Process Mining: Application in Practice

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Abstract — **Process mining is a concept that is not new, and software in this area is well represented on the market. The academic interest is reflected in a relatively large number of articles dealing with this topic. However, the practical implementation does not quite match these development trends. The aim of this study is therefore to investigate (1) the industries in which process mining is used and (2) the specific software used for this purpose. For the study, a systematic literature review was conducted by examining articles published in the last 5 years in Clarivate Analytics' Web of Science (WoS) database. Based on the collected results, a bibliographic analysis was performed, the case studies on the application areas of process mining were analyzed and the software used was systematized. In addition, the identified benefits, current status, trends and challenges in the implementation of this concept in practice were analyzed. Considering the limitations of the research, guidelines for the scientific community are proposed to guide future research. Furthermore, approaches are proposed that could contribute to a stronger application of process mining in business practice.**

Keywords – process mining, software, case study, systematic literature review

I. INTRODUCTION

Process mining (PM) is a concept that scientists [1] see as the intersection of two areas: Data Mining (DM) and Business Process Management (BPM). The goal of PM is to extract knowledge from data about real-world processes using numerous techniques that fall into one of three typical categories: (1) discovery, (2) conformance, and (3) process improvement [2][3]. Although it emerged more than 20 years ago, some studies show that the application of this concept in practice is relatively slow and not sufficiently recognized by business experts [4][5]. According to De Rock and Martin [6], the reason for this is that direct business value is not derived from the discovery and transparency of processes. Rather, specific use cases and human intelligence are needed to identify and implement strategies to improve processes. On the other hand, numerous studies focus on finding new or better algorithms for extracting data from processes [7], while research aimed at identifying use cases for existing PM methods and targeting business processes where the application of these methods can bring added value to the company is relatively rare. Dumas et al. [8] note that the use of PM in companies has increased recently. However, they also emphasize that "a significant research gap is evidenced in the adoption of PM technology by organisations, in its integration into their information system (IS) landscape, and the subsequent impact of this adoption" [8]. Similarly, in the conclusion of a systematic review of the literature (SLR) on the use of PM technology in organizations, Thiede et al. [5] point out that only a better understanding of the applicability of PM can influence its wider use in different business areas.

In accordance with the results of the brief preliminary literature review described above, the goals of this research were defined as (1) the investigation of case studies on the application of PM in specific industries and (2) the investigation of software tools used to apply this concept in business practice. In order to achieve the goals, qualitative research was conducted using the SLR method. This article is structured as follows. The next section presents the theoretical basis of the research, which includes a brief overview of the PM application in practice and the technology used for this purpose (Section 2). This is followed by a description of the research methodology (Section 3). The results of the SLR and the analysis of the results are then described, followed by a discussion (Section 4). Finally, the conclusions are presented and guidelines for future research are given.

II. PROCESS MINING IN PRACTICE

A. Related Research

The purpose of this section is to describe the results of other similar SLR articles on the application of PM and to position our research in this context. Milani et al. [4] conducted a SLR to find prominent use cases for PM and identify business problems and challenges related to these use cases. According to the results of their research, PM use cases can be divided into 5 categories: "transparency, efficiency, quality, compliance and agility" [4]. The framework is intended to help practitioners navigate the spectrum of available PM use cases and identify the PM methods that meet their specific needs.

Corallo et al. [1] conducted a SLR that investigated the applications of PM techniques in an industrial context to emphasize the importance of these innovative techniques for each of the specific scenarios. The results of the analysis confirmed that PM can be used for various activities, especially as more and more data about business processes can be found in companies' ISs. Some of the examples listed by Corallo et al. [1] are: detecting and reducing fraud in companies, improving the performance of internal processes in hospitals, analyzing the efficiency of processes in production and storage, monitoring the behavior of users of the IS, and predicting the outcome of certain processes (e.g. of a loan application process).

Healthcare is an area where PM has been used for more than two decades, and an increase has been observed in

recent years, whether in the area of treatment procedures or internal organizational processes [9][6]. The results of the SLR conducted by De Rock and Martin [6] on 263 articles published in the period 2005-2021 were analyzed from different points of view, of which the one related to 4 categories of KPIs (clinical, financial, time-related and resource-related) is extremely interesting. While Batista and Salonas [10] mentioned the increasing interest in KPIs in healthcare PM projects, the results of De Rock and Martin [6] show that time-related KPIs are most frequently mentioned in published articles (30.8%), followed by clinical KPIs (19%), while other KPIs are rarely mentioned.

Governance, risk management and compliance (GRC) is an area where the benefits of applying PM are being recognized, as evidenced by the increase in academic articles on these topics [11][12][9], most of which focus on the financial sector [13][14] and the manufacturing industry [1].

The field of software engineering is a promising area for a broader implementation of PM. Ghasemi and Amyot [2] conducted a SLR that specifically focuses on research that integrates PM and goal modeling. This review provides precise insights into the current state of goal-oriented PM activities. According to Ghasemi and Amyot [2], the integration of goals and PM has the potential "(1) to improve the precision, rationality and interpretability of the models obtained; and (2) it is expected that this synergy will ultimately improve the ability to meet the expectations of the system's stakeholders more effectively". For requirements engineering, it is important to understand and analyze the real processes, i.e. how users use the existing system [15]. PM can help to extract knowledge about processes and user behavior from event logs. The SLR results conducted by El-Gharib and Amyot [16] show that the number of articles describing the application of PM in cloud systems has increased since 2017. Most research articles describe the use of different techniques to analyze clickstream data in e-commerce applications. Besides, El-Gharib and Amyot [16] point out that there is a lack of research on the application of PM in the area of cross-organizational processes.

The researchers show that PM tools and techniques can be applied to extracted blockchain data for various purposes, such as user behavior analysis, blockchain transaction analysis, GRC (e.g., validation of smart contracts, security audits and blockchain application review) and monitoring business processes executed on blockchain applications [17] [18] [19] [20].

B. Process Mining Software in Practice

Batyuk and Voityshyn [21] emphasize the importance of positioning PM software more broadly, considering that Gartner [22] identified PM as a distinct market segment and linked it to current technology trends, including big data, digital transformation (DX), the Internet of Things (IoT), artificial intelligence (AI), robotic process automation (RPA) and more". Due to the growing number of PM software on the market, Layola-Gonzales [23] conducts a thorough analysis of the 16 leading PM software and provides a comprehensive taxonomy that includes 55 features, such as "data management, process graphing, process analysis and analytics, compliance auditing, operational support, advanced extensibility, views, monitoring and reporting, and security and compliance". Similarly, Drakoulogkonas and Apostolou [24] developed a framework that allows users to compare different PM software based on a comprehensive list of comparative analysis criteria [24].

Layola-Gonzales [23] outlines 2 important trends in PM: "(1) the adoption of the "what-if" approach to simulate and predict future scenarios; and (2) the use of reinforcement learning for process simulation to determine the most efficient end-to-end process". Similarly, Reinkemeyer [25] suggests a shift in the future development of PM "by incorporating AI, proactive and predictive enablement and other mechanisms that improve the execution of processes" [25]. The authors agree that there is a research gap in exploring the intersection of PM with recent advances in machine learning, which poses a challenge for future studies [23][25]. Leno et al. [26] have proposed a vision for a new category of PM tools called "Robotic Process Mining" tools. According to their proposal, these tools are designed to analyze user interaction logs and focus specifically on the detailed user interactions with IT systems to identify routines that can be automated with RPA tools [26].

III. RESEARCH METHODOLOGY

In order to achieve the objectives of the study, the SLR method is used in accordance with the guidelines proposed by Kitchenham [27]. In the planning phase, a search string was first defined with the keywords "process mining" AND ("software" OR "platform" OR "tool") AND "case study" in the "topic" of the article, which match the research objectives. The scientific citation database Clarivate Analytics' Web of Science (WoS) was selected for the search as it is one of the most respected research databases and provides seamless access to 3 major indexes: Science Citation Index Expanded, Social Science Citation Index and Arts & Humanities Citation Index. Next, the selection criteria are defined: the years of publication (2019 to 2023), the type of publication (journal article or conference proceeding article) and the language (English). In the last step of the planning phase, the metadata to be extracted for each document are defined, namely: date of data extraction, title, authors, publication details, key words, abstract.

The search was carried out in December 2023. With regard to the criterion of standard keywords in the topic of the publication, the search yielded a total of 82 articles. Of these articles, 33 articles remained, while the others were omitted due to their language restriction, type of publication and year of publication restriction. A further article was rejected due to the restriction on access to the document. The abstracts of the remaining 32 documents were analyzed. The authors read all articles and compared their notes. In addition, one document was excluded because it was determined that its content did not correspond to the research area, leaving 31 documents for further analysis.

IV. SLR Results: Report, Analysis and Discussion

A. Results

Table 1 contains essential bibliographical information on 31 selected publications, which form the basis for the following analysis. The table contains information such as the reference number, the year of publication, the type of publication (abbreviations are used: publication type = PT; J = journal article; C = conference proceeding article), the context of the case study, case study country and PM software used.

According to the date obtained, the distribution of publications by year appears to be relatively even: 9 articles were published in 2022, 7 in 2019, 6 in 2021 and 5 in 2020. The search results also show 4 articles published in 2023, but it should be noted that not all published articles may have been included in the WoS database at the time of the search. Furthermore, the findings show that 6 articles were published in conference proceedings, while 25 appeared in peer-reviewed journals. This observation indicates a high level of research maturity in this field. In addition, the bibliographic data show that the studies were carried out in different countries, which indicates the interest of both researchers and practitioners in the area studied, regardless of the geographical affiliation and level of development of the country in question.

B. Analysis

The data analysis (Table 1) sheds light on how PM is applied, considering: (1) the objective of the PM application (2) the context of the PM application as described by the case study. In terms of objectives, most of the case studies fall into two categories: (1) business process change (BPC), which involves redesigning, improving, and optimizing internal or cross-boundary processes [28] [29] [30] [31] [32] [33] [34] [35] [36] [37] [38] [39] [40] [41] [42] [43] [44] [45], and (2) software engineering (SE) [46] [17] [47] [48] [49][50][51] [52] [53] [54] [55] [56] [56], which involves multiple perspectives. Besides, in the studies whose primary objective is SE, topics from the GRC area (such as data quality, security, audit, process compliance checking) are also mentioned [17] [50][55].

In the area of PM applications, a significant proportion of the case studies (12) dealing with BPC come from the healthcare (HC) sector [28] [29] [31] [32] [33][35] [37] [38] [40] [42] [43] [44]. Other BPC case studies relate to various business processes in different industries, such as internal processes of a retail company [34], cross-organizational purchase-to-pay processes [45], internal logistics [36], government processes [39], construction project management processes [41] and helpdesk services [30]. In the software engineering (SE) category, on the other hand, the case studies predominantly revolve around existing software solutions such as information systems (ISs), digital platforms, websites, and blockchain applications. The analysis shows the application of PM in the field of SE for specific purposes, such as: goal dependency modeling [48], analysis of websites [46] and social workflows (so called “federated PM”) [53], analysis of users’ behavior from the event logs and software behavioral model development [49][56][55], analysis of software development actions and the software development process itself [54][56], reverse engineering using refactoring techniques [52] and the bug fixing process [47][51].

The results of the analysis show that ProM, whose use is described in 10 case studies [28] [46] [17] [34] [48] [35] [37] [39] [50] [44], is the most frequently used PM software. It is followed by Disco, which is mentioned in 9 case studies [30] [32] [33] [36] [38] [40] [51] [42] [55], and Celonis in 3 case studies [29][43][45]. In addition, the case studies describe the use of software that does not belong to the PM software niche but is used in PM projects, often in combination with PM software. Some of the tools mentioned are: Jira [54][56] and GitHub [47][54] software development tools, Building Information Modeling (BIM) software [41], Tableau business intelligence and data analysis software [43], as well as the discrete event simulation tool Any Logic [31] and SIMUL8 [44]. In addition, some case studies describe the use of software developed for a specific purpose as part of the research (e.g. IBUPROFEN [52], Sow Compact [53], DeMaPMiner [55], BPM-SCA tool [47] and BJUT modeling platform [56]). For example, M’Baba et al. [50] propose and implement an algorithm to extract Artifact-Centric Event Logs (ACEL) from Ethereum (a blockchain platform) using a node.js application.

C. Discussion

The analyzed case studies show that PM projects are carried out in different industries and with different objectives. It can be concluded that both IT experts and managers have identified use cases and recognized the benefits of PM application to a certain extent. Furthermore, the analysis of the case studies, both from the perspective of the objectives and the context of PM application, shows that the state and trends of the research area are similar to those identified in the literature reviews from earlier periods (as shown in Chapter II).

The analysis of the case studies focused on BPC confirmed earlier findings that the application of PM is possible in various industrial contexts[1]. Furthermore, the results of this research evidence that there is a great interest in the application of PM for BPC in healthcare, which is in line with previous research [6], [58] focusing on different perspectives such as: improving, redesigning and optimizing internal hospital processes [43][44][40], resource allocation [31], cross-organizational process improvement [28], customer experience (i.e., patient experience) evaluation and improvement [29][42], and predicting future change requirements [33]. Despite the different perspectives examined in these studies, there is a common focus on identifying and analyzing time- and resource-related key performance indicators (KPIs), commonly referred to as "operational" KPIs [6].

It is noteworthy that only one study deals with the improvement of cross-organizational processes [28]. The remaining studies focus on individual hospital settings although the potential for the application of cross-organizational PM has been observed [5].

TABLE I. RESULTS OF THE LITERATURE RESEARCH

Ref	Paper			
	Year	*PT*	*Objective/context*	*PM software*
[28]	2020	J	BPC/ HC	ProM
[29]	2020	J	BPC/ HC	Celonis
[46]	2023	J	SE/ web site	ProM
[30]	2019	C	BPC/ help desk	Disco
[31]	2023	J	BPC/ HC	AnyLogic
[32]	2022	J	BPC/ HC	Disco
[33]	2021	J	BPC/ HC	Disco
[17]	2021	C	SE/ Blokchain	ProM
[47]	2022	J	SE/ Microservices	Git, BPM-SCA tool
[34]	2021	J	BPC/ retail	ProM
[48]	2021	C	SE/ GDM	ProM
[35]	2020	J	BPC/ HC	ProM
[36]	2019	J	BPC/ logistics	Disco
[37]	2019	J	BPC/ HC	ProM
[38]	2023	J	BPC/ HC	Disco
[39]	2019	C	BPC/ government	ProM
[40]	2022	J	BPC/ HC	Disco
[49]	2020	J	SE/ subscription software	ProM
[50]	2022	C	SE/ Blockchain	ACEL, node.js application
[51]	2019	J	SE/ software in logistics	Disco
[41]	2021	J	BPC/ project management	BIM
[52]	2019	J	SE/ IS of a bank	IBUPROFEN
[42]	2023	J	BPC/ HE	Disco
[53]	2022	J	SE/ social workflows	SOW Compact
[54]	2022	C	SE/ virtual HC system	Jira and GitHub
[55]	2022	J	SE/ Web site (PEPs)	DeMaP miner, Disco
[43]	2022	J	BPC/ HE	Tableau, Celonis
[44]	2020	J	BPC/ HE	ProM, SIMUL8
[45]	2021	J	BPC/ P-to-P process	Celonis
[56]	2022	J	SE/ software development	JIRA
[56]	2019	J	SE/ user behavior	BJUT modelling platform

According to vom Brocke et al. [59], the "datafication" of people's lives and business processes generates digital traces of user behavior that can be analyzed using PM techniques and tools, not only inside but also outside an organization. Still, there is only one case study in this SLR, which describes the process analysis of a government institution [39]. On the other hand, Thiede et al. [5] emphasize that the use of PM could enable the creation of added value through the development of a "citizen-centric view" at the state level. The user behavior recorded in the event logs is used for various PM perspectives [49][46][57], e.g: process models discovery, business process models conformance, discovery of process variants, but also to find bugs and deviations in the software [47][51][54][56]. These findings are consistent with the conclusion of Urrea-Contreras et al. [60] towards which PM and SE are two disciplines that have the potential for comprehensive theoretical and practical integration. This integration “can lead to a transdisciplinary approach where each discipline contributes essential elements to understand a unified problem” [60].

The results of this SLR on the use of PM in the field of goal dependency modeling [48] confirm the conclusions of Ghasemi and Amyot [2] about “the potentially synergetic effects achievable by combining goal-oriented modelling and PM”. Similarly, several studies have described the successful application of PM in extracting authoritative data from blockchains [50][17] to facilitate the analysis of blockchain applications, and the conclusions are consistent with the research of other authors [20]. Software quality [51], security [50] and process compliance [55] are topics mentioned in connection with PM , which confirms that the PM research area is also linked to GRC and auditing [14][19] [4].

According to the findings of the SLR conducted by Corallo et al. [1] different algorithms are used in PM projects, of which Heuristic Miner is the most commonly used, and this SLR shows similar results. Besides, data collection and pre-processing (e.g. log file preparation, data quality and data extraction) are still considered the most critical and difficult aspects of PM application [51]. Finally, the results of this SLR, according to which ProM is the most commonly used PM software, followed by Disco, are fully consistent with previous research [16][60][1].

V. CONCLUSION

In conclusion, this article presents a systematic literature review (SLR) aimed at exploring the practical application of PM in various industries over the past five years. The study investigates both the objectives of PM implementation and the specific software utilized for this purpose. The analysis of case studies reveals a predominant focus on two main objectives: Business Process Change (BPC) and Software Engineering (SE). ProM emerges as the most frequently employed software, followed by Disco.

The results of the analysis show that the use of PM is not equally widespread in all industrial sectors. In this sense, researchers should work on identifying use cases for the application of PM in different sectors. The development of guidelines for the implementation of PM projects and future research to overcome the issues already identified in the implementation of PM in practice are suggested.

One limitation of this search is that it only included a search for articles in the scientific citation database Clarivate Analytics' Web of Science (WoS). In addition, the results of the SLR can always be influenced by the choice of keywords and the selected inclusion/exclusion criteria of the publications. Future studies should also

include other databases (e.g. Scopus). In order to identify use cases for the application of PM, it is proposed to conduct a qualitative empirical research in the form of semi-structured interviews.

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