A Maturity Level Assessment of Process Mining Bottleneck Analysis Techniques

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ABSTRACT

Solving bottlenecks can increase the performance of processes. One way to detect bottlenecks is by using process mining techniques. This research focuses on bottleneck analysis using process mining. The goal is to provide a way to analyze process mining bottleneck analysis techniques. This is done by presenting a conceptual framework that classifies the state-of-the-art based on how mature a bottleneck analysis by using process mining techniques is conducted. The proposed maturity levels are Detect, Predict, and Recommend. The results indicated that most research is about detecting bottlenecks only, while limited attention is given to prediction and recommendation techniques. Therefore, researching prediction and recommendation techniques is a possible future research direction. The presented framework is validated through a demonstration that shows how process mining bottleneck analysis techniques can be applied in practice. The framework can be used to check for a case which maturity level suits.

Keywords

Process mining, Bottleneck, Maturity level

1. INTRODUCTION

Recently, there was a shortage of toilet paper at the grocery stores. People were buying multiple packs at a time which caused empty shelves. There was more than enough stock available at the warehouses, but the problem was getting the stock from the warehouse to the grocery stores [17]. This problem can be seen as the bottleneck in the process. The problem stated above is just one example of where a bottleneck has an impact on society. One way to detect or analyze bottlenecks is by using process mining. Process mining is a discipline whose goal is to discover, check conformance, or enhance processes by using knowledge extracted from event logs [4]. Process mining is a discipline that has gained a lot of interest lately. From 2007 onwards, many papers about process mining have been published [8]. There is a growing number of information systems, e.g., Enterprise Resource Planning (ERP) systems, and a growing number of data available, because of connected devices and the Internet of Things. Therefore, there is also a growing number of available event logs. Event logs can be subtracted from those systems and then be used for process mining. From an event log, it is possible to discover a process model [2]. Those process models can be used, for example, to detect bottlenecks. This research focusses on bottleneck analysis techniques using process mining. Currently, limited research is conducted concerning bottleneck analysis using process mining. Therefore, first the state-of-the-art concerning bottlenecks and process mining within all domains are examined. Based on the gathered information, a framework is proposed that classifies papers based on the maturity level of the bottleneck analysis process mining techniques used. To validate the research, a proof-of-concept demonstration is given. This demonstration uses a data set provided by Bemthuis et al. [5] that contains data about a logistic process. The goal of the research is to find a way to properly analyze the state-of-the-art concerning bottleneck analysis techniques using process mining.

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2. BACKGROUND

2.1 Process Mining

Process mining is a relatively young discipline that attempts to bridge the gap between data mining and process modeling [2]. The goal of process mining is to discover, check conformance, or enhance processes by using knowledge extracted from event logs [3]. Event logs can be gathered from most information systems (e.g. ERP system) [4]. A process mining tool can transform the data from the event logs into a process model (e.g. a Petri net or a Business Process Model and Notation (BPMN) model). On such a process model, several types of analysis can be performed. It depends on the goal which type of analysis is best to reach that goal.

2.2 Bottlenecks

To find bottlenecks, a clear definition of a bottleneck is needed. There are multiple definitions of bottlenecks. According to Roser [14], bottlenecks are processes that influence the throughput of the entire system. The larger the influence, the more significant the bottleneck [14]. Another word for bottleneck is constraint. In [9], a constraint is described as "anything that limits a system from achieving higher performance versus its goal. Every system should have at least one constraint". Heo defines the bottleneck of a process as "the resource pool that has the minimum capacity among all the resource pools that have been involved in the process" [10]. Based on these three definitions a bottleneck can be described as a process within a system that stops or slows down the entire process. If this bottleneck can be improved, the overall performance of the process will be better, which will e.g. result in a reduced flow time or reduced costs.

2.3 Operational support

The proposed maturity levels, described in chapter 2.4, are partly based on the three types of operational support. Those three types, Detect, Predict, and Recommend are described by Van der Aalst in [2]. Process mining can be used to perform those operational support activities. The first operational support activity is Detect. This activity is about detecting behavior that is different from the modeled behavior [3]. The other two operational support activities are Predict and Recommend. Predictions can help in making decisions about the next step to take (e.g., predict remaining flow time or total costs) [3]. With a recommendation, the system will suggest the best decision based on the goal (e.g. minimize remaining flow time, minimize costs, or resource usage) automatically [3]. A combination of multiple of those goals is also possible [2].

2.4 Maturity levels

One of the concepts used in this research is maturity. We will describe maturity as the extent to which a certain concept is implemented or applied. Maturity can be divided into several levels, the maturity levels. In this research, maturity will mean to which extent bottleneck analysis process mining techniques are applied or used. The least mature activity while analyzing bottlenecks using process mining is detecting where the bottlenecks are. Therefore, the first maturity level will be Detect. This should not be confused with the proposed maturity level detect. With the maturity level Detect, it is purely showing where the bottlenecks are, as where the operational support activity is about detecting behavior that is different from the modeled behavior [3]. It is useful to know where the bottlenecks are, in order to solve them. However, more achievements are possible with process mining, e.g., avoiding the bottlenecks by taking another path. Therefore, there needs to be other maturity levels that describe the full potential of process mining. The other two defined maturity levels are partly based on the three types of operational support as described by Van der Aalst [2]. Process mining can be used to perform those operational support activities. Two of those activities, Predict and Recommend, are suitable as a maturity level into which the state-of-the-art about bottleneck analysis process mining techniques mining can be classified. To visualize this, Predict and Recommend activities can be compared with the functionalities of Google Maps [1]. When traveling from one place to another, Google Maps predicts how long this route will take. When driving and an accident happens on the followed route, Google Maps suggests avoiding the traffic jam, the bottleneck, by suggesting a different route.

3. RESEARCH QUESTIONS

This research aims to provide insights into which process mining techniques concerning bottlenecks have been applied. This might be useful when trying to decide which future research directions to pursue. To this end, a classification scheme for determining to which extent process mining bottleneck techniques are applied is designed. The following main question will be answered:

> **RQ 1** How can process mining bottleneck techniques be analyzed?

The following sub-questions will help to answer the main research question:

> **RQ 1.1** Which bottleneck techniques can be distinguished when applying process mining?

> **RQ 1.2** What are suitable maturity levels for classifying the state-of-the-art about process mining bottleneck techniques?

> **RQ 1.3** What is the state-of-the-art of papers that discuss bottleneck analysis by using process mining techniques?

> **RQ 1.4** How can the techniques related to the proposed maturity levels be applied in practice?

4. RELATED WORK

4.1 Bottleneck detection

There have been several studies on the detection of bottlenecks. In [12], a method is proposed that can be used to detect bottlenecks within modern supply chain networks. That study uses network theory and the method proposed in the paper can be used to find on which supplier a company relies the most and therefore most often is the bottleneck. However, the study only proposes a method to detect one type of bottlenecks. This is limited since with process mining it is possible to detect multiple kinds of bottlenecks.

4.2 Refined process mining framework

The refined process mining framework is described in [1]. One element of the framework consists of activities that can be performed using process mining. These activities are divided into three categories; cartography, auditing, and navigation. Based on the goal, one or multiple activities can be performed. Some activities are related to bottlenecks, e.g. Predict or Recommend activities. However, these activities are general process mining activities and do not show how advanced the application or development of those activities are. The conceptual framework that results from the research is partly based on some of the activities of the refined process mining framework, seen in Figure 1. The conceptual framework can, in contrast to the refined process mining framework, show to which extent process mining activities are applied.

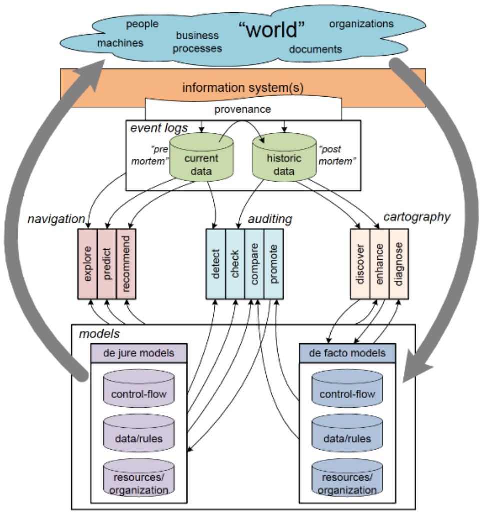

Figure 1. Refined process mining framework [1]

4.3 Tools

Several tools can be used when process mining. The most commonly used tools are ProM [2] and Disco [3]. Disco is a

[1] https://www.google.nl/maps

[2] http://www.promtools.org

[3] https://fluxicon.com/disco

commercial tool whereas ProM is an open-source tool. Disco is rather limited when it comes to functionalities, however, it is easy to use. ProM is an elaborate tool, which has many plug-ins and provides more functionalities. Therefore, ProM is more suitable when diving into the world of process mining.

4.4 Data analytics

In [16], Wang proposes a framework that classifies papers based on three types of data analytics. Descriptive analytics, predictive analytics, and prescriptive analytics. Descriptive analytics makes use of historical data and is useful for identifying problems. Predictive analytics uses algorithms and programming to predict what will happen in the future. With prescriptive analytics, alternative decisions are assessed and the best one is chosen, e.g., to improve business performance. Those three types of data analytics have similarities with the proposed maturity levels and support the conceptual framework proposed in this paper that these are suitable categories to classify the state-of-the-art.

4.5 Contribution

This research will advance the state-of-the-art by presenting a conceptual framework that classifies papers about bottleneck analysis using process mining techniques. A systematic mapping study about process mining techniques and its applications has been carried out by Garcia in [8]. That paper provides an overview of process mining as a whole, including the domains in which process mining is applied and the most mentioned algorithms. However, [8] does not explicitly focus on process mining techniques concerning bottlenecks, as this research does. Based on this conceptual framework, one can check how mature bottleneck analysis techniques are included within the state-of-the-art. This conceptual framework can be used as a direction for future research. Furthermore, a demonstration of how the aforementioned process mining techniques can be applied in practice is given. The majority of the state-of-the-art contain specific case studies (e.g., [7], [15]), while this paper shows a more general approach on how the process mining techniques can be applied in practice.

5. METHODOLOGY

The used methodology for the research is Peffers design science methodology [13]. The identified problem is that right now, the state-of-the-art does not contain a way to analyze process mining bottleneck techniques. To define the objectives of the research, several sub-questions were thought of to help to answer the main question. These sub-questions will help to understand the scope of the research. The third activity was to design a conceptual framework that links the state-of-the-art papers that consider bottleneck analysis using process mining to the determined maturity levels. However, defining the maturity levels was more an iterative process. While assessing the state-of-the-art, new insights arose and the defined maturity levels were updated accordingly.

5.1 Literature review

For assessing the state-of-the-art, a systematic literature review is performed in line with the guidelines proposed by Kitchenham [11].

5.1.1 Search Process

For this research, two databases were examined, Scopus and Web of Science. The original aim of this research was to focus on bottleneck analysis techniques using process mining within the logistics domain and to see how these could be analyzed. However, due to a shortage of available documents concerning bottlenecks and process mining within the logistics domain, it was decided to focus the literature review on all domains.

5.1.2 Selection Criteria

To define the scope of the search, the following search query was used: TITLE-ABS-KEY (("process* mining" OR "workflow* mining") AND (bottleneck*)). This search query, used for both databases, searches in the title, abstract, and keywords. It resulted in a list of documents that concern bottlenecks and process mining, not limited to a certain domain. On Scopus, 111 documents were found. On Web of Science, 67 of those documents were found.

Several inclusion/exclusion criteria were used. All papers that were not written in English were excluded. Only the papers that were accessible online were included. For this research, all found papers could be accessed online. After applying the inclusion and exclusion criteria, the duplicates were removed. This resulted in a list with 98 possibly interesting papers. Sometimes, the database contained twice the same paper, e.g., once as part of a conference and once as a standalone paper. This explains that the number of papers without duplicates was lower than the number of papers found on Scopus. The next step that has been carried out was the first screening based on the title, the abstract, and the keywords. Papers were rejected if the keyword 'bottleneck' was only used as part of an introduction, instead of being the subject of the research. Papers were also rejected if the paper was not about process mining. All other papers were accepted during this first screening round, which resulted in 50 remaining papers.

5.1.3 Determining Relevance

The next round was carrying out a full-text screening. Based on the full text, it could be determined whether a maturity level could be assigned to the paper and which maturity level this should be. Each document was assessed based on the following three criteria. For each maturity level, Detect, Predict, and Recommend, it was checked whether any of the three criteria matched with one of the three maturity levels.

Cr 1 The document does not mention concepts related to bottleneck analysis using process mining;

Cr 2 The document mentions concepts related to bottleneck analysis using process mining;

Cr 3 The document is a complete study about concepts related to bottleneck analysis using process mentions.

If a document with a certain maturity level fulfilled criteria 1, this means that for that maturity level, no relevant concepts concerning bottlenecks and process mining were mentioned. In that case, a score of 0 was assigned. If a document with a certain maturity level matched criteria 2, this means that certain concepts were mentioned that are relevant for that maturity level. In that case, a score of 1 was assigned. Lastly, if a document with a certain maturity level matches criteria 3, this means that certain concepts were mentioned that are relevant for the maturity level and that it is a complete study (e.g., contained a small case study or proof-of-concept demonstration). In that case, it would get a score of 2. For every document, it was observed if one of the maturity levels could be assigned to that document and which score should be assigned. Possibly multiple maturity levels were assigned to the same paper. However, it was never the case that a paper scored a 2 on more than one maturity level. It occurred several times that a paper scored a 2 on one maturity and scored a 1 on one or both of the other maturity levels. Some documents scored a 0 for every maturity level. These documents are excluded from the conceptual framework. The result of the systematic literature review was a list of 45 relevant documents with maturity levels assigned to them. The systematic literature review process can be seen in Figure 2. In Table 1, a visualization of the process explained above can be found.

Table 1. Visualization of the 'Determining the Relevance' process

	Detect	Predict	Recommend
Name of paper	Score {0, 1, 2}	Score {0, 1, 2}	Score {0, 1, 2}

After the systematic literature was carried out, the papers were placed in the framework. Based on the framework, several interesting conclusions could be drawn, which helped with answering the research questions.

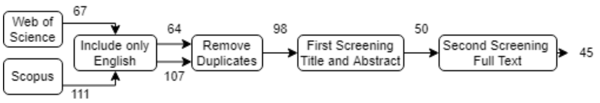

Figure 2. Graphical representation of the systematic literature review, the number represents the number of papers

5.2 Demonstration

How the proposed maturity levels work in practice is showed through a proof-of-concept demonstration. This demonstration first focusses on the first maturity level, detect. It follows the Process Mining Project Methodology, also known as PM^2 [6]. The goal of this demonstration is to show how a bottleneck can be detected using process mining. Knowing where the bottleneck is can help in improving processes. In this case, the bottleneck is the process that has the highest flow time. The dataset used for this demonstration contains data about a logistic process. The dataset is provided by Bemthuis et al. and is also used in [5]. First, the raw data is converted to a CSV file and that file is converted into an event log (XES file). The event log was filtered using the 'Filter Log using Simple Heuristics' plug-in. From this filtered event log, a process model was discovered using the 'Mine Petri net with Inductive Miner' plug-in. This Petri net, together with the event log, can be used for performance and conformance checking. This was done by using the 'Replay a Log on Petri net for Performance/Conformance Analysis'. After using this plug-in, the bottleneck was shown in red within the discovered process model. Further, the demonstration exists of a textual description of how process mining prediction and recommendation techniques can be applied in practice.

6. RESULTS

Maturity levels are used as a way to measure process mining bottleneck techniques. As discussed in chapter two, the determined maturity levels are Detect, Predict, and Recommend. To analyze to what extent those techniques were applied in the state-of-the-art, all papers were scored based on several criteria as described in chapter 5. With the resulting scores, the following conceptual framework that classifies the-state-of-the-art could be constructed, see Table 2.

Table 2. The proposed framework, containing all papers that met criteria 2 or 3

Level 1 Detect	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 36, 37, 39, 40, 41, 43, 44, 45, 46, 47, 48, 49, 50
Level 2 Predict	3, 4, 8, 9, 11, 13, 15, 25, 29, 37, 43, 46, 49
Level 3 Recommend	3, 4, 11, 15, 43, 46

In the table above, every paper that achieved at least a score of 1 for that certain maturity level is included in the framework. Papers can be classified within multiple maturity levels if the aforementioned conditions were fulfilled. The number in the table corresponds with the number of the paper in appendix A. From the table results that 44 papers fit within the first maturity level, 13 within the second level, and only 6 at the most mature level. Therefore it can be said that in the state-of-the-art, detecting bottlenecks using process mining techniques is fairly mature. However, predicting bottlenecks and making recommendations concerning bottlenecks using process mining techniques is currently hardly mature.

Table 3. The proposed framework, containing all papers that met criteria 3

Level 1 Detect	1, 2, 3, 6, 7, 10, 11, 12, 15, 16, 17, 18, 19, 20, 21, 23, 25, 26, 27, 28, 29, 30, 31, 32, 33, 39, 40, 41, 43, 44, 45, 50
Level 2 Predict	8, 9, 13
Level 3 Recommend	-

One of the interesting results gathered from Table 3 is that there has not been a complete study when it comes to making

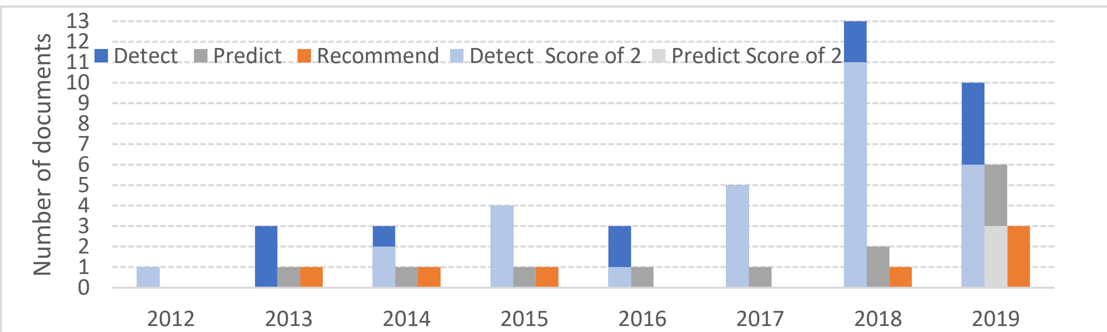

Figure 3. The number of papers per year, if a bar contains two colors, the highest bar indicates the total amount of papers, whereas the smaller bar indicates the number of papers with score 2

recommendations and bottlenecks. Another interesting aspect is that from the 44 papers that detect a bottleneck using process mining, 32 were a complete study. When analyzing the results from the framework, there are several interesting findings if the papers are categorized per year, see Figure 3. The year 2020 was not included since this year is not finished. It seems as if there was an increasing trend in the number of papers that can be classified within the maturity level detect, but that it has reached its top in 2018 and is now decreasing. What also can be seen in Figure 3 is that from 2018 onwards there is an increase in documents that can be classified within the second maturity level, Predict. Therefore it seems that research is shifting from detecting bottlenecks towards making predictions for operational support. Also, a small increase in the number of documents mentioning recommendations can be perceived.

7. DEMONSTRATION

The purpose of this demonstration is to show how process mining techniques related to the proposed maturity levels can be applied in practice. The state-of-the-art mostly contains specific case studies (e.g. [7], [15]). This demonstration shows a more general approach to how process mining bottleneck analysis techniques can be used. The proof-of-concept demonstration first focusses on the first maturity level, Detect. This demonstration is executed using the ProM Lite 1.1 tool. The goal of this demonstration is to show how a bottleneck can be detected using process mining and that the results can be used for improving the process. The dataset used contains data from a logistic process and is provided by Bemthuis et al. [5]. From the systematic mapping of Garcia followed that only 4.67% of the papers about process mining are focused on the logistics domain [8]. This is rather limited, especially compared to the healthcare domain, as 28.03% of the papers about process mining are within the healthcare domain. Therefore, it can be concluded that there is still great potential for future research towards process mining within the logistics domain, hence the reason why this dataset was chosen. Following the steps mentioned in chapter 5.2 resulted in a discovered Petri net, that contains performance data and therefore can show the bottleneck. From the result shown in Figure 4, it follows that the bottleneck, in this case, is present within the transportation processes. If it is known where the bottleneck is located, evasive actions can be taken to avoid the bottleneck, or the process can be improved by eliminating the bottleneck.

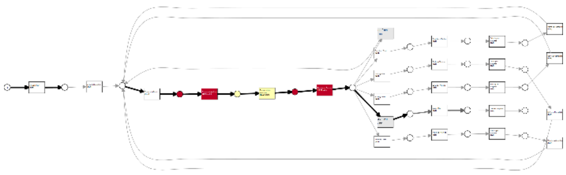

Figure 4. Discovered Petri net with the bottleneck processes shown in red

The detection of the bottleneck in the example above is based on historical data. However, to predict or recommend current data (a partially finished event trace) is needed. In practice, prediction techniques can be used in the following way. Using a process mining tool (e.g., ProM), plug-ins can be used to predict the remaining flow time or predict the total costs. In this case, we assume that a partially finished trace is used and the remaining flow time is predicted. This prediction can be used when making decisions. Based on past experiences, it is known if the predicted remaining flow time is desirable. If a higher than usual remaining flow time is predicted, somewhere down the road a bottleneck will appear. This knowledge can be used to decide which activity is the best next step to take to avoid the bottleneck. Recommending goes one step further. To use recommendation techniques, a partial trace is also needed. Based on the goal, assume that in this case this is the lowest remaining flow time, the system will suggest what will be the best next activity to do, therefore avoiding possible bottlenecks. In this case, this will be the activity that results in the lowest remaining flow time. The benefit of recommendation compared to prediction is that the system will suggest what is the best next step to take automatically. Also, it is possible to make a recommendation based on multiple goals, e.g. a trade-off between minimizing the remaining flow time but also with a minimum total cost.

8. CONCLUSION AND FUTURE WORK

This research focused on a way to analyze the state-of-the-art concerning bottleneck analysis techniques using process mining. Partly based on the operational support activities, three maturity levels, Detect, Predict, and Recommend, were proposed as a way to classify the state-of-the-art. This conceptual framework was validated by a small proof-of-concept demonstration showing how the techniques related to the maturity levels can be applied in practice. To define the maturity levels as well as to classify the state-of-the-art into the maturity levels, a systematic literature review was conducted. The result of the classification gave insights into how mature the state-of-the-art use process mining bottleneck analysis techniques so far. The majority of the documents are about detecting bottlenecks, limited research is done when it comes to predicting and recommending activities.

There are certain limitations when it comes to this research. First, the framework needs more validation. For instance, only a small demonstration was given that showed how the techniques can be applied in practice, whereas the state-of-the-art the majority of the time conducts a full case study. To fully support this conceptual framework, more validation is needed. Another issue might be that the framework is not complete. It was not the intention to provide a conclusive framework, but this research aimed to provide a way to analyze the state-of-the-art. It might be possible that there are more suitable maturity levels. Lastly, although this research is not tailored to a specific domain, one may also want to extend the work with domain-specific bottleneck constructs (e.g., from the logistics discipline). To gain specific future research directions, there should be more specific research within the desired domain.

Multiple possible future research directions result from this research. First, there might be more research done to validate the proposed framework, for example by conducting more elaborate case studies to validate the maturity levels. Another possible research direction is focusing more on prediction and making recommendations by using process mining. Currently, the number of documents published concerning those subjects are lagging compared to the number of documents that are about detecting bottlenecks. Further, this researched used a dataset containing data from the logistics domain. In the future, it can be interesting to use datasets from other domains as well to gain more specific knowledge.

This study attempted to provide a framework that classified the state-of-the-art about bottleneck analysis process mining techniques. Future research is necessary to overcome its limitations and to provide more knowledge when it comes to prediction and recommendation techniques.

9. ACKNOWLEDGMENTS

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APPENDIX

A. RESULTS FULL-TEXT SCREENING

This table contains a list of the papers that were screened during the full-text screening and which scores were assigned to each maturity level. The table is first ordered based on a descending year of publication and then alphabetically based on the author's last name. Five of the documents in the table below are excluded from the framework proposed in the research because those documents got assigned a score of 0 on all maturity levels.

#	Authors	Title	Year	Detect	Predict	Recommend
1	S. Kouhestani and M. Nik-Bakht	IFC-based process mining for design authoring	2020	2		
2	I. E. Yazici and O. Engin	Use of process mining in bank real estate transactions and visualization with fuzzy models	2020	`2		
3	J. A. Aguirre, A. C. Torres, M. E. Pescoran, and S. A. Mayorga	Evaluation of operational process variables in healthcare using process mining and data visualization techniques	2019	2	1	1
4	R. Ahmed, M. Faizan, and A. I. Burney	Process Mining in Data Science: A Literature Review	2019	1	1	1
5	M. G. Dorrer, A. A. Popov, and A. N. Bartuzanova	Analysis of information resource life cycle	2019			
6	A. S. Dzihni, R. Andreswari, and M. A. Hasibuan	Business process analysis and academic information system audit of helpdesk application using genetic algorithms a process mining approach	2019	2		
7	I. A. Fitriansah, R. Andreswari, and M. A. Hasibuan	Business process analysis of academic information system application using process mining (case study: Final project module)	2019	2		
8	L. Galdo Seara and R. M. De Carvalho	An approach for workflow improvement based on outcome and time remaining prediction	2019	1	2	
9	G. Li and R. M. De Carvalho	Process Mining in Social Media: Applying Object-Centric Behavioral Constraint Models	2019	1	2	
10	R. A. Quintano Neira et al.	Analysis and Optimization of a Sepsis Clinical Pathway Using Process Mining	2019	2		
11	A. H. M. Shani, R. Sarno, K. R. Sungkono, and C. S. Wahyuni	Time Performance Evaluation of Agile Software Development	2019	2	1	1
12	S.-C. Shin, S. Y. Kim, C.-M. Noh, S.-S. Lee, and J.-C. Lee	Manufacturing process improvement of offshore plant: Process mining technique and case study	2019	2		
13	Y. Spenrath and M. Hassani	Ensemble-based prediction of business processes bottlenecks with recurrent concept drifts	2019		2	
14	Q. Wu, Z. He, H. Wang, L. Wen, and T. Yu	A business process analysis methodology based on process mining for complaint handling service processes	2019	1		
15	J. A. Caballero-Hernández, J. M. Dodero, I. Ruiz-Rube, M. Palomo-Duarte, J. F. Argudo and J. J. Domínguez-Jiménez	Discovering Bottlenecks in a Computer Science Degree through Process Mining techniques	2018	2	1	1
16	R. Anggrainingsih, B. O. P. Johannanda, and D. E. Cahyani	Business process evaluation of outpatient services using process mining	2018	2		

17	Y. Caesarita, R. Sarno, and K. R. Sungkono	Identifying bottlenecks and fraud of business process using alpha ++ and heuristic miner algorithms (Case study: CV. Wicaksana Artha)	2018	2		
18	K. Ganesha, S. M. Swapnil Raj, and S. Dhanush	Process mining approach for efficient utilization of resources in a hospital	2018	2		
19	R. Gerhardt, J. F. Valiati, and J. V dos Santos	An Investigation to Identify Factors that Lead to Delay in Healthcare Reimbursement Process: A Brazilian case	2018	2		
20	J. Gonzalez-Dominguez and P. Busch	Automated business process discovery and analysis for the international higher education industry	2018	2		
21	G. Heo, J. Lee, and J.-Y. Jung	Analyzing bottleneck resource pools of operational process using process mining	2018	2		
22	J. Jesus Roldan, M. A. Olivares-Mendez, J. del Cerro, and A. Barrientos	Analyzing and improving multi-robot missions by using process mining	2018	1		
23	A. Meincheim, C. D. S. Garcia, J. C. Nievola, and E. E. Scalabrin	Combining process mining with trace clustering: Manufacturing shop floor process-an applied case	2018	2		
24	R. Rahardianto, R. Sarno, and G. Intani Budiawati	Performance Time Evaluation of Domestic Container Terminal Using Process Mining and PERT	2018	1		
25	R. Ribeiro, C. Analide, and O. Belo	Improving productive processes using a process mining approach	2018	2	1	
26	C. Satitcharoenmuang, P. Porouhan, A. Nammakhunt, N. Saguansakiyotin, and W. Premchaiswadi	Benchmarking efficiency of children's garment production process using alpha and ILP replayer techniques	2018	2		
27	A. Stefanini, D. Aloini, E. Benevento, R. Dulmin, and V. Mininno	Performance analysis in emergency departments: a data-driven approach	2018	2		
28	W. Abo-Hamad	Patient pathways discovery and analysis using process mining techniques: An emergency department case study	2017	2		
29	O. Belo, N. Dias, C. Ferreira, and F. Pinto	A process mining approach for discovering ETL black points	2017	2	1	
30	K. Ganesha, S. Dhanush, and S. S. M. Raj	An Approach to Fuzzy Process Mining to Reduce Patient Waiting Time in a Hospital	2017	2		
31	E. R. Mahendrawathi, S. O. Zayin, and F. J. Pamungkas	ERP Post Implementation Review with Process Mining: A Case of Procurement Process	2017	2		
32	S. Shrivastava and S. N. Pal	A big data analytics framework for enterprise service ecosystems in an e-Governance scenario	2017	2		
33	P. Juneja, D. Kundra, and A. Sureka	: An Algorithm and Case-Study on Improving the Goodness of Software Process Models Generated by Mining Event-Log Data in Issue Tracking Systems	2016	2		

34	A. Leppäkoski and T. D. Hämäläinen	PROMOTE: A process mining tool for embedded system development	2016			
35	A. Meethip, P. Arpasat, and W. Premchaiswadi	Performance analysis of a bank call canter customer service using Fuzzy Miner technique	2016			
36	N. Saelim, P. Porouhan, and W. Premchaiswadi	Improving organizational process of a hospital through Petri-net based repair models	2016	1		
37	A. Senderovich et al.	Conformance checking and performance improvement in scheduled processes: A queueing-network perspective	2016	1	1	
38	T. Toyawanit and W. Premchaiswadi	Applying inductive Visual Miner technique to analyze and detect problems in procedures of a hospital in Thailand	2016			
39	E. R. Mahendrawathi, H. M. Astuti, and I. R. K. Wardhani	Material movement analysis for warehouse business process improvement with process mining: A case study	2015	2		
40	P Porouhan, N Jongsawat, and W Premchaiswadi	Process and deviation exploration through Alpha-algorithm and Heuristic miner techniques	2015	2		
41	W. Premchaiswadi and P. Porouhan	Process modeling and bottleneck mining in online peer-review systems	2015	2		
42	W. Premchaiswadi and P. Porouhan	Process simulation and pattern discovery through alpha and heuristic algorithms	2015			
43	B. Trinkenreich, V. T. F. Confort	using business process intelligence to support incident management metrics selection and service improvement	2015	2	1	1
44	M. Gupta and A. Sureka	Nirikshan: Mining bug report history for discovering process maps, inefficiencies and inconsistencies	2014	2		
45	M. Gupta, A. Sureka, and S. Padmanabhuni	Process mining multiple repositories for software defect resolution from control and organizational perspective	2014	2		
46	W. M. P. van der Aalst	Process mining in the large: A tutorial	2014	1	1	1
47	R. P. J. C. Bose, F. M. Maggi, and W. M. P. Van Der Aalst	Enhancing declare maps based on event correlations	2013	1		
48	S.-K. Lee, B. Kim, M. Huh, S. Cho, S. Park, and D. Lee	Mining transportation logs for understanding the after-assembly block manufacturing process in the shipbuilding industry	2013	1		
49	M. Spott, D. Nauck	Modern analytics in field and service operations	2013	1	1	
50	S. Anuwatvisit, A. Tungkasthan, and W. Premchaiswadi	Bottleneck mining and Petri net simulation in education situations	2012	2		