Exploring the Integration of Agent-Based Modelling, Process Mining, and Business Process Management through a Text Analytics–Based Literature Review

Faiza Bukhsh, Ruben Govers, Rob Bemthuis, and Maria Iacob

Abstract

Agent-based modelling and business process management are two interrelated yet distinct concepts. To explore the relationship between these two fields, we conducted a systematic literature review to investigate existing methods and identify research gaps in the integration of agent-based modelling, process mining, and business process management. Our search yielded 359 research papers, which were evaluated using predefined criteria and quality measures. This resulted in a final selection of forty-two papers. Our findings reveal several research gaps, including the need for enhanced validation methods, the modelling of complex agents and environments, and the integration of process mining and business process management with emerging technologies. Existing agent-based approaches within process mining and business process management have paved the way for identifying the validation methods for performance evaluation. The addressed research gaps primarily concern validation before delving deeper into specific research topics. These include improved validation methods, modelling of complex agents and environments, and a preliminary exploration of integrating process mining and business process management with emerging technologies.

Keywords: process mining; business process management; agent-based systems; multiagent systems; systematic literature review

1. Introduction

The field of business process management (BPM) has gained increasing importance in both the literature and the industry (van der Aalst 2013; Roeser and Kern 2015) due to the value it offers to businesses (Zairi 1997). BPM is a discipline that encompasses a wide range of methods for discovering, modelling, analysing, improving, pruning, and automating business processes. Business processes can be represented through languages such as the Business Process Management Notation (BPMN) (Decker et al. 2009) or petri nets (van der Aalst 1998).

The methods associated with business process discovery and analysis are generally knowledge and labour intensive. This can lead to variations in the quality of business process models across different modellers and modelling frameworks (Claes et al. 2012). Additionally, business processes can change over time, making remodelling costly and error prone.

Process mining is a discipline that addresses the challenges of varying quality and continuous change of business process models (Tiwari, Turner, and Majeed 2008; van der Aalst 2012). This discipline involves the discovery, analysis, and improvement of business process models (van der Aalst et al. 2012). The discovery phase typically employs algorithms to extract a process model from an event log. An event log consists of activities with an accompanying identifier and performer. Such event logs are collected by information systems such as enterprise resource planning (ERP) systems. Examples of mining techniques are the alpha-miner (Medeiros et al. 2004), heuristic miner (Weijters, van der Aalst, and Medeiros 2006), or fuzzy miner (Günther and van der Aalst 2007). These techniques are accessible through process mining tools such as ProM (van Dongen et al. 2005). In the context of business processes, the presence of multiple performers or agents, who execute activities independently to achieve their respective objectives, is commonplace. These agents, operating under resource constraints, can be found in diverse systems such as manufacturing plants, interorganizational supply chains, and software development teams. While a universally accepted definition of the term ‘agent’ remains elusive (Macal and North 2008), for our purpose, we adopt the notion of an agent as a computational entity endowed with the capacity to perceive and act within its environment (Weiss 1999). Thus, an agent may encompass both human entities and (automated) software systems.

Our chapter seeks to advance knowledge in the intersection of BPM and agent-based systems by identifying research gaps and providing a comprehensive understanding of the domain. This is particularly important given the existing literature’s frequent absence of practical applications and reliance on limited empirical evidence (Tour, Polyvyanyy, and Kalenkova 2021). To achieve this, we conducted a structured literature review. This methodological approach lays the foundation by surveying the existing body of knowledge and relevant studies. In doing so, we can identify gaps and discrepancies in the field, guiding the formulation of precise and well-directed research inquiries and approaches. The review methodology is outlined in section 2. Subsequently, section 3 presents and discusses the obtained results, while section 4 examines potential threats to the validity of the study and concludes our findings.

2. Methodology

This section describes the systematic literature review (SLR) methodology employed in this research, based on Kitchenham’s guidelines for conducting SLRs (Kitchenham et al. 2009). Figure 1 provides an overview of the literature search strategy and the number of articles at each step.

Insert Figure 1. here

To delineate the scope of the review, we defined the following research questions (RQs):

- RQ1: What agent-based approaches exist for process mining and/or business process management?

- RQ2: What validation methods are used and how are they performed?
- RQ3: What are the research gaps in the joint field of agent-based modelling, process mining, and business process management with regard to the approaches found in RQ1?

The second step in Kitchenham's methodology is to define a search strategy. Three databases were selected based on their size, relevance, and query possibilities: Springer, Scopus, and IEEE. These databases serve as a foundation for conducting a comprehensive literature search.

Based on the research goals stated in section 1 and defined research questions, the following search query was devised: **'process mining' AND ('bpm' OR 'business process management') OR ('agent' OR 'multi-agent' OR 'multiple agents' OR 'MAS').** The search string was derived from the keyword of the research questions. We used the keyword 'multi-agent' even though it is not part of the research questions to reduce the threat of missing relevant papers. We also utilized multiple synonymous terms such as 'agent', 'agents', and 'multiple agents', as well as abbreviated terms, to minimize the risk of missing relevant papers. The query was applied to the full text of the papers rather than just the title, abstract, and keywords. This was necessary because the Springer database does not support searching only specific fields, and we desired a consistent search strategy across all databases. The search was limited to conference papers and journal articles as the source type. This resulted in 351 papers from Springer, 10 from Scopus, and 4 from IEEE, totalling 365. After removing 6 duplicates, the final data set comprised 359 papers. For details, see Figure 1.

According to Kitchenham's guideline (Kitchenham et al. 2009), an accompanying set of inclusion criteria (ICs) and exclusion criteria (ECs) should be formulated. For this study, we established the following set of ICs and ECs:

- IC1: The article is related to defined research questions.
- IC2: The article is written in English.
- IC3: The article is available through our university's access profile.
- EC1: The article does not provide new techniques or methodologies in the scope of agent-based or multiple agent-based process mining or business process management.
- EC2: The article is not peer-reviewed (e.g., white papers or blogs).

After applying these criteria to filter the articles, we selected fifty research papers for further analysis. These papers underwent a quality assessment based on multiple criteria, which were evaluated using a scoring system of 0 (does not comply), 0.5 (partially complies), or 1 (fully complies). During this stage of the selection process, all fifty papers were thoroughly read and evaluated.

Papers were excluded after the quality assessment for two reasons: first, if the paper did not fulfil Q1, indicating that it was not an agent-based study and therefore did not adhere to IC1. This occasionally happened as the initial inclusion was based solely on the paper's abstract, title, and keywords. Second, papers scoring a total quality score of 5 or lower were also excluded. Table 1 lists the quality criteria, while Table 2 in Appendix A provides detailed appraisal scores.

Insert Table 1: here

After the initial filtering and quality assessment, twenty-six articles remained for further analysis. To expand the pool of papers for data extraction, we employed one iteration of the backward snowballing technique (Wohlin 2014), checking the references of the twenty-six papers for additional relevant studies. These additional papers were initially evaluated based on their title and, subsequently, their abstract. This process resulted in the identification of sixteen additional papers, bringing the total number of papers to forty-two. A list of these papers can be found in Appendix A.

The articles that passed the quality assessment and were identified through the snowballing technique (see Table 3 in Appendix B) were then subjected to qualitative data extraction. The goal of this data extraction was to answer the research questions and included the following items:

- The research field, such as agent-based simulation and process mining
- The research method, such as a structured literature review, case study, or opinion paper
- The effectiveness, based on the article's validation method, results, and discussion
- The applications of the methodology or artefact
- Whether the research is multiagent based or single agent based
- The underlying techniques used by the researchers, which can range from general (e.g., graph theory) to specific (e.g., 'Fuzzy Miner in ProM')
- Any future research areas mentioned by the authors

3. Agent-Based Modelling and Business Process Management

This section discusses the relationship between business process management and agent-based modelling and the grounds for this relationship. This section addresses each research question posed in section 2. We begin by categorizing the literature found and providing a brief summary of the key points discussed. In the subsequent part, we examine the validation methods used in the papers and discuss common issues associated with these methods. Finally, in the concluding subsection, we identify research gaps that emerged from our analysis using natural language processing (NLP)–based categorization and SLR methodology.

3.1. Text Analytics for Article Categorization

This section presents a qualitative analysis of the data collected during our SLR. Based on Kitchenham's guidelines, the next step is to find answers to research questions. Extracting knowledge from papers can be a challenging and time-consuming task. To identify the most prominent points of attention from all selected papers, we used keyword and word occurrence analysis. We performed the following three methods: (1) word cloud, (2) NLP clustering for importance identification, and (3) Lingo3G analysis. These methods are based on an analysis of the title, abstract, and keywords of the selected papers. We used the following tooling:

- Word cloud: Identifying high-frequency words can be efficiently achieved using word clouds. For this investigation, we utilized the 'moneylearn' platform, publicly accessible for analysis. The findings revealed prominent terms, with 'process mining', 'simulation', and several others standing out significantly. The obtained word cloud, presented in Figure 2, visually confirms the dominance of 'simulation' and 'process mining' in the analysed corpus.

Insert Figure 2. here

- Google Cloud NLP API: The Google Cloud Natural Language API offers an advanced solution for exploring the foundational structure and semantic aspects of textual content by leveraging its pretrained classifiers. In the context of our research, this service proved invaluable for evaluating designated scholarly papers and facilitating the formation of clusters based on their content. The graphical representation in Figure 3 showcases the key terms alongside their corresponding salience values. Note that higher salience values indicate a greater level of confidence in the relevance and significance of each term in relation to the analysed text.

Insert Figure 3. here

- Lingo3G analysis: The clustering technique Lingo3G offers an extensive approach to generating information-rich clusters. The resulting clusters are visually presented as treemaps, exemplified in Figures 4 and 5. Our hierarchical clustering process utilized a maximum clustering size of 0.4, and the base cluster count base was set as 7, indicating the number of clusters discovered during each clustering pass. Additionally, a minimum cluster size of 10 was established for subclustering, signifying the prerequisite number of documents required for creating subclusters within a cluster. Regarding cluster merging settings, a merge threshold of 0.7 was applied. If the overlap between clusters surpassed this threshold, the clusters were merged. An analysis of the text's results section can be found in Figure 5, complementing the insights provided in Figure 4. It is noteworthy that process mining emerges as a prominent trend in both figures, reinforcing its significance within the context of the study.

Insert Figure 4. here
Insert Figure 5. here

Word clouds and NLP-based clustering methodologies have been instrumental in facilitating an initial categorization of information for subsequent analysis. Leveraging Figures 2 to 5, we have classified the papers into five main categories. Each category is examined in distinct subsections, wherein we emphasize the research objectives, validity, and promising avenues for future investigation pertaining to each category.

3.2. Research Question 1

3.2.1. Category 1: Simulation

In this subsection, we discuss papers that focus on agent-based simulations. We have identified eleven papers in this category. Among these papers, we will identify the simulation techniques used and their relation to agent-based modelling.

A paper of relevance (Halaška and Šperka 2019) demonstrates the application of process mining to a multiagent simulated company, emphasizing the issue of data availability. Similarly, Šperka et al. (2013) address the challenge of generating usable event logs. However, both papers lack proper validation and suggestions for future research. In the absence of studies utilizing real-world data, studies such as those conducted by Larsen et al. (2019) and Saha et al. (2016) focus on simulated data for process mining. These results employ simulated agents to generate predictive models for real-world scenarios, such as emergency rooms. The simulation process encompasses data creation, agent–environment interaction, discretization, and comparison. For example, the simulator replicates the CASAS data set (Di Federico et al. 2021; Fajar, Sarno, and Fauzan 2018), although results vary due to the discrete simulation's inability to account for interagent communication (Fauzan, Sarno, and Machfud 2019; Halaška and Šperka 2018). As noted by Šperka et al. (2013) and Larsen (2019), minor alternations in experimental settings can significantly impact simulation outcomes and subsequent decisions. Additionally, Siebers et al. (2007), Bonabeau (2002), Wagner (2003), and Slaninová et al. (2013) propose multiple statistically significant hypotheses for agent-based simulation.

In summary, the relationship of agent-based simulation and process mining can be characterized as follows:

- Although simulations serve as effective validation tools, they often lack validation themselves.

- Various types of simulation studies exist, each focusing on distinct aspects such as identifying agent profiles, evaluating business performance, or generating data sets.

3.2.2. Category 2: Process Mining

In this section, we briefly examine papers that explore the interaction of process mining and agent-based modelling.

The work of Ou-Yang, Juan, and Li (2009) presents a process mining approach for converting multiple agent systems into petri nets. Simulation experiments yielded successful results under the assumption that there are no more than two agents and that they are in a successive relationship. The ultimate objective of these experiments was to determine whether a developed multiagent system conforms to reality, rather than merely to the developer's understanding of reality (Ou-Yang, Juan, and Li 2009; Ou-Yang and Juan 2010). Process mining tools play a key role in comprehending and experimenting with agent-based modelling, as demonstrated by López Castro et al. (2021), Jimenez et al. (2018), and Ferreira, Szimanski, and Ralha (2013).

They employ tools such as Apromore, Nirdizati, and ProM to create predictive models in self-organized manufacturing systems with multiple agents. Another application of process mining involves the development of architecture-aware process models for composition-based multiagent systems (Nesterov et al. 2023; Schönig et al. 2018). Furthermore, process mining in a self-organizing manufacturing system provides a foundation for more statistically significant experimentation with multiple agents (Jimenez et al. 2018). The research by Nesterov and Lomazova (2019) lays the groundwork for Nesterov et al. (2023) and the opinion paper by van Dongen, van Luin, and Verbeek (2006). The latter proposes a compositional process mining approach based on graph morphisms to generate interaction patterns. These patterns can then be used to model typical interfaces for multiagent systems.

In summary, the key points distilled from this discussion on process mining are:

- Process mining can be utilized in an agent-based setting to create models that capture the behaviour of multiagent systems.
- Process mining in combination with agent-based modelling is applied across a wide range of domains.

3.2.3. Category 3: Subject-Oriented Business Process Management

This subsection discusses papers that address the three common themes of subject-oriented business process management (S-BPM). S-BPM is a business process management methodology that offers an executable, communication-based perspective on multiple agents, often referred to as subjects or actors. Agents are modelled in three states: two of which are through messages that can be received and sent, and the third is through signals.

The research paper by Singer (2016) explores the transformation of an S-BPM model into an executable through functional programming and a virtual machine environment. The work of Fleischmann et al. (2013) also examines the meta-model and highlights the operational advantages of S-BPM, although it does not propose any validation solutions due to the lack of standardization. The final paper related to S-BPM, by Sellitto et al. (2020), employs an architectural approach to security and safety by design in the internet of actors with multiagent systems.

In summary, this discussion on S-BPM can be characterized by the following key points:

- There is a lack of standardization in the adoption of S-BPM in practice.

- While BPM has potential applications in agent-based business process management and Industry 4.0, further research is required in this area.

3.2.4. Category 4: Business Process Management and Modelling

In this subsection, we discuss papers that focus on business process management and modelling. We have identified several papers in this category that examine various business process management techniques and their impact on agent-based modelling.

The work of Szimanski et al. (2013) explores an agent–object relationship, utilizing a hierarchical model to discover the connection between a process model and runtime behaviour. The enhancement of business models with messaged multiagent systems is addressed by Halaška and Šperka (2020). The work of Halaška and Šperka (2018) and Šperka et al. (2013) highlights various domains, such as trading and health care, where business process modelling is used for understanding. Agent evaluations are performed in many different ways, including methods proposed by Jablonski and Talib (2009) and Kabicher and Rinderle-Ma (2011). Machine learning and postprocessing simulation experiments have demonstrated potential for new validation methodologies in agent-based modelling and simulation. However, more extensive simulation studies are needed to enhance validity. The work of Sandita and Popirlan (2015) and Onggo and Karpat (2011) aimed to research mining agent assignment rules for input data that lack adequate data patterns. A conceptual model can play a role in pattern identification, as advocated by Wooldridge, Jennings and Kinny (2000) with the GAIA methodology.

Lau et al. (2006) discuss information sharing through agents, analysing and evaluating the impact of different levels of information sharing and comparing agent-based versus centralized approaches. Similar work by Ferber, Gutknecht, and Michel (2004) introduced organization-centred multiagent system design, addressing security and compositional approaches to solve weaknesses of agent-centred multiagent system (MAS) design for organizations. Further research is required to understand the nature of roles, extend functional views of MASs, establish norms for institutions, and reflect on MAS design principles.

Multiple different solutions can yield correct preference process models, as highlighted by Deen and Jayousi (2006). The work of Cimino and Marcelloni (2011) discusses autonomic tracing of production processes. Experiments using simulations yielded positive results, verifying the theoretical model. The approach uses mobile and agent-based computing. The presented model (MOAT) has been applied to real-world forms with positive results on training costs, supply chain stability, and business decision speed. Although challenges or failures are not investigated, it is mentioned that a potential loss of autonomy could pose a problem for management and workers.

From the literature discussed in this subsection, we can draw several conclusions:

- There is a correlation between business process management, business process modelling, process mining, and simulation studies.
- There is a need for more extensive validation studies.
- Business process management and business process modelling are applicable across various domains with the aim of describing agent-based conceptual models, business processes, and multiagent systems.
- Business process management and business process modelling have applications at both the management and operational levels.
- The studies found only occasionally explain or validate the business value of proposed approaches.

3.2.5. Category 5: Others

This category encompasses four topics: ontologies, workflows, interactive agents, and robot process automation. These topics, while overlapping and not distinct, are related to agent-based modelling and therefore grouped in one subsection. In the following, we will discuss each topic:

- **Ontology.** The paper by Hunka and Kervel (2019) introduces a generic design engineering methodology for organizations (DEMO) model that facilitates both cocreation and coproduction through the resource–event–agent (REA) approach. The REA model originated from the accounting domain and matured into a conceptual framework and ontology for enterprise information architecture, as per Hunka and Zacek (2014). The subsequent paper by Ito et al. (2018) delineates the multiagent REA (MAREA) ontology, which is applicable to multiagent business architectures and simulations. Assessing the ontology was challenging due to a lack of comparable literature, but it was successfully applied in a process mining and simulation case study (Halaška and Šperka 2018; Šperka et al. 2013). The authors suggested further research into why the alpha algorithm yielded incorrect results in the experiment. Hence, it can be concluded that while ontologies are not a prevalent research topic within agent-based research, they do exist. The REA and MAREA ontological representations can assist with agent-based modelling. Additional validation across multiple domains is needed to prove their effectiveness.
- **Workflows.** The initial paper in the workflows division by Appio et al. (2018) proposes business rules to foster open, collaborative networks among companies. The approach uses the semantic web and coordinates process execution through workflow models. The subsequent paper by Both et al. (2012) presents an

intelligent agent model that aids human functioning by monitoring workflows and maintaining process awareness. The simulation study led to positive results and efficient decision-making by the agent. Therefore, considering static and deterministic approaches, workflows can serve as a fundamental tool in analysing agent-based models. Supporting reactivity would increase workflow use cases and allow for real-world validation.

- **Interactive Agents.** Lins et al. (2021) concentrate on broadening the use cases of process-aware conversational agents that communicate with workflow management systems. BPMN standard provides an aligned foundation for interaction between agent and business process. The subsequent paper by Rizk et al. (2020) develops a conversational digital assistant that operates with the support of multiple agents in the background. These agents utilize an understand–act–respond pipeline with an overhead orchestrator. Therefore, it can be summarized that interactive agents constitute only a small part of agent-based research. However, the papers found did show that successful approaches can be developed and that combining the field with BPM and interactive agents is promising. Additional validation is needed to confirm these claims.
- **Robot Process Automation.** The paper by Oberhauser and Stigler (2018) explores agile business process modelling with microflows, a topic that also pertains to the previous discussion on workflows. The proposed artefact represents an automatic, lightweight, and declarative approach for the workflow-centred orchestration of semantically annotated micro-services. Its implementation involves agent-based clients, graph-based methods, semantic

vocabularies, and constraint mining. The paper authored by Jennings et al. (2000) explores the independent execution of business processes within their exclusive business process management system. The agents function in a modular fashion. A case study conducted at a British telecommunication company demonstrated the functionality and benefits of the method to the company. Although robotic process automation does not seem to be closely integrated with the fields of process mining and business process management, the reviewed papers indicate potential for future research. Expanding BPMN2.0 to include process mining presents an interesting avenue for research.

3.3. Research Question 2: Validation Methods

This section discusses validation methods commonly used in the field and addresses some persistent issues.

Case studies and experiments are common types of validation in agent-based process mining and business process management. Both rely on event logs or on a multiple-agent simulation for process mining. Despite papers providing formal proof of an algorithm or modelling theory, concerns persist from a validation perspective.

One issue pertains to the lack of validation among papers. In the quality appraisal phase, twenty-four papers were removed. Eighteen of twenty-four papers scored 0.5 or 0 for Q5 and Q6 (of Table 1). This suggests that both the validation and its explanation were insufficient or nonexistent in eighteen articles.

We found that while papers perform a case study, they often do not extensively investigate or report on performance instead of critically evaluating the performance of the artefact or theory. For example, Fleischmann et al. (2013) and Sandita and Popirlan (2015) provide preliminary validation only. This could enable future researchers and industry participants to apply and validate the artefact or theory themselves. The lack of sound case studies could be attributed to a shortage of companies or cases for conducting validation studies, or time constraints associated with longer-lasting case studies.

It must be acknowledged that performing real-world case studies is difficult due to the risk companies face in losing their competitive advantage, creating an unwillingness to share information for publicized research. One known example of a real-world case study was performed by N. R. Jennings et al. (2000). This case study was readapted for Wooldridge, Jennings and Kinny (2000), a strategy that can be useful for future studies. An example of a simulated company case study can be found in Halaška and Šperka (2019). Their strategy using MAREA suffers from a narrow use case (as it is solely trade company oriented) and a large set of assumptions, but it still suffices to show the limitations and benefits of a new approach.

Finally, we will discuss agent-based simulation experiments, a tool used in thirteen papers identified through the SLR. In the previous section, it was mentioned how simulations in combination with a case study (or experiment) can provide an alternative to real-world validations. However, simulation experiments occasionally suffer from problems, such as a range of assumptions that undermines the simulation quality. Such assumptions include a strong limitation of the number of agents and interactions between agents (i.e., only replies and responses, no spontaneous reactions). Other issues with simulation experiments include experiments conducted in just a single scenario, a lack of evaluative metrics, and a lack of comparison to previous methodologies. The lack of comparable techniques could explain the latter.

RQ2 can be answered through the following highlights:

- Validation is often missing or is lacking.
- Illustrations of use are often used as replacements for proper validation.
- Case studies that rely on real data are difficult to find.
- Simulation case studies are common but often suffer from numerous assumptions and limitations.
- Validation studies often lack metrics and comparative analysis.

3.4. Research Question 3: Research Gaps

The preceding subsection addressed RQ1 and RQ2. This subsection aims to address the third research question by synthesizing this information and identifying gaps that could enhance the quality of future research. The proposed research gaps are in no particular order.

The first identified research gap is that authors frequently advocate for the expansion of models and the validation of these models. Hence, the first proposed research gap involves conducting comprehensive validation studies. However, such validation should precede the expansion of these models to demonstrate to both the industry and the scientific community that further research in this area is warranted. The lack of adequate validation can be attributed in part to industry secrecy and to the variable nature of agent-based artefacts. An effort to standardize metrics for assessing the quality of a multiagent system, akin to how machine learning models are trained, could constitute a significant scientific contribution. A suggested approach for this involves integrating the fields of agent-based simulations and process mining. Additionally, comparing centralized approaches with distributed agent-based approaches could yield fresh insights into both artefact performance and general agent-based performance.

The second identified research gap pertains to standardizing methodologies encompassing models, programming languages, and tools. Despite researchers presenting examples or prototypes of artefacts for validation or illustration purposes, documentation for future use or integration with other tools is often lacking. For instance, S-BPM requires a comprehensive specification language, according to Fleischmann et al. (2013), despite extensive research on S-BPM. Standardization coupled with improved usability could also enhance accessibility for researchers and practitioners using tools for agent-based approaches.

The third identified research gap pertains to the need for research on reactive and asynchronous agent relations, as opposed to successive and deterministic relations and communication. Numerous simulation studies make assumptions about successive relationships between agents acting in an undisturbed environment. However, reality does not match this. Communication noise and unpredictable events might cause a simulation to be overly stable, predictable, or mismatched with reality. Additionally, it would be interesting to know how different levels of information sharing between agents affect a multiagent system.

This leads us to the fourth identified research gap, which involves the impact of a complex versus a simple multiple-agent environment on the quality of a simulation. Noise or unpredictable events in experiments could potentially assist in designing more stable multiagent systems for real-world applications.

The fifth research direction could involve expanding compositional approaches for architecture-aware process models. The idea is that architecture-aware process models can be (re)generated and formally proven valuable by design. It does require an expansion of proven interfaces that represent agent interactions and an efficient way to extract these from event logs.

The sixth area of research focuses on visualizations and explanations of a multiagent system. Visualizations, including statistics that can enhance business decisions, might help people using such systems better understand how the targeted multiagent system functions and how agents interact within it. Examples of beneficiaries include managers attempting to improve business processes in a large retail store or manufacturing plant operators who can gain better real-time insight through live-process mining and visualization.

The topic of self-interested and evolving agents has been briefly mentioned in several papers. Research into the effect of more complex agents on the quality of multiagent systems and simulations might prove useful for future implementations. This is because changes occur not only in business environments but also in the people, roles, and processes within this environment.

A single paper briefly links process mining to Industry 4.0, with mentions of digital twins found in the SLR. Increased volumes of data and the emergence of self-organizing systems might provide a new use case for process mining and improved production. The work by Osman and Ghiran (2019) conducted exploratory research, demonstrating that the combination of these fields offers potential benefits. There is much to be discovered, rendering it an intriguing area for exploration.

Lastly, we identified a research gap related to another emerging technology. Despite the relative commonality of cloud-based and decentralized data management solutions at the time of writing, there could still be room for agent-based data management solutions. Sandita and Popirlan (2015) proposed a multiagent data management system in JADE. Expanding this research could potentially lead to future developments.

4. Discussion

The previous section has highlighted research areas, validation methods, and opportunities for future research based on the results of the SLR. This section provides a brief recap, discussing the key findings for each research question.

To answer RQ1, ‘What agent-based approaches exist for process mining and/or business process management?’ (addressed in subsection 3.2), within the scope of the SLR search query, it was found that methods vary significantly across multiple domains. Approaches for simulation studies were developed to validate models, measure business performance, and generate data. Process mining was often used in conjunction with a multiagent system and simulations to capture the multiagent system’s behaviour. Business process management was closely related to process mining and multiagent system simulation, mainly with the goal of describing agent-based conceptual models, business processes, and multiple-agent systems at various levels of abstraction. At lower levels of abstraction, representations of workers are similar to multiagent systems, while higher levels of abstraction relate to organizational structures. Other fields occasionally incorporating agent-based approaches are ontology, workflow, interactive agents, and robotic process automation.

Validation methods for RQ2, ‘What validation methods are used and how are they performed?’ were discussed in subsection 3.3. This section concludes that validation is often missing or inadequate. Validation approaches were characterized by illustrations using analytical analysis methods such as mathematical proofs. Additionally, while case studies and experiments using simulations were common, there was a noticeable lack of noisy and perturbation event data, as well as metrics and comparative studies. Furthermore, real-life agent data for multiagent systems validation are largely absent, possibly due to security and trust concerns.

However, the explored approaches often perform well in experimental settings under certain assumptions, such as a limited number of agents and solely reactive communication between them. Few studies have tested these approaches for business use; those that have found that the frameworks are often not user-friendly and difficult to understand without visualizations of the agent-based approach.

Only a small number of papers were statistically insignificant or underperformed in experimental settings, which indicates that the field of agent-based techniques holds promise.

RQ3, 'What are the research gaps in the joint field of agent-based modelling, process mining, and business process management with regard to the approaches found in RQ1?' (subsection 3.4) concerns the identification of research gaps and future research directions.

The answers to all the research questions are provided through a systematic literature review. We have followed Kitchenham's approach (Kitchenham et al. 2009) with slight modifications, where we applied a text analytics approach for literature categorization. The identified categorization helped us structure the information into relevant and identifiable groups for better understanding and exploration of results.

In this chapter, we conducted a text analytics–based systematic review to address our research question. However, our systematic approach presents several threats to validity. First, although our inclusion criteria were clearly defined and agreed upon by the assessors, we may have inadvertently excluded relevant articles by only considering those with relevant titles and abstracts. The content of the papers themselves could have been important. Nevertheless, as our research primarily focuses on identifying structured methods—typically defined once and applied multiple times—the risk of missing a method is relatively low. Furthermore, through snowballing, we may have identified any missing articles, thus mitigating this threat to validity. Another potential threat to validity is the potential for bias in the selection of studies and data extraction. To address this concern, we developed a set of quality evaluation questions (refer to section 2.3) for the critical appraisal of each study (see Appendix A for details). Each study was evaluated against these quality assessment criteria to minimize bias.

We conducted an evaluation of various validation methods employed in the research. Among the eighteen analysed, a significant portion utilized experiments or case studies involving simulation. This trend can be attributed to the prevalent focus on agent-based simulations within the scope of the studies, making simulations an intuitive choice for validation. In contrast, a lesser number of papers opted for case studies conducted at real companies, which emerged as a less common approach. An additional group of papers adopted case studies to demonstrate the usability of a particular approach or prototype. However, these case studies only mostly scratched the surface and did not delve deeply into the performance or limitations of the proposed methodologies.

Thus, the added value of this research is that it provides an overview of current agent-based methods in process mining and business process management. Furthermore, text analytics for article categorization proved to be useful. Additionally, this work allows future researchers and practitioners to identify and improve upon the identified research gaps, outlining a selection of concrete suggestions for future research with the goal of inspiring communities within the field.

References

Adamo, Greta, Stefano Borgo, Chiara Di Francescomarino, Chiara Ghidini, Nicola Guarino, and Emilio M. Sanfilippo. 2017. 'Business Processes and Their Participants: An Ontological Perspective'. In *Conference of the Italian Association for Artificial Intelligence*, edited by F. Esposito, R. Basili, S. Ferilli, and F. Lisi, 215–228. Springer. https://link.springer.com/chapter/10.1007/978-3-319-70169-1_16

Alberti, Marco, Federico Chesani, Marco Gavanelli, Evelina Lamma, Paola Mello, Marco Montali, Sergio Storari, and Paolo Torroni. 2006. 'Computational Logic for Run-Time Verification of Web Services Choreographies: Exploiting the Socs-Si Tool'. In *Web Services and Formal Methods*, 58–72. Springer.

Appio, Francesco P., Mario G. C. A. Cimino, Alessandro Lazzeri, Antonella Martini, and Gigliola Vaglini. 2018. 'Fostering Distributed Business Logic in Open Collaborative Networks: An Integrated Approach Based on Semantic and Swarm Coordination'. *Information Systems Frontiers* 20 (3): 589–616. https://doi.org/10.1007/s10796-016-9691-5.

Baumgärtel, Philipp, Johannes Tenschert, and Richard Lenz. 2014. 'A Query Language for Workflow Instance Data'. In *New Trends in Databases and Information Systems: 17th East European Conference on Advances in Databases and Information Systems*, 79–86. Springer.

Bonabeau, Eric. 2002. 'Agent-Based Modeling: Methods and Techniques for Simulating Human Systems'. *Proceedings of the National Academy of Sciences* 99 (suppl. 3): 7280–7287.

Both, Fiemke, Mark Hoogendoorn, Andy van der Mee, Jan Treur, and Michael de Vos. 2012. 'An Intelligent Agent Model with Awareness of Workflow Progress'. *Applied Intelligence* 36 (2): 498–510. https://doi.org/10.1007/s10489-010-0273-9.

Chakraborti, Tathagata, Yara Rizk, Vatche Isahagian, Burak Aksar, and Francesco Fuggitti. 2022. 'From Natural Language to Workflows: Towards Emergent Intelligence in Robotic Process Automation'. In *International Conference on Business Process Management*, 123–137. Springer.

Chesani, Federico, Paola Mello, and Marco Montali. 2017. 'Abductive Reasoning on Compliance Monitoring: Balancing Flexibility and Regulation'. In *Foundations of Intelligent Systems*, 3–16. Springer.

Cimino, Mario G. C. A., and Francesco Marcelloni. 2011. 'Autonomic Tracing of Production Processes with Mobile and Agent-Based Computing'. *Information Sciences* no. 5: 935–953. https://doi.org/10.1016/j.ins.2010.11.015.

Claes, Jan, Irene Vanderfeesten, Hajo A. Reijers, Jakob Pinggera, Matthias Weidlich, Stefan Zugal, Dirk Fahland, Barbara Weber, Jan Mendling, and Geert Poels. 2012. 'Tying Process Model Quality to the Modeling Process: The Impact of Structuring, Movement, and Speed'. In *Business Process Management. BPM 2012. Lecture Notes in Computer Science*, vol. 7481, edited by A. Barros, A. Gal, and E. Kindler, 33–48. Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-642-32885-5_3.

Debenham, John, and Simeon Simoff. 2012. 'The Co-Creation Machine: Managing Co-Creative Processes for the Crowd'. In *Advancing Democracy, Government and Governance*, 170–177. Springer.

Deen, S. Misbah, and Rashid Jayousi. 2006. 'A Preference Processing Model for Cooperative Agents'. *Journal of Intelligent Information Systems* 26 (2): 115–147. https://doi.org/10.1007/s10844-006-8436-1.

Di Ciccio, Claudio, Massimo Mecella, Monica Scannapieco, Diego Zardetto, and Tiziana Catarci. 2012. 'MailOfMine–Analyzing Mail Messages for Mining Artful Collaborative Processes'. In *Data-Driven Process Discovery and Analysis*, 55–81. Springer.

Di Federico, Gemma, Erik Ravn Nikolajsen, Mamuna Azam, and Andrea Burattin. 2021. 'Linac: A Smart Environment Simulator of Human Activities'. In *International Conference on*

Process Mining, 60–72. Eindhoven, Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-98581-3_5.

Dorrer, Mikhail, and Alexandra Dorrer. 2020. 'Forecasting e-Learning Processes Using GERT Models and Process Mining Tools'. In *Proceeding of the International Science and Technology Conference*, '*FarEastCon 2019' October 2019, Vladivostok, Russian Federation, Far Eastern Federal University*, 857–866. Singapore: Springer Singapore.

Fajar, Aziz, Riyanarto Sarno, and Abd Charis Fauzan. 2018. 'Comparison of Discrete Event Simulation and Agent Based Simulation for Evaluating the Performance of Port Container Terminal'. In *2018 International Conference on Information and Communications Technology*, *(ICOIACT)*, 259–265. Yogyakarta, Indonesia: IEEE. https://doi.org/10.1109/ICOIACT.2018.8350717.

Fauzan, Abd Charis, Riyanarto Sarno, and Imam Machfud. 2019. 'Simulation of Agent-Based and Discrete Event for Analyzing Multi Organizational Performance'. In *2019 International Seminar on Application for Technology of Information and Communication (iSemantic)*, 224–229. Jawa Tengah, Indonesia: IEEE Indonesia Section. https://doi.org/10.1109/ISEMANTIC.2019.8884350.

Ferber, Jacques, Olivier Gutknecht, and Fabien Michel. 2004. 'From Agents to Organizations: An Organizational View of Multi-agent Systems'. In *Agent-Oriented Software Engineering IV*, 214–230. Melbourne, Australia: Springer.

Ferreira, Diogo R., Fernando Szimanski, and Celia Ghedini Ralha. 2013. 'A Hierarchical Markov Model to Understand the Behaviour of Agents in Business Processes'. In *Business Process Management Workshops: BPM 2012 International Workshops, Tallinn,* *Estonia, September 3, 2012. Revised Papers 10*, 150–161. Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-642-36285-9_16.

Fleischmann, Albert, Udo Kannengiesser, Werner Schmidt, and Christian Stary. 2013. 'Subject-Oriented Modeling and Execution of Multi-Agent Business Processes'. In *Proceedings—2013 IEEE/WIC/ACM International Conference on Intelligent Agent Technology, IAT 2013*, vol. 2, 138–145. Atlanta, GA: IEEE. https://doi.org/10.1109/WI-IAT.2013.102.

Günther, Christian W., and Wil M. P. van der Aalst. 2007. 'Fuzzy Mining—Adaptive Process Simplification Based on Multi-Perspective Metrics'. In *International Conference on Business Process Management*, 328–343. Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-540-75183-0_24.

Halaška, Michal, and Roman Šperka. 2018. 'Is There a Need for Agent-Based Modelling and Simulation in Business Process Management?' *Organizacija* 51 (4): 255–269. https://doi.org/10.2478/orga-2018-0019.

Halaška, Michal, and Roman Šperka. 2019. 'Advantages of Application of Process Mining and Agent-Based Systems in Business Domain'. In *Agents and Multi-Agent Systems: Technologies and Applications 2018: Proceedings of the 12th International Conference on Agents and Multi-Agent Systems: Technologies and Applications (KES-AMSTA-18) 12*, 177–186. Gold Coast, Australia: Springer International Publishing. https://doi.org/10.1007/978-3-319-92031-3_17.

Halaška, Michal, and Roman Šperka. 2020. 'Messaged Multi-agent System as a Tool for Strengthening Innovative Capabilities of Business Models'. In *Agents and Multi-agent Systems: Technologies and Applications 2019: 13th KES International Conference, KES-*

AMSTA-2019 St. Julians, Malta, June 2019 Proceedings, 355–365. Springer Singapore. https://doi.org/10.1007/978-981-13-8679-4_29.

Han, Cunliang, Xiaojun Zhang, Huijuan Jiao, Min Wang, and Tiantian Han. 2021. 'A Review on Financial Robot Process Auto-Mining Based on Reinforcement Learning'. In *International Forum on Digital TV and Wireless Multimedia Communications*, 471–484. Singapore: Springer Singapore.

Hanachi, Chihab, Walid Gaaloul, and Ravi Mondi. 2012. 'Performative-Based Mining of Workflow Organizational Structures'. In *E-Commerce and Web Technologies*, 63–75. Springer.

Huang, Biqing, Peng Zhu, and Cheng Wu. 2012. 'Customer-Centered Careflow Modeling Based on Guidelines'. *Journal of Medical Systems* 36: 3307–3319.

Hull, Richard, and Hamid R. Motahari Nezhad. 2016. 'Rethinking BPM in a Cognitive World: Transforming How We Learn and Perform Business Processes'. In *International Conference on Business Process Management*, 3–19. Rio de Janeiro, Brazil: Springer.

Hunka, Frantisek, and Steven van Kervel. 2019. 'A Generic DEMO Model for Co-creation and Co-production as a Basis for a Truthful and Appropriate REA Model Representation'. In *Business Process Management: Blockchain and Central and Eastern Europe Forum: BPM 2019 Blockchain and CEE Forum, Vienna, Austria, September 1–6, 2019, Proceedings 17*, 203–218. Springer International Publishing. https://doi.org/10.1007/978-3-030-30429-4_14.

Hunka, Frantisek, and Jaroslav Zacek. 2014. 'Detailed Analysis of REA Ontology'. In *Advances in Enterprise Engineering VIII: 4th Enterprise Engineering Working Conference, EEWC 2014, Funchal, Madeira Island, Portugal, May 5–8, 2014. Proceedings 4*, 61–75. Springer International Publishing. https://doi.org/10.1007/978-3-319-06505-2_5.

Ito, Sohei, Dominik Vymětal, Roman Šperka, and Michal Halaška. 2018. ‘Process Mining of a Multi-Agent Business Simulator’. *Computational and Mathematical Organization Theory* 24 (4): 500–531. https://doi.org/10.1007/s10588-018-9268-6.

Jablonski, Stefan, and Ramzan Talib. 2009. ‘Agent Assignment for Process Management: Pattern Based Agent Performance Evaluation’. In *Agents and Data Mining Interaction: 4th International Workshop, ADMI 2009, Budapest, Hungary, May 10–15, 2009, Revised Selected Papers 4*, 155–169. Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-642-03603-3_12.

Jennings, Ben, and Anthony Finkelstein. 2010. ‘Micro Workflow Gestural Analysis: Representation in Social Business Processes’. In *Business Process Management Workshops: BPM 2009 International Workshops, Ulm, Germany, September 7, 2009. Revised Papers 7*, 278–290. Berlin, Heidelberg: Springer.

Jennings, Nicholas R., Timothy J. Norman, Peyman Faratin, Paul O’Brien, and Brian Odgers. 2000. ‘Autonomous Agents for Business Process Management’. *Applied Artificial Intelligence* 14 (2): 145–189. https://doi.org/10.1080/088395100117106.

Jiang, Xuesong, Xiumei Wei, and Cui Jing. 2012. ‘Business Process Analysis and Modeling Based on Agent’. In *Emerging Research in Artificial Intelligence and Computational Intelligence: International Conference, AICI 2012, Chengdu, China, October 26–28, 2012. Proceedings*, 253–257. Berlin, Heidelberg: Springer.

Jimenez, Jose-Fernando, Gabriel Zambrano-Rey, Santiago Aguirre, and Damien Trentesaux. 2018. ‘Using Process-Mining for Understating the Emergence of Self-Organizing Manufacturing Systems’. *IFAC-PapersOnLine* 51 (11): 1618–1623. https://doi.org/10.1016/j.ifacol.2018.08.258.

Kabicher, Sonja, and Stefanie Rinderle-Ma. 2011. 'Human-Centered Process Engineering Based on Content Analysis and Process View Aggregation'. In *Advanced Information Systems Engineering: 23rd International Conference, CAiSE 2011, London, UK, June 20-24, 2011. Proceedings 23*, 467–481. Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-642-21640-4_35.

Kindler, Ekkart, Vladimir Rubin, and Wilhelm Schäfer. 2005. 'Incremental Workflow Mining Based on Document Versioning Information'. In *Software Process Workshop*, 287–301. Berlin, Heidelberg: Springer.

Kitchenham, Barbara, O. Pearl Brereton, David Budgen, Mark Turner, John Bailey, and Stephen Linkman. 2009. 'Systematic Literature Reviews in Software Engineering—A Systematic Literature Review'. *Information and Software Technology* 51 (1): 7–15. https://doi.org/10.1016/j.infsof.2008.09.009.

Larsen, John Bruntse. 2019. 'Adding Organizational Reasoning to Agent-Based Simulations in GAMA'. In *Engineering Multi-Agent Systems: 6th International Workshop, EMAS 2018, Stockholm, Sweden, July 14-15, 2018, Revised Selected Papers 6*, 242–262. Springer International Publishing.

Larsen, John Bruntse, Andrea Burattin, Christopher John Davis, Rasmus Hjardem-Hansen, and Jørgen Villadsen. 2019. 'A Data Driven Agent Elicitation Pipeline for Prediction Models'. In *International Conference on Business Process Management*, 570–582. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-37453-2_46.

Lau, Jason S. K., George Q. Huang, Kai-Ling Mak, and L. Liang. 2006. 'Agent-Based Modeling of Supply Chains for Distributed Scheduling'. *IEEE Transactions on Systems, Man, and*

Cybernetics—Part A: Systems and Humans 36 (5): 847–861. https://doi.org/10.1109/TSMCA.2005.854231.

Lins, Luis Fernando, Glaucia Melo, Toacy Oliveira, Paulo Alencar, and Donald Cowan. 2021. ‘PACAs: Process-Aware Conversational Agents’. In *International Conference on Business Process Management*, 312–318. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-94343-1_24.

López Castro, Laura María, Sonia Geraldine Martínez, Nestor Eduardo Rodriguez, Luna Violeta Lovera, Hugo Santiago Aguirre, and Jose-Fernando Jimenez. 2021. ‘Development of a Predictive Process Monitoring Methodology in a Self-Organized Manufacturing System’. In *Service Oriented, Holonic and Multi-Agent Manufacturing Systems for Industry of the Future: Proceedings of SOHOMA LATIN AMERICA 2021*, 3–16. Springer International Publishing. https://doi.org/10.1007/978-3-030-80906-5_1.

Ly, Linh Thao, Stefanie Rinderle-Ma, David Knuplesch, and Peter Dadam. 2011. ‘Monitoring Business Process Compliance Using Compliance Rule Graphs’. In *On the Move to Meaningful Internet Systems: OTM 2011: Confederated International Conferences: CoopIS, DOA-SVI, and ODBASE 2011, Hersonissos, Crete, Greece, October 17-21, 2011, Proceedings, Part I*, 82–99. Berlin, Heidelberg: Springer.

Macal, Charles M., and Michael J. North. 2008. ‘Agent-Based Modeling and Simulation: ABMS Examples’. In *2008 Winter Simulation Conference*, 101–112. Miami, FL: IEEE.

Marrella, Andrea. 2019. ‘Automated Planning for Business Process Management’. *Journal on Data Semantics* 8 (2): 79–98.

Medeiros, A. K. Alves de, Boudewijn F. van Dongen, Wil M. P. van der Aalst, and Anton J. M. M. Weijters. 2004. *Process Mining: Extending the Alpha-Algorithm to Mine Short Loops*. BETA Publicatie: Working Papers. Eindhoven: Technische Universiteit Eindhoven.

Nesterov, Roman, Luca Bernardinello, Irina Lomazova, and Lucia Pomello. 2023. 'Discovering Architecture-Aware and Sound Process Models of Multi-Agent Systems: A Compositional Approach'. *Software and Systems Modeling* 22 (1): 351–375. https://doi.org/10.1007/s10270-022-01008-x.

Nesterov, Roman, and Irina A. Lomazova. 2019. 'Asynchronous Interaction Patterns for Mining Multiagent System Models from Event Logs'. In *Proceedings of the MACSPro Workshop*, 62–73. Vienna.

Oberhauser, Roy, and Sebastian Stigler. 2018. 'Microflows: Leveraging Process Mining and an Automated Constraint Recommender for Microflow Modeling'. In *Business Modeling and Software Design: 7th International Symposium, BMSD 2017, Barcelona, Spain, July 3–5, 2017, Revised Selected Papers 7*, 25–48. Springer International Publishing. https://doi.org/10.1007/978-3-319-78428-1_2.

Decker, G., Dijkman, R., Dumas, M., and García-Bañuelos, L. 2009. The business process modeling notation. In *Modern Business Process Automation: YAWL and its Support Environment*, 347–368. Berlin, Heidelberg: Springer.

Onggo, Bhakti S. S., and Onder Karpat. 2011. 'Agent-Based Conceptual Model Representation Using BPMN'. In *Proceedings—Winter Simulation Conference (WSC)*, 671–682. Phoenix Arizona: IEEE. https://doi.org/10.1109/WSC.2011.6147795.

Osman, Cristina-Claudia, and Ana-Maria Ghiran. 2019. 'When Industry 4.0 Meets Process Mining'. *Procedia Computer Science* 159: 2130–2136. https://doi.org/10.1016/J.PROCS.2019.09.386.

Ou-Yang, C., and Yeh-Chun Juan. 2010. 'Applying Process Mining Approach to Support the Verification of a Multi-Agent System'. *Journal of Systems Science and Systems Engineering* 19 (2): 131–149. https://doi.org/10.1007/s11518-010-5132-z.

Ou-Yang, C., Yeh-Chun Juan, and C. S. Li. 2009. 'Applying Petri Net to Analyze a Multi-Agent System Feasibility—A Process Mining Approach'. In *Global Perspective for Competitive Enterprise, Economy and Ecology: Proceedings of the 16th ISPE International Conference on Concurrent Engineering*, 93–103. London: Springer London. https://doi.org/10.1007/978-1-84882-762-2_9.

Poggi, Nicolas, Vinod Muthusamy, David Carrera, and Rania Khalaf. 2013. 'Business Process Mining from e-Commerce Web Logs'. In *International Conference on Business Process Management: 11th International Conference, BPM 2013, Beijing, China, August 26-30, 2013. Proceedings*, 65–80. Berlin, Heidelberg: Springer.

Poletaeva, Tatiana, Habib Abdulrab, and Edward Babkin. 2013. 'Developing a Multi-Facet Abstractions Framework for Designing a New Class of Traceability Applications'. In *Enterprise and Organizational Modeling and Simulation: 9th International Workshop, EOMAS 2013, Held at CAiSE 2013, Valencia, Spain, June 17, 2013, Selected Papers 9*, 115–129. Berlin, Heidelberg: Springer.

Reijers, Hajo A., Minseok Song, and Byungduk Jeong. 2009. 'Analysis of a Collaborative Workflow Process with Distributed Actors'. *Information Systems Frontiers* 11: 307–322.

Rizk, Yara, Vatche Isahagian, Scott Boag, Yasaman Khazaeni, Merve Unuvar, Vinod Muthusamy, and Rania Khalaf. 2020. ‘A Conversational Digital Assistant for Intelligent Process Automation’. In *Business Process Management: Blockchain and Robotic Process Automation Forum: BPM 2020 Blockchain and RPA Forum, Seville, Spain, September 13–18, 2020, Proceedings 18*, 85–100. Springer International Publishing. https://doi.org/10.1007/978-3-030-58779-6_6.

Roeser, Tobias, and Eva-Maria Kern. 2015. ‘Surveys in Business Process Management—A Literature Review’. *Business Process Management Journal* 21 (3): 692–718.

Saha, Ratul, Madhavan Mukund, and R. P. Jagadeesh Chandra Bose. 2016. ‘Time-Bounded Statistical Analysis of Resource-Constrained Business Processes with Distributed Probabilistic Systems’. In *International Symposium on Dependable Software Engineering: Theories, Tools, and Applications*, 297–314. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-47677-3_19.

Sandita, Adrian Victor, and Claudiu Ionut Popirlan. 2015. ‘Developing a Multi-Agent System in JADE for Information Management in Educational Competence Domains’. *Procedia Economics and Finance* 23: 478–486. https://doi.org/10.1016/S2212-5671(15)00404-9.

Schönig, Stefan, Cristina Cabanillas, Ciccio Di Ciccio, Stefan Jablonski, and Jan Mendling. 2018. ‘Mining Team Compositions for Collaborative Work in Business Processes’. *Software and Systems Modeling* 17 (2): 675–693. https://doi.org/10.1007/s10270-016-0567-4.

Sellitto, Giovanni Paolo, Helder Aranha, Massimiliano Masi, and Tanja Pavleska. 2020. ‘Security and Safety by Design in the Internet of Actors: An Architectural Approach’. In *Subject-Oriented Business Process Management. The Digital Workplace–Nucleus of*

Transformation: 12th International Conference, S-BPM ONE 2020, Bremen, Germany, December 2-3, 2020, Proceedings 12, 133–142. Springer International Publishing. https://doi.org/10.1007/978-3-030-64351-5_9.

Siebers, Peer-Olaf, Uwe Aickelin, Helen Celia, and Christopher Clegg. 2007. 'A Multi-Agent Simulation of Retail Management Practices'. In *Proceedings of the 2007 summer computer simulation conference. Society for Computer Simulation International 2007. Simulation International*, San Diego, CA, United States. https://doi.org/10.48550/arXiv.0803.1598.

Singer, Robert. 2016. 'Agent-Based Business Process Modeling and Execution: Steps Towards a Compiler-Virtual Machine Architecture'. In *Proceedings of the 8th International Conference on Subject-Oriented Business Process Management*, 1–10. https://doi.org/10.1145/2882879.2882880.

Slaninová, Kateřina, Jan Martinovič, Roman Šperka, and Pavla Dráždilová. 2013. 'Extraction of Agent Groups with Similar Behaviour Based on Agent Profiles'. In *Computer Information Systems and Industrial Management: 12th IFIP TC8 International Conference, CISIM 2013, Krakow, Poland, September 25–27, 2013. Proceedings*, 348–357. Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-642-40925-7_32.

Šperka, Roman, Marek Spišák, Katerina Slaninová, Jan Martinovič, and Pavla Dráždilová. 2013. 'Control Loop Model of Virtual Company in BPM Simulation'. In *Soft Computing Models in Industrial and Environmental Applications: 7th International Conference, SOCO'12, Ostrava, Czech Republic, September 5th-7th, 2012*, 515–524. Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-642-32922-7_53.

Szimanski, Fernando, Célia G. Ralha, Gerd Wagner, and Diogo R. Ferreira. 2013. 'Improving Business Process Models with Agent-Based Simulation and Process Mining'. In *International Workshop on Business Process Modeling, Development and Support*, 124–138. Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-642-38484-4_10.

Tiwari, Ashutosh, Chris J. Turner, and Basim Majeed. 2008. 'A Review of Business Process Mining: State-of-the-Art and Future Trends'. *Business Process Management Journal* 14 (1): 5–22. https://doi.org/10.1108/14637150810849373.

Tour, Andrei, Artem Polyvyanyy, and Anna Kalenkova. 2021. 'Agent System Mining: Vision, Benefits, and Challenges'. *IEEE Access* 9: 99480–99494. https://doi.org/10.1109/ACCESS.2021.3095464.

van der Aalst, Wil M. P. 1998. 'The Application of Petri Nets to Workflow Management'. *Journal of Circuits, Systems and Computers* 8 (1): 21–66. https://doi.org/10.1142/S0218126698000043.

van der Aalst, Wil M. P. 2012. 'Process Mining: Overview and Opportunities'. *ACM Transactions on Management Information Systems* 3 (2): 1–17. https://doi.org/10.1145/2229156.2229157.

van der Aalst, Wil M. P. 2013. 'Business Process Management: A Comprehensive Survey'. *International Scholarly Research Notices Software Engineering* 2013 (1): 1–37.

van der Aalst, Wil, Arya Adriansyah, Ana Karla Alves De Medeiros, Franco Arcieri, Thomas Baier, Tobias Blickle, Jagadeesh Chandra Bose, P. . . . & Wynn, M. 2012. 'Process Mining Manifesto'. In *Business Process Management Workshops: BPM 2011 International Workshops, Clermont-Ferrand, France, August 29, 2011, Revised Selected*

Papers, Part I 9, 169–194. Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-642-28108-2_19.

van Dongen, Boudewijn F., J. van Luin, and H. M. W. Verbeek. 2006. 'Process Mining in a Multi-Agent Auctioning System'. In *Proceedings of the Fourth International Workshop on Modelling of Objects, Components and Agents, Turku*, 145–160. Hamburg: Bericht Universität Hamburg, Department Informatik, University of Hamburg.

van Dongen, Boudewijn F., Ana Karla A. de Medeiros, H. M. W. Verbeek, A. J. M. M. Weijters, and Wil M. P. van der Aalst. 2005. 'The ProM Framework: A New Era in Process Mining Tool Support'. In *Applications and Theory of Petri Nets 2005: 26th International Conference, ICATPN 2005, Miami, USA, June 20-25, 2005. Proceedings 26*, 444–454. Berlin, Heidelberg: Springer.

Wagner, Gerd. 2003. 'AOR Modelling and Simulation: Towards a General Architecture for Agent-Based Discrete Event Simulation'. In *International Bi-Conference Workshop on Agent-Oriented Information Systems*, 174–188. Berlin, Heidelberg: Springer.

Weijters, Anton J. M. M., Wil M. P. van der Aalst, and A. K. Alves de Medeiros. 2006. *Process Mining with the HeuristicsMiner Algorithm*. BETA Publicatie: Working Papers. Eindhoven: Technische Universiteit Eindhoven.

Weiss, Gerhard. 1999. *Multiagent Systems: A Modern Approach to Distributed Artificial Intelligence*. Cambridge, MA: MIT Press.

Witschel, Hans Friedrich, Bo Hu, Uwe V. Riss, Barbara Thönssen, Roman Brun, Andreas Martin, and Knut Hinkelmann. 2010. 'A Collaborative Approach to Maturing Process-Related Knowledge'. In *International Conference on Business Process Management*, 343–358. Hoboken, NJ: Springer.

Wohlin, Claes. 2014. ‘Guidelines for Snowballing in Systematic Literature Studies and a Replication in Software Engineering’. In *Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering*, 1–10. London, England.

Wooldridge, Nicholas R., Jennings, Michael, and David Kinny. 2000. ‘The Gaia Methodology for Agent-Oriented Analysis and Design’. *Autonomous Agents and Multi-Agent Systems* 3 (3): 285–312. https://doi.org/10.1023/A:1010071910869.

Yaeli, Avi, Segev Shlomov, Alon Oved, Sergey Zeltyn, and Nir Mashkif. 2022. ‘Recommending Next Best Skill in Conversational Robotic Process Automation’. In *International Conference on Business Process Management*, 215–230. Münster, Germany; Cham: Springer International Publishing.

Zairi, Mohamed. 1997. ‘Business Process Management: A Boundaryless Approach to Modern Competitiveness’. *Business Process Management Journal* 3 (1): 64–80. https://doi.org/10.1108/14637159710161585.

4.1 Appendix A.

Quality Appraisal of the Papers

Insert Table 2: here

4.2 Appendix B.

Snowballed Papers

Insert Table 3: here

Figure 1.

An overview of the literature search strategy.

Figure 2.

The research areas identified through word cloud.

Figure 3.

The research areas identified through Google Cloud Natural Language API.

Figure 4.

The research areas discussed in the results section and the number of papers in each such category (foam tree map).

Figure 5.

The research areas and sub-areas discussed in the results section and the number of papers in each such category and sub-category (pie chart).

Table 1.

The quality requirements used for the quality step

Requirement	**Evaluation description**
Q1	Does the paper propose a new agent-based approach or new agent-based application of an approach?
Q2	Does the paper propose a method within the scope of process mining or business process management?
Q3	Is the approach based on defined methods found in Q1 and Q2?
Q4	Is the method of research clearly described?
Q5	Is the proposed method empirically evaluated or validated?
Q6	Is the evaluation and its result explicitly stated?
Q7	Is the method supported by the evaluation?
Q8	Is the purpose of the study clearly defined?

Table 2.

Quality appraisal of papers after the criteria assessment, including papers that were excluded from the SLR due to not meeting the requirements

Item	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Score**
Bonabeau 2002	1	1	1	1	0	0	0	1	5

Item	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Score
Szimanski et al. 2013	1	1	1	1	1	1	1	1	8
Halaška and Šperka 2019	1	1	1	0	1	1	1	0	6
Poggi et al. 2013	0	1	1	1	1	1	0	1	6
Šperka et al. 2013	1	0.5	1	1	1	1	1	1	7.5
Oberhauser and Stigler 2018	0.5	1	1	1	1	1	0.5	1	7
Ou-Yang, Juan, and Li 2009	1	1	1	1	1	1	1	1	8
Halaška and Šperka 2020	1	1	1	1	0.5	1	1	0.5	7
Jiang, Wei, and Jing 2012	1	1	0	0	0	0	0	0	2
Dorrer and Dorrer 2020	0	1	1	1	1	1	0.5	1	6.5
Hull and Nezhad 2016	0	1	0	0	0	0	0	1	2
Larsen et al. 2019	1	1	1	1	1	0.5	0.5	1	7
Hanachi, Gaaloul, and Mondi 2012	1	1	0	1	0	0	0	1	4
Ferreira, Szimanski, and Ralha 2013	1	1	0.5	1	1	1	0.5	1	7
Rizk et al. 2020	1	1	1	1	1	0.5	1	1	7.5
Poletaeva, Abdulrab, and Babkin 2013	1	0.5	1	1	0	0	0	1	4.5
Slaninová et al. 2013	1	0	1	1	1	1	1	1	7
B. Jennings and Finkelstein 2010	1	0	1	0	0	0	0	1	3
Kabicher and Rinderle-Ma 2011	1	1	1	1	1	1	1	1	8
López Castro et al. 2021	1	1	1	1	1	1	1	1	8
Han et al. 2021	0.5	0	1	0.5	1	0	0.5	1	4.5
Lins et al. 2021	1	1	1	1	1	0	0.5	1	6.5
Witschel et al. 2010	0	1	1	1	1	0.5	1	1	6.5
Saha, Mukund, and Bose 2016	1	1	1	1	1	0.5	1	1	7.5
Chakraborti et al. 2022	0	1	1	0.5	0	0	0	1	3.5
Alberti et al. 2006	0.5	0	1	1	0.5	0.5	0.5	1	5
Di Ciccio et al. 2012	0	1	0	1	1	1	1	1	6
Kindler, Rubin, and Schäfer 2005	0	1	1	1	0	0	0	1	4
Chesani, Mello, and Montali 2017	1	1	1	1	0	0	0	1	5
Yaeli et al. 2022	1	0.5	0	0.5	0	0	0	1	3
Debenham and Simoff 2012	1	0.5	0	0.5	0	0	0	1	3
Ly et al. 2011	0	1	0	1	0	0	0	1	3
Sellitto et al. 2020	0.5	1	1	1	0.5	0	1	1	6
Hunka and Kervel 2019	0.5	1	1	1	1	1	0.5	1	7
Jablonski and Talib 2009	1	1	1	1	1	1	1	1	8
Di Federico et al. 2021	1	1	1	1	1	1	1	1	8

Item	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Score
Baumgärtel, Tenschert, and Lenz 2014	0	0	1	1	1	1	0.5	1	5.5
Adamo et al. 2017	0.5	1	1	1	0	0	0	1	4.5
Tour, Polyvyanyy, and Kalenkova 2021	0.5	1	1	1	0	0	0	1	4.5
Fauzan, Sarno, and Machfud 2019	1	1	1	1	1	1	0	1	7
Halaška and Šperka 2018	1	1	1	1	1	1	0	1	7
Ou-Yang and Juan 2010	1	1	1	1	1	1	1	1	8
Ito et al. 2018	1	1	1	1	1	1	1	1	8
Marrella 2019	0	1	1	1	0.5	0	0	1	4.5
Nesterov et al. 2023	1	1	1	1	1	1	1	1	8
Schönig et al. 2018	0.5	1	1	1	1	1	1	1	7.5
Reijers, Song, and Jeong 2009	0	1	1	1	1	1	1	0.5	6.5
Both et al. 2012	1	0.5	1	1	1	1	1	1	7.5
Appio et al. 2018	0.5	1	0.5	1	0.5	1	0.5	0.5	5.5
Huang, Zhu, and Wu 2012	0	1	0	1	0.5	0.5	0.5	1	4.5

Table 3.

Overview of the papers found through snowballing after the quality appraisal

Title	Author
‘Agent-Based Modeling: Methods and Techniques for Simulating Human Systems’	Bonabeau
‘AOR Modelling and Simulation: Towards a General Architecture for Agent-Based Discrete Event Simulation’	Wagner
‘Autonomous Agents for Business Process Management’	Jennings et al.
‘Agent-Based Business Process Modeling and Execution: Steps Towards a Compiler-Virtual Machine Architecture’	Singer
‘A Preference Processing Model for Cooperative Agents’	Deen and Jayousi
‘Developing a Multi-Agent System in JADE for Information Management in Educational Competence Domains’	Sandita and Popirlan

‘Adding Organizational Reasoning to Agent-Based Simulations in GAMA’	Larsen
‘Using Process-Mining for Understating the Emergence of Self-Organizing Manufacturing Systems’	Jimenez et al.
‘Comparison of Discrete Event Simulation and Agent Based Simulation for Evaluating the Performance of Port Container Terminal’	Fajar, Sarno, and Fauzan
‘A Hierarchical Markov Model to Understand the Behaviour of Agents in Business Processes’	Ferreira, Szimanski, and Ralha
‘Subject-Oriented Modeling and Execution of Multi-Agent Business Processes’	Fleischmann et al.
‘Agent-Based Conceptual Model Representation Using BPMN’	Onggo and Karpat
‘A Multi-Agent Simulation of Retail Management Practices’	Siebers et al.
‘The Gaia Methodology for Agent-Oriented Analysis and Design’	Wooldridge and Kinny
‘Agent-Based Modeling of Supply Chains for Distributed Scheduling’	Lau et al.
‘Process Mining in a Multi-Agent Auctioning System’	van Dongen, van Luin, and Verbeek
‘Asynchronous Interaction Patterns for Mining Multiagent System Models from Event Logs’	Nesterov and Lomazova
‘From Agents to Organizations: An Organizational View of Multi-Agent Systems’	Ferber, Gutknecht, and Michel
‘Autonomic Tracing of Production Processes with Mobile and Agent-Based Computing’	Cimino and Marcelloni