systematic method for identifying, evaluating, and

synthesizing research evidence that follows a structured protocol to ensure comprehensiveness and minimize bias.

The rest of the study is organized as follows: Section II presents the background of the study. Section III presents the review of ontology-based business process modeling. In Section IV, research challenges and opportunities are discussed, and finally, in Section V, the conclusion and prospective future research areas are discussed.

II. BACKGROUND

A. What is BPM?

Business process management (BPM) is an approach to improve the activities to get work done, satisfy customer needs, and generate business value. It includes concepts, methods, and techniques to support the design, administration, configuration, enactment, and analysis of business processes [2, 23, 24]. To assess the effectiveness of implemented BPM in any organization, different factors can be used; a few among them are the process owner's awareness, engagement of top management, close communication, linking process goals with personal as well as strategic goals, the degree of innovation,

corrective and preventive measures, collaborative environment, process documentation, etc.

Fig. 3 depicts the core activities of business process management. Business process modelling is the core phase of process design. Once an initial design of a business process is developed, it needs to be validated.

Fig. 4 shows the BPM reference architecture [26] where the designer uses the design tools to create models describing the processes and the structure of the organization. The manager uses management tools to monitor the flow of work and act if necessary. The worker interacts with the enactment service.



Fig. 3. BPM life cycle core activities [25].

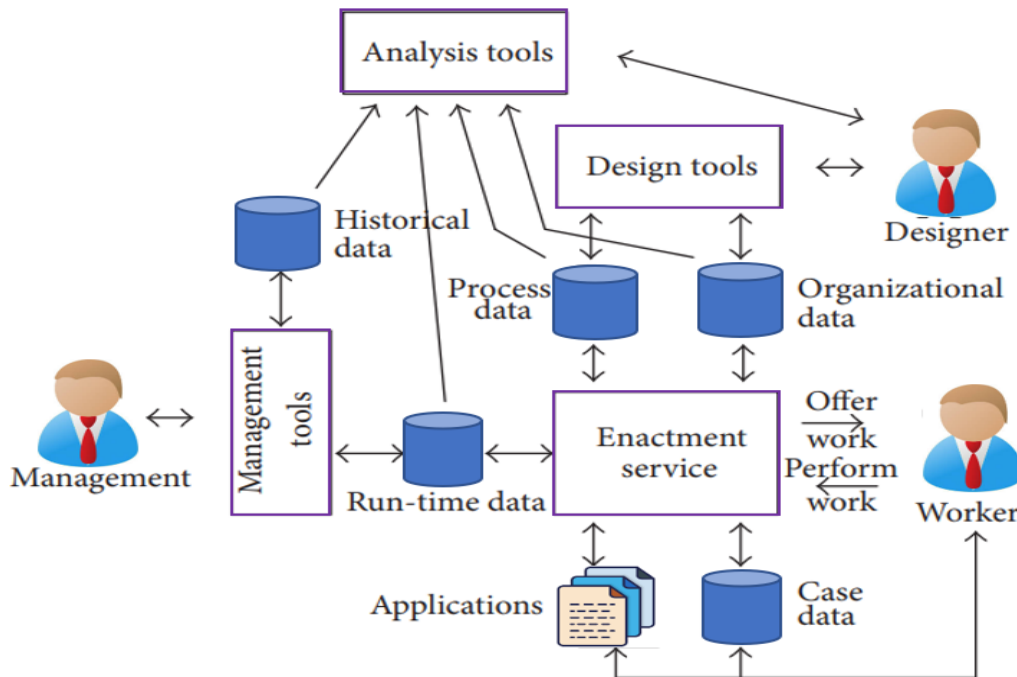


Fig. 4. BPM reference architecture.

B. What is an Ontology?

Ontology is the philosophical study of being, existence, and reality, which investigates what kinds of things exist and how they are categorized. In the context of computer science and information science, it refers to a formal, explicit specification of a conceptualization, essentially a structured representation of a domain's concepts and their relationships. A generic ontology overview is presented in Fig. 5.

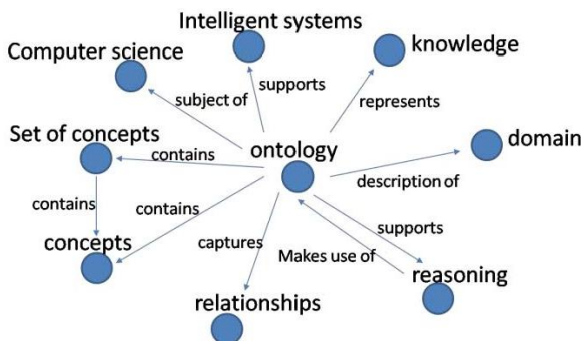


Fig. 5. Generic overview of an ontology.

Key issues in ontology-based business process modeling include the complexity of building and maintaining ontologies, lack of clear semantics in traditional modeling tools, the potential for mismatches between modeling approaches and technological trends, and the need for improved methods to capture complex business rules. Additionally, there can be difficulties in achieving interoperability and handling dynamic, complex business environments.

C. Why BPM Leverages Ontology?

Business process (BP) models are conceptual models; when implemented, they create value for the underlying business. This is why companies are focusing on defining and refining their business processes. However, BP modeling is a difficult task that needs trained experts. Although business process models are very similar to conceptual models, they are much more complex [12]. Because these models are used to draw the dynamic behavior of the business, that's why it requires a good understanding of domain knowledge. Whereas domain knowledge in the Information Systems (IS) discipline refers to the knowledge provided by both the domain experts and the application repositories [27]. Moreover, the next generation of

BPM requires machine-understandable semantics to automate the process composition, mediation, and execution. But the lack of explicit semantics hinders this task [28]. To address this challenge, different semantic modeling techniques like ontologies, semantic annotation, knowledge graphs, and rule-based systems can be used. Semantic annotation is good to ensure the quality of the model, but manual annotation is prone to errors and time-consuming [57]. Whereas in the case of Knowledge Graphs, knowledge extraction and integration from heterogeneous sources in complex scenarios is very difficult [55] while in Rule-Based Systems, combining rule logic with graph control flow may lead to modeling inconsistencies in business logic [56]. In contrast, ontologies can play their role between business process modeling and technical implementations by defining concepts, their attributes, and relations formally [20]. Hence, enabling the process models to be understood and manipulated by software systems, resulting in a higher degree of automation and execution.

D. Issues and Challenges While Integrating Ontologies Into BPM

The basic aim of integrating ontologies into BPM is to enhance semantic interoperability, formalize process models, and enable automated reasoning, but it faces several technical, conceptual, and practical hurdles. A few key challenges are discussed below and presented graphically in Fig. 6. The first challenge is that creating and maintaining a comprehensive ontology that covers all business domains, rules, and processes is very difficult. Moreover, with the evolution of the business and related processes, updating the ontology is another challenging task [29]. Different businesses may use different terms for the same concept, leading to the semantic mismatch problem. To resolve such issues, aligning heterogeneous ontologies is another major technical problem [30].

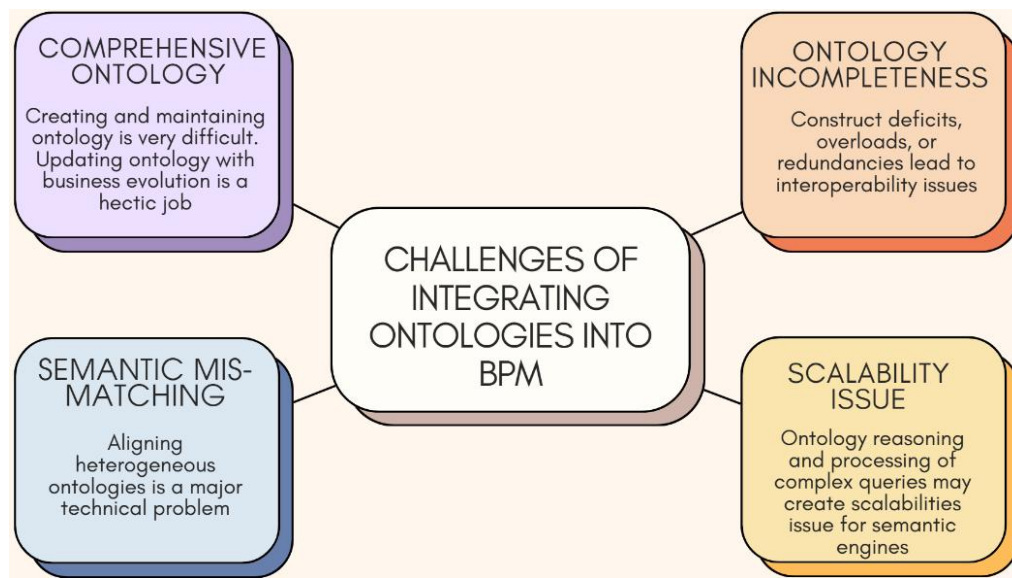


Fig. 6. Ontology integration challenges into BPM.

Ontological incompleteness (missing a crucial type of object or relationship) may lead to construct deficits, overloads, or redundancies, which undermine clear semantic mappings and interoperability [31]. Such issues arise because BPMN has no way to formally model the rules, resulting in writing them in text on the diagram or in a separate document. The ontology of business rules is not complete within BPMN [32]. Ontology reasoning, consistency checking, and processing of complex queries in the presence of a high volume of BPM scenarios may create scalability issues for the semantic engines [33].

There is a gap between conceptual ontological models and their implementation through BPM tools that support both process modeling and ontology development [31]. Developing and adopting standardized, integrated methods and tools should be a focus.

E. Ontology-Based BPM Framework

With the ever-increasing complexity of evolving businesses, there is a need for organizations to continuously refine, redefine, and formalize their business processes to create maximum value.

However, business process modeling for large businesses is a complex and time-consuming activity that requires deep domain expertise. Moreover, the absence of explicit machine-understandable semantics in traditional BPM tools poses limitations in automation, interoperability, and process intelligence. To address these limitations, ontologies can play their role by offering means to formalize the specification of domain concepts, relationships, and rules, resulting in enhanced semantic interoperability and automated reasoning. Hence, researchers are exploring the integration of ontologies into BPM [30, 31, 33].

However, the integration of domain ontologies into BPM has numerous challenges, such as semantic heterogeneity (different organizations use different terms for the same concept), ontology evolution, maintaining comprehensive ontologies, reasoning scalability, and ontological incompleteness (missing relationships or business rules), etc. These limitations highlight the need for a structured framework that systematically links the semantic and procedural dimensions of BPM. In this regard, an Input Process Output (IPO) BPM Framework (Fig. 7) to

integrate ontologies into BPM as a three-stage transformation mechanism is needed. At the input stage, the framework will capture domain knowledge, ontological definitions, and business rules from both experts and organizational repositories. In the second stage (Process), semantic alignment, reasoning,

and the transformation of conceptual models into machine-interpretable forms will be performed. Finally, the output stage will generate executable, semantically enriched process models that will support automation, consistency checking, and interoperability.

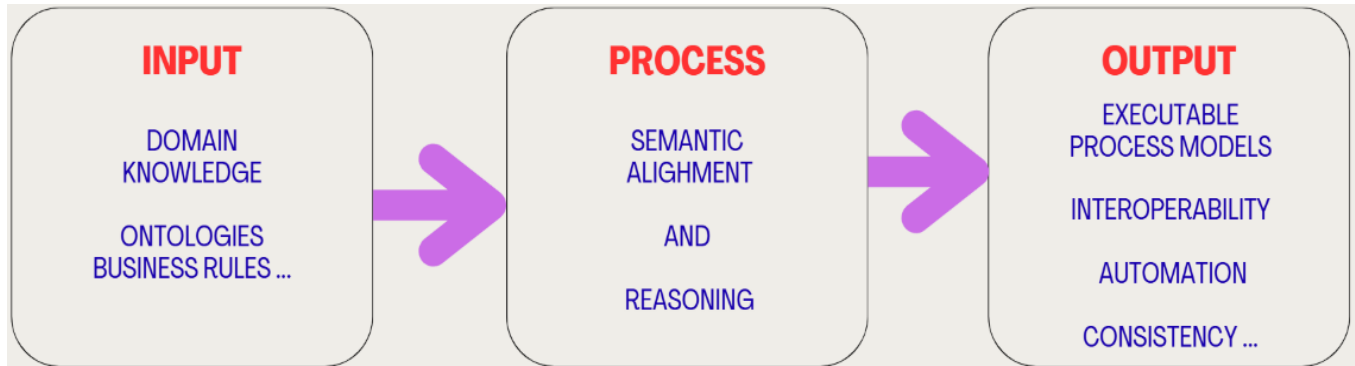


Fig. 7. Ontology-based conceptual IPO framework for BPM derived from literature.

An ontological framework where BPM integration structures around the IPO model may have the ability to ensure traceability and modularity across semantic and procedural layers. Thus, the ontology-based IPO framework for BPM not only addresses the technical and conceptual limitations of current BPM models but also contributes to establishing a unified foundation for semantic-driven business process automation.

III. REVIEW METHODOLOGY

Ontology-based business process modeling (OBPM) uses an ontology to provide a formal, shared vocabulary for defining business processes, which allows for greater automation, reasoning, and interoperability. It integrates domain knowledge, process activities, and organizational context into a semantic model, enabling tasks like semantic gap analysis and automated metric computation that are difficult with traditional methods. While promising, the widespread adoption of OBPM is currently limited by the manual effort required for ontology creation and annotation.

A. Research Questions

The research question defines the scope of the research along with the specific issues to be investigated. Moreover, without such questions, the reader may face problems in understanding the rationale of the research. Therefore, the following are the research questions defined for this study.

- What challenges or limitations are reported in ontology-based BPM research?
- What ontological types are required to represent BPM effectively?
- How can OBPM support interoperability between heterogeneous business organizations?
- How have ontology-based BPM approaches been evaluated or validated in existing studies?

The rationale of each research question is presented in Fig. 8.



Fig. 8. Rationale of research questions.

Review protocol validation is an important step to minimize bias (in study selection, data extraction, and analysis) and to ensure transparency (allowing other researchers to replicate the methodology and to verify and validate the findings) of a

review's findings. Therefore, a well-defined and validated protocol can guide the researcher throughout the review process and promote methodological rigor. In this regard, a review protocol validation questionnaire is defined in Table I.

TABLE I. REVIEW PROTOCOL VALIDATION QUESTIONNAIRE

Sr.	Components	Questions
1	Background	Is the review's context and motivation clearly established?
2	Research questions	Are research questions focused specifically on ontology-based business process modeling?
3	Search strategy	Is the completeness of searching of relevant studies ensured?
4	Study Selection	Are inclusion and exclusion criteria clearly defined?
5	Quality of studies	Are the reliability and validity of the selected studies evaluated and justified?
6	Data extraction	Is the collected information from each study relevant, consistent, and in a structured form?
7	Data synthesis	Is the extracted data integrated and analyzed properly to answer the research questions?
8	Reporting	Are findings presented clearly, ensuring others can reproduce the same if replicated?

B. Search Strategy

The search strategy is an important component of a systematic literature review methodology, which determines the scope and comprehensiveness of the review. This strategy

ensures that all relevant studies are identified without being biased. Moreover, it also serves as a tool for evaluating the quality of a search. It allows replication upon updating a review. In this regard, a search strategy for this survey is designed in Fig. 9.

A search string is a combination of keywords and operators (like AND & OR) to form and perform complex, targeted queries and filter relevant results crucial for research. These strings are used for searching the databases to find specific information. A well-defined string makes the search more precise than single words. Below are the search strings used in this research.

- (("Ontology" OR "Ontologies" OR "Ontological") AND ("Business Process" OR "Business Process Model"))
- ("Business Process" OR "Business Process Model" OR "Business Process Management" OR "BPM")
- (("Ontology-based" OR "Ontology-driven" OR "Ontology based" OR "Ontology driven") AND ("ontology supported" OR "Semantic"))
- ("Business Process Model" OR "BPMN" OR "OBPM")

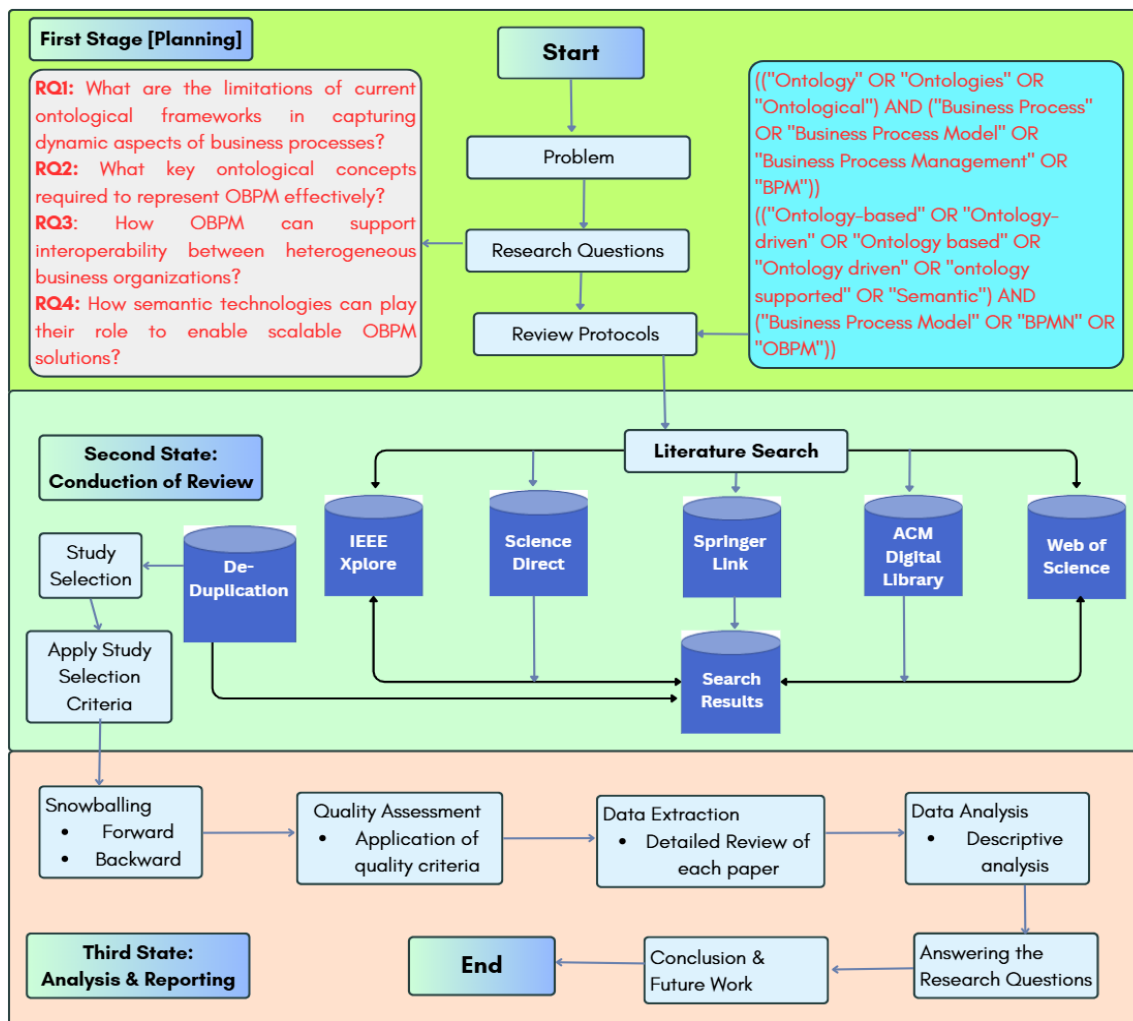


Fig. 9. Literature research methodology.

Databases provide a collection of published research for review on any topic. To search relevant papers, a researcher can define and refine the search filters to ensure only peer-reviewed articles are available. In order to ensure that no relevant study is missing, a researcher must search multiple databases. In this regard, below is the list of databases that are searched for literature for this review.

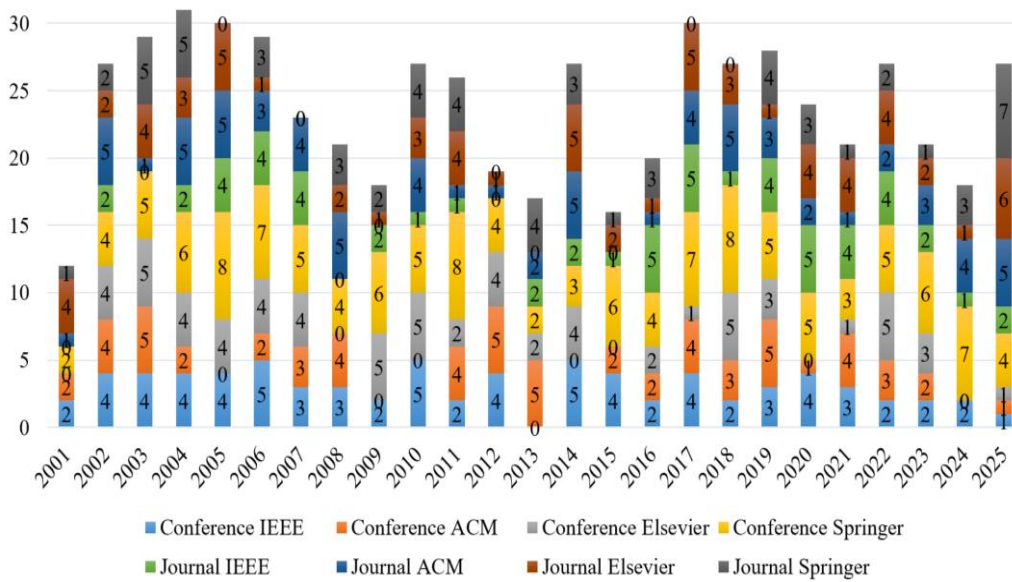
- ACM Digital Library (<https://dl.acm.org/>)
- IEEE Explore Digital Library (<https://ieeexplore.ieee.org/>)
- Springer Link Online Library (<https://link.springer.com/>)
- Elsevier ScienceDirect (<https://www.sciencedirect.com/>)
- Web of Science (<https://www.webofscience.com/>)

C. Study Selection Criteria

The inclusion and exclusion criteria to select the relevant studies to the research questions are given below in Table II.

TABLE II. THE INCLUSION AND EXCLUSION CRITERIA FOR STUDIES

Inclusion Criteria	
IC-1	The paper written in English
IC-2	Peer-reviewed conferences or journals
IC-3	Published after the year 2000
Exclusion Criteria	
EC-1	The paper is not peer-reviewed
EC-2	Papers not written in English
EC-3	Form duplicate studies (one in conference and one in journal on same topic); conference paper was excluded
EC-4	Short research papers (less than 5 pages)



Conference Papers

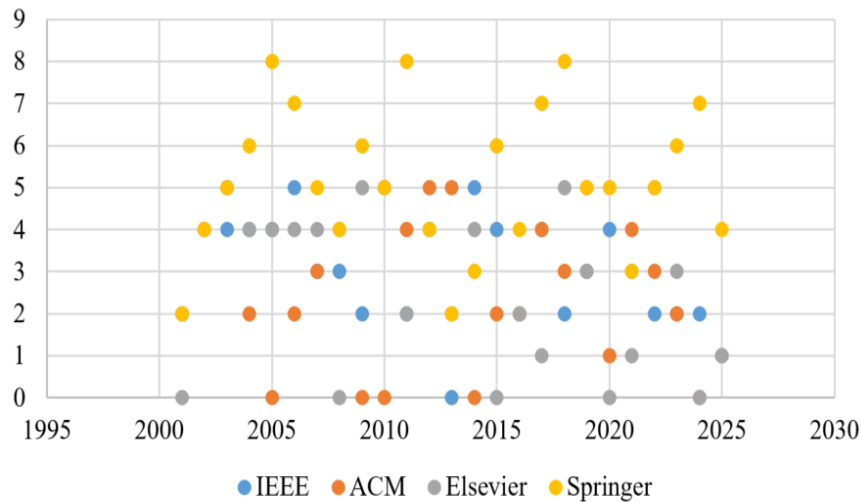




Fig. 10. (a). Year and publisher-wise study categorization. (b). Year and publisher-wise conference papers. (c). Year and publisher-wise journal papers. (d). Publisher-wise percentage of papers.

1) *Selection process*: After searching results from the defined databases based on the search strings, the screening process started. At this stage, one of the authors shortlisted papers based on the criteria defined in Table I. At the second stage, full papers were reviewed based on predefined inclusion and exclusion criteria (Table II). In case of confusion, conflict resolution techniques were applied, and the process was reinitiated (Table III). The second stage was concluded with the selection of 77 papers out of 127. After full paper text analysis, another 36 irrelevant papers were dropped. The final 41 papers were assessed for quality against the checklist defined in Table IV, and data were extracted according to Table V. In this survey, forward (Google Scholar) and backward snowballing methods were conducted, resulting in the selection of another VII papers after following all defined selection criteria. In total,

this study considers 48 studies, and all data extraction and analysis results are based on these selected studies. The year- and publisher-wise details of selected studies are presented in Fig. 10.

TABLE III. SEARCH AND SELECTION RESULTS

Source	Search Results	Initially scrutinized Results	After full paper analysis	After Snowballing
ACM	17	9	5	6
Springer	25	14	7	9
Elsevier	45	25	11	13
IEEE Xplore	19	12	7	8
Web of Science	21	17	11	12

According to the inclusion and exclusion criteria, 79 papers were rejected among which 31 were not directly related to the business process modeling, 14 were duplicate, 18 were not related to ontology (all were discussing other semantic technologies), 10 were short papers (less than 5 pages) while 6 were basic papers (no details).

2) *Selection process problems*: During the process of primary studies selection for the SLR, several challenges were faced.

a) One common problem was: the author published the same study at a conference and the extended version in a journal. In this case, the journal paper was considered.

b) Studies with slightly different titles published in multiple journals. In such cases, after reviewing the title, authors, objectives, research problem, and contributions carefully, the whole team discussed and decided to keep or drop these studies.

c) To ensure the validity of the search process. Few research papers were selected based on the prior knowledge and then the most relevant search string was used to verify that strings produce the same results.

To address these challenges, conflict resolution techniques were adopted. Hence, the reliability and completeness of the survey were ensured.

D. Quality Assessment

To assess the quality of selected studies, Quality Assessment (QA) checklists were prepared. The checklist consists of 11 quality assessment criteria used to evaluate each study, as described in Table IV.

TABLE IV. THE QUALITY ASSESSMENT CHECKLIST

Quality assurance Questions	
Q1	Is the study related to business process modeling?
Q2	Are the study objectives SMART?
Q3	Does the study answer any of the research questions?
Q4	Are the research methods clearly described?
Q5	Is the contribution clearly described?
Q6	Is the study evaluation process well explained?
Q7	Is the data along with the source credible?
Q8	Are the implementation methods well explained?
Q9	Are the results and findings properly analyzed and reported?
Q10	Are the results compared with any benchmark?
Q11	Are the research challenges and limitations mentioned?
Q12	Can the results be generalized?

E. Data Extraction

Data extraction from papers is important because it allows researchers to evaluate study quality, along with identifying the strengths and weaknesses. Moreover, upon data extraction, researchers can statistically analyze, summarize, and interpret by ensuring that findings from multiple studies are combined and compared meaningfully. In this regard, data extraction fields used in this study are defined in Table V.

TABLE V. THE DATA EXTRACTION FIELDS

Data Extracted	Description
Research Problem	Research Problem addressed by the study
Research objectives	The research objective of the study
Contributions to existing body of knowledge	The contributions made by the study to the existing body of knowledge.
Data Issues	The challenges faced in data collection
Results	Results reported in the study.
Comparisons results	The results achieved over the benchmark
Key challenges	The main challenges the study encountered

IV. OBPM: A REVIEW

In this section, a concise description of the selected primary studies is presented. Studies are categorized into four major categories (Ontology Driven Process Modeling, Process Integration, & Interoperability, Ontology-Based Business Process Adaptation, and Tools, Frameworks & Applications) based on the research questions. A brief introduction of each category is presented below.

A. Ontology Driven Process Modeling

Ontology-Based Business Process Modeling (OBPM) has emerged as a powerful paradigm for addressing semantic ambiguity, improving interoperability, and enhancing analytical capabilities in modern enterprise systems. Across recent literature, ontologies are consistently positioned as a means to strengthen the semantic foundations of business process management by enabling shared understanding, automated reasoning, and intelligent alignment between business and IT.

In the first paper, Bouroumi et al., [31] discuss how ontologies and context-awareness can improve Business Process Modeling (BPM) by enriching process semantics, supporting context-sensitive adaptations of business processes, bridging gaps between business-level and IT-level understanding, and improving interoperability and reusability of process models. However, the authors have not performed a thorough quantitative evaluation. In another paper, Tao et al., [32] presents a solid contribution in the field of ontology-based information extraction. The authors design an IPO domain ontology capturing key concepts like issuer, underwriter, issue price, risk factors, financial indicators, and company type, etc., from business and financial documents. However, the proposed ontology is primarily used for annotation rather than reasoning or inferencing. A work by Fan et al. [33] proposes a comprehensive process ontology to standardize process elements, clarify terminology, and eliminate inconsistencies. By enforcing explicit semantics, the approach significantly improves communication between stakeholders and prevents misunderstandings in model interpretation. Inter-organizational workflows are addressed in [34]. This paper integrates process mining with ontological mapping to align heterogeneous models across organizational boundaries. This highlights ontology's central role in supporting collaboration where organizations use disparate modeling conventions. Semantic modeling with the help of artificial intelligence is studied in [35]. The authors combine ontological domain knowledge with deep learning to automatically assess process maturity. The hybrid approach represents a growing trend toward augmenting OBPM with

advanced analytics to support intelligent organizational decision-making. Hinkelmann et al. [36] integrate enterprise ontology with an enterprise architecture framework, enabling continuous alignment of business goals with IT structures. Practical alignment is performed by Sánchez et al. [37] using ontology to map processes to web service specifications; the method supports automated model-driven modernization, enabling seamless transition from business design to IT execution environments. BPMO [38] provides a complete formal ontology for describing process models. While Thomas and Fellmann [39] extend this foundation by presenting an ontology-based representation that enhances consistency checking, semantic validation, and process standardization.

All these research works demonstrate that ontology-based approaches significantly improve the clarity, interoperability, intelligence, and performance of business process modeling, positioning OBPM as a critical enabler for next-generation systems.

B. Process Integration and Interoperability

Smith et al. [40] have introduced a logic programming-based framework for business process modeling using ontologies. They used ontologies for reasoning about business process models because traditional process modeling languages like BPMN lack formal semantics, resulting in difficult or incomplete automated reasoning. However, the proposed framework is complex, which makes it difficult to be implemented in large organizations without semantic technology experts. A semantic modeling framework is proposed by Akatkin et al. [41] extends conventional BPM with an ontology. A prototype is implemented for a small-scale government process to show how the framework has improved interoperability. The paper should discuss how ontologies will be maintained, versioned, and aligned with regulatory changes. In a paper [42], the author has merged the process workflows with semantic domain knowledge for improving interoperability, model consistency, and intelligent system behavior. Ontologies developed in isolation lead to inconsistencies, limited interoperability, and difficulties in reusing knowledge across systems. Pfaff et al. [43] have designed an ontology-based framework to support semantic data integration within IT benchmarking environments. Authors argue that different organizations generate different type of data which might create significant challenges like data heterogeneity, inconsistency, and incompatibility. However, for evaluation, a limited dataset is used. The authors have not discussed the integration tools, automated reasoning, or user interface considerations, which makes their work difficult to implement by non-technical users.

The above-discussed papers highlight the advancement of Semantic Business Process Management and ontology-based integration. The papers collectively discuss the strengths of formal semantics for process modeling and improving business integration through shared ontologies. Whereas the proposed works are facing challenges of scalability, ontology maintenance, and deployment at the enterprise level.

C. Ontology-Based Business Process Adaptation

In this section, different research works are reviewed which collectively highlight how ontology engineering enhances

business process modeling, semantic consistency, and adaptability.

In a paper, Preisig et al. [44] have proposed an ontology to capture physical entities formally along with their relationships, constraints, and operational dependencies. In their work, they demonstrated an example of linking physical topology with business processes and performed automated reasoning to check consistency of system structures and detect invalid process sequences. However, they did not discuss the scalability issues for large-scale physical systems. In a paper, Kord et al. [45] focused on dynamic business process adaptation through context ontology. To demonstrate their achievement, a context ontology along with reasoning rules was used to infer the need of adaptation. However, they have not discussed how their proposed system can be applied in a real-world industrial scenario. Samhan et al. [46] have extended the Riva methodology [52] for business process architecture. They extended the Riva methodology with an ontology for automatic interpretation and converted an informal architectural methodology into a semantically enriched framework. But the proposed system does not provide support for executable process modeling tools. Poss et al. [47] in their work have focused on the operational aspects (tasks, resources, preconditions, and effects) of business process modeling. They claim that they have provided a foundation for process execution verification, simulation, and compliance enforcement. However, the proposed ontology is very complicated, which might confuse typical process designers. Thuan et al. [48] have addressed the process flexibility challenge of business process modeling for organizations that work in highly dynamic environments. However, their work highly relies on manually encoded rules. Moreover, the performance issues of their work are also not fully assessed.

All above discussed papers demonstrate that traditional BPM languages lack semantic clarity, leading to ambiguity and inconsistency. Whereas ontologies support precision, adaptation, and enable reasoning-based improvements in flexibility. However, ontology adoption in terms of complexity and scalability is a big challenge for the next-generation intelligent BPM systems.

D. Tools, Frameworks & Applications

Ontology-based techniques, due to formal semantics, reasoning, and improved interoperability across heterogeneous business environments, are becoming fundamental in Business Process Management. In this section, the literature on Tools, Frameworks & Applications is reviewed for synthesizing their contributions, methodological approaches, limitations, and collective significance for the field of semantic business process management.

Ghasemi et al. [49] have developed a unified ontology to classify and configure the business process management techniques which consists of Six Sigma, Lean, BPMN, simulation tools, and workflow engines etc. The major contribution of this work is the BPM maturity assessment framework, which can map organizational needs to appropriate techniques via semantic reasoning. However, the proposed mechanism is not evaluated through different case studies for performance. In a paper, Annane et al., [50] evaluate different

business process ontologies (on criteria like expressiveness, modularity, reasoning capabilities, domain flexibility, and alignment with BPMN) to know their suitability for task monitoring. Through evaluation, they identified ontological gaps like limited support for adaptation, temporal constraints, and the organizational context. However, it is a conceptual study that must be supported with empirical evaluation using real-time monitoring systems. Adams et al., [51] have addressed the challenge of complexity of large business process models through ontology-based views which represent different dimensions of a process like functional, behavioral, organizational, and data perspectives. The proposed mechanism has the ability to generate automatically customized views based on stakeholder roles and analytical needs without losing semantic consistency. However, the process of designing these views requires a considerable semantic expertise.

In the above discussed papers, it is revealed that ontologies enable precise definitions of process models by eliminating ambiguities inherent in traditional modeling languages and the formal semantics enables the automated process validation, compliance checking, and real-time decision support. Moreover, ontology-based process modeling approaches improve context-awareness and interpretability in discovering and analyzing business processes. However, certain challenges are still open to investigation. For example, ontology creation & maintenance and computational overhead along with scalability issues are not studied in detail considering industry-grade case studies.

E. Comparative Evaluation

In this section, a comparative evaluation of ontology-based business process modeling studies is performed on criteria: Tool Support, Empirical Validation, Quantitative Metrics, Reasoning

Capabilities, Adaptability, Context-awareness, Generalizability, and Limitations. Criteria requirements are divided into two sections 1) general requirements (Tool Support, Empirical Validation, Quantitative Metrics) and 2) ontology specific requirements (Reasoning Capabilities, Adaptability, Context-awareness, Expressiveness, and Limitations). The objective of the evaluation is to know the strengths and limitations of these studies. Evaluation criteria requirements are defined in Table VI, while the evaluation results are presented in Table VII and Table VIII, respectively.

TABLE VI. LITERATURE EVALUATION CRITERIA REQUIREMENTS

Evaluation criteria	Description
Tool Support	Availability of software tools for BPM platforms or support for automation and semantic validation
Empirical Validation	Experimental demonstration to improve accuracy or efficiency of ontology or non-ontology BPM approaches
Quantitative Metrics	Performance measures like modeling time or complexity analysis of ontology integration
Reasoning Capabilities	Incorporation of formal semantics to demonstrate automated process validation, compliance checking, and real-time decision support.
Adaptability	System has the ability to modify process execution based on semantic or contextual conditions.
Context-awareness	Research captures dynamic context like roles, locations, events, and rules.
Generalizability	Flexibility to adapt to evolving processes and ontologies or have potential for reuse in other knowledge-intensive domains
Limitations	The constraints (methodological, theoretical, or practical) that restrict the findings, scope, or generalizability.

TABLE VII. STUDIES EVALUATION ON GENERAL CRITERIA REQUIREMENTS

Study	Tool Support	Empirical Validation	Quantitative Metrics
[31]	Prototype-level	Small case examples	Not reported
[32]	Prototype implemented for document analysis	Experiments on IPO documents	Extraction accuracy / precision/recall
[33]	Prototype and mapping examples discussed	Experimental evaluation	Some evaluation metrics (e.g., ambiguity reduction measures).
[34]	Methodology and implementation details hinted	Experiments / case studies	Process discovery / conformance metrics reported.
[35]	Prototype and experimental pipeline described.	Datasets used for capability assessment.	Performance metrics for assessment (accuracy, F1, etc.).
[36]	Methodological framework; tool prototypes in some implementations	Case studies in industry contexts	Not the main focus; some alignment indicators discussed.
[37]	Prototype tools and model transformations	Demonstration and experiments reported.	Some performance / correctness metrics for transformations
[38]	Research prototypes and semantic tooling described	Example scenarios and prototype evaluations.	Not central; mostly conceptual/qualitative evaluation
[39]	Implementation details and prototype frameworks	Examples and small evaluations.	Not emphasized
[40]	Implementation (logic programming engine).	Examples and reasoning case studies provided	Some performance discussions; not heavily empirical.
[41]	Frameworks and prototypes discussed in paper	Government examples; conceptual demonstrations	Not the focus
[42]	Methodology and tooling recommendations, possible prototype	Case studies	No central methodological focus
[43]	Web-based architecture for ontology-driven integration	Demonstrations and validation examples	Integration performance / mapping accuracy discussed.
[44]	Implementations and examples in journal article.	Case examples and model demonstrations	Not emphasized
[45]	Prototype and reasoning components described	Examples and limited experiments	Not heavily emphasized
[46]	Conference paper with prototype	Limited empirical evaluation	Not reported

[47]	GitHub implementation available	Prototypical demos	Not a major focus; qualitative validation present.
[48]	Conceptual prototype; limited tooling.	Conceptual validation and examples	Not central; few evaluation metrics.
[49]	Ontology artifact published	Limited; mainly conceptual and illustrative.	Not emphasized.
[50]	Comparative analysis; no single tool proposed	Analytical comparison	Comparative criteria used; not performance metrics.
[51]	Prototype and formal definitions	Examples and comparative discussion	Not central; usability discussion present.

TABLE VIII. STUDIES EVALUATION ON ONTOLOGY SPECIFIC CRITERIA REQUIREMENTS

Study	Reasoning Capabilities	Adaptability	Context-awareness	Generalizability	Limitations
[31]	Ontology reasoning for context interpretation (limited).	Targets adaptive behaviors tied to context	Central focus; explicit context modeling	Domain-agnostic idea; validation limited	Evaluation small-scale; maintenance overhead noted
[32]	Semantic enrichment and mapping; basic inference for IE.	Focused to IPO domain; adaptable with new ontology work.	No central document	Needs rework for non-financial domains	Domain specificity; ontology construction cost.
[33]	Ontology reasoning for equivalence	Aimed at heterogeneous modeling environments	Not in focus	Intended to be transferable across domains	Ontology engineering overhead; scalability concerns for very large mode
[34]	Semantic mapping to align logs	Built for heterogeneous partner systems.	Indirect focuses on organizational context.	Targeted to inter-org settings; transferable with mapping	Complexity with noisy or incomplete logs; mapping effort required.
[35]	Ontology supports semantic features; DL handles pattern detection	Relatively adaptable; dependent on retraining and ontology updates	Limited explicit context modeling	Promising; requires dataset and ontology alignment for new domains	Data requirements for DL; ontology upkeep.
[36]	Ontology-based reasoning for alignment checks	Designed for organizational adoption; flexible modelling approach.	Captures organizational and technical context.	Strong enterprise applicability; requires customization	Implementation cost; governance/maintenance challenges
[37]	Semantic mapping and matching for service binding.	Focus on re-use in legacy modernization scenarios	Limited; more about mapping semantics to services	Applicable to modernization projects broadly	Complexity of mapping and runtime orchestration.
[38]	Supports reasoning for discovery, validation and mapping.	Designed to be extensible and reusable.	Includes organizational and service context modelling	Developed to be reusable across domains	Ontology complexity need tool support.
[39]	Used for validation and semantic queries.	Focused on improving model interchange and reuse.	Some attention to context and organizational info.	Designed for general BPM settings.	Tool maturity and scaling concerns
[40]	Strong (logical inference, consistency checks).	Method applicable where formal verification needed.	Not primary	Technically general but requires expertise	Complexity; scalability for very large models
[41]	Supports semantic alignment for cross-agency workflows	Tailored to public services; generalizable with work	Includes citizen/service context in examples	Framework transferable to other public sectors.	Organizational barriers; real deployments are complex
[42]	Enables semantic checks during development	Designed to fit organizational practices	Can incorporate context if modeled	Method intended to be generic	Resource intensity; requires ontology expertise.
[43]	Semantic mapping and mediation supported	Domain-specific but extensible	Limited to IT benchmarking context.	Useful template for other benchmarking domains	Domain restriction; ontology maintenance needs
[44]	Ontology used for semantics and consistency checks.	Targeted at engineering/process industries	Physical context modeled explicitly.	Good for industrial contexts	Domain specificity; complexity of physical modelling.
[45]	Central: ontology reasoning for adaptation decisions	High; designed for dynamic adaptation	Core focus.	Applicable where contextual data is available	Real-time data acquisition and reasoning overhead
[46]	Basic semantic alignment and mapping	Focused to RIVA architectures may be generalize	Some architectural context captured	Needs adaptation for other architectures	Specialized scope; limited empirical proof.
[47]	Reasoning for resource allocation and integration checks	Targeted to SMEs but extensible	Includes operational context (equipment state).	Applicable to domains with physical resources.	Implementation maturity and runtime constraints.
[48]	Enables classification and reasoning about flexibility types.	Helps design flexible processes; supports reasoning about variability.	Flexibility linked to context and exceptions.	Intended to be broadly applicable.	Needs tooling and empirical validation
[49]	Supports semantic queries and mappings	Useful for tool recommendation tasks; needs updating.	Not central.	Broad for BPM community; needs maintenance.	Rapid tool evolution requires updates; limited validation.

[50]	Assesses ontologies' support for monitoring reasoning.	Guides selection/extension for monitoring tasks	Evaluates how ontologies capture execution context.	Comparative results help across domains.	Lacks experimental runtime evaluation.
[51]	Ensures semantic consistency across views.	Highly adaptable by adding view extensions.	Views can encode contextual perspectives.	Broad applicability to enterprise modeling.	Complexity in authoring view-extensions; tooling required.

TABLE VIII (A). STUDIES EVALUATION ON ONTOLOGY SPECIFIC CRITERIA REQUIREMENTS

Paper	Ontology Complexity	Scalability & Performance	Tool Integration	Heterogeneity	Semantic Interoperability	Syntactic Interoperability	Process Interoperability	Context Interoperability
[31]	✓	✓	✓		✓		✓	✓
[32]	✓	✓		✗	✓	✓		
[33]	✓		✓		✓		✓	
[34]				✓		✓	✓	
[35]	✓	✓			✓			
[36]	✓		✓		✓	✓	✓	
[37]	✓		✓		✓	✓	✓	
[38]	✓		✓	✗	✓		✓	
[39]	✓	✓	✓		✓		✓	
[40]	✓	✓		✗	✓		✓	✓
[41]	✓	✓	✓	✓	✓	✓	✓	
[42]	✓		✓		✓	✓	✓	✓
[43]	✓			✓	✓	✓		
[44]	✓	✓			✓		✓	
[45]	✓	✓			✓		✓	✓
[46]	✓		✓	✗	✓		✓	
[47]	✓	✓	✓	✗	✓	✓	✓	
[48]	✓	✓			✓		✓	✓
[49]	✓			✓	✓			
[50]	✓		✓	✓	✓		✓	
[51]	✓	✓	✓					

The above-evaluated papers describing frameworks, tools, and methodologies provide thorough and clear but varying explanation details. Papers focusing on ontology-based business process modeling [38, 40] provide a strong semantic foundation by clearly differentiating the process concepts, control-flow structures, behavioral semantics, and organizational perspectives. Whereas few papers [35, 36] explain how ontologies improve knowledge representation, data interoperability, and process alignment, they combine ontology with deep learning or enterprise architecture and prefer architectural descriptions over detailed ontology specifications. Papers addressing context-aware modeling [31, 45] provide detailed descriptions of contextual elements like environmental variables, dynamic conditions, roles, and resources. Although these elements strengthen the conceptual clarity of context modeling but also increase the complexity of the model.

However, a number of framework-based papers are conceptual, discussing architectural designs without presenting any software artifacts. For example, papers focusing on process capability assessment [35] or enterprise alignment [36] describe tool requirements but do not produce a complete toolset. In

short, about thirty-three percent of papers offer strong tool support, while thirty-three percent of papers provide partial or prototype-level tools, and the remaining are just conceptual. Papers providing semantic model-based prototypes, especially on the context adaptation [45] and semantic process alignment [37] provide working implementations by integrating workflow engines with semantic annotation systems.

The evaluated works present strong development in ontology-based business process modeling while considering enhanced semantic expressiveness, improved reasoning capabilities, better interoperability, enriched context modeling, improved semantic clarity and alignment, and the combination of ontologies with process mining using ML. Whereas, the major weaknesses of these studies are limited empirical validation, established tool support, the use of highly varying quantitative metrics, and evaluation (often limited to case studies), restricts the generalizability.

V. RESULTS AND DISCUSSION

Most of the papers cover a broad range of BPM lifecycle phases like process modeling-focused works [38, 51] emphasize

semantic representation and structural modeling; context-aware approaches [31, 45, 60] extend models to dynamic adaptation; papers on process integration [34, 37, 46] highlight cross-enterprise interactions; process flexibility paper [48] and ambiguity resolution paper [33] focus on behavioral aspects. Whereas a paper considering domain-specific ontology integration [43] constrains the scope to IT benchmarking. Papers in the process mining and integration [34, 50] domain have a tendency to consider robust empirical investigations using event logs, organizational datasets, or inter-organizational workflows. These studies evaluate performance, model accuracy, or integration improvements based on real-world or semi-real datasets. While papers on ontology engineering [38, 39, 51] include case studies involving business process scenarios in domains like manufacturing, e-government, logistics, and service management. These case studies help to illustrate the ontology applications but lack quantitative or statistically significant validation. Whereas papers that have considered ontology with AI [35] (hybrid deep learning + ontology) consider detailed evaluation methods but primarily focus on model performance rather than ontology quality. Likewise, some papers lack empirical validation altogether, particularly high-level conceptual works on enterprise architecture alignment [36] or adaptability frameworks [48]. These limitations reduce practical reliability and impact. Traditional ontology-based modeling papers [38, 39] treat processes as static artifacts. Integration works [37, 41] occasionally incorporate adaptation but typically focus more on interoperability than real-time flexibility. However, despite these limitations, the papers collectively advance ontology-based BPM significantly.

A. RQ1: What Challenges or Limitations are Reported in Ontology-Based BPM Research?

Ontology-based Business Process Management (OBPM) has been widely studied for its potential to enhance semantic clarity, interoperability, process automation, and organizational alignment. However, the major limitation reported is the complexity involved in developing and maintaining ontologies [31, 38, 39]. Creating semantically rich process ontologies depends on domain knowledge and expertise in ontology engineering. Many organizations lack personnel with such skills, making ontology construction costly and time-consuming. Moreover, a few common challenges discussed in each study are the narrowness of ontological scope, absence of formal reasoning, limited empirical evaluation, lack of standardized tool support, and integration issues [37, 47].

Many studies also highlight scalability and performance issues [33, 45, 51]. Reasoning engines used for ontology alignment, context inference, or semantic disambiguation face such issues in large organizations. Kord et al., [45] discuss that in real-time environment, the reasoning can be computationally costly due to the fast change in context or in data, resulting in delays in monitoring and decision support [51].

Another reported challenge is the semantic heterogeneity across organizations. A number of researchers [33, 41, 43] have noted that different organizations use different ontological terms, modeling conventions, and process structures, which requires a lot of effort for consensus building and mapping. A

few studies have pointed out the need for limited real-world validation [46, 48]. In [48], a rich conceptual model is presented that lacks extensive empirical testing across industries. As a result, scalability, user adoption, and practical impact are not evaluated.

Further research dimensions reported in [32] and [35] are the integration of ontologies with advanced analytics and machine learning. As ontologies provide structure, while machine learning systems demand large datasets and flexible representations. Hence, integration of both techniques may result in clashes between symbolic and statistical paradigms. Similarly, studies like [50] and [49] report the lack of standardization across BPM ontologies. That results in duplication of concepts, incompatibilities, and difficulties in selecting the right ontology for a given use case.

B. RQ2: What Ontological Types are Required to Represent BPM Effectively?

Ontology-based Business Process Management (OBPM) research has emphasized a set of core ontological types required to represent business processes in a semantically rich, interoperable, and machine-processable way. These types can broadly be categorized into process structure, behavioral semantics, organizational context, data and information flow, resources and capabilities, and finally into contextual or environmental factors. Each category has a strong representation of processes that enable reasoning, interoperability, and automation.

Similarly, few ontology-based BPM studies [33, 38, 39, 50, 51] represent the basic building blocks of a process like activities, events, control-flow constructs, composite activities, and the sequence relations. These building blocks formalize the BPM structure and eliminate semantic ambiguity by defining the meaning of each element in a machine-processable format, and without these structural types, process reasoning and consistency checking become impossible [39, 41]. A few papers [37, 40, 47] discuss that structural elements alone are insufficient. For effective business process modeling, demand ontologies to capture execution semantics, including pre and post-conditions, state transitions, temporal constraints, concurrency and synchronization semantics, along with the business rules. These types allow ontologies to support logical reasoning, detect inconsistencies, and enable automated process execution.

Papers [36, 41, 46] have discussed the impact of the integration of context into BPM ontologies. Organizational context includes actors, roles, management units, actor responsibilities, and the relationships among stakeholders. This context helps in mapping the business processes to the enterprise architecture, ensuring alignment between business and IT. In addition, several papers [35, 37, 49] highlight that BPM ontologies must represent capabilities and resources to support dynamic adaptation and process capability assessment. This includes human resources, system applications, services, skills, and competencies. It allows process execution engines to bind tasks to appropriate real-world resources. Papers [32, 43, 49] emphasize the need to integrate semantic data models like data objects or business entities, information flows, document types, and Input, output dependencies into BPM ontology frameworks.

These data models enable semantic data integration, reduce ambiguity, and support analytics and process mining. Furthermore, papers [31, 45, 48, 44] highlight the need to represent context (environmental, organizational, user, and device context) for adaptive and flexible processes. These types of contexts are critical for context-driven process adaptation and dynamic reconfiguration.

The reviewed literature on BPM ontology, effective representation requires a multi-layer ontology that integrates structural, behavioral, organizational, resource, data, and contextual types. These ontological categories enable semantic clarity, automated reasoning, interoperability, and adaptability, which is the ultimate goal of present ontology-based BPM research.

C. RQ3: How can OBPM Support Interoperability Between Heterogeneous Business Organizations?

Ontology-Based Business Process Management plays a central role in enabling interoperability between heterogeneous business organizations by providing a shared semantic foundation for representing, aligning, and integrating processes. A number of papers [32, 33, 38, 39, 43, 50] contribute to interoperability through four major mechanisms: semantic harmonization, cross-organizational alignment, context-aware integration, and machine-reasonable process representations. Together, these mechanisms allow organizations with different models, terminologies, systems, and workflows to communicate, integrate, and execute processes coherently. OBPM has the ability to harmonize semantics across organizations that use different vocabularies or modeling conventions. Authors of papers [33, 38, 50] show that ontologies remove ambiguity from process elements by providing precise definitions of tasks, events, roles, resources, and data objects. When organizations map to a common ontology, they can compare and integrate processes that were previously incompatible due to terminology differences.

Papers [32, 43] report on how ontology-based semantic data integration consolidates heterogeneous information sources, which is crucial when organizations exchange documents or transactional data. Similarly, a few other studies [34, 36, 37, 41] demonstrate that OBPM supports interoperability by aligning business processes across organizational boundaries. Ontologies can map one organization's processes to another through process mapping and equivalence identification, cross-organizational workflow integration, semantic matching between business services, and automatic transformation of process models into executable forms. Aouachria et al. [34] have demonstrated how ontology-driven process mining can detect correspondences between heterogeneous inter-organizational processes, enabling integrated workflow execution. Akatkin et al., [41] discusses how shared process ontologies facilitate the integration of seamless public services in an e-government scenario. Interoperability among organizations usually fails when processes behave differently in different contexts. OBPM uses context ontologies to capture environmental conditions, policies, and constraints, etc. [31, 45, 48]. Contextual knowledge can be used in business process models to adapt processes when exchanged in organizational environments or to ensure that cross-organizational workflows respect local rules

and constraints and, finally, to resolve conflicts caused by differing operational contexts. In the case of the reasoning capability of OBPM, papers [40, 47, 42] show that ontology-based models support automated reasoning to check compatibility, identify inconsistencies, and verify the alignment of processes across organizations by allowing the validation of the process conformance, resolution of semantic conflicts, inferencing of the missing relationships, and composition or orchestration of services [37].

Papers on OBPM enable interoperability by providing a shared vocabulary, a formal mechanism for alignment, adaptive contextualization, and automated reasoning. It allows organizations to collaborate effectively, integrate seamlessly, and automate cross-organizational processes without worrying about the differences in terminology, technology, or workflow design. OBPM, therefore, can resolve the issue of interoperability among organizational business process integrations.

D. RQ4: How have Ontology-Based BPM Approaches been Evaluated or Validated in Existing Studies?

In ontology-based BPM research, evaluation and validation methods vary with respect to semantic enrichment, process integration, context modeling, system alignment, and interoperability. These methods include case studies, prototype implementation, comparative analysis, reasoning tests, process mining, and expert judgment [31, 51]. In the case of study evaluations, many studies [31, 32, 35, 41] are validated through domain-specific ontologies demonstrating applicability in real-world process scenarios. In these studies, context-based modeling is validated through contextualized business processes to show increased expressiveness and accuracy. For IPO documents analysis, financial prospectus datasets are used to validate information extraction accuracy [32]. For process capability assessment, deep learning and ontology reasoning are integrated [35] to test in organizational scenarios. Papers [38, 39, 45, 47] introducing new modeling techniques are often supported with tools, like in a paper proposing Business Process Modeling Ontology [38] is evaluated with a prototype demonstrating how models can be instantiated and queried. In the semantic process modeling prototype [39], the author demonstrates model creation, storage, and reasoning in an ontology-backed environment. Similarly, in a paper on process adaptation systems [45], the author validated context-driven adaptation via prototype reasoning engines. Likewise, the author of operational perspective formalization [47] has performed a tool integration experiment to validate interoperability.

Since formal semantics are central to OBPM, many studies validate their ontologies through logic-based reasoning tests. For example, Smith et al. [40] used logic programming to test completeness, consistency, and inferential accuracy. In another study [33], the author evaluated semantic disambiguation by checking whether the ontology correctly resolves conceptual overlaps. Similarly, Thuan et al. [48] tested flexible process configurations using reasoning rules to validate variability and adaptability. Furthermore, few studies compare new ontologies with existing standards, frameworks, or business process ontologies. Annane et al. [50] evaluated multiple ontologies on expressiveness, support for monitoring constructs, and

reasoning capabilities. Aouachria et al. [34] used process mining to validate semantic alignment by showing improved cross-organization trace matching. In another study, Pfaff et al. [43] evaluated effectiveness through data integration tests across heterogeneous IT performance datasets.

However, in the case of validation through expert judgment to assess ontology structure, coverage, and practicality. Hinkelmann et al. [36] validated Enterprise ontology alignment through expert walkthroughs. For the validation of Riva-driven architecture adaptation [46], the author applied expert assessment to validate the generality of adapted ontological constructs. OBPM approaches proposed in the above-discussed studies are validated through case studies, prototypes, logical reasoning, comparative analysis, process mining, data integration experiments, and expert evaluation, reflecting the multidimensional nature of ontology-driven BPM research.

In Table IX, a few prominent review studies are presented that discuss semantic business process management and ontology-based management systems. Unlike these reviews [55 - 57], this study comprehensively reviews the ontology-based business process modeling approaches, identifies emerging research trends, analyzes challenges and opportunities, and proposes a conceptual Input-Process-Output (IPO) framework derived from the reviewed literature.

TABLE IX. EXISTING SYSTEMATIC REVIEWS ON BPM

Review	Focus	Number of Studies	Research Gaps
[53]	Semantic technologies to business process management (SBPM)	36	Limitations in semantic BPM
[54]	Integration of Knowledge Management and business process management	88	Challenges in integrating BPM and KM
This Review	Ontology-Based BPM	49	Comprehensive taxonomy and trend analysis of semantic BPM

VI. CONCLUSION AND FURTHER WORK

Business Process Modeling (BPM) represents an organization's business processes in a formal and structured way. A business process consists of a set of interrelated activities, their dependencies, roles, data flows, and constraints that collectively achieve a specific organizational goal, such as order fulfillment or customer support. Stakeholders, analysts, and IT professionals use a few common modeling notations of BPM, like BPMN, UML, Petri Nets, and EPCs for a shared understanding of process analysis, compliance verification, performance measurement, redesign, and automation. However, traditional BPM approaches lack explicit semantics, which leads to several challenges, like business process models frequently suffering from ambiguous interpretations of activities (same concept may refer to different meanings in different contexts), roles, and data elements, resulting in limited automated analysis and restricted communication among stakeholders. Similarly, different tools and languages used in modeling cannot interoperate seamlessly. This is a big problem in dynamic environments where multiple systems must collaborate. Moreover, the difference between high-level business process

models and their technical implementation may lead to increased maintenance costs and inconsistent behavior of business systems. Additionally, BPM notations focus on graphical representation and provide limited support for automated reasoning, validation, and consistency checking, resulting in a restricted ability of error detection and optimization of processes systematically. However, in order to resolve these issues, ontologies can be used because ontologies provide a formal, explicit, and shared conceptualization of a domain by defining concepts, relationships, constraints, and rules in a machine-interpretable manner. Therefore, supporting process models with ontologies can ensure semantic consistency across models, resulting in reduced ambiguity and misinterpretation. Although many researchers have worked on ontology-based business process modeling, a lot of issues need to be investigated. Ontology-based BPM frameworks proposed by many studies still lack the adoption of standards, causing interoperability issues. So, developing domain-independent ontologies with the ability to be adapted to specific organizational contexts while maintaining semantic consistency across systems is a challenge. Similarly, scalability and performance optimization issues need to be addressed in systems where ontologies are used with machine learning (integration addresses the issue of computationally expensive ontology-based reasoning in large-scale or data-intensive environments). The integration of both techniques may result in clashes between symbolic and statistical paradigms. Moreover, the integration of ontologies (for improving transparency, trust, and interpretability) with deep learning, process mining, and decision support with explainable AI in BPM is a highly promising research direction. Within the OBPM body of knowledge, two important aspects are crucial. First, how should the process ontology be designed? Second, how should the designed process ontology be used or leveraged? Further research needs to explore the best approach to utilize the ontology supporting business process modeling, which will lead to a fundamental contribution to OBPM literature.

A. Review Limitations

This review has a number of limitations. 1) due to English language publications consideration only, a large number of relevant studies published in other languages are omitted resulting in compromised survey quality. 2) Grey literature, industrial reports, and technical white papers are not considered, which is another quality question on the survey. 3) Year-wise restricted publication selection may have omitted relevant studies. 4) other databases must also be considered as specified above to enhance the likelihood of relevant studies consideration. Overall, the incorporation of these limitations in the literature may provide a more comprehensive perspective on the selected topic. Moreover, as this study is descriptive in nature, a formal statistical sensitivity analysis is not performed.

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