A Classification of Process Mining Bottleneck Analysis Techniques for Operational Support

Rob Bemthuis[1][a], Niels van Slooten[1][b], Jeewanie Jayasinghe Arachchige[2][c], Jean Paul Sebastian Piest[1][d] and Faiza Allah Bukhsh[1][e]

[1] *University of Twente, Drienerlolaan 5, 7522 NB, Enschede, The Netherlands*

[2] *University of Ruhuna, Matara, Sri Lanka*

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Abstract: A bottleneck usually is a sub-process in the main process which delays the process. The performance of a process can be increased by eliminating the bottlenecks. To this end, opportunities to analyze and mitigate bottlenecks by using process mining techniques can be an interesting direction to utilize. This paper aims to classify literature on process mining bottleneck analysis techniques and propose a model for operational support regarding bottleneck analysis utilizing process mining. To this end, we first propose a model for classifying bottleneck analysis techniques. Then, we conduct a systematic literature review to identify existing papers that address bottleneck analysis by utilizing process mining techniques. The results indicate that many researchers are focusing on detecting bottlenecks, while limited attention is paid to predicting bottlenecks or recommending actions on what to do with bottlenecks. The proposed classification model is validated through a demonstration, showing how process mining bottleneck analysis techniques can be applied to a logistics case study.

1 INTRODUCTION

There are many bottlenecks that can impede the efficient functioning of processes. If no action is taken, a bottleneck can cause delays, impact productivity, and waste resources. There is a multitude of reasons why a bottleneck may develop, but the effects it can have are almost always negative. For example, a big container ship was blocking global traffic (Samaan et al., 2021), causing a significant backlog of ships waiting in the area. More generally, bottlenecks determine the throughput of a process. The resources that require the longest time in operations play a critical role in mitigating bottlenecks. It is key to know what causes bottlenecks and how to address them.

One way to detect or analyze bottlenecks is by using process mining. Process mining is a discipline that aims to discover, check conformance, and enhance processes by using knowledge extracted from event logs (Van der Aalst et al., 2010). Event logs are used to discover a process model (Van der Aalst, 2016). In turn, those process models can be used to analyze bottlenecks.

Bottleneck analysis have been performed in several domains, such as concurrent environments (Chen et al., 2020), traffic monitoring (Dabir and Matrawy, 2007), and supply chains (Buddas, 2014; Subramaniyan et al., 2018). However, to our knowledge, limited research has been done on the identification and resolution of bottlenecks by utilizing process mining. Therefore, the objective of this paper is to map papers that utilize process mining for the analysis of bottlenecks. We focus on the use of process mining for operational support (see Section 2). To achieve this goal, we first propose a model for classifying bottleneck analysis techniques. Then, we conduct a systematic literature study on existing papers and, consequently, map the papers to the classification model. As a means of validating the proposed model, we give a demonstration of a logistics case study. The contribution of this paper is threefold: (1) a bottleneck classification model, (2) a literature mapping, and (3) preliminary insights in the state of research on process mining techniques concerning bottleneck analysis.

Let us briefly address some related work. A recent systematic mapping study about process mining techniques and their applications has been carried out by Garcia in (dos Santos Garcia et al., 2019). That

[a] https://orcid.org/0000-0003-2791-6070
[b] https://orcid.org/0000-0003-4403-3149
[c] https://orcid.org/0000-0001-8619-6523
[d] https://orcid.org/0000-0002-0995-6813
[e] https://orcid.org/0000-0001-5978-2754

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paper provides an overview of domains in which process mining is applied and the used algorithms. In (Jacobi et al., 2020), a maturity model is proposed for the application of process mining in supply chains. Their work mainly focuses on the transport and logistic domain. Although this can indicate that the logistic domain seems a promising demarcation, supported by other initiatives such as the open trip model (Piest et al., 2021), we do not restrict ourselves to a particular domain. Furthermore, both works do not focus on process mining techniques concerning bottlenecks. A classification model could be useful, because one may check how mature bottleneck analysis techniques are within the state-of-the-art. Our classification can also be used as a direction for future research. Furthermore, we describe a brief case study for demonstrating our classification model. The majority of papers that address bottleneck analysis by using process mining contain specific case studies (e.g., (Stefanini et al., 2018; Seara and De Carvalho, 2019)), while our paper shows a more general approach on how the process mining techniques can be applied to address multiple views on bottleneck analysis.

The used methodology for the present work is the design science research methodology (Peffers et al., 2007). Figure 1 explains the methodology in detail. Above, we addressed the problem identification and objective of this position paper. Section 2 addresses background materials. In Section 3, we describe the proposed model for classifying bottleneck analysis techniques that use process mining. Section 4 discusses the systematic literature review and findings with respect to the mapping. To validate the proposed model (i.e., the artifact), a demonstration is given in Section 5. Finally, Section 6 concludes this paper.

2 BACKGROUND

Process mining is a relatively young discipline that attempts to bridge the gap between data mining and process modeling (Van der Aalst, 2016). The goal of process mining is to discover, check conformance, or enhance processes by using knowledge extracted from event logs (Van der Aalst et al., 2011). Event logs can be gathered from information systems (e.g., ERP system) (Van der Aalst et al., 2010). Consequently, process mining discovery algorithms can transform the data from the event logs into a process model. With these process models bottlenecks can be identified. In the following subsections, we will define and discuss bottlenecks and bottleneck classification levels.

2.1 Bottlenecks

There have been several studies performed on bottleneck analysis. For example, in (Mizgier et al., 2013), a method is proposed that can be used to detect bottlenecks within supply chain networks. That study uses network theory and their proposed method can be used to find on which supplier a company relies the most and, therefore, might be a bottleneck. This study focuses on classifying the bottlenecks.

To find bottlenecks, a clear definition of a bottleneck is needed. There are multiple definitions of bottlenecks. According to Roser, bottlenecks are processes that influence the throughput of the entire system (Roser et al., 2015). The larger the influence, the more significant the bottleneck. The concept bottleneck might also be linked to constraint. In (Heo et al., 2018), 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” (Heo et al., 2018). Based on these definitions, a bottleneck can be described as a subprocess within a system that stops or slows down the entire process. If this bottleneck can be improved, the overall performance of the process can become better, which can result in, e.g., increased performance or reduced costs.

2.2 Classification Phases

One of the concepts used in this research is classification. We will describe classification as the extent to which a certain concept is implemented or applied. In this research, classification will mean how far bottleneck analysis and resolution steps have been applied. We define three phases of classification, based on operational support as described by Van der Aalst (Van der Aalst, 2016): detect, predict, and recommend.

As a first step, it is important to identify the bottleneck. Therefore, the first classification phase will be to detect. Bottleneck identification provides the foundation towards many improvement paths, such as avoiding and resolving bottlenecks. The second phase includes the prediction of bottlenecks. That is, saying or estimating that a bottleneck will happen in the future (or that it will be a consequence of something). The third classification phase involves recommendation, which is about suggesting that someone or something would be suitable for managing (e.g., mitigating) a bottleneck, or to suggest that a particular action

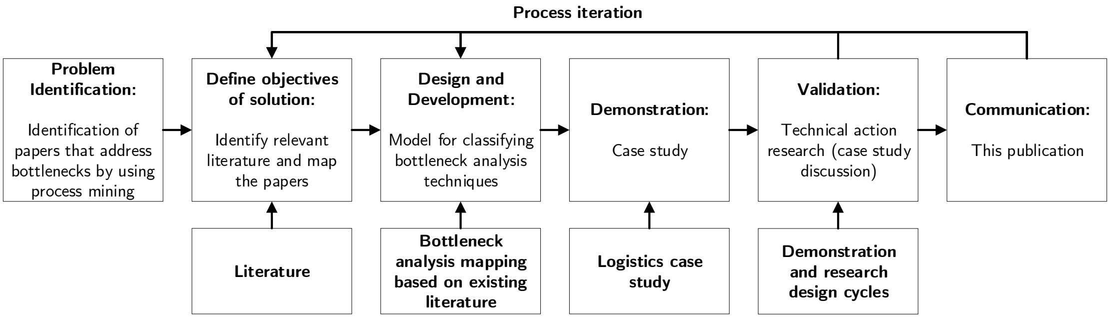

Figure 1: Research methodology.

should be done. An example is a route planning algorithm that can predict how long a route will take or that can suggest avoiding a sudden traffic jam (e.g., the bottleneck) by taking a different route.

3 BOTTLENECK CLASSIFICATION MODEL

Our model, which we describe hereafter, is based on activities of the refined process mining framework. The refined process mining framework is described in (Van der Aalst, 2011). 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. Some activities can be related to bottlenecks, e.g., to predict or recommend certain activities. However, these activities are general process mining activities and do not show how advanced the application or development of those activities with respect to bottlenecks are. Our model can show to which extent process mining activities are applied.

Figure 2 presents our proposed bottleneck classification model. The model relies on one of the fundamentals of process mining, namely event logs. Based on event logs, process mining can be used to extract data about what happened in a process and when. These event logs are the input for what we describe as the Business Process Management (BPM) step. BPM covers the design, implementation, usage, and adjustment of processes from end to end. It concerns techniques to better organize and automate operational processes and keeping operations aligned with goals and strategies. We used BPM here and not, for example, process mining only, because (1) we do not want to limit ourselves to process model and event log analysis only and (2) BPM covers a broader field of study including also KPIs which go beyond the typical considerations within the process mining discipline.

The classification phases shown in Figure 2 are

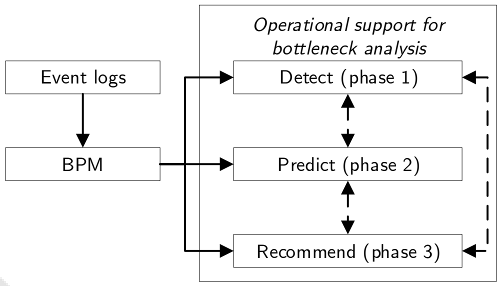

Figure 2: Bottleneck analysis classification model.

based on the three types of operational support: detect, predict, and recommend, as described by Van der Aalst in (Van der Aalst, 2016). Process mining can be used to perform those operational support activities. The first operational support activity is detecting bottlenecks. This activity is about detecting behavior that is different from the modeled behavior (Van der Aalst et al., 2011). The other two operational support activities are predicting and recommending. Predictions can help in making decisions about the next step to take (e.g., predict remaining flow time or total costs) (Van der Aalst et al., 2011). With a recommendation, the system will suggest the best decision based on a goal (e.g. minimize remaining flow time, minimize costs, or resource usage) automatically (Van der Aalst et al., 2011). A combination of multiple goals is also possible (Van der Aalst, 2016).

4 LITERATURE REVIEW

In this section, we describe the literature review conducted to gather papers of relevance. We followed the guidelines for performing a systematic literature review as proposed by Kitchenham (Kitchenham, 2004). Below, we first describe the search process. Then, we discuss the assessment criteria for determining relevant papers. This section closes with discussing the findings.

4.1 Search Process

An overview of the literature search process is shown in Figure 3. Two scientific article databases were examined, namely Scopus and Web of Science. As the initial step of the selection, a search query was defined as TITLE-ABS-KEY ((“process* mining” OR “workflow* mining”) AND (bottleneck*)) covering the search in the title, abstract, and keywords. There were 111 and 67 research articles found in Scopus and Web of Science respectively.

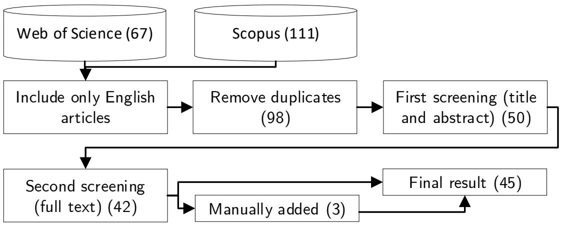

Figure 3: Literature review process.

Following inclusion and exclusion criteria, the search result was narrowed down by excluding non-English articles and eliminating duplication. Among the rest of the articles, on-line accessible papers were included which has concluded to 98 papers.

As a result of a first screening, based on the title, the abstract, and the keywords, several papers were excluded due to insufficient details of the required context. More precisely, 48 papers were excluded that do not address topics of process mining. After the first screening, only 50 papers were selected for further study.

4.2 Determining Relevance

In the next step, a full-text screening was carried out. The papers were screened under three criteria to check if and, possibly, to which degree the papers cover any of the classification phases. That is, we assessed the “maturity” of the phases detect, predict and recommend according to three criteria. The criteria are as follows:

- **Criteria 0:** The document does not mention concepts related to bottleneck analysis using process mining.
- **Criteria 1:** The document describes concepts related to bottleneck analysis using process mining.
- **Criteria 2:** The document is a complete study related to bottleneck analysis using process mining.

Each paper was assessed based on the criteria. Each paper was assessed by two authors and in the case no consensus was reached, a third author was involved. The results are discussed in the next subsection. The papers which are assigned to criteria 0 for all the phases, were not relevant for our study and are, therefore, eliminated from the sample set. The result of the systematic literature review was a list of 42 relevant documents with an indication of which extend bottleneck analysis techniques using process mining were addressed. Additionally, we added three papers that were suggested by the authors of this paper (Bemthuis et al., 2019; Badakhshan and Alibabaei, 2020; Bemthuis et al., 2020). The papers from (Bemthuis et al., 2019; Bemthuis et al., 2020) were added because some of the authors and project partners are also involved in the present work and considered the papers as relevant within the realm of the present paper. Although those papers did not explicitly focus on the term bottleneck, a manual assessment and discussion among the authors resulted in the inclusion. The usefulness of (Bemthuis et al., 2019) is also illustrated in the demonstration of Section 5.

4.3 Findings

Following the three criteria proposed in the previous section, we classified all the filtered papers using the three phases (detect, predict and recommend). However, as we have to align with the limited number of pages, only the summary of the classification is described in this section. The results show that none of the papers satisfied criteria 2 for all three bottleneck phases. There were papers that are aligned with criteria 2 for one classification phase and criteria 1 for other classification phases.

Table 1 shows the papers that meet criteria 1 and Table 2 shows the papers that meet criteria 2. It can be observed that some papers (e.g., (Van der Aalst, 2013; Trinkenreich et al., 2015)) were classified into multiple maturity phases. The results show that 44 unique papers are classified to the first phase (detect), 14 unique papers were classified to the second phase (predict) and only 7 unique papers were at phase three (recommend). Therefore, it may be observed that detecting bottlenecks using process mining techniques is fairly mature.

The papers classified according to criteria 1 are depicted in Table 1. A total of 17 papers match this criteria, and out of that 11 and 9 papers have discussed the bottleneck phase 1 and 2 respectively. Only 6 papers are classified into the phase 3. Some of the papers are classified into more than one phases, such as (Van der Aalst, 2013; Spott et al., 2013; Trinkenreich et al., 2015).

This study found that 36 papers can be catego-

Table 1: Papers that meet criteria 1, categorized per year.

Year	Phase 1: detect	Phase 2: predict	Phase 3: recommend	Number of unique papers
2012	-	-	-	0
2013	(Bose et al., 2013; Lee et al., 2013; Spott et al., 2013; Van der Aalst, 2013)	(Spott et al., 2013; Van der Aalst, 2013)	(Van der Aalst, 2013)	4
2014	-	-	-	0
2015	-	(Trinkenreich et al., 2015)	(Trinkenreich et al., 2015)	1
2016	(Saelim et al., 2016; Senderovich et al., 2016)	(Senderovich et al., 2016)	-	2
2017	-	(Belo et al., 2017)	-	1
2018	(Roldán et al., 2018)	(Caballero-Hernández et al., 2018; Ribeiro et al., 2018)	(Caballero-Hernández et al., 2018)	3
2019	(Li and De Carvalho, 2019; Wu et al., 2019; Seara and De Carvalho, 2019)	(Armas et al., 2019; Shani et al., 2019)	(Armas et al., 2019; Shani et al., 2019)	5
2020	(Bemthuis et al., 2020)	-	(Bemthuis et al., 2020)	1
Total	11	9	6	17

rized under criteria 2. However, the majority of them are classified only to the detect phase. Table 2 shows the papers which have a complete study on bottleneck analysis at the detect, predict and recommend phases. Yet, in 2019 a series of papers were using process mining addressing the predict phase (Ahmed et al., 2019; Seara and De Carvalho, 2019; Li and De Carvalho, 2019; Neira et al., 2019; Spenrath and Hassani, 2019). Only 1 paper (Ahmed et al., 2019) covers the recommendation phase. Therefore, it can be observed that predicting bottlenecks and making recommendations using process mining techniques are only marginally addressed in the literature.

5 DEMONSTRATION

This section demonstrates how process mining bottleneck analysis techniques can be applied in a case study. This demonstration entails a way to validate the artifact, intending to discuss how the three phases of bottleneck analysis could be examined. More precisely, we demonstrate how the detect phase can be operationalized. We further describe how the predict and recommend phase may be executed.

We use a logistic case study of (Bemthuis et al., 2019), involving event logs of activities that took place during the movements of Autonomous Guided Vehicles (AGVs). Collaborative AGVs make sure that products flow from a start station to one or more intermediate stations and, ultimately, reach a final station.

It would be of interest to know what bottlenecks exist and how bottlenecks could play a role in obtaining an efficient workflow of the AGVs as well as the throughput of the system. Systems using AGV technology are known for their complexity and can involve many aspects such as vehicle scheduling, vehicle routing, conflict resolution, obstacle avoidance, and battery management. Bottlenecks hindering an effective workflow may be present in any of these circumstances. Let us consider a bottleneck as an activity that is causing a relatively high throughput time of the products.

Please notice that below we give some hypothetical examples supported by the case study. These examples may not fully represent practice, because one may base the actual implementations/decisions on the business logic of the use case. Instead, we decide to illustrate the functioning of process mining bottleneck techniques by using examples. This can be justified because of (1) the limited amount of mature literature on predict and recommend techniques, (2) the demonstration fulfills a proof-of-concept implementation only and not a thorough validation study (hence, this paper only outlines intentions regarding a particular matter), and (3) the data relies on a simulation model resembling a simplified optimization problem, which is easily verifiable.

For the execution of process mining algorithms, we used the ProM Lite 1.1 tool. We pre-processed the raw data by first converting the CSV-file to a standard format for event log files (XES-file). Consequently,

Table 2: Papers that meet criteria 2, categorized per year.

Year	Papers	Number of unique papers
2012	**Phase 1:** (Anuwatvisit et al., 2012)	1
2013	-	0
2014	**Phase 1:** (Porouhan et al., 2014; Gupta and Sureka, 2014; Gupta et al., 2014)	3
2015	**Phase 1:** (Mahendrawathi et al., 2015; Premchaiswadi and Porouhan, 2015; Trinkenreich et al., 2015)	3
2016	**Phase 1:** (Juneja et al., 2016)	1
2017	**Phase 1:** (Caesarita et al., 2017; Ganesha et al., 2017b; Meincheim et al., 2017; Abo-Hamad, 2017; Belo et al., 2017; Ganesha et al., 2017a; Mahendrawathi et al., 2017; Shrivastava and Pal, 2017)	8
2018	**Phase 1:** (Caballero-Hernández et al., 2018; Gerhardt et al., 2018; Gonzalez-Dominguez and Busch, 2018; Heo et al., 2018; Rahardianto et al., 2018; Ribeiro et al., 2018; Stefanini et al., 2018)	7
2019	**Phase 1:** (Bemthuis et al., 2019; Armas et al., 2019; Ahmed et al., 2019; Dzihni et al., 2019; Fitriansah et al., 2019; Shani et al., 2019; Neira et al., 2019) **Phase 2:** (Ahmed et al., 2019; Seara and De Carvalho, 2019; Li and De Carvalho, 2019; Neira et al., 2019; Spenrath and Hassani, 2019) **Phase 3:** (Ahmed et al., 2019)	10
2020	**Phase 1:** (Kouhestani and Nik-Bakht, 2020; Badakhshan and Alibabaei, 2020; Yazici and Engin, 2020)	3
Total	-	36

we filtered the event log using the ‘Filter Log using Simple Heuristics’ plug-in.

Let us start with the **bottleneck detection**. From the filtered event log, we discovered a process model using the inductive miner plug-in. Then, the constructed Petri net and the event log are used for performance and conformance checking by using the ‘Replay a Log on Petri net for Performance/Conformance Analysis’ plug-in. The resulting model is shown in Figure 4 (for illustration purposes).

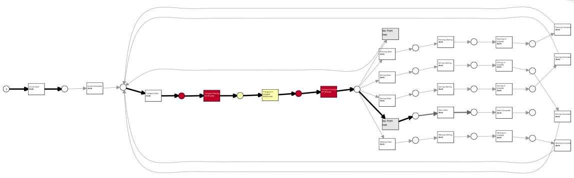

Figure 4: Discovered Petri net indicating bottlenecks.

The figure indicates (with red color) that there are bottlenecks present within the transportation process. Identifying bottlenecks is a first step to identify improvement potential. One may for instance come up with evasive actions that go beyond the use/exploit of event logs only. For instance enforcing new strategies to shorten the time-span of a particular activity (e.g., better collision avoidance maneuvers). Yet, the maturity phase detect is solely about the identification of one or more (potential) bottlenecks.

Bottleneck Prediction can be considered as follows. Using a process mining tool (e.g., ProM), one can predict the remaining throughput time. Suppose that a trace is partially finished and that the remaining time in the system of a product can be predicted. This predicted remaining time can be used when making projections of what is going to happen and, consequently, support in making better-informed decisions. For example, based on past experiences one may observe that the predicted remaining time of a product to be finished is too high. This insight can be used to decide which activity (or intervention) could be incorporated to eliminate or reduce a bottleneck’s obstructive impact.

Consider the visualized process model of Figure 5. Suppose that a product is planned to go from the sawing activity to the painting activity. After the product has been processed at the sawing station, an AGV decides to pick up this product. Imagine now that another AGV’s events log indicates that the route in-between those two stations is suddenly facing traffic congestion. Hence, the expected remaining time in the system for this product has increased.

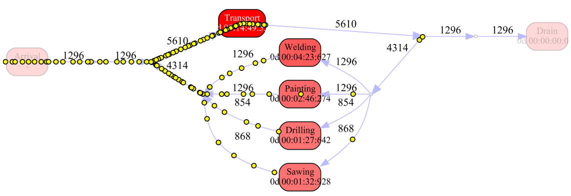

Figure 5: Visualized process model indicating sojourn times per activity.

As **bottleneck recommendation** technique, consider again the example above of a partially finished trace. The approach could suggest what is the best activity to do while taking into account the (accumulated) effects of bottlenecks or expected bottlenecks. A strategy could include avoiding bottlenecks as much as possible. In the example of Figure 5, one could decide to change the sequence of visiting the processing stations. For example, the AGV can decide to travel first to the drilling station instead of the painting station. In the recommendation approach, one can base decisions on multiple goals, such as a trade-off between minimizing the remaining time in the system versus the total costs. It may be promising to deploy such decision-making capabilities by using agent-based modeling techniques, such as shown in (Bemthuis et al., 2020).

6 CONCLUSION

This paper gives an overview of literature on bottleneck analysis techniques utilizing process mining. Based on operational support activities, we proposed a classification model to categorize papers. The classification model entails three phases: detect, predict, and recommend. A systematic literature review was conducted to identify relevant papers that could be categorized according to the bottleneck "maturity" phases. Lastly, a demonstration showed how the three phases of bottleneck analysis could be considered.

The results give insights into how mature the literature is on process mining bottleneck analysis techniques. The majority of the papers are about detecting bottlenecks, while limited research is done when it comes to predicting and recommending activities. With a demonstration, we aimed to provide a direction on how bottlenecks can be detected and predicted, but also what next steps could be done to, ultimately, mitigate the impact of bottlenecks or prevent the occurrence of bottlenecks. Despite its exploratory nature, this study offers some insight into how bottlenecks could be classified, how mature the literature is, and what research directions were given limited attention.

There are certain limitations when it comes to this research. The model needs more validation. There may be more suitable maturity phases. Also, only a concise demonstration was given that showed how the techniques can be applied, whereas a comprehensive case study based on real-life data could be more valuable. Another issue concerns that the model may not be complete. However, it was not the intention to provide a conclusive model, but this research provides a way to analyze the state-of-the-art.

A possible direction for future research, which resulted from our literature study, is to focus more on prediction and making recommendations on bottlenecks by using process mining. Currently, the number of papers in that regard is limited. Lastly, the development of a taxonomy or implementation guidance based on the classification model may be promising.

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REFERENCES

Abo-Hamad, W. (2017). Patient pathways discovery and analysis using process mining techniques: An emergency department case study. In *International Conference on Health Care Systems Engineering*, pages 209–219. Springer.

Ahmed, R., Faizan, M., and Burney, A. I. (2019). Process mining in data science: A literature review. In *2019 13th International Conference on Mathematics, Actuarial Science, Computer Science and Statistics (MACS)*, pages 1–9. IEEE.

Anuwatvisit, S., Tungkasthan, A., and Premchaiswadi, W. (2012). Bottleneck mining and petri net simulation in education situations. In *2012 Tenth International Conference on ICT and Knowledge Engineering*, pages 244–251. IEEE.

Armas, J., Aguirre, S., Coronado, A., and Evangelista, M. (2019). Evaluation of operational process variables in healthcare using process mining and data visualization techniques. In *Proceedings of the 17th LACCEI International Multi-conference for Engineering, Education and Technology. Latin American and Caribbean Consortium of Engineering Institutions, Montego Bay*.

Badakhshan, P. and Alibabaei, A. (2020). *Using Process Mining for Process Analysis Improvement in Prehospital Emergency*, pages 567–580. Springer International Publishing, Cham.

Belo, O., Dias, N., Ferreira, C., and Pinto, F. (2017). A process mining approach for discovering etl black points. In *World Conference on Information Systems and Technologies*, pages 426–435. Springer.

Bemthuis, R., Mes, M., Iacob, M.-E., and Havinga, P. (2020). Using agent-based simulation for emergent behavior detection in cyber-physical systems. In *2020 Winter Simulation Conference (WSC)*, pages 230–241.

Bemthuis, R. H., Koot, M., Mes, M. R., Bukhsh, F. A., Iacob, M.-E., and Meratnia, N. (2019). An agent-based process mining architecture for emergent behavior analysis. In *2019 IEEE 23rd International Enterprise Distributed Object Computing Workshop (EDOCW)*, pages 54–64. IEEE.

Bose, R. J. C., Maggi, F. M., and van der Aalst, W. M. (2013). Enhancing declare maps based on event correlations. In *Business process management*, pages 97–112. Springer.

Buddas, H. (2014). A bottleneck analysis in the ifrc supply chain. *Journal of Humanitarian Logistics and Supply Chain Management*.

Caballero-Hernández, J. A., Dodero, J. M., Ruiz-Rube, I., Palomo-Duarte, M., Argudo, J. F., and Domínguez-Jiménez, J. J. (2018). Discovering bottlenecks in a computer science degree through process mining techniques. In *2018 International Symposium on Computers in Education (SIIE)*, pages 1–6. IEEE.

Caesarita, Y., Sarno, R., and Sungkono, K. R. (2017). Identifying bottlenecks and fraud of business process using alpha++ and heuristic miner algorithms (case study: Cv. wicaksana artha). In *2017 11th International Conference on Information & Communication Technology and System (ICTS)*, pages 143–148. IEEE.

Chen, D., Li, H., Chen, M., Dai, Z., Li, H., Zhu, M., and Zhang, J. (2020). Pebao: A performance bottleneck analysis and optimization framework in concurrent environments. In Silhavy, R., editor, *Intelligent Algorithms in Software Engineering*, pages 248–260, Cham. Springer International Publishing.

Dabir, A. and Matrawy, A. (2007). Bottleneck analysis of traffic monitoring using wireshark. In *2007 Innovations in Information Technologies (IIT)*, pages 158–162.

dos Santos Garcia, C., Meincheim, A., Junior, E. R. F., Dallagassa, M. R., Sato, D. M. V., Carvalho, D. R., Santos, E. A. P., and Scalabrin, E. E. (2019). Process mining techniques and applications–a systematic mapping study. *Expert Systems with Applications*, 133:260–295.

Dzihni, A. S., Andreswari, R., and Hasibuan, M. A. (2019). Business process analysis and academic information system audit of helpdesk application using genetic algorithms a process mining approach. *Procedia Computer Science*, 161:903–909.

Fitriansah, I. A., Andreswari, R., and Hasibuan, M. A. (2019). Business process analysis of academic information system application using process mining (case study: Final project module). In *2019 5th International Conference on New Media Studies (CONMEDIA)*, pages 189–194. IEEE.

Ganesha, K., Dhanush, S., and SM, S. R. (2017a). An approach to fuzzy process mining to reduce patient waiting time in a hospital. In *2017 International Conference on Innovations in Information, Embedded and Communication Systems (ICIIECS)*, pages 1–6. IEEE.

Ganesha, K., Raj, S. S., and Dhanush, S. (2017b). Process mining approach for efficient utilization of resources in a hospital. In *2017 International Conference on Innovations in Information, Embedded and Communication Systems (ICIIECS)*, pages 1–5. IEEE.

Gerhardt, R., Valiati, J. F., and dos Santos, J. V. C. (2018). An investigation to identify factors that lead to delay in healthcare reimbursement process: A brazilian case. *Big data research*, 13:11–20.

Gonzalez-Dominguez, J. and Busch, P. (2018). Automated business process discovery and analysis for the international higher education industry. In *Pacific Rim Knowledge Acquisition Workshop*, pages 170–183. Springer.

Gupta, M. and Sureka, A. (2014). Nirikshan: Mining bug report history for discovering process maps, inefficiencies and inconsistencies. In *Proceedings of the 7th India Software Engineering Conference*, pages 1–10.

Gupta, M., Sureka, A., and Padmanabhuni, S. (2014). Process mining multiple repositories for software defect resolution from control and organizational perspective. In *Proceedings of the 11th Working Conference on Mining Software Repositories*, pages 122–131.

Heo, G., Lee, J., and Jung, J.-Y. (2018). Analyzing bottleneck resource pools of operational process using process mining. *ICIC express letters. Part B, Applications: an international journal of research and surveys*, 9(5):437–441.

Jacobi, C., Meier, M., Herborn, L., and Furmans, K. (2020). Maturity model for applying process mining in supply chains: Literature overview and practical implications. *Logistics Journal: Proceedings*.

Juneja, P., Kundra, D., and Sureka, A. (2016). Anvaya: An algorithm and case-study on improving the goodness of software process models generated by mining event-log data in issue tracking systems. In *2016 IEEE 40th Annual Computer Software and Applications Conference (COMPSAC)*, volume 1, pages 53–62. IEEE.

Kitchenham, B. (2004). Procedures for performing systematic reviews. *Keele, UK, Keele University*, 33(2004):1–26.

Kouhestani, S. and Nik-Bakht, M. (2020). Ifc-based process mining for design authoring. *Automation in Construction*, 112:103069.

Lee, S.-k., Kim, B., Huh, M., Cho, S., Park, S., and Lee, D. (2013). Mining transportation logs for understanding the after-assembly block manufacturing process in the shipbuilding industry. *Expert Systems with Applications*, 40(1):83–95.

Li, G. and De Carvalho, R. M. (2019). Process mining in social media: applying object-centric behavioral constraint models. *IEEE Access*, 7:84360–84373.

Mahendrawathi, E., Astuti, H. M., and Wardhani, I. R. K. (2015). Material movement analysis for warehouse business process improvement with process mining: a case study. In *Asia-Pacific Conference on Business Process Management*, pages 115–127. Springer.

Mahendrawathi, E., Zayin, S. O., and Pamungkas, F. J. (2017). Erp post implementation review with process mining: A case of procurement process. *Procedia Computer Science*, 124:216–223.

Meincheim, A., dos Santos Garcia, C., Nievola, J. C., and Scalabrin, E. E. (2017). Combining process mining with trace clustering: Manufacturing shop floor process-an applied case. In *2017 IEEE 29th International Conference on Tools with Artificial Intelligence (ICTAI)*, pages 498–505. IEEE.

Mizgier, K. J., Jüttner, M. P., and Wagner, S. M. (2013). Bottleneck identification in supply chain networks. *International Journal of Production Research*, 51(5):1477–1490.

Neira, R. A. Q., Hompes, B. F. A., de Vries, J. G.-J., Mazza, B. F., de Almeida, S. L. S., Stretton, E., Buijs, J. C., and Hamacher, S. (2019). Analysis and optimization of a sepsis clinical pathway using process mining. In *International Conference on Business Process Management*, pages 459–470. Springer.

Peffers, K., Tuunanen, T., Rothenberger, M. A., and Chatterjee, S. (2007). A design science research methodology for information systems research. *Journal of management information systems*, 24(3):45–77.

Piest, J. P. S., Cutinha, J., Bemthuis, R. H., and Bukhsh, F. A. (2021). Evaluating the use of the open trip model for process mining: An informal conceptual mapping study in logistics. In *Proceedings of the 23rd International Conference on Enterprise Information Systems*, pages 290–296. INSTICC.

Porouhan, P., Jongsawat, N., and Premchaiswadi, W. (2014). Process and deviation exploration through alpha-algorithm and heuristic miner techniques. In *2014 Twelfth International Conference on ICT and Knowledge Engineering*, pages 83–89. IEEE.

Premchaiswadi, W. and Porouhan, P. (2015). Process modeling and bottleneck mining in online peer-review systems. *SpringerPlus*, 4(1):1–18.

Rahardianto, R., Sarno, R., and Budiawati, G. I. (2018). Performance time evaluation of domestic container terminal using process mining and pert. In *2018 International Seminar on Application for Technology of Information and Communication*, pages 469–475. IEEE.

Ribeiro, R., Analide, C., and Belo, O. (2018). Improving productive processes using a process mining approach. In *World Conference on Information Systems and Technologies*, pages 736–745. Springer.

Roldán, J. J., Olivares-Méndez, M. A., del Cerro, J., and Barrientos, A. (2018). Analyzing and improving multi-robot missions by using process mining. *Autonomous Robots*, 42(6):1187–1205.

Roser, C., Lorentzen, K., and Deuse, J. (2015). Reliable shop floor bottleneck detection for flow lines through process and inventory observations: the bottleneck walk. *Logistics Research*, 8(1):1–9.

Saelim, N., Porouhan, P., and Premchaiswadi, W. (2016). Improving organizational process of a hospital through petri-net based repair models. In *2016 14th International Conference on ICT and Knowledge Engineering (ICT&KE)*, pages 109–115. IEEE.

Samaan, M., Tawfeeq, M., and Smith-Spark, L. (2021). Syria forced to ration fuel as stricken ship keeps suez canal blocked. *CNN*. https://edition.cnn.com/2021/03/28/africa/suez-canal-ship-blockage-intl/index.html.

Seara, L. G. and De Carvalho, R. M. (2019). An approach for workflow improvement based on outcome and time remaining prediction. In *MODELSWARD*, pages 473–480.

Senderovich, A., Weidlich, M., Yedidsion, L., Gal, A., Mandelbaum, A., Kadish, S., and Bunnell, C. A. (2016). Conformance checking and performance improvement in scheduled processes: A queueing-network perspective. *Information Systems*, 62:185–206.

Shani, A. H. M., Sarno, R., Sungkono, K. R., and Wahyuni, C. S. (2019). Time performance evaluation of agile software development. In *2019 International Seminar on Application for Technology of Information and Communication (iSemantic)*, pages 202–207. IEEE.

Shrivastava, S. and Pal, S. N. (2017). A big data analytics framework for enterprise service ecosystems in an e-governance scenario. In *Proceedings of the 10th International Conference on Theory and Practice of Electronic Governance*, pages 5–11.

Spenrath, Y. and Hassani, M. (2019). Ensemble-based prediction of business processes bottlenecks with recurrent concept drifts. In *EDBT/ICDT Workshops*.

Spott, M., Nauck, D., and Taylor, P. (2013). Modern analytics in field and service operations. In *Transforming field and service operations*, pages 85–99. Springer.

Stefanini, A., Aloini, D., Benevento, E., Dulmin, R., and Mininno, V. (2018). Performance analysis in emergency departments: a data-driven approach. *Measuring Business Excellence*.

Subramaniyan, M., Skoogh, A., Salomonsson, H., Bangalore, P., Gopalakrishnan, M., and Sheikh Muhammad, A. (2018). Data-driven algorithm for throughput bottleneck analysis of production systems. *Production & Manufacturing Research*, 6(1):225–246.

Trinkenreich, B., Santos, G., Confort, V. T., and Santoro, F. M. (2015). Toward using business process intelligence to support incident management metrics selection and service improvement. In *SEKE*, pages 522–527.

Van der Aalst, W. (2011). Process mining - discovery, conformance and enhancement of business processes. Springer.

Van der Aalst, W. (2016). Process mining - data science in action. Springer.

Van der Aalst, W., Adriansyah, A., De Medeiros, A. K. A., Arcieri, F., Baier, T., Blickle, T., Bose, J. C., Van Den Brand, P., Brandtjen, R., Buijs, J., et al. (2011). Process mining manifesto. In *International Conference on Business Process Management*, pages 169–194. Springer.

Van der Aalst, W. M. (2013). Process mining in the large: a tutorial. In *European Business Intelligence Summer School*, pages 33–76. Springer.

Van der Aalst, W. M., Pesic, M., and Song, M. (2010). Beyond process mining: From the past to present and future. In *International Conference on Advanced Information Systems Engineering*, pages 38–52. Springer.

Wu, Q., He, Z., Wang, H., Wen, L., and Yu, T. (2019). A business process analysis methodology based on process mining for complaint handling service processes. *Applied Sciences*, 9(16):3313.

Yazici, I. E. and Engin, O. (2020). Use of process mining in bank real estate transactions and visualization with fuzzy models. In *International Conference on Intelligent and Fuzzy Systems*, pages 265–272. Springer.