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Evolution of BPMN and Simulation Integration: Trends, Challenges, and Future Directions

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Abstract

This study examines the use of simulation tools to overcome limitations in Business Process Model and Notation (BPMN), a widely used language for modeling business processes across various industries. Conducting a structured bibliometric analysis with Scopus as the primary database, the study reviewed 75 articles meeting specific inclusion criteria, highlighting key trends in BPMN simulation research. Using keyword and thematic analysis through VOS viewer, four primary research clusters were identified, illustrating BPMN's applications in fields such as healthcare, logistics, and cybersecurity. An analysis of pivotal articles demonstrates how BPMN simulations have improved resource management, performance optimization, and decision-making support. This paper shows current research directions, challenges, and the potential for BPMN extensions to increase modeling accuracy, suggesting avenues for future research within BPMN-supported simulation frameworks.

Keywords: Business process model and notation; simulation; optimization; management;

1. Introduction

Business Process Model and Notation (BPMN) is an extensively adopted graphical representation language used to map and analyze business processes across various domains. Designed to enhance process clarity and communication, BPMN's key advantage is its ability to represent workflows in a visually standardized format accessible to both technical and non-technical stakeholders. However, as business processes grow more complex and data-driven,

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the static nature of BPMN's basic elements presents limitations, especially when used in simulations that require dynamic resource allocation, real-time decision points, or event-driven modifications. This gap highlights the disparity between BPMN's descriptive strengths, and the needs of businesses aiming to optimize and innovate through process simulation.

Simulation technology, on the other hand, has proven valuable for evaluating dynamic systems, predicting outcomes, and supporting decision-making in uncertain environments. By integrating BPMN with simulation tools, researchers and practitioners can extend the language's functionality to model complex scenarios, run multiple process iterations, and test performance under various conditions. This integration allows for a deeper exploration of workflows, providing insights into potential process improvements, resource management strategies, and organizational efficiency. BPMN's adaptability is particularly beneficial in fields such as healthcare, logistics, cybersecurity, and digital transformation, where the ability to simulate detailed processes is crucial for managing risks and responding to changing demands.

The goal of this paper is to explore the current research landscape on BPMN-enhanced simulation tools, focusing on how these tools are applied to overcome BPMN's inherent limitations. To achieve this objective, a systematic bibliometric analysis was conducted, resulting in a robust dataset that acts as a foundation for identifying research trends and mapping the evolution of BPMN-related advancements in simulation.

After that, a co-occurrence analysis of keywords was performed to visualize the research network and identify prevalent themes within the BPMN simulation field, that are computer science, engineering, and management, with significant contributions from healthcare, logistics, and emerging technologies like artificial intelligence and blockchain. This distribution underscores BPMN's versatility and its potential to evolve as a core tool for digital transformation.

Furthermore, the literature review highlighted two principal categories of research on BPMN simulations: (1) empirical studies that apply BPMN in real-world scenarios to assess and improve existing processes, and (2) theoretical advancements aimed at enhancing BPMN itself through simulation tools. In empirical studies, BPMN's applicability spans six thematic areas; in contrast, theoretical research focuses on extending BPMN with new functionalities, such as discrete-event simulation for queuing and decision-point modeling or enhancements for resource reliability, aiming to increase BPMN's efficacy as a simulation tool.

This paper contributes to the existing body of knowledge by offering a structured overview of BPMN's role in process simulations and the advancements that simulation tools bring to BPMN's analytical capabilities. Through this lens, we identify key challenges in BPMN simulation research, such as managing resource constraints, enhancing real-time adaptability, and bridging the gap between BPMN's descriptive format and its potential as a decision-support tool. Additionally, the study outlines future directions for BPMN research, including the development of tailored BPMN extensions, integration with IoT systems, and improvements for handling big data in real-time simulations. By synthesizing current research trends, this work aims to guide further investigations and inspire the development of innovative BPMN solutions tailored to complex, data-driven business environments.

2. Evaluation approach

The literature review on the use of simulation tools to optimize BPMN languages was conducted through a structured analysis that follows several phases, as outlined in Figure 2.1. These steps are widely used in existing research and have been customized for the context of this study.

2.1. Database

The database selected for this analysis was Scopus, which is the largest abstract and citation database for peer-reviewed literature. It includes over 25,000 active journals from 7,000 publishers, all carefully reviewed and approved by an independent evaluation board. Scopus provides a broad view of global research across various disciplines, including life sciences, social sciences, physical sciences, and health sciences. Additionally, it offers supplementary information such as author profiles, including their affiliations, publication counts, references, and the citation count for each published work.

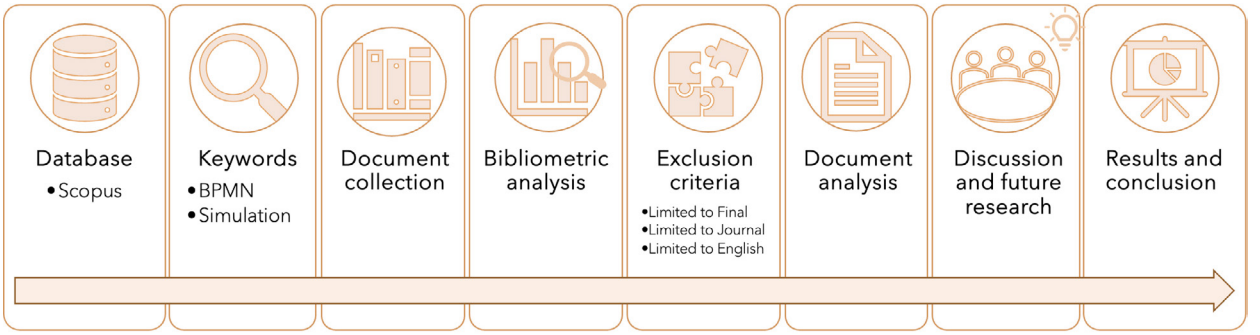

Fig. 1. Review methodology.

2.2. *Keywords*

To conduct a comprehensive review of how simulation technologies have contributed to responding to the business prosses modelling and notation limits, the authors selected a set of keywords to combine with the term “BPMN”. They focused on “BPMN” AND “Simulation”, to carry out an analysis as much exhaustive as possible. The initial search yielded 394 publications.

3. Bibliometric analysis

In order to carry out the bibliometric analysis, the software Vos viewer was partially used.

3.1. *Publications over the years*

As showed in Fig. 2, as expected, the trend of documents is notably increasing, so for the scientific community it can be interesting to observe the phenomenon. Indeed, a demonstration is that in 2018-2019 there are more articles from previous years and despite a degrowth during the COVID-19 period, the authors notice a new increase in the following two years.

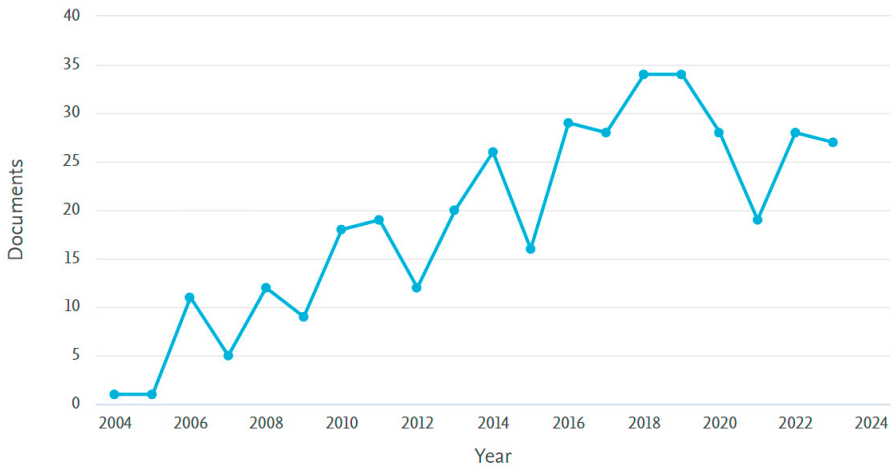

Fig. 2. Documents over the years.

3.2. Documents by Country and Field

In this subsection, the authors explored the subject areas of the selected documents and examined the geographical distribution of the scientists. As illustrated in Fig. 3. (a), the primary field of study is computer science, with mathematics and engineering following behind. Additionally, it is noteworthy that other disciplines also show a relatively balanced distribution, which highlights the versatility of the topic across various academic fields. Moreover, it's analyzed the number of documents produced by each country, as displayed in Fig. 3. (b). The results reveal that Germany ranks first, followed by Italy and France.

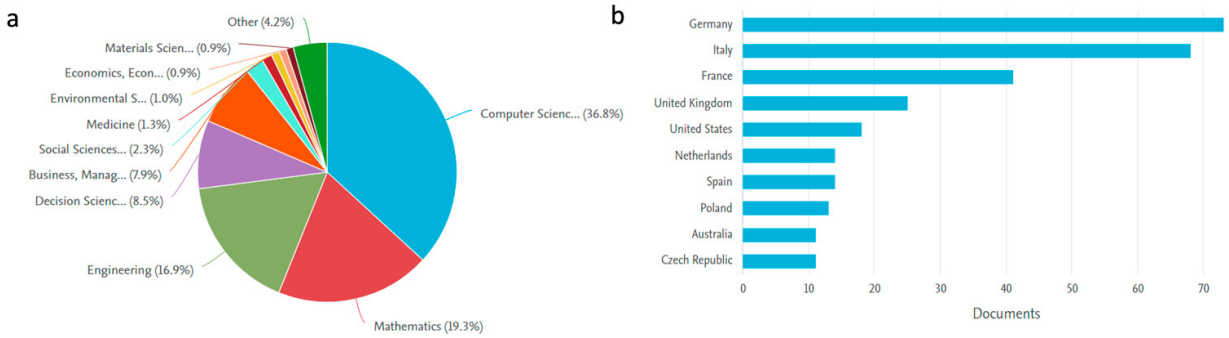

Fig. 3. (a) Document's pie chart by subject areas; (b) Document's number by country.

3.3. Keywords insight

In Table 1 are shown the most common keywords with the related number of occurrences in terms of documents where they are contained.

Table 1. The top keywords.

Keyword	N. of occurrences
Bpmn	139
Systems engineering	77
Enterprise resource management	47
Computer simulation	66
Administrative data processing	39
Process engineering	40
Business process simulation	38
Business process management	36
Modeling languages	32
Semantics	30
Discrete event simulation	31

As previously mentioned, the connections between the main topics were identified using VOSviewer software, which does not filters out duplicates. Consequently, some entries were manually removed by the authors to ensure clarity. The outcome reveals an interesting range of potential insights: while terms directly associated with BPMN and simulation were expected due to BPMN being the primary keyword in the search, it is noteworthy that terms related to engineering and resource management also emerged prominently. This highlights the broader relevance of BPMN beyond its immediate context.

To better illustrate the relationships between the various keywords used in the 394 selected documents, a co-occurrence analysis was conducted. Only keywords with more than 10 occurrences were considered, resulting in a total of 49 keywords.The result of this analysis, removing duplicates, is depicted in Fig. 4.

Fig. 4. Co-occurrence analysis applied to the keywords of all documents.

In the bibliometric network, the size of each node corresponds to the frequency of occurrence of the keyword, while the lines connecting the nodes represent the co-occurrence of the terms within the same research work. Additionally, the shorter the distance between two nodes, the more frequently those two keywords co-occurred. As shown in Fig. 5. four distinct clusters, each represented by a different colour, were identified, reflecting different areas of study.

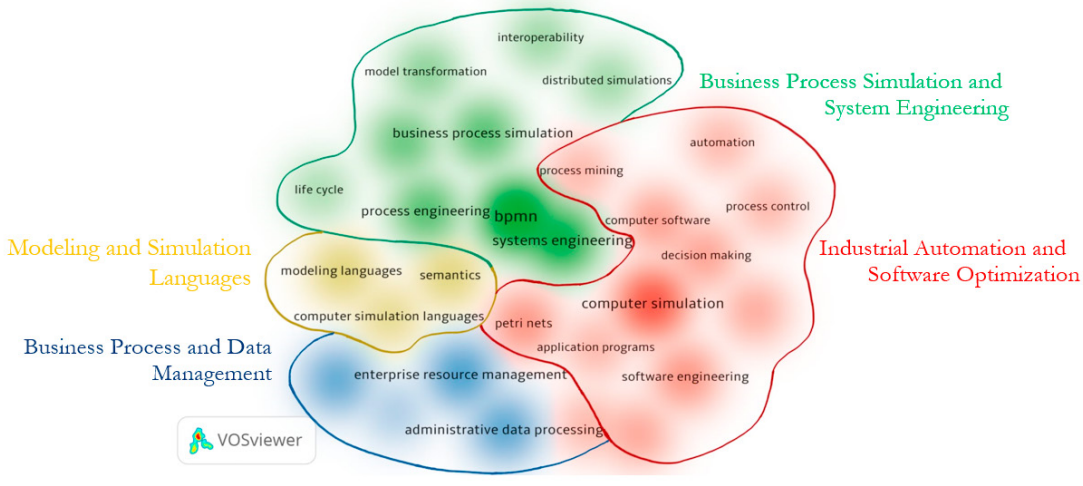

Fig. 5. Research areas represented by different clusters.

4. Document analysis

The first search returned a total of 394 publications. However, to enhance accuracy and reliability, the authors implemented specific selection criteria, narrowing the focus to only final works and limiting the review to articles published in English and those from peer-reviewed journals. This rigorous filtering resulted in a refined total of 75 articles. Following this initial selection, further refinement was conducted by excluding review papers and articles not directly related to simulation, which ultimately reduced the final sample to 50 articles.
The documents reviewed can be categorized into two main types: (1) those that present case studies from various subject areas where BPMN is applied for analysis and optimization, and (2) those that introduce simulation tools aimed at enhancing BPMN by addressing its limitations.In the first category, BPMN proves to be highly versatile, with applications spanning a wide range of industries, which can be grouped into six clusters:

1. Logistics and Production [1-4].
2. Healthcare [5-14].
3. Process Simulation and Modeling [15-21].
4. Technology and Cybersecurity [22-24].
5. Artificial Intelligence and Blockchain [13-14].
6. Other Specific Applications such as [25] on renewable energy, [26] on the Internet of Things, and [27] on construction.

However, to investigate how simulation tools can enhance BPMN for process optimization, the authors focused on the second category. From the initial set of 393 papers, 23 were selected for in-depth analysis. Once sorted by relevance on Scopus, Table 2 summarizes these selected papers, highlighting key aspects such as subject areas, topics, and contributions. The followig table captures the key concepts highlighted by the authors in their publications, offering a brief overview of their findings and insights.

Ref.	Subject area	Topic	Contribution	Year
[28]	Mathematics & Business, Management and Accounting & Decision Science	Proposing a BPMN extension for discrete-event simulation in healthcare, addressing limitations in representing queues, attributes, and decision points.	Introduces BPMN4SIM for more accurate simulations in healthcare, tested in a UK hospital for elderly emergency care pathways.	2018
[29]	Decision Science	Analyzing BPMN tools for simulation capabilities.	Compares BPM tools to highlight their limitations in simulation and proposes a framework for users to select tools based on their simulation needs.	2019
[30]	Multidisciplinary	Business process re-engineering using reverse engineering to convert simulation models into BPMN.	Develops a framework to translate simulation models to BPMN, saving time and resources for businesses.	2023
[31]	Computer science	Introducing a novel business process simulation approach using interval-valued parameters and genetic algorithms, based on BPMN.	Proposes a new simulation method that captures organizational process behavior using interval-valued data, improving accuracy over single-valued parameters. The model incorporates genetic algorithms to handle variability and uncertainty in processes.	2014

[32]	Computer science	Formal verification of BPMN models using Time Petri Nets (TPN).	Introduces a method to verify functional properties (liveness and reachability) of BPMN models by translating them into TPN.	2016
[33]	Computer science	Extending BPMN to support software process tailoring.	Proposes BPMNt, which adds tailoring mechanisms to BPMN for software process adaptations, improving model reuse and consistency.	2015
[34]	Engineering & Business, Management and Accounting & Decision Science	Evaluating the feasibility of BPMN models using Petri nets.	Proposes a Petri-net-based approach to assess BPMN model feasibility, focusing on identifying deadlocks and infinite loops.	2008
[35]	Computer science	Automating BPMN models into blockchain smart contracts.	Presents a system to automatically transform BPMN models into methods for blockchain smart contracts, enhancing efficiency and privacy.	2023
[36]	Computer science & Mathematics & Decision Science	Stakeholder engagement in discrete-event simulation in healthcare	Investigates how to involve stakeholders in model coding using BPMN, particularly in healthcare, identifying barriers like data complexity.	2017
[37]	Business, Management and Accounting	Measuring business process performance using BPMN and BPSim.	Proposes a method combining BPMN and BPSim to analyze operational performance and test potential process improvements via simulations	2016
[38]	Computer science & Mathematics	Service process modeling and simulation.	Introduces the SLMToolBox, which integrates BPMN models into simulation workflows, aiding in enterprise service management.	2016
[39]	Computer science & Mathematics	Evaluating resource provisioning strategies for BPMN processes.	Proposes techniques to analyze business process execution relative to resource provisioning strategies using BPMN and Maude framework.	2021
[40]	Computer science & Mathematics	BPMN event log generation for process mining.	Develops a tool that generates event logs from BPMN models, helping in process simulation and testing process mining techniques.	2017
[41]	Computer science	Simulation project life cycle based on process management.	Proposes a life cycle model for simulation projects, emphasizing managerial, operational, and support aspects for simulation-based decision-making.	2023

[42]	Computer science & Mathematics	Extending BPMN for resource reliability simulation.	Enhances BPMN with resource reliability modeling for more accurate simulation-based business process analysis.	2020
[43]	Mathematics & Decision Science & Economics, Econometrics and Finance	Addressing BPM tools' limitations in simulating batch processes.	Identifies limitations in BPMN tools for dynamic batch processing simulation and suggests temporary solutions using activity-based costing models.	2018
[44]	Computer science & Mathematics	Construction project simulation using BPMN and BIM.	Presents a simulation framework that integrates BPMN-based process models with BIM data for collaborative construction project planning.	2017
[45]	Computer science & Engineering & Social and Environmental Sciences & Energy	Distributed simulation for smart production systems.	Proposes a framework that enhances interoperability between simulation components in smart manufacturing systems, tested in the automotive industry.	2020
[46]	Multidisciplinary	Implementing digital twin technology in supply chains.	Introduces a method for digital twin integration into supply chain processes using BPMN, demonstrating efficiency improvements.	2023
[47]	Computer science & Materials science & Chemical Engineering & Physics and Astronomy	Workflow process modeling with a focus on resource characteristics	Proposes a method using BPMN for visual workflow modeling that emphasizes resource performance in process simulation.	2020
[48]	Computer science	Integrating IoT with BPMN for business process management.	Introduces a BPMN extension for IoT-aware business processes, supporting IoT integration in process simulation and decision-making.	2023
[49]	Business, Management and Accounting	Risk management in industrial processes.	Proposes a tool for managing risks in industrial processes, using BPMN for process modeling and stochastic simulation for risk analysis.	2021
[50]	Computer science & Mathematics	Verifying model transformations from BPMN to Petri nets.	Extends previous work on formal verification of model transformations using BPMN and Petri nets, focusing on structural correctness.	2019

5. Discussion and Future Research Perspectives

This study highlighted how simulation tools significantly contribute to overcoming the inherent limitations of BPMN in complex and dynamic business environments. Through bibliometric and thematic analysis, our research revealed both the adaptability and limitations of BPMN, particularly in sectors such as healthcare, logistics, and cy-

bersecurity, where the ability to simulate dynamic scenarios and allocate resources effectively is crucial. Our findings underscore BPMN's role in supporting decision-making and enhancing resource management, emphasizing its potential to address urgent industry needs.

1. **BPMN's Current Challenges and the Role of Simulation Tools** A central finding of this research is the growing trend toward integrating BPMN with simulation tools to bridge the gap between static modeling and real-time adaptability. Simulation tools enable BPMN to model scenarios that go beyond mere descriptions, incorporating dynamic, event-driven elements that promote organizational agility. However, several challenges persist. BPMN often struggles to represent real-time decision points and lacks the functionality for resource optimization, which are vital for industries focused on streamlining processes in real-world applications.
   Simulation methodologies, such as discrete-event simulation, agent-based modeling, and system dynamics, present pathways to overcome these limitations by enabling BPMN to handle dynamic, real-time processes. These tools provide a framework for testing various configurations and scenarios, an approach that is essential in areas such as healthcare, where patient flows and resource demands change rapidly, or logistics, where demand can vary unpredictably. In cybersecurity, where quick responses are paramount, these tools could support BPMN in modeling adaptive and resilient processes.

2. **Advancing BPMN with Specialized Extensions** As mentioned previously, to address BPMN's inherent limitations, future research should focus on developing specialized extensions that can support real-time adaptability and predictive analytics. BPMN, in its current form, is largely a descriptive tool; however, it could be transformed into a decision-support framework through these enhancements. Promising extensions include:

   - Discrete-Event Simulation (DES) and Real-Time Data Integration: By incorporating DES, BPMN could model time-sensitive, resource-constrained processes. This capability is crucial in environments like emergency healthcare, in which real-time patient data and resource status influence treatment decisions.
   - Agent-Based Modeling (ABM) to Reflect Complex Interactions: ABM extensions could simulate the behaviors of individual agents within a system, such as suppliers, customers, or competitors, providing insights into how their interactions impact overall processes. Such extensions could be invaluable in industries with complex stakeholder dynamics, like finance or supply chain management, allowing organizations to better anticipate process bottlenecks and optimize resource allocation.

3. **Integrating BPMN with Emerging Technologies** A highly promising area for future research lies in integrating BPMN with IoT, AI, and big data frameworks. These technologies could enable BPMN to evolve into a tool capable of supporting real-time decision-making and automation, expanding its utility across increasingly complex domains. Key areas for integration include:

   - IoT Integration for Real-Time Monitoring and Control: In manufacturing and logistics systems, IoT devices provide real-time data on equipment performance, location, and environmental factors. By incorporating IoT data, BPMN models could enable proactive responses, such as triggering actions based on real-time conditions, improving process control, enabling predictive maintenance and demand forecasting.
   - AI and Machine Learning for Enhanced Predictive Analytics: AI and machine learning could bring predictive and prescriptive capabilities to BPMN models, enabling dynamic adjustments to workflows. For instance, AI could analyze historical customer service data to predict customer needs, making BPMN workflows more responsive.
   - Big Data Integration for Scalability and Comprehensive Insights: Big data could empower BPMN to process vast amounts of information from multiple sources, identifying patterns and insights that would otherwise go unnoticed. For example, in financial services big data could enable BPMN to manage real-time information from different channels to detect fraud or assess risk, dynamically adapting workflows to respond to emerging patterns.

4. **Cross-Industry Applications and Digital Transformation** Finally, future research should explore BPMN's versatility across various industries to refine its adaptability to sector-specific challenges. As industries increasingly adopt digital transformation strategies, BPMN could become instrumental in navigating domain-specific complexities. Exploring cross-industry applications would not only enhance BPMN's flexibility but also allow the development of specialized extensions and standards to meet the unique requirements of each field.

By focusing on these directions, future research can unlock BPMN's full potential as a sophisticated decision-support tool. This evolution would equip BPMN to better manage the complexities of modern, data-intensive business environments, addressing the critical need for adaptable and real-time process management in the digital era.

6. Conclusion

This study provides a comprehensive overview of how simulation tools are employed to enhance BPMN's capacity for business process optimization. By conducting a structured bibliometric analysis, the authors have identified four primary research clusters and examined BPMN's applications across diverse fields, highlighting both its strengths and limitations. The findings reveal a significant opportunity for BPMN to evolve from a static, descriptive modeling language to a dynamic tool capable of supporting complex, real-time decision-making.

Overall, this research reinforces BPMN's pivotal role in process simulation and underscores the need for continued development to meet industry demands. With ongoing advancements in digital technology and the emergence of data-driven management approaches, BPMN has the potential to become an indispensable tool for business process optimization. Future work should aim to explore BPMN's potential in simulation frameworks that integrate IoT, AI, and other advanced technologies, paving the way for more efficient, responsive, and adaptable business processes.

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