



Faculty of Business Economics Master of Management

Master's thesis

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Literature Review on Process Mining in Auditing

Thesis presented in fulfillment of the requirements for the degree of Master of Management, specialization Data

Prof. dr. Mieke JANS

Mevrouw Manal LAGHMOUCH



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Mohammed Daoudi

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Abstract

Process mining as a novel data mining technique has grown tremendously over the years. In the field of auditing, process mining is being used more frequently due to the value it adds. It provides auditors with the means to keep pace with current technological developments and challenges. Its Implementation increases the reliability of the audit conclusions and improves the robustness of audit evidence. This study conducts a thorough literature review to examine the relationship between process mining and auditing. With a goal to investigate how can process mining enhance the effectiveness of auditing. Guided by one central research question and three sub-questions, the study investigates the intersection between the two fields through conducting a thorough literature review. Using a qualitative approach and relying on trustworthy sources, the results of this study provided a spotlight on the three main process mining techniques used in auditing: process discovery, conformance checking and process enhancement. Each type contribute to the effectiveness of auditing. Process discovery provides a solid empirical basis for understanding and evaluating an organization's operations. Conformance checking verifies if the actual processes as shown by event logs, matches the intended process design. While process enhancement offers valuable insights that allow organizations to optimize workflows by identifying and addressing inefficiencies. Furthermore, the key benefits of implementing process mining techniques In auditing, and how each technique contribute to audit effectiveness. Benefits including improved process insights, increased efficiency and enhanced transparency. All contributing to more effective audits. At the same time, our study demonstrates the challenges organizations usually face while the implementation of this innovative technology in auditing. Challenges such as data availability and accuracy, complex and unstructured processes and privacy and security concerns were also identified and investigated. These obstacles can significantly impact the effectiveness of the auditing domain by leading to weakening trust in the audit process, therefore flawed conclusions. Ultimately, this study reveals how process mining can enhance audit effectiveness, by offering valuable tools for auditors to navigate the complexities of modern business. The findings set the stage for future advancements, ensuring that auditing evolves alongside technological innovation.

Keywords: Process mining, auditing, audit effectiveness, process discovery, conformance checking, process enhancement

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1. Introduction

In the modern era of big data, businesses are increasingly dependent on extensive datasets obtained from both internal and external sources. The data provides them with novel tools to examine their internal and inter-firm procedures, thereby enabling them to gain valuable insights (Jones 2019). However, despite the availability of such data, companies continue to face numerous challenges in improving their business processes.

According to Hammer (2007), since 2000 hundreds of companies struggled with significant challenges while trying to improve their business processes. Despite investments and intentions, the majority of these companies have made slow progress. Even businesses that succeeded in transforming their business processes have found the journey exhausting and extremely distressing. The main struggle of these companies comes from the complexity of redesigning workflows, redefining jobs, increasing training, and realigning reward systems and organizational cultures (Hammer, 2007).

This is where the importance of auditing business processes becomes evident. According to Gantz (2013), the "Audit" term is often defined as an independent inspection or review. While it is generally applied to various fields, it is essentially used to examine an organization's financial statements or accounts (Gantz, 2013). Auditing business processes, including financial and accounting functions, marketing and sales, human resources are crucial for an organization efficiency and effectiveness. Audit effectiveness can be defined as the degree to which an audit achieves its intended outcomes, which include the accurate identification of financial misstatements, ensuring compliance with relevant laws and regulations, improving the reliability of financial reporting, and enhancing the overall governance and control environment of an organization (Turley & Willekens, 2008). These auditing key functions help in identifying inefficiencies, ensuring compliance and prevent fraud (Chambers & Rand, 2011). For instance, auditing financial audits ensure the accuracy of reporting and compliance. Auditing marketing and sales improve the generation of revenue. Moreover, Human Resources audits ensure an effective management and legal compliance (Chambers & Rand, 2011).

Process mining, which involves analyzing business process models and their execution records, has gained attention in recent years by taking advantage of the availability of data (Loyola-González, 2022). According to van der Aalst (2016), Process mining is an analytical technique that falls under the category of big data analytics (BDA) and its main aim is discovering, monitoring, and improving real processes by extracting knowledge from event logs readily available in today's information systems. Process mining endeavors to derive insights from event logs by employing a range of tools, techniques, and approaches for the purpose of recognizing, overseeing, and enhancing real-world processes (Van der Aalst, 2012).

Nowadays, Process mining brings transparency to an organization's as is process variations, including lesser known and infrequent processes, as long as they are captured in its IT systems (Jans et al. 2014). Therefore, process mining represents a game changer for many firms, as they begin to become aware of their process diversity for the first time. Particularly in the field of auditing, some traditional methods such as manual review of ledgers, receipts and financial transactions were manual and time-consuming, which requires auditors to physically review them (Basu, 2006).

The scope was also limited, which focuses primarily on compliance and error detection in financial statements. As revealed by the research conducted by Rvan Cruchten and Hans Weigand (2022) the adoption of this technologies' techniques offers a significant transformation, it provides auditors with a set of tools that not only allow them to detect and prevent errors and fraudulent activities but additionally enhance their understanding of a company's processes. Current research (van der Aalst et al., 2007, 2010, 2011; Jans et al., 2011, 2013, 2014) proposed and tested the use of this innovative technology in the auditing field.

The popularity of process mining approaches in the auditing industry has notably increased due to their potential to enhance audit efficiency, detect fraudulent activities, and provide valuable data for informed decision-making (Laporta et al., 2021). Building upon the work of Jans et al. (2014), auditors leverage process mining techniques to visualize and analyze ongoing processes using event logs and transaction data. Their study demonstrated the successful application of process mining algorithms to event logs from a European financial services provider, highlighting the significant potential and value of this approach in the field of auditing. Through process mining techniques, auditors can obtain a broader and deeper understanding of an organization's processes, pinpoint potential risks, identify inefficiencies, and assess the effectiveness of internal control (Chiu & Jans, 2019). Moreover, auditors can efficiently develop accurate process models that can be relied upon for audit purposes (Werner, 2019).

The main motivation behind this research comes from the growing adoption of process mining in various sectors and its ability to transform the auditing field entirely by tackling the existing challenges encountered by professionals. Through a comprehensive examination of existing literature and case studies on process mining application in auditing, this study aims to explore how process mining can enhance the effectiveness of the auditing domain. In order to achieve this objective a thorough literature review will be conducted, and the main research questions will be addressed, contributing to the ongoing discourse on the application of process mining and its applications in auditing. This thorough literature review aims to explore the intersection between process mining and auditing, with a particular focus on understanding how process mining can enhance the effectiveness of auditing practices. Mainly guided by the research question: How can process mining enhance the effectiveness of auditing?

The effectiveness of process mining in auditing is studied due to its growing importance in the field and its potential to significantly enhance the overall audit process. As organizations continue to rely on vast datasets and complex processes, traditional auditing methods often fall short in providing a comprehensive understanding of an organization's operations (Jans et al., 2014). This limitation could lead to inefficiencies and potential risks that may go undetected. To thoroughly address this inquiry, the review is structured around three sub-questions, each aimed at uncovering different facets of process mining's impact on auditing. Firstly, we explore which types of process mining are described in academic literature in the context of auditing and their contributions to audit effectiveness. This includes the identification of the three main types of process mining techniques that are recognized by academics and practitioners. Secondly, the review seeks to understand the benefits of using process mining techniques in auditing as highlighted in academic literature, particularly focusing on how these advantages contribute to audit effectiveness. Thirdly, we explore the various challenges and obstacles process mining faces while being implemented in the auditing field and how these hurdles impacts the overall effectiveness of auditing.

To the best of our knowledge, our study provides a thorough review of the topic. We've carefully classified the literature to highlight the main themes and identify areas for further investigation. This effort not only maps out where process mining in auditing currently stands but also points to where it might head next. The implications of our study are significant for both researchers and practitioners, particularly in understanding how process mining in auditing contributes to the existing body of knowledge. Our findings provide a foundation for future studies to investigate the impact of process mining on audit effectiveness. We encourage further research that could lead to the development of new methodologies and techniques in both process mining and auditing, therefore ultimately improving auditing practices' overall effectiveness. For practitioners, our findings offer valuable insights into the practical applications of process mining in auditing, which enables them to make use of this powerful tool to improve audit effectiveness. By understanding the benefits, challenges, and various types of process mining techniques in auditing, practitioners can enhance their auditing practices.

The study is structured as follows: Section 2 provides background on process mining in auditing. Section 3 details the research methodology applied, including the research design, selection criteria, and data collection and analysis methods. Section 4 presents this thorough literature review findings, which are organized around the three sub-questions guiding the research. It identifies the types of process mining techniques prevalent in academic literature, discussing how each technique contributes to enhancing audit effectiveness. Additionally, it explores the benefits of using process mining in auditing, highlighting how these advantages improve audit effectiveness. Finally, it investigates the challenges and obstacles associated with implementing process mining in the auditing field, and their impact on the overall effectiveness of auditing presented earlier in that section. Section 6 summarizes key findings and offers recommendations for future research.

2. Background

The Background section of this literature review lays the groundwork for our exploration of how process mining, a cutting-edge technology in business process analysis, can enhance audit effectiveness when integrated into the domain of auditing. Initially, we will start by briefly introducing process mining, as an innovative data-driven technology designed to analyze and optimize business processes. We then explore the integration of process mining in auditing practices, showcasing its journey from a novel concept to a vital tool for audit professionals. Finally, we examine the current state of process mining adoption in auditing.

2.1 Introduction to Process Mining

Process mining is a research field that aims to extract meaningful insights from the vast amount of data stored in information systems, thereby offering a comprehensive view of the processes that have been executed. It is a relatively young research discipline that sits between machine learning and data mining on the one hand and process modeling and analysis on the other hand (Van Der Aalst, 2016). Process mining is an umbrella term for data-driven process analysis techniques that combine data mining and Business Process Management (BPM) to gain insights into business processes. It involves analyzing a set of data to accurately understand operational processes and enterprise activities (Jans & Laghmouch, 2023). The primary goal of process mining is discovering, monitoring, and enhancing the actual processes by leveraging the vast amount of knowledge embedded within event logs, readily available in today's information systems (van der Aalst, 2011). Among its main objectives are the improvement of process efficiency, ensuring compliance with regulations and standards, and pinpointing any operational bottlenecks that may hinder workflow efficiency (Martin et al., 2020).

As explained in van der Aalst et al. (2012), process mining is classified into three types: discovery, conformance, and enhancement. The Figure below shows these three primary types of process mining.



Figure 1: The three main types of process mining: discovery, conformance, and enhancement (adapted from Van der Aalst, 2016).

Emerging in the early 21st century, process mining is used as an analytical methodology to analyze an entity's business processes based on event logs that have been automatically recorded in the accounting information systems prior to the analysis (Chiu et al., 2020). Information systems, such as Workflow Management Systems (WFMSs), Enterprise Resource Planning (ERP), and Customer Relationship Management (CRM) systems, play a crucial role by providing the rich, detailed data required for the accurate modeling of business processes (Aghabaghery et al., 2020).

Big data analytics has played a crucial role in the development of process mining, by allowing businesses to process large volumes of event data, resulting in a more comprehensive understanding of their processes. These technological enablers have paved the way for the widespread adoption of process mining in various domains, including healthcare, finance, and manufacturing (Batista & Solanas, 2018).

According to Jans et al. (2014), to analyze the information contained in event logs, it is essential to derive four variables from the system: Activity, Process Instance, Resource, and Timestamp. When Process Mining is used to analyze an event log, at least five analyses can be conducted (Jans et al., 2010, 2013; Alles et al., 2011). Process discovery reveals the actual execution of the business process, providing a picture of how each task is being performed. Conformance checking verifies the alignment of the actual process with the predefined process model, ensuring that operations comply to the established standards. Performance analysis facilitates process efficiency improvements and early detection of process failures. Social network analysis monitors individual behaviors and the dynamics within network interactions. Decision mining and verification identify decision-making points within the process and detect significant deviations, ensuring that critical choices are made correctly.

2.2 Event Logs

Event log is considered as the point of start for process mining. According to Sarno et al. (2015), an event log is collection of process operations that record the various business activities (Sarno et al., 2015). These logs are essential as they record a sequence of events that occurs in detail. For example, table 1 below shows an example of an event log with key attributes like case ID, timestamp, activity and resources.

Case ID	Timestamp	Activity	Resource
55	2022-05-03 16:55:06	Upload	Stef
55	2022-05-03 17:58:43	Admit	Nienke
56	2022-05-05 18:03:33	Register	Hendrik
56	2022-05-05 10:06:54	Verify	Stef
56	2022-05-05 10:30:50	Upload	Stef
56	2022-05-05 10:46:29	Admit	Nienke
57	2022-05-07 11:16:12	Register	Hendrik
57	2022-05-07 11:44:32	Verify	Stef

Table 1: Example of an event log (Van Coillie, 2022).

In Auditing, event logs is also referred to as audit trails. It is a chronological record of a computer system activities that are saved to a file on the system, which can be later reviewed by an administrator, therefore helping in identifying user's actions on the system or processes (Jans et al., 2010). Event log offers a unique advantage by providing automatic, independent meta-data that captures behavior, This distinctiveness opens doors to novel analytical procedures, surpassing traditional audit tools in revealing insights (Jans et al., 2014).

2.3 Process Mining in Auditing

In the auditing context, process mining has become a crucial analytical tool, it empowers auditors to examine event logs, extracting valuable insights essential for the auditing process. This capability boosts the efficiency and effectiveness of audits, providing a more profound understanding of an organization's operations and facilitating a more comprehensive audit process (Jans et al., 2014).

The process mining analysis during an audit involves several phases as shown below in Figure 2: building the event log, process discovery, comparing the discovered process with predefined models, ensuring compliance with business rules, conducting variant analysis to understand deviations, and performing case analysis for detailed insights. This detailed methodology helps auditors obtain a clear, visual representation of business processes, making it easier to detect inefficiencies and ensure compliance (Jans & Laghmouch, 2023).



Figure 2: The phases of a process mining analysis during an audit (adapted from Jans & Laghmouch, 2023).

The early implementation of process mining in the field of auditing impacted the way auditors are assessing risk, compliance, and operational efficiency. By allowing them to analyze business processes in greater depth and with more data, process mining provides them with the tools to identify inefficiencies, detect deviations from compliance, and pinpoint potential risks with unparalleled accuracy, ultimately enhancing audit effectiveness (Jans et al., 2014; Santoro et al., 2020). Initially, the focus was on rules-based auditing, which proved to be successful, but this approach was limited because it could not automatically update or adapt the audit rules based on new data or changing conditions (Santoro et al., 2020).

Recent technological advancements in data processing and storage have further improved process mining's applicability and effectiveness in auditing. These technological advancements have considerably reduced the difficulties in managing large volumes of event data, making it possible to analyze and interpret complex business processes efficiently (Werner & Gehrke, 2015). Notably, process mining has the ability to generate new audit evidence, potentially transforming traditional audit procedures and reshaping how auditing is evaluated and conducted (Chiu & Jans, 2019). As the field continues to evolve, embracing process mining technology could lead to substantial value addition and a marked shift towards data-driven auditing practices.

Several studies illustrate the contributions and successful implementation of process mining in auditing. Jans et al. (2011) reported on how process mining can aid in internal audit. Jans et al. (2012) presented the concept of process mining in the financial audit domain. Jans et al. (2013) highlighted opportunities of process mining in auditing. Jans et al. (2014) highlighted the benefits of employing process mining in an auditing context. Jans et al. (2015) provided a guideline to use process mining in business process audit and designed an application to support audit. Werner & Gehrke (2018) reviewed external auditing techniques. Imran et al. (2018) highlighted challenges related to business process audit. Anwer Butt et al. (2019) highlighted trends on the evolution of compliance checking in audit using process mining. Rozinat et al. (2008) demonstrated its effectiveness in uncovering deviations between anticipated and actual process behaviors. Werner & Wiese (2021) explore embedding process mining into financial statement audits, revealing a wealth of opportunity in internal auditors' event data. In healthcare, it has improved the auditing of patient flow processes, demonstrating its versatility and effectiveness across different industries (Chiu & Jans, 2019). In the finance sector, process mining has been used to streamline transactional flow audits and enhance compliance checks (Anwer Butt et al., 2023). Additionally, Jans et al. (2010) envision process mining as a catalyst for improving internal auditing by extracting insights from event logs within a business's information system. A year later, their study on procurement processes at a major European financial services provider demonstrates the value of process mining in uncovering insights from entire populations (Jans et al., 2011).

As research in the field of process mining continues to grow, more companies are adopting process mining techniques (Jans & Laghmouch, 2023). In the auditing field, process mining is gaining momentum as more organizations increasingly recognize its value in enhancing transparency, efficiency, and compliance. However, according to Jans et al. (2014), while process mining has been extensively used in various domains like business process improvement, healthcare, and network security, its widespread implementation in the auditing industry is yet to be realized. This gap signifies an opportunity for growth and innovation in audit methodologies, highlighting the potential for process mining to revolutionize the industry.

3. Methodology

3.1 Introduction

In this section, the purpose is to outline the research methodology employed in this study, which primarily focuses on conducting a thorough literature review to investigate how process mining can improve the effectiveness of auditing. The aim is to synthesize findings from various sources, ensuring a comprehensive examination and a well-supported response to the research questions. We will go into details explaining the steps taken to carry out the literature review, the criteria for selecting the relevant literature/sources, describe the methodology for data collection, and discuss the approach used for data analysis.

3.2 Research Questions

This body of work guides our investigation, centered around the pivotal question: "How can process mining enhance the effectiveness of auditing?" This overarching inquiry aims to understand the

potential improvements that process mining can bring to the auditing process. For the purpose of this study, audit effectiveness is defined as the combination of competence, procedural arrangements, quality control, and quality assurance. It involves the tools and methods used by audit firms and individuals to ensure that audits comply with technical standards, legal requirements, regulators' requirements and auditing standards (Bender, 2006).

The main question is broken down into three sub-questions. These questions were chosen to provide a comprehensive understanding of process mining's potential to improve auditing effectiveness. (1) by investigating the types of process mining techniques in academic literature and their contribution to audit effectiveness. (2) the benefits of these techniques and their impact on audit effectiveness. (3) the challenges and difficulties related to the implementation and their impact on audit effectiveness.

• What types of process mining are described in academic literature in the context of auditing, and how do they contribute to audit effectiveness?

This sub question was chosen because it is important in exploring and identifying different techniques of process mining that are used in the field of auditing. Through understanding how they improve various aspects of auditing. For instance, improving the accuracy, efficiency and the ability to uncover hidden process inefficiencies. Therefore, we can determine their contribution to the overall effectiveness of auditing.

• What benefits of using process mining techniques in auditing are highlighted in academic literature, and how do they contribute to audit effectiveness?

This question aims to uncover the specific advantages of applying process mining in auditing. By examining these benefits, such as improved fraud detection, enhanced compliance monitoring, and more efficient audit processes, we can better understand how these techniques contribute to making audits more effective and reliable. This understanding is essential for practitioners looking to adopt these methods in their auditing practices.

This sub question aims to identify the numerous advantages of implementing process mining techniques in auditing. Through analyzing these advantages. For instance, improved fraud detection and prevention, enabling auditing of smart contracts and enhanced regulatory compliance, we can therefore understand better how each of these techniques contribute to auditing effectiveness.

• What challenges and difficulties related to the implementation of process mining in auditing are discussed in academic literature, and how do they impact audit effectiveness?

This sub question focuses on identifying the obstacles that comes with the implementation of process mining in auditing. Through understanding each of these challenges. For instance, data quality and privacy issues, dealing with unstructured processes and technical complexities. We can determine how these hurdles impact the effectiveness of auditing.

3.3 Research Design

Exploring how process mining can enhance the effectiveness of auditing presents a detailed research challenge. Therefore, we considered a qualitative approach to be particularly suitable for investigating such a novel and complex phenomenon (Dube´ and Pare´ 2003; Yin 2014). The study's main focus is to explore how process mining can enhance audit effectiveness. Qualitative research is characterized by its inductive nature, where non-numerical data is collected and analyzed to develop deeper understanding of the topic. This approach is particularly suitable for our investigation since it allows for a detailed examination of the academic literature concerning process mining in the context of auditing.

In particular, we chose an exploratory and descriptive research approach. The purpose of this investigation is to uncover new insights and understandings about the different types of process mining, their benefits and the challenges and their impact on the effectiveness of auditing practices. This approach was chosen because it will provide a comprehensive examination of existing academic discussions and debates on process mining in auditing, contributing to a deeper understanding of its potential to enhance audit effectiveness.

3.4 Selection criteria

This thorough literature review applies well-defined inclusion and exclusion criteria to select highquality and relevant scholarly works. The guidelines for conducting the literature review include a comprehensive search of peer-reviewed academic journal articles, conference papers, and scholarly books, ensuring that only the most credible and reliable sources are included. Articles must directly relate to the application of process mining in the audit context to be included, ensuring the selected literature reflects the research focus and contributes to investigating how process mining can enhance audit effectiveness.

We consider peer-reviewed academic journal articles, conference papers and scholarly books because these sources undergo a rigorous evaluation process, which offers the credibility and reliability of the research presented. We choose readily accessible online sources, such as Scopus, Web of Science, IEEE Xplore, and Google Scholar. To capture the latest developments and insights from process mining in the audit domain, we will consider publications from 2000 to 2024. This range is chosen to include the most relevant advancements in the field, ensuring a comprehensive understanding of the evolution and current state of process mining and its application in auditing.

Focusing on English-language sources is a deliberate choice, as English is the predominant language in academic discourse, particularly in the domains of auditing and information systems. This selection criterion serves the dual purpose of maximizing the accessibility and comprehension of the literature for the reader while also enabling us to access a wide range of studies from various countries.

We excluded articles published on SSRN because, although SSRN hosts a large repository of research papers, many of the documents are preprints and also have not undergone the rigorous peer-review process that is essential for ensuring the credibility and reliability of academic research. By excluding SSRN, we ensure that our selected literature maintains a high standard of quality and reliability, which is essential for drawing accurate and trustworthy conclusions.

Table 2 below lists the inclusion criteria (IC) used to select articles for the study. These criteria ensure that the articles directly address the topic of process mining in auditing. They should be published in peer-reviewed academic journals, conference papers or scholarly books from the year 2000 to 2024 and also are written in English. This table also lists the exclusion criteria (EC). Articles are excluded if the full text is not available, not written in English, not peer-reviewed, published on SSRN or if they are one-pagers, summaries, abstracts, proposals, interviews, posters, calls for papers, or tables of contents.

Inclusion Criteria	Description	Exclusion Criteria	Description
IC 1	The article directly addresses process mining in auditing	EC 1	The full text of the article is not available
IC 2	Articles in peer-reviewed academic journals, conference papers, scholarly books	EC 2	The article is not written in English
IC 3	Articles published from 2000 until 2024	EC 3	The article has not been published in a peer-reviewed scientific journal or in peer-reviewed conference proceedings
IC 4	Articles published in English	EC 4	The article is a one-pager, executive summary, abstract, research proposal, interview, poster, call for papers or table of contents.
		EC 5	The article is published on SSRN

	Table 2:	Inclusion	and	Exclusion	Criteria
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3.5 Data Collection

To ensure construct validity, we conducted an extensive search using a set of keywords and phrases, such as 'process mining in auditing,' 'audit effectiveness,' and 'audit efficiency,' to precisely target studies that addresses the application of process mining technologies in auditing and their impact on audit effectiveness.

The initial search found a total of 787 articles. After removing 118 duplicates, we had 669 articles remaining. These were then screened based on relevance to the research question, study design and quality assessment. From this screening, 171 articles were excluded, leaving 498 articles. After

applying our eligibility criteria, 54 articles were additionally excluded, which resulted in 444 articles. We then verified the full-text availability of these articles, which led to another exclusion of 179 articles, leaving 265 articles.

Finally, after a comprehensive quality assessment based on research design, methodological rigor, relevance to the research question, clarity and coherence, 202 articles were excluded. Therefore, resulting in a final selection of 63 articles. This selection process is illustrated below in Figure 2.



Figure 3: Article Selection Process

3.6 Data analysis

Our data analysis processes involved an examination of the qualitative data we gathered from the articles we selected earlier. We employed a step-by-step approach to identify, categorize and analyze the information that is relevant to our research question on how can process mining enhance auditing effectiveness? Firstly, we reviewed the data we collected earlier to identify findings that are addressing the types, benefits and challenges of implementing process mining techniques in auditing. Next, we extracted insights on the impact of these aspects on the effectiveness of auditing.

This way, we used the existing literature to draw meaningful conclusions and also contribute to the understanding of process mining's role in enhancing auditing effectiveness.

4. Findings

Integrating process mining into the auditing domain signifies a transformative shift in how businesses understand and optimize their internal processes, driven by rapid technological advancements. This thorough literature review examines the role of process mining in enhancing auditing effectiveness, focusing on its types (Section 4.1), benefits (Section 4.2), and implementation challenges (Section 4.3). By analyzing each category's contribution to audit effectiveness, we explore our main research question: how process mining can enhance auditing effectiveness.

4.1 Process Mining Types in Auditing Literature and their Contribution to Audit Effectiveness

In the context of auditing, Process mining provides an exclusive set of techniques that can greatly bolster the auditing process, offering a better understanding of operational workflows, ensuring compliance, and pinpointing possible areas of inefficiencies. As outlined by Aalst et al. (2012), the domain of process mining is defined by three principal techniques that serve as the cornerstone for understanding and improving business processes: process discovery, process conformance, and process enhancement. Fahland and van der Aalst (2015) highlight that process discovery and conformance checking are the two primary analyses of process mining. The primary objective of process discovery is to utilize event log information to create models that describe how events occur. It involves using system data to figure out exact steps in the process as they happen. Conformance checking evaluates the extent to which the designed process models match the real-life logs (Fahland and van der Aalst, 2015) and process enhancement refines models for better process performance.

In the following section, we will discuss each of these three primary process mining techniques. By examining their practical applications and transformative potential, we will demonstrate how each technique can impact audit effectiveness and contribute to the evolution of traditional auditing practices.

4.1.1 Process discovery

Process discovery is one of the primary and most challenging process mining tasks. It serves as the starting point for process improvements using event data (Norouzifar & van der Aalst, 2023). Existing process discovery techniques construct process models from event logs to best describe and capture the observed behavior (Van der Aalst, 2016).

According to Jans et al. (2013), process discovery plays an essential role in the immediate extraction of process models from event logs. This technique reveals the finely detailed complexity of operational workflows inside businesses, making it invaluable for auditing. Traditional auditing methods often rely on sampling and manual verification, which can miss nuances and detailed operational flows. In contrast, process discovery provides a comprehensive view of real processes, enhancing transparency and operational understanding (Jans et al., 2013). The insights from process discovery help auditors identify inefficiencies, spot potential compliance issues, and find areas for improvement with remarkable precision. For instance, by analyzing event logs, auditors can detect bottlenecks and deviations that indicate potential fraud or inefficiency. This data-driven approach allows auditors to make informed decisions, enhancing the reliability and accuracy of their findings (Werner et al., 2021).

However, while process discovery substantially benefits auditors by enhancing transparency and operational insights, it encounters significant hurdles due to data quality and complexity issues (Elkhovskaya et al., 2023). For example, automatic tools like the alpha miner struggle to accurately model complex behaviors, often resulting in either inaccurate or overly complex models (Elkhovskaya et al., 2023). Despite these challenges, advancements in AI and machine learning offer potential solutions. For example, integrating supervised learning methods can help improve the accuracy of automated models (Augusto et al., 2022). Moreover, combining manual adjustments with automated tools can achieve a balance between complexity and accuracy (Augusto et al., 2022).

Additionally, creating connections between processes within a network for comprehensive analysis poses challenges, thereby obstructing the full realization of process analytics in complex systems (Sommers, Menkovski, & Fahland, 2021). However, recent studies suggest using network analysis techniques to map out complex interactions within processes, facilitating a more comprehensive analysis. Despite these challenges, process discovery significantly boosts audit effectiveness by offering a solid empirical basis for understanding and evaluating an organization's operations. It enables auditors to identify illegal or non-standard practices and evaluate the effectiveness of process flows, providing a more accurate and comprehensive understanding of a business process (Werner et al., 2021).

For instance, in a case study on software quality management, process discovery uncovered hidden inefficiencies and identified opportunities for cost savings, demonstrating real process improvement (Elliott, Dawson, & Edwards, 2007). This leads to more effective audits by ensuring optimal resource allocation and reducing waste (Van der Aalst, 2016).

Furthermore, process discovery promotes transparency and adherence to standards by evaluating compliance with regulatory requirements or internal policies. By comparing discovered process models with expected or desired process models, auditors can proactively address potential risks and ensure compliance, ultimately improving audit effectiveness (Werner et al., 2021).

An example of process discovery contribution to audit effectiveness can be seen below in Figure 4, which shows the procure-to-pay process map from a case study of a large European bank Chiu & Jans, 2019). This figure highlights the frequency and direction of different activities, which helps auditors to easily identify and analyze in detail the actual business process. Through providing a clear visualization of the process flow, auditors are able to pinpoint the areas where deviations could occur. Therefore, enhancing their ability to conduct a thorough and an effective audit (Chiu & Jans, 2019).



Figure 4: Procure-To-Pay Process Map (adapted from Chiu & Jans, 2019).

Building on the strengths of process discovery. The recent advancements in AI, particularly the integration of AI-based models have further enhanced the effectiveness of the auditing domain. Through the employment of these AI-based models, which combine both supervised learning methods and graph convolutional neural networks, auditors can smoothly transform complex event logs from real-world auditing situations into easy-to-understand and precise process models (Augusto et al., 2022).

In summary, process discovery not only enhances transparency and compliance but also supports auditors in making data-driven decisions. By uncovering real operational processes and addressing both inefficiencies and compliance issues, it significantly improves the effectiveness of audits (Werner et al., 2021).

4.1.2 Conformance checking

Conformance checking in process mining has been highly valued in academic discussions due to its role in comparing the actual execution of business processes with predefined models or norms. This method plays a crucial role in auditing as it thoroughly compares the actual execution of processes, as recorded in event logs, with predefined process models. Auditors can use this comparison to identify deviations, non-compliance, and anomalies that may indicate fraud, errors, or inefficiencies (Van der Aalst, 2016). By pinpointing these discrepancies, conformance checking helps auditors assess an organization's internal controls and operational procedures' integrity and reliability.

The primary goal of conformance checking is to verify if the actual process, as shown by the event log, matches the intended process design, or if the process model accurately reflects what truly happens. There are four different dimensions used to evaluate the alignment between model and reality, but fitness and precision are the most commonly used (Jans & Hosseinpour, 2019).

The fitness dimension indicates the extent to which the behavior observed (i.e., data in the event log) is encompassed by or matches the process model. This dimension is closely associated with compliance. By ensuring that the observed behavior aligns with the process model, fitness helps auditors verify adherence to established procedures, thereby identifying deviations that may indicate errors or fraud. Conversely, the precision dimension begins with the event log and evaluates the model. This approach determines how well the model represents only those behaviors that are executed, as recorded in the event log. Ideal precision implies that the model does not predict more activities than those empirically evidenced, ensuring every potential path defined by the model has a corresponding real-world action. This accurate representation helps auditors understand the true operational flow, making it easier to spot discrepancies or inefficiencies (Jans & Hosseinpour, 2019).

As an example of this, table 3 below from Zerbino et al. (2018) provides a detailed summary of significant deviations found during the process mining audit, which includes their frequency, duration, and potential impact. By understanding these deviations, auditors can pinpoint where the actual process deviates from the intended models. Therefore, they can assess the severity of non-conformances and take corrective actions.

Code	From	То	Absolute frequency	Case frequency	Total duration	Median	Mean	Max	Min
А	Receiving the Customs Answer	Modifying the BoL	119	104	17.8 days	15 min	3.6 h	48.4 h	3.4 s
В	Receiving the Customs Answer	Sending the CM	322	211	29.9 days	14.3 min	2.2 h	4 days	14.4 s
1	Saving the BoL	COARRI	54	54	17.8 weeks	23.7 h	55.5 h	25.9 days	66 min
2	Saving the BoL	Receiving the Customs Answer	459	244	9 days	3.3 min	28.3 min	49.4 h	218 ms
3	Sending the CM	COARRI	29	29	36.1 days	25.5 h	29.9 h	4.8 days	94.7 min
4	Sending the CM	Receiving the BoL	352	214	6.2 days	2.7 min	25.3 min	45.4 h	796 ms

Table 3: Details about the six major deviations (adapted from Zerbino et al, 2018).

Despite the significant benefits offered by conformance checking, such as its ability to detect deviations and errors in real-time through sensor data, implementing its techniques can be challenging. Auditors may encounter hurdles like handling complex process models and potential data misinterpretation, introducing uncertainties into event logs during conformance checking, particularly when dealing with probabilistic models (Schuster et al., 2022). These hurdles can

significantly impact conformance checking's reliability and accuracy, creating discrepancies between observed behavior and process models.

Conformance checking plays an important role in enhancing audit effectiveness by identifying deviations from prescribed regulations and process models (Pufahl, 2021), as well as assessing process integrity and promoting compliance. Recent advancements in conformance checking aim to improve visualization for non-expert users, making conformance checking results more accessible and comprehensible (Rinderle-Ma et al., 2023). This increased accessibility enables auditors to better interpret and act on conformance checking results, facilitating more informed decision-making processes and ultimately increasing audit effectiveness (Stertz et al., 2020).

Semantic audit tools further contribute to audit effectiveness by detecting organizational operations and deviations, promoting a more comprehensive audit process (Ternai, 2016). Conformance checking also enables auditors to identify and evaluate potential risks, allowing them to provide targeted recommendations to improve risk mitigation strategies (Dunzer, 2019; Pufahl, 2021).

Recent research has enhanced conformance checking techniques. Bauer and colleagues (2020) introduced a novel statistical method that utilizes trace sampling and result approximation to enhance the efficiency of conformance checking by reducing runtime while maintaining accuracy (Bauer et al., 2020). Lu et al. (2014) developed an innovative approach that incorporates flexibility, uncertainty, and concurrency into conformance checking, thereby achieving more reliable results (Lu et al., 2014). Stertz (2020) introduced a data-driven approach that distinguishes between intended and unintended deviations, enabling the automatic classification of deviation causes. Collectively, these advancements empower auditors to analyze large volumes of data more efficiently, reducing the time and resources needed for manual data analysis. As a result, auditors can focus on higher-value tasks, ultimately improving the overall effectiveness of the auditing process.

4.1.3 Process enhancement

Process enhancement, though not well covered in academic literature, is still an important type of process mining. It utilizes insights from event logs to significantly enhance business operations. This technique is particularly effective as it allows for adjustment of existing process models based on the insights gained from actual process executions, aiming to optimize both performance and compliance (Jans & Eulerich, 2022).

According to Jans et al. (2013), the technique of process enhancement uses process mining valuable insights, giving organizations the ability to optimize processes by locating inefficiencies within processes and then redesign workflows, thereby enhancing overall process performance and effectiveness. In order to provide a more efficient process flow, this alignment involves tackling critical inefficiencies like bottlenecks and deadlocks as well as improving the throughput times of certain activities (Zerbino et al., 2021).

An example of this can be seen below in figure 5 from Dees et al. (2017). provides a detailed methodology for process enhancement, illustrating how various steps contribute to optimizing business processes and enhancing audit effectiveness. This figure offers a detailed methodology for processes improvement, by including steps like conformance checking, alignment with key

performance indicators (KPIs), and creating event log clusters for better process optimization. By identifying and analyzing deviations, auditors are able to pinpoint inefficiencies and compliance issues. Eventually, achieving the targeted process improvements (Dees et al., 2017).



Figure 5: Details of the Deviation Analysis (adapted from Dees et al, 2017).

Similarly, Imran et al. (2023) emphasize that process enhancement plays an essential role in fostering a proactive continuous improvement culture and correcting existing process discrepancies. This enables organizations to dynamically adapt their processes in response to evolving market demands and regulatory landscapes, thus maintaining operational excellence and compliance (Imran et al., 2023).

Moreover, integrating process enhancement with AI and machine learning technologies allows organizations to proactively address potential inefficiencies or compliance issues through predictive process optimization. Wang & Aviles (2023) and de Leoni (2022) both discuss how analyzing historical process data with machine learning algorithms can help organizations identify patterns and trends, allowing them to respond quickly to upcoming challenges (Wang & Aviles, 2023), (de Leoni, 2022).

However, Patel & Chauhan (2023) note that while process enhancement offers significant opportunities for auditing, its implementation comes with challenges such as data security concerns, potential threats from emerging technologies, and skill gaps (Patel & Chauhan, 2023). Moreover, critical business systems like Enterprise Resource Planning (ERP) must be meticulously planned and organized to avoid failures and ensure effectiveness (McGregor & Carpenter, 2020).

By addressing these challenges, organizations can ensure audit effectiveness and fully realize the potential of process enhancement within the auditing field. Shu et al. (2010) demonstrate through a case study that process enhancement can provide practical benefits in quantitative process audit analysis, while Zhang (2019) highlights the role of intelligent process automation (IPA) in combining RPA, AI, and other technologies to improve audit efficiency (Shu et al., 2010), (Zhang, 2019).

Ultimately, the successful implementation of process enhancement techniques contributes to more efficient, accurate, and reliable audits, directly enhancing audit effectiveness and ensuring that organizations maintain trust and transparency in their operations.

4.2 Benefits of Process Mining Techniques in Auditing and Their Impact on Audit Effectiveness

The integration of process mining into the auditing field represents a significant advancement, markedly enhancing audit effectiveness through technological innovation by providing auditors with tools to analyze vast amounts of data swiftly and accurately. therefore, boosting the effectiveness of their audits. This approach leverages the analysis of digital event logs to provide profound insights into business processes, increasing the precision and efficiency of audits (Werner & Gehrke, 2015; Dos Santos Garcia et al., 2019). By enabling auditors to quickly identify discrepancies and prioritize critical areas, process mining facilitates a more strategic allocation of resources and accelerates the audit process (Jans et al., 2010; Dos Santos Garcia et al., 2019). Moreover, it plays a crucial role in ensuring rigorous compliance and boosting the effectiveness of security audits, substantially reducing the need for manual effort and shifting audit practices from sample-based checks to comprehensive data analysis (Jans et al., 2013). These capabilities underscore process mining's value in significantly enhancing the accuracy, efficiency, and security of audits. Figure 6 below shows the frequency of added value categories by using process mining in auditing. The most frequent category is 'Improved Process Insights' at 16.1%, followed by 'Improvement of Audit Efficiency' at 12.9%, and 'Increased Transparency' at 9.7%. In the following sections, we will explore each of these benefits in detail, assessing their specific contributions to enhancing audit effectiveness.



Figure 6: Frequently of different categories of added value by using process mining in auditing (adapted from Abshoori, 2023).

• Increased Efficiency and Effectiveness

Process mining can significantly improve the efficiency and effectiveness of auditing by automating the analysis of large amounts of data (De Weerdt et al., 2013). This technology identifies discrepancies and anomalies within business processes, allowing auditors to focus their attention strategically. Similarly, Werner & Gehrke (2015) observed that as a result, the audit process becomes more focused, with efforts concentrated on areas of highest risk or potential for improvement, optimizing the audit cycle and outcomes. Automating data analysis reduces the manual effort required and enhances the accuracy and reliability of audit evidence, thus improving audit procedures (Werner et al., 2021).

Moreover, process mining helps to efficiently discovers business processes by analyzing event logs, providing a comprehensive view of process flows and quickly identifying deviations or anomalies. This aligns with Jans et al. (2013), who noted that this enables auditors to better identify high-risk areas and focus their efforts strategically, optimizing the audit cycle and improving overall outcomes. Figure 7 below shows the structured implementation of process mining in audit tasks which highlights phases such as data extraction, modeling, and evaluation. This framework ensures a systematic approach to enhance auditing efficiency and effectiveness.



Figure 7: Audit Process Mining Framework (adapted from Föhr et al., 2023).

Additionally, it also offers detailed insights into the business processes, which helps auditors understand the details of the processes and identify inefficiencies or irregularities in a more effective way. This technology supports compliance and controls testing by providing quantitative data, which enhances the effectiveness of audits (Jans, 2012). This integrated approach not only focuses auditors' efforts on high-risk areas but also streamlines the audit process, providing a thorough and accurate assessment of operational and compliance risks, thus improving the overall audit strategy (Chiu et al., 2020). By leveraging process mining to identify and prioritize potential risks and areas of non-compliance, auditors can focus their efforts where they are most needed, enhancing the strategic effectiveness and overall quality of audits (Jans et al., 2013).

In terms of efficiency and cost savings, process mining can significantly streamline the audit process by automatically analyzing financial entries and reconstructing process instances. This automation reduces the need for manual analysis and face-to-face interviews, allowing auditors to trace balance sheet items more efficiently. As well as saving time and reducing the amount of man-hours required for audits, leading to potential cost savings on audit engagements (Gehrke, 2010).

• Enhanced Process Modeling and Performance Improvement

Process mining also facilitates developing precise process models, which allow auditors to identify and pinpoint inefficiencies and improve the overall performance of process effectively. The impact of process mining on auditing is significant as it provides detailed insights and detects irregularities, thereby enhancing audit effectiveness. This advancement streamlines and enriches audits with granular process analysis, enabling auditors to identify and address inefficiencies with unprecedented precision (Gehrk, 2010). Figure 8 below from Werner et al. (2021), demonstrates how process mining can be embedded into various phases of contemporary financial statement audits and supporting audit activities and aligning with relevant audit standards. This shown figure highlights the audit phases, the supported audit activities and also relevant audit standards. Ultimately, showing how process mining enhances the effectiveness of auditing through a structured approach.

Audit Phase		Supported Audit Activities	Relevant Audit Standard
Unc		Obtain an understanding of the composition of the balance sheet and income statement accounts.	ISA 240.22, ISA 300.2, ISA 315.6
lers e en		Initial assessment if reliance on the internal controls system is feasible.	ISA 315.20, ISA 315.26, ISA 330.6
tand tity		Documentation of obtained understanding regarding the audited entity.	ISA 315.32, ISA 230.8, ISA 330.28
Id	Þ	Obtain an understanding of the significant classes of transactions related to the analyzed processes.	ISA 315.18, ISA 315.20, ISA 315.26
entif	►	Determination if the processing of significant classes of transactions is highly automated.	ISA 315.30, ISA 330.8
y & as risks	Þ	Assessment of relevant risks via automated analysis of identified business processes for each relevant assertion and each significant account or disclosure.	ISA 315.5, ISA 315.6, ISA 315.25
sess	•	Assessment if control activities are implemented in the analyzed processes for significant risks and whether these have been designed and implemented to achieve relevant control objectives.	ISA 315.13, ISA 315.20, ISA 315.21 ISA 315.29
▼execut	►	Identification of activities in the analysed process that represent control activities relevant to the audit. A control exception is indicated if such an activity was missing in a process variant to a material extent.	ISA 330.6, ISA 330.15
sign an le respo lo risks	Þ	Assessment when and by whom a control activity was executed. Evaluating the operating effectiveness of controls relevant to the audit by directly analysing the recorded transaction data values within a process.	ISA 330.8, ISA 330.10
d nses	Þ	Identification of deviations from standard procedures to assess potential impact on the reliance of internal controls and to guide further substantive audit procedures.	ISA 330.17
8	Þ	Documentation of the number of transactions and their total posted amount that is affected by a control exception.	ISA 230.2, ISA 315.20, ISA 330.17
Con a	►	Assessment whether the control exception rate exceeds acceptable tolerances.	ISA 530.13
clude nd unicat	Þ	Modification of risk assessment if the types of exceptions are systematic and no compensating controls can be identified.	ISA 315.20, ISA 330.17
C C	•	Observation and communication of possible root causes of control exceptions to the auditee.	ISA 265.5, ISA 330.17, ISA 530.12

Figure 8: Embedding process mining into contemporary financial statement audits (adapted from

Werner et al, 2021).

• Improved Process Insight and Transparency

Another benefit of process mining in auditing is its ability to improve process insight. The increased transparency and detailed process insights provided by process mining allow auditors to detect errors and inconsistencies more accurately, leading to enhanced audit effectiveness through more reliable and validated audit outcomes. It allows auditors to gain an in-depth understanding of business processes, providing a level of insight previously unattainable with traditional auditing methods. This transparency allows auditors to identify inefficiencies and potential areas for improvement within the audited processes. By providing a clear and comprehensive view of business processes, free from biases or presumptions, process mining significantly enhances the reliability of audit results and deepens understanding. Moreover, process transparency, which aids in identifying bottlenecks and bolsters effective auditing processes, thereby supporting more robust risk management strategies (Jans et al., 2013).

Process mining tools analyze historical data from event logs, which allow auditors to discover deviations from standard processes and assess compliance more accurately. The technology offers a comprehensive view of the actual business processes, enhancing transparency and enabling auditors to understand the underlying operations and also identify inefficiencies or irregularities that may indicate any potential issues" (Vasarhelyi et al., 2012). Consistent with Jans et al. (2010), by utilizing process mining, auditors gain detailed insights into the execution of business processes. This approach provides a more accurate picture of process flows and helps in identifying anomalies that traditional auditing techniques might miss. The use of event logs enables a thorough analysis of processes which leads to the detection of irregularities and potential control weaknesses that enhance the overall audit quality" (Jans et al., 2010).

• Enabling Auditing of Smart Contracts

Process mining enables the auditing of smart contracts. These contracts are self-executing contracts with terms directly written in code that can be applied into different domains, including the auditing field. Using smart contract-enabled blockchain technology allows auditors to achieve distributed and trustworthy access control, therefore enhancing the audit process (Zhang et al., 2019). This methodology reduces both the time and cost that are associated with manual audits, improves the effectiveness of the audit by ensuring that all transactions are examined and facilitates the identification of deviations and anomalies in real-time (Corradini et al., 2019).

Corradini et al. (2019) state that process mining transforms the auditing of smart contracts through a variety of critical functions. In the beginning, it enables real-time monitoring of smart contracts by capturing and analyzing the data generated during the execution of these contracts. By continuously monitoring, auditors can spot deviations or anomalies that could potentially represent fraudulent activity early on, which significantly boosts the reliability and integrity of their audits. Process mining also plays a crucial role in enhancing transparency and tracking abilities for transactions related to smart contracts. Through extracting transaction data from the blockchain and analyzing it, process mining provides auditors with a clear visual representation of transaction flows, therefore enabling them to verify the reliability of financial records and the adherence to terms of contract in real time. Within such a level of details, each stage of a contract's execution is recorded and checkable, which simplifies the auditing process and improves the reliability of financial statements. Additionally, the use of specialized tools such as CLawK further sharpens this process. CLawK taps into the specifics of business processes to ensure these smart contracts execution and ensuring that each contract operates exactly as intended (Eshghie et al., 2023). Moreover, process mining enhances the auditing processes efficiency, particularly for smart contracts through the automation and analysis of complex transaction data in blockchain systems. Through this automation the need for human assistance in interpreting complex data streams decreases, thereby enabling auditors to devote more time to strategic evaluations and compliance within the audit. As a result, the auditing of smart contracts becomes not only faster but more precise and comprehensive. This increase in efficiency is essential in handling the complex nature of smart contracts, which instantly enhances the effectiveness of audits by ensuring higher accuracy, better compliance to regulatory requirements, as well as an overall better quality of audits (Corradini et al., 2019). In addition, process mining effectiveness is significantly determined by the quality of the data being analyzed. Ekici et al. (2019) proposed an approach that leverages smart contracts to effectively clean event logs. This invention ensures the accuracy and anomaly-free nature of the data fed into process mining tools, which is essential for providing reliable audit outcomes.

The case study conducted by Corradini et al. (2019) on the RotoHive smart contracts provides empirical evidence supporting the earlier discussed benefits of process mining in enhancing audit effectiveness. RotoHive operates weekly fantasy sports tournaments centered around National Football League (NFL) games. A new tournament starts every Tuesday, requiring participants to evaluate and rank NFL players based on their predicted performance for the next week. Following the conclusion of Monday night football, the participants' predictions are assessed based on the actual performances of the players, and the highest scorers are awarded accordingly. The study demonstrates the efficacy of process mining methods in ensuring adherence to contractual terms and conditions on the Ethereum blockchain by offering continuous monitoring and thorough transaction analysis in real-time. The ability to swiftly detect deviations and non-compliance not only promotes the transparency and accountability of the auditing process, but also significantly improves its reliability and accuracy. These enhancements in the audit process are essential for effectively handling the different complexities of smart contracts, resulting in faster, more accurate, and comprehensive audits. The results of this case study demonstrate the significant impact of process mining on enhancing the comprehensiveness, dependability, and effectiveness of audits, especially in complex digital environments involving smart contracts (Corradini et al., 2019).

• Improved Regulatory Compliance

In terms of process compliance and evidence-based auditing, process mining enhances regulatory compliance. It provides powerful tools for compliance checking by assisting auditors in verifying process compliance against predefined models or standards (van der Aalst, 2016). This systematic approach allows auditors to assess whether business processes conform to expected models and rules by comparing the 'As-is' state of a business process with the 'To-be' state, ultimately identifying discrepancies and ensuring regulatory compliance (Elhagaly et al., 2019).

As the regulatory landscape becomes increasingly complex, there is a growing necessity to develop and implement new technological solutions that complement existing regulatory compliance management activities. Such innovations are crucial for institutions grappling with the burgeoning quantity and complexity of regulations. Boella et al. (2013) emphasize that financial institutions may struggle to keep up with the continuous evolution of regulatory requirements without these advanced technological tools. Additionally, the digitalization of business processes has led to an influx of highfrequency data that institutions must manage, underscoring an escalating need for powerful analytical tools capable of processing large volumes of data from diverse sources and providing deeper analytical insights (van Liebergen, 2017).

To fully build upon the foundational understanding of the importance of compliance checking, Elhagaly et al. (2019) examine specific techniques that leverage process mining to ensure that auditing processes not only meet but exceed regulatory standards. Compliance checking techniques are essential for ensuring that business processes comply with regulatory standards, which is fundamental in enhancing audit effectiveness. These techniques are automated compliance checking, real-time monitoring, and comprehensive coverage. Each one of them plays a significant role in transforming traditional audit practices into more dynamic, accurate, and efficient processes.

Table 4 below illustrates the correlation between the smart auditing framework's modules and PROM's plug-ins and therefore highlighting their contribution to compliance checking. This table demonstrates how process mining tools systematically support compliance efforts by ensuring all business processes are thoroughly analyzed and aligned with regulatory standards.

Module Name	PROM Plug-in	Tasks
Input Data	Log Analysis: Inspecting and Cleaning Log	Prepare data for processing
Data Analysis and IST Gen- eration	Performance Sequence Dia- gram, Mine Petri net Using Alpha Algorithm	Mining the control flow perspective Mining case- related information
SOLL Generation and Com- pliance Checking	LTL checker Default Plug- in	Auditing based on norma- tive structure

Table 4: Correlation Between Smart Auditing Framework's Modules And PROM'S Plug-In (adapted from Bukhsh & Weigand, 2017).

Automated compliance checking, as described by Elhagaly et al. (2019), utilizes process mining technologies to systematically analyze business process logs and compare them against predefined compliance rules and models. This technique significantly enhances the efficiency and accuracy of audits by reducing the reliance on manual checks that are susceptible to errors and oversight. By automating the compliance checking process, auditors can rapidly identify deviations from required standards, allowing for quicker corrective actions and ensuring that business processes consistently align with regulatory demands. Further extending the utility of process mining, Werner et al. (2021) highlight that this technology automates the analysis of business processes by extracting data from operational systems, thereby providing a more accurate and thorough examination of the internal controls and transaction processes. Together, these capabilities not only streamline the audit process but also support auditors in maintaining stringent compliance environments, which is critical in highly regulated industries. The integration of automated checks and real-time data analysis through

process mining ensures that audits are not only comprehensive but also proactively managed, significantly enhancing the overall effectiveness of regulatory compliance efforts.

Real-Time Monitoring, a technique that enables ongoing surveillance of business processes through process mining. By continuously analyzing transaction data, this method ensures that all activities comply with regulatory standards as they occur. For auditors, real-time monitoring offers the unique advantage of immediate feedback, which is essential for sectors that handle sensitive transactions, such as finance and healthcare. This immediate oversight helps prevent potential compliance breaches before they escalate, significantly reducing risk and enhancing the trustworthiness of audit outcomes (Elhagaly et al., 2019).

Feedback loops play a crucial role in process mining within auditing contexts, enabling the continuous enhancement of audit processes and compliance strategies. The integration of feedback mechanisms in process mining supports the iterative improvement of audit procedures, which are refined based on insights gained from analyzing audit trails and compliance data (Ivers et al., 2014). Effective feedback, as highlighted by Whalen et al. (2021), should be provided by respected individuals, establish clear goals, and include actionable plans to boost performance. Moreover, research by Chan et al. (2017) and Belizán et al. (2011) demonstrates that audit and feedback interventions are vital for enhancing the quality of care and clinical outcomes, underscoring their importance across various sectors. These studies affirm that integrating feedback loops into audit processes leads to sustainable practices and improved compliance with regulations, ensuring that organizations can continuously adapt and uphold high standards of regulatory compliance.

Additionally, Elhagaly et al. (2019) emphasize the importance of Comprehensive Coverage, which entails the analysis of entire datasets rather than selective sampling. This approach ensures that no transaction is overlooked, providing a holistic view of a company's compliance status. Comprehensive coverage is crucial for achieving a complete and accurate audit, as it allows auditors to assess every aspect of business operations against regulatory requirements. This exhaustive examination is particularly crucial in complex business environments where transactions are numerous and varied across different departments or regions.

• Enhanced Risk Assessment and Management

Process mining improves risk assessment by identifying potential risks, instances of non-compliance, and weaknesses within processes that might be overlooked using traditional methods. This capability aligns with findings from Jans et al. (2010), who highlight that process mining can identify audit-relevant transactions that standard internal audit procedures may overlook, including internal control failures such as unapproved payments and violations of segregation of duty controls.

Similarly, Chiu et al. (2020) emphasize that process mining enables auditors to apply the audit risk model more efficiently and enhances their ability to perform essential process walkthroughs and analytical procedures. This integrated approach not only focuses their efforts on high-risk areas but streamlines the audit process, providing a thorough and accurate assessment of operational and compliance risks, thus improving the overall audit strategy (Chiu et al., 2020; Jans et al., 2013).

By leveraging process mining to identify and prioritize potential risks and areas of non-compliance, auditors can focus their efforts where they are most needed, enhancing the strategic effectiveness and overall quality of audits. Alles et al. (2020) further support this by demonstrating that process mining enables a more thorough and continuous monitoring of business processes, allowing auditors to detect anomalies and control failures in real-time. This proactive approach enables timely corrective actions and enhances the overall reliability of the audit process. In addition, Jans et al. (2010) concur that analyzing detailed event logs through process mining significantly enhances the effectiveness of internal controls and risk management strategies. Collectively, these authors illustrate that using process mining tools, auditors can better detect non-compliance issues and operational risks, thus strengthening the audit risk model and ensuring comprehensive risk management.

Enhanced Social Relationship Insights and Comprehensive Data Analysis

Process mining reveals the social relationships between individuals involved in processes, enhancing auditors' understanding of communication patterns and potential collusion risks. It allows the auditor to conduct analyses not possible with existing audit tools, such as discovering the ways in which business processes are being carried out in practice and to identify social relationships between individuals (Jans et al., 2013). Similarly, van der Aalst et al. (2007) emphasize the importance of process mining in uncovering social structures and communication patterns within organizations, thereby facilitating a more comprehensive analysis of interactions and workflows. Furthermore, Process mining transforms the audit process by analyzing the entire population of data, rather than the traditional reliance on selected samples. This change in methodology allows auditors to draw more accurate, reliable conclusions and gain comprehensive insights into the entire data, significantly improving the quality and reliability of audit evidence (Jans et al., 2013). Additionally, the rich information extracted from event logs through process mining enhances the scope of analysis for auditors by providing extra context beyond the data entered by the auditee (van der Aalst, 2012).

• Improved Fraud Detection

Process mining is particularly effective in detecting fraudulent activities within an organization. According to Chiu, T., Wang, Y., & Vasarhelyi, M. A. (2020), the application of process mining in financial statement fraud detection can assist auditors in detecting potential fraud by examining potentially fraudulent process patterns. One of the key advantages of process mining is its ability to visually map out business processes based on actual data, aiding auditors in quickly understanding complex process flows, identifying irregularities, and understanding the overall process structure (Jans et al., 2013). This align with the findings of Bruin and Hendriksen (2016), who noted that process mining can be an automated tool for detecting abnormal transactions and potential fraud when a process mining fraud detection system is embedded with the association rules that link fraud schemes with non-standard variants. Table 5 below summarizes notable activities associated with potential fraud schemes and their risk levels. This table shows how can process mining be used to manage and detect fraud risks effectively.

ccounting	Fraud Scheme	Notable Activity	Suspicious Pattern Example	Risk	
ycle				Level	
rder-to-Cash	Altering Documentation	 Order Adjusted: Goods Issue Date Invoice Adjusted 	ed: Date sted Frequent occurrence of order adjusted and/or invoice adjusted activities without approval process during fiscal year end period.		
rder-to-Cash	Bill and Hold	Goods Issue Payment Received	Missing goods issue and/or payment received.		
rder-to-Cash	Channel Stuffing	 Order Adjusted: Order Return invoice adjusted: invoice credit note 	Frequent occurrence of order return or invoice credit note immediately after fiscal year end without approval process.		
rder-to-Cash	Up-Front Fees	 Payment Received Good Issue Order Adjusted: Change Goods Issue Date 	d Payment received occurs before goods issue or invoice created. Order adjusted without approval process.		
rder-to-Cash	Failure to Record Sale Allowances	 Payment Received 	Missing payment received or incomplete payment		
rder-to-Cash	Inflating the Value of Inventory	• Order Adjusted: Net Price	t Order adjusted without approval process Putting in improper price comparing to market value		
rocure-to-Pay	Off-site or Fictitious Inventory	• Goods Receipt	Abnormal goods receipt records: missing goods receipt and/or have duplicate or more than one goods receipt in one purchase order		
thers	Fraudulent Audit Confirmation	All Activities	Matching trading partners corresponding event logs		
thers	Refresh Receivables	 Invoice Adjusted 	Invoices adjusted occurs for many transactions without approval process		
thers	Promotional Allowance Manipulation	Invoice Adjusted: Cash Discount	/		
thers	Intercompany Manipulations	Invoice Posted: Revenue Intercompany	/		
thers	Bribery and Corruption • All Activities Using resource information in event logs to identify potential violation of segregation of duty controls		Medium		

Table 5: Accounting Fraud Schemes and Suspicious Process Patterns (adapted from Chiu et al., 2017).

This capability provides early detection of potential fraud, enabling organizations to act quickly to investigate such issues, protecting their assets and reputation. Furthermore, process mining has been used by industry for real-time fraud detection. For example, according to Bruin and Hendriksen (2016), the European Bank ING applied process mining to analyze a user's click path on a distributed stream computing platform. In a comparable study, Jans et al. (2011) applied process mining techniques to detect internal transaction fraud. Their findings demonstrated that process mining facilitates auditing not only by offering theory and algorithms to verify compliance, but also by providing tools that enable the auditor to identify fraud or other errors at an earlier stage. Process mining can be used in auditing analytical procedures to detect anomalous transactions that traditional auditing analytical procedures are unable to identify.

One of process mining's most impactful features in auditing is the automated analysis of every transaction. This process involves a comprehensive examination of each transaction and event log, ensuring that not a single detail is being missed or overlooked. Automated analyses of every transaction through process mining tools significantly improves the detection of fraudulent activities in auditing. According to Baader et al. (2018), techniques such as 'Filtering,' 'Statistical Analysis,' and 'Duplicates' are emphasized as effective tools for identifying fraudulent activities. Filtering

involves selecting specific parts of datasets based on criteria indicative of fraud, allowing auditors to focus on potentially problematic transactions. Statistical analysis applies mathematical models to data to identify unusual patterns and outliers, which could suggest fraudulent activities. Similarly, checking for duplicates in transaction entries, such as invoices or vendor entries, aids in pinpointing possible fraud. Collectively, these techniques together enhance the auditor's ability to scrutinize financial data in detail, thus facilitating early detection of fraud. When integrated into modern process mining tools, these techniques significantly contribute to the integrity and reliability of financial reporting, thereby enhancing audit effectiveness by ensuring more accurate and efficient audits.

Building on these advanced capabilities, process mining tools facilitate the creation of detailed process models from recorded transaction data, as noted by Werner & Gehrke (2018). This enables a detailed examination and analysis of each transaction, enhancing auditors' ability to identify and address anomalies effectively. Furthermore, the integration of predictive analytics extends these capabilities, allowing auditors to not only detect existing discrepancies but also to anticipate potentially fraudulent activities. This proactive approach is crucial for enhancing the overall security and reliability of financial operations, enabling auditors to address risks before they materialize, and especially vital in large and complex corporations where traditional methods often prove inadequate and struggle to keep pace, as highlighted by Li et al. (2012).

Enhanced visualization of business processes through the use of process mining can significantly help auditors in identifying fraudulent activities. Auditors can use process mining techniques, such as dotted charts, trace alignment, and fuzzy miner, to analyze large amounts of data and detect patterns that may indicate fraud (Rodríguez-Quintero et al., 2021). A Dotted Chart according to van der Aalst (2016), is a visualization tool in process mining that represents and displays events as dots on a chart, which allows for an examination of patterns and trends over time. Each dot represents an event with its occurrence time on the horizontal axis and the event class on the vertical axis. Therefore, the timing and frequency of these events can be crucial indicators of anomalies and patterns. For instance, operations that exceeded the expected timeframes could be spotted as possible fraudulent activities. The fuzzy Miner as explained by van der Aalst (2016), is a process mining technique that is developed to deal with the complexities and variabilities of vast amounts of data by constructing simplified models that still retain the essential process information. It emphasizes important activities and provides a very simplified view of the process while abstracting less important details, which makes it valuable for initial exploratory analysis. In line with this, the way this process mining technique helps in identifying the main paths and the connections between activities in a process is very crucial for auditors to identify fraudulent activities by helping them ignore the noise and focus on significant events, ultimately spotting unusual patterns. Van der Aalst (2016) describes Trace Alignment as a process mining technique that aligns traces to identify similarities and differences between them. This method is useful in the comparison between actual behavior recorded in the event logs with the predefined process models. Through the alignment of traces, auditors can effectively spot outliers and inconsistencies in the sequence of activities that might suggest manipulation or unauthorized actions, making it easier to compare the actual and predefined process models. Therefore, highlighting deviations that could indicate any type of possible fraudulent activities.

Real-time detection capability in process mining tools is essential for expediting responses to fraudulent activities in auditing (Hawkins et al., 2023). Similarly, Lee et al. (2022) highlighted the crucial role of real-time analytics in anomaly detection. Considering that most existing process mining techniques focus on anomaly detection in an offline setting, the authors investigated the use of advanced machine learning models such as RF (Random Forest) and XGBoost and deep models such as LSTM, to predict the probabilities of future activities and identify the unlikely events that are predicted as anomalies. The results of the paper showed that the online event anomaly detection, machine learning models generally outperform deep models, and both ML and deep models outperform classical approaches in the detection of anomalies. Although Lee et al. (2022) do not discuss auditing specifically, the significance of their findings can be directly linked to enhancing audit effectiveness. Real-time analytics' capacity to detect anomalies enables auditors to proactively tackle potential fraud, thereby maintaining the accuracy and reliability of financial statements. Incorporating these sophisticated machine learning models into auditing processes markedly improves audit effectiveness, fostering a safer and more reliable financial landscape.

• Improved Financial Analysis and Integration

Exploring further into the realm of process mining's benefits in auditing, we observe its ability to improve financial analysis and integration, enabling auditors to automatically analyze financial entries, reconstruct process instances and integrate the financial dimension with the process view. This feature enables auditors to understand how a sequence of transactions generated financial entries, to trace how balance sheet items were generated, and to efficiently link processes to financial data (Gehrke, 2010). Additionally, the integration of process mining with advanced analytics improves auditing by revealing hidden patterns and predicting risks in complex financial processes. This streamlines the audit process, providing auditors with deeper insights and improving financial oversight. It represents a step towards more insightful, data-driven auditing practices (Jans & Eulerich, 2022).

• Continuous Auditing

The adoption of process mining supports the concept of continuous auditing, by offering detailed analysis of event logs and process data collected from information systems, allowing auditors to continually monitor, analyze and improve processes (Dzihni et al. S., 2019). Comparatively, Vasarhelyi et al. (2012) highlight how continuous auditing enables real-time assurance by continuously collecting and analyzing data which allow auditors to provide timely insights and detect anomalies as they occur. This proactive approach enhances the auditor's ability to monitor processes and ensure compliance on an ongoing basis. Furthermore, Mans et al. (2015) emphasize that process mining facilitates continuous auditing by automatically extracting event logs from information systems, enabling a dynamic and ongoing evaluation of business processes. This technique provides auditors with a detailed and up-to-date view of the operational landscape which improves their capacity to identify irregularities and inefficiencies promptly.

As evidenced, the integration of process mining tools across various facets of auditing directly enhances audit effectiveness. This is achieved through improved accuracy, efficiency, and compliance, ultimately leading to more reliable and effective audit processes.

4.3 Challenges and Difficulties in Implementing Process Mining in Auditing and Their Impact on Audit Effectiveness

Process mining has emerged as a powerful tool within auditing, as demonstrated by the work of (Rozinat et al., 2008; Jans et al., 2010; Werner & Wiese, 2021; Chiu & Jans, 2019; Anwer Butt et al., 2023). Its implementation in the audit field represents an important step towards the use of data-driven insights to revolutionize audit practices. However, the path to fully integrate process mining within auditing is fraught with challenges and difficulties. These challenges range from collecting and processing data to gaining stakeholder buy-in and adapting organizational culture. Each of these challenges, including the requirement for technical skills to use process mining tools effectively and concerns about data privacy and security, underlines the complicated nature of these issues. As we explore these challenges, we aim to understand how they affect audit effectiveness as discussed in academic literature. This exploration seeks to uncover the impact of these difficulties on improving audit processes through the implementation of process mining and to provide a clear view of the obstacles to the adoption of this innovative technology.

• Handling Unstructured Processes

A major obstacle that has been highlighted in the academic literature relates to the handling of unstructured processes within process mining, an issue that traditional methodologies are often struggling to address effectively (Günther & Aalst, 2007). The nature of unstructured processes, characterized by their variability and lack of predictive patterns, poses significant challenges for data interpretation and subsequent analysis. Such difficulties directly compromise the audit's effectiveness by limiting the auditor's ability to extract meaningful insights from complex data sets.

To address the complexity of unstructured processes, various techniques have been proposed. According to van der Aalst and Günther (2007), abstraction and clustering techniques can be effectively used to bring structure to unstructured processes. Abstraction simplifies the process by focusing on higher-level activities rather than detailed steps, making the models more comprehensible. Clustering, on the other hand, groups similar activities together, which helps reduce complexity and makes the models more manageable. These techniques help in creating more understandable process models, which are crucial for effective auditing. The use of these methods ensures that even unstructured processes can be analyzed in a systematic manner, which provide auditors with a clearer insights and more actionable information (van der Aalst & Günther, 2007).

Lamghari et al. (2019) further discuss the challenges of dealing with unstructured business processes, particularly focusing on the complexity, variability, and the need for dynamic adaptation. The paper highlights that process mining often encounters difficulties in handling complex event logs properly. To mitigate this, the decomposition of processes is proposed as an effective technique. By breaking down complex processes into smaller, more manageable sub-processes, auditors can analyze each part individually, which simplifies the overall process and enhances understanding. This

decomposition approach is particularly beneficial in dynamic environments where processes frequently change because it allows for more flexible and adaptable auditing strategies (Lamghari et al., 2019). Moreover, the need for real-time adaptation to changes in unstructured processes is emphasized. In dynamic business environments, processes are often subject to unexpected variations and exceptions. The ability to adapt process mining models in real-time ensures that they remain accurate and relevant, which is essential for maintaining the effectiveness of audits. Lamghari et al. (2019) point out that managing variability and ensuring that process mining techniques can dynamically respond to changes are critical for handling unstructured processes effectively. This capability allows auditors to continuously refine their models and improve the accuracy of their insights and ultimately enhancing the reliability of the audit findings (Lamghari et al., 2019).

• Complexity of Real-Life Processes

Continuing on the theme of challenges, the complexity challenge emerges as a major obstacle in process mining. Literature analysis reveals significant hurdles auditors face in implementing process mining in audit tasks, mainly due to the inherent complexity of business processes. This complexity impacts the clarity and usability of process mining findings, making it difficult for auditors to draw actionable insights (Rodríguez-Quintero et al., 2021). Real-life processes demonstrate a wide range of behaviors to accomplish different tasks, resulting in complicated and challenging models for auditors to understand (Myers et al., 2018); (Spagnolo et al., 2016).

Process mining can detect anomalies that traditional audit procedures might miss but integrating it into the audit process can be complex (Jans et al., 2014). Developing continuous audit models requires thorough knowledge of both auditing practices and process mining techniques (Caron et al., 2013). Techniques such as clustering, abstraction, filtration, and pattern mining may help address these challenges, but their efficient use is another hurdle for auditors (Imran et al., 2022). Given the trade-off between complexity and model precision, simplifying processes could reduce the level of evidence required to support audits, decreasing confidence in audit findings (Imran et al., 2022).

Moreover, complexities often result in model representations that are difficult to interpret due to finegranular details in logs. This interpretative difficulty hinders auditors from fully utilizing process mining outputs, reducing audit effectiveness by preventing clear and actionable insights. The issue of duplicate tasks within a process adds another layer of complexity, introducing significant confusion and making it challenging to distinguish between unique roles and impacts (Tiwari et al., 2008).

• Data Quality and Availability

Another critical obstacle in the field of process mining for auditing arises from data availability and inaccuracy. According to Imran, Hamid, and Ismail (2023), the issue of data availability arises when crucial information is unavailable, outdated, or incomplete, which prevents a holistic view and the ability to obtain a comprehensive understanding of the audited process. These gaps in data can significantly decrease audit effectiveness by leading to potentially flawed audit conclusions. Meanwhile, data inaccuracy issues arise from incorrect data entry or processing errors, potentially leading to erroneous audit conclusions. These challenges highlight the value of not only having access

to extensive data sets, but also ensuring the high quality and accuracy of this data for the efficient implementation of process mining (Imran et al., 2023).

Similarly, Werner et al. (2021), emphasizes that process mining requires high-quality and comprehensive data to create accurate process models. However, in practice, data often suffer from issues such as missing values, inconsistencies, and inaccuracies. These issues can severely compromise the effectiveness of process mining. Data quality issues can lead to incorrect process models, resulting in flawed audit conclusions and potentially overlooking critical discrepancies. This makes it challenging for auditors to rely on process mining outputs without substantial data cleaning and validation efforts (Werner et al., 2021). Furthermore, Jans et al. (2013) stated that poor data quality can undermine the entire process mining exercise. Data quality issues such as errors in data entry, lack of standardization, and incomplete data sets pose significant obstacles. These issues can result in inaccurate or incomplete process models, which diminish the reliability of audit findings. Ensuring data accuracy and completeness is therefore critical, because any compromise can lead to misguided audit judgments and reduced confidence in the audit outcomes (Jans et al., 2013).

• Privacy and Security Concerns

One of the significant challenges in implementing process mining in the field of auditing is addressing the concerns related to privacy and security. If these privacy and security issues are not managed effectively, they can undermine trust in audit processes and, consequently, negatively impact overall audit effectiveness. The implementation of process mining within auditing raises significant privacy and security concerns due to the sensitivity of data involved. Data privacy insurance is a critical consideration in process mining, since the event logs used for analysis may include personal and confidential information about the organization's personnel. Audit data and results require protection from the following misuse and exposure (Imran et al., 2023).

According to Bade et al. (2022), process mining is reliant on logs, frequently in CSV format that contain rich information, some of which may exceed audit requirements, such as personal details. This wealth of data, while useful in understanding complex processes, also raises significant privacy concerns (Bade et al., 2022). Ensuring that this information is properly handled to protect the privacy of individuals while at the same time exploiting the data's potential for insightful analysis presents a critical challenge. Appropriate measures and considerations are required to ensure that the benefits of process mining are balanced with the imperative of protecting sensitive information.

Privacy and security are critical when using process mining in audits due to the sensitive nature of the data involved. Protecting sensitive financial information requires strong measures to prevent unauthorized access and data breaches. This includes using encryption methods and access controls, along with continuously monitoring and updating security protocols. Additionally, complying with legal standards is essential to avoid legal problems and maintain trust (Accorsi et al., 2013). Consequently, these concerns are increasingly being identified as a critical issue that can impact the implementation and effectiveness of this technology in audit practices. To mitigate privacy-related risks, various techniques for preserving privacy have been suggested. One of these

techniques is Differential Privacy, which offers a strong privacy guarantee. However, the suggested techniques assume that event data are released in a one-time manner, while business processes are executed continuously (Rafiei & Aalst, 2021).

Navigating the balance between extracting valuable insights and protecting the confidentiality of sensitive information is crucial. Techniques such as Differential Privacy are recommended to anonymize data while preserving its utility for analysis. However, current privacy-preserving techniques often fall short in dynamic auditing environments, where real-time data processing is essential. This gap underscores the need for advanced privacy-enhancing technologies tailored to the specific requirements of audit processes (Dumas & La Rosa, 2013).

According to researchers Accorsi et al. (2013), Accorsi et al. (2012), and De Weerdt et al. (2013), the current privacy-preserving techniques are insufficient to completely protect privacy. They point to a gap between the capabilities of these methods and the complex requirements of protecting personal data against sophisticated threats. This discrepancy highlights the importance of more sophisticated and more robust data security strategies that can efficiently address possible vulnerabilities in data handling and analysis (Bade et al., 2022).

• Handling Noise and Anomalies

Addressing the challenges of handling noise and anomalies in process mining for auditing is essential for ensuring the reliability and accuracy of audit results. In the landscape of process mining based audits, the management of anomalies and log noise is emerging as a critical challenge. Handling noise and anomalies in process mining requires the identification and filtration of irregular data that can distort audit results. Accurate management of log noise and identification of truly positive anomalies are crucial in process mining for auditing (Imran et al., 2023).

Bezerra and Wainer (2013) concur that noisy event logs can bias the resulting process models and consequently the audit conclusions. The presence of noise in event logs, such as missing or incorrect data, complicates the creation of accurate process models, making it challenging to identify genuine process deviations. Furthermore, Bose and van der Aalst (2012) emphasize that noise and anomalies can obscure significant patterns and lead to erroneous conclusions. Effective noise-handling mechanisms, such as filtering and anomaly detection algorithms, are imperative to ensure that the process models derived from event logs accurately represent the actual processes.

Auditors need to distinguish between genuine abnormal behavior, which may indicate problems, and variations that may appear to be unusual but are normal in the context (Post et al., 2022). According to Bezerra et al. (2009), as well as Bahaweres et al. (2021), a failure to accurately identify abnormal behavior and to understand its consequences on the organization can lead to inaccurate conclusions about anomalous behavior, particularly in financial auditing where the consequences of misinterpreting unusual behavior can be severe. Handling noise and anomalies can significantly impact audit effectiveness.

Noise in audit data, for example incomplete or inaccurate information, can complicate the establishment of a standard profile for detecting anomalies. This difficulty in differentiating between

normal data and anomalies can decrease the accuracy of the intrusion detection system, thereby reducing the effectiveness of the audit overall (Patcha & Park, 2007). Although advanced machine learning models such as autoencoders can theoretically enhance the detection and analysis of anomalies, their implementation is often complex and resource-intensive, posing an additional challenge for auditors (Nolle et al., 2018).

• Log Extraction and Transformation

Focusing on another crucial issue, we come across the challenges of log extraction and transformation. Log extraction and transformation is considered a crucial difficulty in the implementation of process mining in auditing. Preparing data for analysis is a critical step that requires careful handling to ensure that the extracted logs accurately represent the audited processes. The transformation process must maintain the integrity and relevance of the data. Process mining changes the way auditing is being conducted by leveraging event logs to obtain insights into the way processes are actually executed. This approach provides a complete review of the complete set of logs, a significant advantage compared to traditional auditing methods which often depend upon sampling (Jans et al., 2011); (Zerbino et al., 2018).

However, according to Jans (2019), Converting the data collected into formats that are compatible with process mining tools is a major challenge. This is primarily due to a lack of expertise in selecting the appropriate process instances and attributes for practical process analysis. This highlights the need for more specialized training or resources to fill the skills gap and to ensure that process mining results are accurate and insightful. The challenges of extracting, transforming, and integrating log data in process mining significantly affect audit effectiveness while integrating process mining techniques into audits, because the extraction, transformation, and loading of event logs from information systems are crucial initial steps in process mining (Berti et al., 2021).

Moreover, the process of extracting event data from systems like SAP ERP presents substantial challenges due to the size and complexity of the data involved. Developing effective methods to store and manage this data in formats compatible with process mining tools is critical. This complexity is compounded when multiple process executions are recorded in a single log, making it difficult to identify the correct process for auditing (Berti et al., 2021); (De Weerdt et al., 2013).

This challenge is further complicated by the need to isolate specific data relevant to a single audit focus from a mix of information related to different processes (Wiersma, 2017). Ensuring that the extracted data maintains its integrity and relevance throughout the whole transformation process is vital for the accuracy and reliability of the audit findings.

• Integration with Existing Systems

The integration of process mining within the audit landscape emerges as a significant hurdle (Werner et al., 2021). This shift not only requires adapting audit practices to incorporate data-driven insights, but also ensuring that the process mining tools are aligned with the objectives of the audit. Process mining based audits primarily focused on analyzing the activities captured within the system boundaries (Maldonado-Mahauad et al., 2018), which resulted in a limitation where the actions that

occurred outside of these boundaries went unrecorded and consequently unexamined and unaudited (Lee et al., 2013; Thaduri et al., 2019).

Integrating process mining into audit practices entails some technical challenges. Many legacy systems are not designed to support advanced data analysis tools which leads to issues such as data format incompatibility and system integration difficulties. This often requires substantial IT infrastructure upgrades and specialized knowledge about the implementation of business processes within ERP systems (Werner et al., 2021). Moreover, the construction of comprehensive event logs from these systems is crucial for effective process mining. The varying configurations and data storage practices across different IT systems poses a challenge in obtaining audit-relevant information. Ensuring that event logs accurately and completely capture all relevant activities is critical for the reliability of process mining-based audits (Jans et al., 2014).

Additionally, aligning process mining tools with audit objectives is essential to ensure that the datadriven insights provided by process mining are relevant and actionable within the audit context. This alignment is critical for maximizing the effectiveness of process mining tools in enhancing audit quality and providing deeper insights into business processes (Zerbino et al., 2018).

According to Jans et al. (2014), the implementation of process mining within audits expands the scope of the audit from the transactional data to the metadata recorded by IT systems, increasing the depth and breadth of the analysis of audits. Process mining holds substantial promise for enhancing auditing through deep insights and automated analysis. However, it confronts significant challenges, including issues with privacy, security, data complexity, noise management, and integration into existing audit processes. If these challenges are not effectively addressed, they may severely hinder the transformative potential of process mining in auditing, and it is also imperative that the auditing community develops more sophisticated strategies and solutions to overcome these barriers, ensuring that process mining can fully realize its potential in enhancing audit effectiveness. To properly address these issues, it is important that auditors and audit researchers should have an understanding of the unique aspects of process mining in order to facilitate its acceptance within auditing practice (Saleh, 2019).

Table 6 below from Imran et al. (2023), summarize these challenges and obstacles associated with the implementation of process mining in auditing.

Challenges	Description
Complexity challenge	Challenges of complexity arise in process mining-based auditing due to the large and complex data sets involved, which can lead to difficulties in analyzing, interpreting, and visualizing the results
Log extraction and transformation issue	Extracting and transforming log data requires a deep understanding of the process and domain knowledge to correctly identify and transform the relevant events.as multiple process executions may be present in the same log
Representational and algorithmic bias	To promote objectivity and fairness in audit, discovery of suitable process discovery algorithm and representative models is imminent as it can affect the accuracy of the findings
Handling noise and anomalies	Auditing noisy event logs makes it challenging to differentiate between typical and unusual activity
Data availability and inaccuracy challenge	Partial data availability and imprecision impacts audit outcomes resulting in incomplete process models that do not accurately reflect the actual process thereby promoting inaccurate conclusions.
Privacy concerns	Sensitive personal data that may be revealed during audit process urging the need for secure anonymization techniques to protect sensitive data
Integration of PM into existing audit landscape	Challenges related to reference audit model and cross-organizational audit

Table 6: Challenges associated with process mining-based auditing (adapted from Imran et al,

2023).

5. Discussion

The purpose of the discussion section is to thoroughly analyze and explain the results of the study. The primary aim of this comprehensive literature review is to investigate how process mining can enhance audit effectiveness. This study focuses on three key areas: examining process mining techniques used in auditing and their contributions to audit effectiveness, exploring the benefits of implementing process mining in auditing, and analyzing the challenges related to this implementation and their impact on audit effectiveness.

5.1 Which Types of Process Mining Techniques Are Commonly Used in Auditing and How Do They Contribute to Audit Effectiveness?

The literature highlights that various process mining techniques are essential in the enhancement of auditing effectiveness, providing auditors with a comprehensive array of tools to navigate the complexities of auditing. Among these techniques, process discovery, conformance checking, and process enhancement are the most prominent, as each one of them contributes uniquely to the audit process.

• Process Discovery

In our results, the first technique we identified was process discovery due to its value as it is considered one of the main techniques of process mining in auditing. Process discovery is highly regarded in the academic literature due to its ability to extract detailed process models from event logs, providing a comprehensive view of actual business operations (Norouzifar & van der Aalst, 2023; Van der Aalst, 2016). According to Jans et al. (2013), process discovery captures the intricate

details of operational workflows that traditional auditing methods often miss, and therefore enhancing transparency and operational understanding. This technique is invaluable for identifying inefficiencies and compliance issues, enabling auditors to detect bottlenecks and deviations that might indicate any potential fraud activities or inefficiency. Werner et al. (2021) highlighted that the insights derived from process discovery enhance the accuracy and reliability of audit finding which help auditors to make more informed decisions. By examining event logs, auditors are able to also detect non-standard practices and evaluate the effectiveness of process flows which results in a more comprehensive and accurate understanding of business processes. Additionally, Van der Aalst (2016) points out that process discovery aids compliance by contrasting actual process models with expected ones. This comparison allows auditors to proactively address any potential risks and ensures adherence with regulatory requirements.

In summary, the technique of process discovery contributes to audit effectiveness through the enhancement of many aspects such as enhanced transparency, improved compliance, and supported continuous process improvement. This technique provides auditors with the tools necessary to conduct more effective and reliable audits which ensure a comprehensive evaluation of organizational operations.

• Conformance checking

In our results the second technique we identified is conformance checking. Conformance checking is highly valued in academic discussions for its role in comparing actual business process executions with predefined models, which is essential in the field of auditing. Our findings suggests that conformance checking is crucial for auditors, as it helps them to identify deviations, non-compliance, and anomalies, thereby assessing internal controls' integrity and reliability (Van der Aalst, 2016). By identifying these potential risks, conformance checking enables auditors to provide targeted recommendations for risk mitigation, as noted by Dunzer (2019) and Pufahl (2021). This proactive approach as evidenced in our results, ensures that organizations can address issues promptly, thereby enhancing overall audit effectiveness. Furthermore, Pufahl (2021) emphasizes that conformance checking promotes audit effectiveness by ensuring compliance with regulations and process models. Recent advancements highlighted by Rinderle-Ma et al. (2023) and Stertz et al. (2020) improve the accessibility and interpretation of conformance results. These improvements make it easier for auditors to act on findings, thereby increasing audit effectiveness. Additionally, our results aligns with Ternai (2016) notes that semantic audit tools enhance this process by comprehensively detecting operations and deviations, further contributing to audit thoroughness.

Overall, conformance checking significantly boosts audit effectiveness by ensuring that business processes align with predefined models, promoting compliance, and providing auditors with the tools to identify and mitigate risks effectively. These advancements make conformance checking an indispensable technique in modern auditing practices.

• Process enhancement

The third and the last main technique of process mining in auditing we identified in our results was process enhancement. Although not extensively covered in academic literature, process enhancement plays a crucial role in process mining by leveraging insights from event logs to improve business operations. According to Jans & Eulerich (2022), this technique allows for the adjustment of existing process models to optimize performance and compliance. Our results suggest that process enhancement identifies inefficiencies and redesigns workflows to address bottlenecks and improve throughput times, thereby enhancing overall process effectiveness (Zerbino et al., 2021). Moreover, Imran et al. (2023) emphasize that the technique of process enhancement fosters a proactive culture of continuous improvement. This approach and as evidenced in our results, enables organizations to adapt dynamically to the evolvement of market demands and regulatory changes, maintaining operational excellence and compliance. This adaptability is important for ensuring ongoing compliance and sustaining audit effectiveness.

Integrating process enhancement with AI and machine learning technologies further amplifies its effectiveness. Wang & Aviles (2023) and de Leoni (2022) highlight how analyzing historical process data with machine learning can uncover patterns and trends which enable organizations to proactively address inefficiencies or compliance issues. Our findings suggest that this predictive process optimization ensures audits are thorough and effective by anticipating and mitigating challenges.

In summary, process enhancement plays a pivotal role in the enhancement of audit effectiveness through the continuous optimization of business processes. By systematically addressing inefficiencies, fostering a culture of continuous improvement, and integrating advanced technologies, process enhancement not only ensures high performance and compliance standards but also enhances the reliability and accuracy of audits.

5.2 What Are the Benefits of Implementing Process Mining in Auditing and How Do They Enhance Audit Effectiveness?

Our thorough literature review highlights numerous benefits related to the implementation of process mining in the field of auditing, and how they enhance audit effectiveness. Our findings revealed that process mining automates data analysis which reduces manual efforts and increases the accuracy of audit evidence, therefore improves the effectiveness and the efficiency of audits (De Weerdt et al., 2013; Werner et al., 2021). This indicates that data analysis automation enables auditors to focus on high-risk areas, which results In optimizing audit cycles and outcomes (Werner & Gehrke, 2015; Jans et al., 2013).

Additionally, our study showed that process mining enhances process modelling through identifying inefficiencies and redesigning workflows, resolving bottlenecks and increasing throughput times, which contributes to an overall enhanced audit effectiveness. (Zerbino et al., 2021; Gehrke, 2010). Furthermore, we found that process mining improves process insights and transparency, which provide auditors with the details needed and accurate views of business processes, therefore enhancing the reliability of audits and helps in the detection of errors and inconsistencies (Jans et

al., 2013; Vasarhelyi et al., 2012). This innovative technology also enables the auditing of smart contracts, allowing real-time monitoring and analysis of transactions, and therefore enhancing audit integrity and reducing the time and costs associated with manual audits (Zhang et al., 2019; Corradini et al., 2019). Another benefits we identified due to this implementation is improved regulatory compliance, as process mining provides auditors with tools for verifying compliance again predefined standards, which helps to ensure that business processes conform to expected regulations (van der Aalst, 2016; Elhagaly et al., 2019). Moreover, the research indicates that process mining enhances risk assessment and management through the identification of potential risks and noncompliance, streamlining audit processes, and enhancing strategic effectiveness (Jans et al., 2010; Chiu et al., 2020). Process mining also offers insights into social relationships within organizations, therefore revealing communication patterns and potential collusion risks, which improve comprehensive data analysis and audit quality (Jans et al., 2013; van der Aalst et al., 2007). In addition, process mining has the capability to detect fraudulent activities by mapping out business processes and identifying irregularities, which is essential for maintaining financial integrity (Chiu et al., 2020; Jans et al., 2011). Lastly, our findings indicates that continuous auditing facilitated by process mining greatly supports real-time assurance, which provides ongoing monitoring and immediate feedback on process compliance, and therefore enhancing the responsiveness and effectiveness of audits (Dzihni et al., 2019; Vasarhelyi et al., 2012).

5.3 What Challenges Are Associated with Implementing Process Mining in Auditing and How Do They Impact Audit Effectiveness?

Our findings revealed several significant challenges associated with the implementation of process mining in auditing, each impacting audit effectiveness in distinct ways. Firstly, our findings showed that handling unstructured processes is a major obstacle. Traditional methodologies often struggle with the variability and lack of predictive patterns in unstructured processes, which makes data interpretation and analysis difficult. This limitation directly impacts audit effectiveness by restricting auditors' ability to extract meaningful insights from complex datasets (Günther & van der Aalst, 2007). Techniques like abstraction and clustering can help bring structure to unstructured processes, making them more manageable and providing clearer insights for auditors (van der Aalst & Günther, 2007). However, the complexity and variability of these processes still pose challenges, which lead to the need for dynamic adaptation and real-time model updates to maintain audit accuracy and reliability (Lamghari et al., 2019). Secondly, The complexity of real-life processes also emerges as a serious hurdle. The inherent complexity of business processes makes process mining findings less clear and usable, making it difficult for auditors to draw actionable insights (Rodríguez-Quintero et al., 2021). Techniques such as clustering, abstraction, and pattern mining can help manage these complexities, but using them efficiently requires substantial expertise (Imran et al., 2022). The intricate nature of process models, along with detailed logs and duplicate tasks, further complicates the interpretation and therefore reducing audit effectiveness by hindering clear and actionable insights (Tiwari et al., 2008). Our findings also identified data quality and availability challenges, as they present another critical obstacle related to this implementation. Issues such as missing, outdated, or inaccurate data prevent a comprehensive understanding of audited processes and can lead to flawed audit conclusions (Imran et al., 2023). High-quality and comprehensive data are essential for creating accurate process models. Poor data quality, such as missing values and

inconsistencies, can severely compromise the effectiveness of process mining in auditing, resulting in the need for substantial data cleaning and validation efforts (Werner et al., 2021; Jans et al., 2013). Privacy and security were also highlighted as critical challenge in implementing process mining in auditing. The sensitivity of audit data necessitates robust measures to protect against unauthorized access and data breaches. Ensuring the privacy and security of personal and confidential information within event logs is crucial for maintaining trust and compliance (Imran et al., 2023; Bade et al., 2022). Handling noise and anomalies in process mining is essential for ensuring reliable and accurate audit results. Noisy event logs and anomalies can distort process models and obscure critical patterns, leading to inaccurate audit conclusions (Bezerra & Wainer, 2013; Bose & van der Aalst, 2012). Effective noise-handling mechanisms, such as filtering and anomaly detection algorithms, are imperative for accurately representing actual processes and maintaining audit reliability (Post et al., 2022). Log extraction and transformation also pose challenges. Preparing data for analysis requires careful handling to ensure that extracted logs accurately represent audited processes. The transformation process must maintain the integrity and relevance of the data. However, converting data into compatible formats for process mining tools is often a major challenge due to the complexity and size of the data involved (Jans, 2019; Berti et al., 2021). Ensuring that extracted data maintains its integrity and relevance throughout the transformation process is vital for the accuracy and reliability of audit findings (Wiersma, 2017). Lastly, integrating process mining with existing systems presents technical challenges. Many legacy systems are not designed to support advanced data analysis tools, leading to issues such as data format incompatibility and system integration difficulties. Solving these problems often requires IT infrastructure upgrades and specialized knowledge (Werner et al., 2021). Ensuring that event logs accurately and completely capture all relevant activities is critical for reliable process mining-based audits. However, varying configurations and data storage practices across different IT systems complicate this task (Jans et al., 2014).

In summary, addressing these challenges is essential for realizing the full potential of process mining in auditing. Effective handling of unstructured processes, managing complexity, ensuring data quality, safeguarding privacy and security, handling noise and anomalies, efficiently extracting and transforming logs, and integrating with existing systems are all important steps towards enhancing audit effectiveness.

6. Conclusion

This study embarked on a comprehensive exploration of the synergy between process mining and auditing, with a particular focus on understanding how process mining can enhance audit effectiveness, through uncovering a variety of techniques, benefits, and challenges. Guided by one central research question, followed by three sub questions, our study navigated the complex interplay between these fields. The results of this study provided a spotlight on the main process mining techniques used in auditing: process discovery, conformance checking and process enhancement. Each type contribute to the effectiveness of auditing. Process discovery offers a solid empirical basis for understanding and evaluating an organization's operations, providing a more accurate and comprehensive understanding of a business process. Conformance checking verify if the actual process, as shown by the event log, matches the intended process design or if the process model accurately reflects what truly happens. Process enhancement uses process mining valuable insights, giving organizations the ability to optimize processes by locating inefficiencies within processes and then redesign workflows. The findings of the study highlights several benefits of implementing process mining in auditing. benefits such as improved fraud detection by allowing for the early identification of potentially fraudulent activities through analyzing process patterns. Enhanced process insights and transparency by offering auditors a detailed and accurate view of business operations, which enables a better detection of errors and inconsistencies. Improved regulatory compliance through the use of process mining tools that ensure business processes adhere to predefined standards and reduces the risk of non-compliance and legal penalties. All together contributing to more effective audits. However, the study also identifies the hurdles of this implementation like data availability and inaccuracy which can lead to incomplete or incorrect analysis, and therefore undermining audit reliability. Unstructured and complex processes, which pose difficulties in applying process mining techniques effectively, as these processes may not follow predictable patterns. Privacy and security concerns which arise from the sensitive nature of the data used in process mining, and it must be carefully managed to avoid breaches and maintain trust in the audit process. Each of these hurdles negatively impacts the effectiveness of auditing by leading to potentially flawed audit conclusions, preventing auditors from fully utilizing process mining outputs, and weakening trust in the audit process and risking the exposure or misuse of sensitive information. To sum up, this thorough literature review clarifies the relevance of the intersection between process mining and the auditing domain, thereby enhancing its effectiveness. The results underscore the mutual benefit between process mining and auditing, setting the groundwork for future research.

6.1 Limitations and future research:

In conducting this thorough literature review which focuses on how can process mining enhance audit effectiveness, we have faced challenges that shaped our conclusions. Because our research focuses specifically on enhancing auditing effectiveness using process mining, generalizing our findings was challenging. This specific research question means our results are particularly tailored to auditing environments and may not be directly applicable to other contexts or industries. The second challenge concerned the extensive scope of relevant literature. Ensuring a comprehensive coverage and analysis of all other relevant studies was demanding, which have limited the depth of our review

in some areas. Third, the reliance on available peer-reviewed articles and exclusion of sources such as SSRN may have led to missing some valuable insights, particularly those found in high-quality preprints that have not yet undergone peer review. These limitations should be considered when interpreting the results of our study. Despite these challenges, we believe our review provides valuable insights into the role of process mining in enhancing audit effectiveness.

Future studies should aim to analyze specific aspects of process mining implementation with both big data technologies and advanced analytics techniques. By conducting case studies on the application of such technologies in different industries and auditing scenarios, they could highlight their impact on audit effectiveness. For example, a detailed analysis of audits outcomes can provide a clearer understanding of their benefits in different auditing contexts and applications. Additionally, future studies could explore the integration of process mining with emerging technologies such as artificial intelligence and machine learning to improve predictive capabilities and automate complex audit tasks. Investigating the potential for real-time auditing needs could also be valuable. Furthermore, long term studies that assess the long-term benefits and challenges of implementing process mining in auditing practices across different regions and sectors would provide deeper insights. By addressing these areas, future research can contribute to advancing the field of process mining in auditing and enhancing its practical application.

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