# A Systematic Review to Identify Patterns Types and Analysis Objectives for the Discovery of Business Rules from Event Logs Using Machine Learning

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Abstract: Business processes are structured and executed based on business rules. Information systems executing the business processes store the execution data in event logs. The event logs can be analyzed using machine learning algorithms to discover business rules in the business process execution. In which various algorithms can be applied to event log data to discover rules/patterns related to the business process. The application of machine learning on event log data to discover the business rules needs extensive process mining expertise and knowledge from the process analyst; therefore, there is a need to facilitate the application of machine learning on event log data to reach different analysis objectives. This can be done through identifying the pattern types related to performing different machine learning tasks on event log data, and the different analysis objectives for the discovery of business rules from event logs. However, it was found that no systematic review was previously conducted to collect this information; therefore, the focus of this paper is to conduct a systematic review to collect from research the different pattern/rule types within the event log data that can be discovered and the different analysis objectives for the discovery of business rules from event logs.



## 1 INTRODUCTION

Business processes are events and activities that are performed to achieve business objectives. Business process execution is recorded through event logs, which are stored in information systems that support the execution of the business processes. An event log is composed of cases; each case consists of a number of events that are performed as part of a case. The business process consists of a collection of events and cases. Furthermore, business processes are structured, modelled, and executed based on business rules (Berti & van der Aalst, 2023). Business rules from a business process perspective are statements or constraints that describe the business process behavior (Graml et al., 2007; Campos et al., 2018). They are incorporated in different patterns within process data (Thi et al., 2011)

Business rules discovery is important. The extracted rules or patterns support reaching organizational goals, eliminating costly mistakes, improving data-driven decision-making, performing business process re-engineering, and checking the compliance of the business process with legal requirements (Polpinij et al., 2015). Mining of rules from the business process event logs facilitates understanding the process analysis results, as it shows the results of the analysis as declarative business statements. Moreover, By discovering the business rules, it is possible to reach different process-related analysis objectives (Bemthuis et al., 2023). The discovery can be done through process mining techniques. Process mining techniques analyze event logs to perform tasks such as process discovery, conformance checking, or process enhancement. In addition, business rules can be discovered through machine learning techniques, in which several machine learning algorithms can be applied to event logs to discover patterns or rules within event log data (Polppinij et al., 2015; Polpinij et al., 2010). Rule learning and rule mining are both machine learning

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techniques that are used to discover business rules from event logs (Bozorgi et al., 2020).

Business rules may not be followed or may be in the form of tacit knowledge. Consequently, discovery of business rules using machine learning is important to reveal hidden business logic (Bemthuis et al., 2023). Moreover, Business rules discovered through the application of machine learning algorithms are related to different pattern types, in which each pattern type is the result of performing different machine learning tasks on the data (Polppinij et al., 2015; Corea & Delfmann, 2020; Nelson and Sen, 2014; Swinnen et al., 2011; Polpinij et al., 2010).

Furthermore, the work of the process analyst to analyze the event log data to reach different process-related analysis objectives is not easy and straightforward. As it requires the process analyst to have massive process mining and machine learning expertise and knowledge. Therefore, there is a need to provide the process analyst with information that would help perform process-mining tasks using machine learning techniques. This information would facilitate the process of analyzing event logs using machine learning (Seeliger, 2020).

Since machine learning can be used to reach different pattern/rule types, it is important to identify the types of patterns and the analysis objectives that can be discovered from event logs by performing different machine learning tasks. This information can facilitate utilizing machine learning algorithms to reach process-related analysis objectives (Chen et al., 2023).

## 2 RELATED WORK

One systematic review conducted by Chen et al., (2023) investigated the application of machine learning algorithms to event log data to reach different healthcare-related analysis objectives such as chronic diseases management and prediction. Other relevant research done regarding this topic can be categorized into: articles that discussed the discovery of business rules from event logs using machine learning to achieve a specific analysis objective or articles that investigated the application of machine learning algorithms to event logs to achieve analysis objectives related to a specific domain. One example of papers that discovered business rules from event logs using machine learning to achieve a specific analysis objective is Abou Rida et al., (2019), in which the article analyzed the event log using the association rule mining algorithm to discover access control rules. One example of papers that investigated the application of machine learning algorithms to event logs to achieve analysis objectives related to a specific domain is Bemthuis et al., (2023), in which the article focused on the logistics domain analysis objectives.

Consequently, no previous systematic review was conducted to guide the process analyst on how to apply machine learning algorithms on event log data to discover business rules related to the different analysis objectives or pattern types. This paper aims to fill this gap by collecting from research information regarding types of business rules and analysis objectives that can be discovered through the application of different machine learning algorithms.

This paper is structured in sections: after this introductory section, the second section is about performing the systematic literature review. In the third section, the findings of the systematic literature review are presented. Finally, the last section concludes the paper and presents limitations and future recommendations.

## 3 SYSTEMATIC LITERATURE REVIEW

The Systematic Literature Review (SLR) was performed by following the review process proposed by Imran et al. (2022), which comprises three main steps: review planning, review conducting, and review reporting. This section will focus on discussing the first two steps, while the subsequent section will present the findings of the review process.

### 3.1 Planning the Review

In this step, the objectives of the review, the specific review questions, and the review protocol were established.

#### 3.1.1 Review Objectives

This SLR aims to address the need for identifying patterns within event log data that are associated with different machine learning tasks and the different analysis objectives for discovering business rules from event logs. Performing the SLR is important as it was found that no previous research has been conducted to gather this information. Therefore, the purpose of this study is to perform a Systematic Literature Review (SLR) to identify the pattern types found in event log data that are related to different machine learning tasks. Additionally, the research

aims to identify the analysis objectives for the discovery of business rules from the event log.

### 3.1.2 Review Questions

RQ1. What are the common pattern types related to performing different machine learning tasks on event log data to discover business rules?
RQ2. What are the analysis objectives for the discovery of business rules from event logs?

### 3.1.3 Review Protocol

The SLR protocol included identifying the (search terms, relevant databases, inclusion criteria, exclusion criteria), which are discussed in this section in detail.

The search terms deduced from the review questions were (patterns, rules, business rules, event log, data mining, machine learning, and business process). The Boolean AND was used to connect the search terms and the Boolean OR was used to express alternative terms that can be used. Based on the search terms, the following search queries were used for searching: ("business rules" OR "rules" OR "patterns) AND ("machine learning" OR "data mining") AND ("business process" OR "event log").

Three scholarly and international online databases, namely Science Direct, IEEE Explore, and Google Scholar were chosen due to their recognized relevance in the field of information technology. The inclusion criteria were used to select papers that meet some important requirements and the exclusion criteria were used to remove papers that do not meet some important requirements.

**The Inclusion Criteria.**
- The research paper is written in English.
- The research paper focuses on the discovery of rules from event logs.
- The research paper uses machine learning for the discovery of business rules from the event logs.

**The Exclusion Criteria.**
- The research paper focuses on the discovery of rules from sources other than the event log
- The Research paper does not use machine learning algorithms to discover the business rules.

## 3.2 Conducting the Review

The second step involved conducting the review and extracting the necessary data to address the review questions. In which a manual search was conducted across the three chosen databases using the identified search queries to retrieve conference proceedings and journal papers. To capture all relevant articles and ensure comprehensive coverage of relevant articles, the review was not limited to a specific period. The number of articles found in the three databases are 605 articles, comprising 405 from ScienceDirect, 100 from IEEE Explore, and 100 from Google Scholar (limited to the first ten pages due to lack of relevance in subsequent pages). Subsequent screening based on title and abstract eliminated duplicates, resulting in 100 unique articles. Further screening based on inclusion and exclusion criteria reduced the articles to 40 after examining full texts. Furthermore, the quality of the articles was assessed according to the following quality criteria: the number of citations, and the degree of providing a clear methodology and a thorough discussion of the results. Articles lacking citations or with unclear methodology/results were excluded, resulting in a total of 31 articles.

The 31 research papers were used to extract data that answered the review questions. Data extracted from each article were:

- The reference of the paper.
- The pattern type that was discovered from event log data.
- Explanation of the pattern discovered.
- The machine learning task related to the discovery of that pattern type.
- The objectives for the discovery of each pattern type from event log data.
- The analysis objective for the discovery of the business rules from event logs and the explanation of each analysis objective.

# 4 RESULTS AND DISCUSSION

In the following subsections, findings of each review question are presented.

## 4.1 First Review Question

Regarding the first review question, the results of the review identified different pattern types within event log data related to performing different machine learning tasks. The identified patterns within event log data resulted from the application of machine learning algorithms on event log data to fulfill a specific task. Depending on the machine learning tasks performed on event log data, each pattern type can be discovered in the form of patterns or rules. Three different patterns within event log data were commonly and repeatedly mentioned, which are

frequent patterns, rare patterns, and classification patterns. Table 1 summarizes the results of the first review question findings. Each pattern is explained in details in the following sub-sections.

Table 1: Summary of first review question findings.

| Pattern/Rule type | Description | ML task needed to extract the pattern |
|---|---|---|
| Frequent patterns | Reflect frequent correlation between process attributes. The frequent correlation could be related to sequential or time-ordered attributes. | To extract frequent association/sequential patterns, apply:<br>- frequent item set mining<br>- association rule mining<br>- sequential pattern mining<br>- sequential rule mining |
| Rare patterns | Reflect correlated attributes that occur infrequently | To extract rare patterns, apply:<br>- rare pattern mining<br>- rare association rule mining<br>- rare sequential pattern mining |
| Classification patterns | Reflect the classification of event log attributes according to a class label attribute. | To extract classification patterns, apply:<br>- rule learning<br>- classification rule mining |

### 4.1.1 Frequent Patterns Within Process Data

Frequent patterns within process data reflect frequently associated event log attributes (Djenouri et al., 2018). This pattern type is related to performing machine learning tasks such as frequent item set mining, association rule mining, sequential pattern mining, and sequential rule mining tasks on event log data. Frequent patterns within process data can be discovered in the form of frequent association rules or frequent sequential rules.

**Frequent association rules** reflect frequent correlations between process attributes such as activities, resources, and time-related attributes (Acheli et al., 2021; Djenouri et al., 2018). Analysis objectives that required the discovery of frequent association rules from event logs include:

- Discovery of frequent itemsets in an event log. This analysis objective was satisfied by discovering association rules that reflect correlations between process attributes like task, temporal, or resource-related attributes (Djenouri et al., 2018).
- Discovery of access control policies given to resources. This analysis objective was satisfied by discovering association rules that detect frequent correlations between process tasks, process data, and the different resources (Abou Rida et al., 2019).
- Discovery of resource allocation rules to ensure each activity is performed by the right resource. This analysis objective was satisfied by discovering association rules that reflect frequent correlations between activities and resources. (Liu et al., 2012).

**Frequent sequential patterns/rules** reflect correlated process attributes that are sequential or time-ordered (Fournier-Viger et al., 2020; Özdağoğlu et al., 2018; Dalmas et al., 2017). Sequential patterns could be ordered subsequences of process events (Fournier-Viger et al., 2020). Analysis objectives that required the discovery of frequent sequential patterns/rules from event logs include:

- Discovery of a process model (Acheli et al., 2021; Fournier-Viger et al.,2020; Dalmas et al., 2017). This analysis objective was satisfied by discovering the sequential patterns within process activities
- Discovery of profitable sequential process patterns. This analysis objective was satisfied by discovering high-utility sequential patterns within event log data (Fournier-Viger et al.,2020; Dalmas et al., 2017).
- Discovery of low-cost sequential process patterns that can be used to lower process costs. This analysis objective was satisfied by discovering low-cost sequential patterns within event log data (Fournier-Viger et al.,2020; Dalmas et al., 2017).

### 4.1.2 Rare Patterns Within Process Data

Rare patterns within process data reflect infrequent associations of event log attributes (Djenouri et al., 2018). Rare patterns are correlated attributes that occur infrequently. Furthermore, they could show an accepted behavior that should be enforced or an unacceptable behavior that should be further analyzed (Bezerra & Wainer, 2013). In addition, rare patterns can reveal important information like risks and fraud (Marin-Castro & Tello-Leal, 2021; Fani Sani et al.,

2018; Pourmasoumi et al., 2017; Mannhardt et al., 2017; Abou Rida et al., 2019).

Moreover, rare patterns can be detected by identifying patterns that have support values below a user-specified support threshold (Fani Sani, 2018) or by detecting rules that have low support and high confidence values (Romero et al., 2011). This pattern is related to performing machine learning tasks such as rare pattern mining, rare association rule mining, and rare sequential pattern mining tasks on event logs to discover rare association/sequential rules that reflect rare process patterns. Analysis objectives that required the discovery of rare patterns within process data in the form of association patterns/rules or sequential patterns/rules:

- Improving process discovery results (Marin-Castro & Tello-Leal, 2021; Fani Sani et al., 2018; Pourmasoumi et al., 2017). This analysis objective was satisfied by discovering rare sequential rules within event log data, and then the rules were examined to determine if they were correct or noisy patterns.
- Detecting violated data access permissions given to resources (Abou Rida et al., 2019). This analysis objective was satisfied by discovering rare association rules that are below the user support and confidence values and then examining these patterns.
- Detecting security violations like fraud and risks (Mannhardt et al., 2017). This analysis objective was satisfied by discovering rare patterns that are below the user support value and then examining these patterns.

#### 4.1.3 Classification Patterns Within Process Data

Classification patterns within process data reflect the classification of event log attributes according to a class label attribute. Classification patterns can be discovered in the form of classification patterns or rules, which show the relationship between a response attribute and a set of predictor attributes (Khanbabaei et al., 2018; Suriadi et al., 2012). Rules discovered could be used for the prediction of unseen event log class attributes (Márquez-Chamorro et al., 2017). This pattern is related to performing machine learning tasks such as rule learning and classification pattern/rule mining tasks on event log data. Analysis objectives that required the discovery of classification patterns within process data:

- Discovery and prediction of process model constructs, in which the constructs reflect activity relations such as the parallel, exclusive choice, and causal relations. Classification rules are discovered through the classification of labeled classes of relations (Acheli et al., 2021; Măruşter et al., 2006)
- Decision point analysis that analyzes and predicts the relationship between the event log data attributes and the routing choices of process execution. Decision point analysis generates classification rules by classifying the event log data attributes according to a class attribute which is the different routing decisions that could be made (Sarno et al., 2014; Sarno et al., 2013; Rozinat & van der Aalst, 2006).
- Discovery of Resource patterns that identify the required profile of resources to perform a process activity instance. Classification rules are discovered by classifying attributes like the process tasks, organizational agents, organizational positions, and roles into performers or non-performers of a process activity instance (Ly, et al., 2005).
- Discovery of classification rules that reflect the root cause of risk incidents like overtime cases (Suriadi et al., 2012) or analyze and explain the deviant process cases by classifying cases into deviant or normal (Genga et al., 2020; Gupta et al., 2015; Nguyen et al., 2014).

### 4.2 Second Review Question

Regarding the second review question, the results of the review identified a list of different analysis objectives that can be reached through the discovery of business rules from event logs using machine learning; the following list summarizes and explains the different analysis objectives:

- Process model constructs analysis and prediction: To discover rules related to process model constructs like sequences, parallel, and exclusive choices (Măruşter et al., 2006).
- Process performance analysis: To discover rules that detect patterns within process data related to the cost, time, or quality attributes (Van der Aalst, 2016).
- Decision point analysis: To discover decision rules that capture the effect of data attributes on the routing of a process instance, by analyzing and predicting the relationship between the event log data attributes and the routing choices of a case (Rozinat & van der Aalst, 2006).
- Discovery of low-cost/high-utility process patterns: To discover rules that detect profitable or low-cost patterns within process data (Fournier-Viger et al., 2020; Dalmas et al., 2017).

- Causal relationship discovery: To discover causal rules that detect causal relationships between event log data attributes (Acheli et al., 2021).
- Root cause analysis: to discover rules that explain the reason behind a specific process phenomenon or behavior by analyzing event log data attributes (Suriadi et al., 2012).
- Resource performance analysis: To discover rules that reflect resource behavioral patterns within process data. Discovered rules can reflect productivity, and utilization of resources (Pika et al., 2017).
- Staff assignment/Resource allocation rules discovery: To discover rules that determine the profile of a resource needed to perform a certain activity. Business rules discovered help managers allocate the right resources to the right tasks and allocate alternative resources to a specific task if a required resource is busy (Liu et al., 2012). Moreover, the business rules discovered help managers ensure each activity is performed by the right resource (Liu et al., 2012; Huang et al., 2011; Ly, et al., 2005).
- Organizational roles analysis: To discover rules that determine patterns within process data related to organizational roles, permissions, rights, and the interaction between different roles (Zhao & Zhao, 2014).
- Organizational structure analysis: To discover rules that determine patterns within process data that reflect the structure of the organization (Zhao & Zhao, 2014).
- Detection of violated process policies: To discover rules related to infrequent patterns within process data that might indicate fraud, violations, or deviation from the accepted behavior (Mannhardt et al., 2017; Abou Rida et al., 2019; Van der Aalst & de Medeiros, 2005).
- Access control rules discovery: To discover rules that detect patterns within process data that are related to granted access permissions given to users. The discovery aims to protect against unauthorized access to process data (Abou Rida et al., 2019). The below figure summarizes the analysis objective that could be reached through the application of machine learning algorithms to process data.

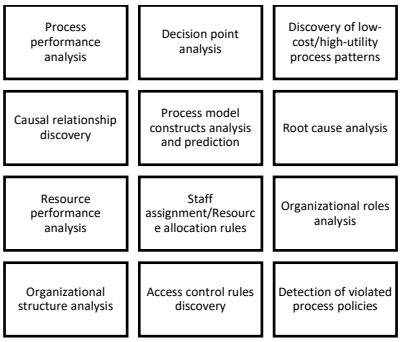


Figure 1: Summary of analysis objectives.

# 5 CONCLUSION AND OUTLOOK FOR FUTURE WORK

The paper emphasizes the need to guide process analysts in achieving different process-related analysis objectives through the identification of pattern types and analysis objectives related to applying machine learning to event log data. It also discusses the importance of discovering business rules from event logs. It points out the lack of research conducting a systematic literature review to collect information on pattern types and analysis objectives for the discovery of business rules from event logs using machine learning techniques.

To address this gap, a systematic literature review was performed. The review follows a three-step process: review planning, review conducting, and review reporting. The objectives of the review are to identify common pattern types associated with different machine learning tasks on event log data and to determine the analysis objectives for discovering business rules from event logs. The results of the systematic literature review revealed three common pattern types within event log data: frequent patterns, rare patterns, and classification patterns. These patterns are discovered through various machine learning tasks applied to event log data. The paper also identifies different analysis objectives for the discovery of business rules from event logs.

In conclusion, the systematic literature review provides valuable insights into pattern types and analysis objectives related to the discovery of business rules from event logs using machine learning. The findings contribute to guiding process analysts in applying machine learning algorithms to event log data and achieving several analysis objectives. In addition, the findings will support the development of frameworks that aim to standardize the process of process analysis and business rules

discovery from event logs using machine learning algorithms, the frameworks can then be used to design future process mining systems.

Limitations of this research include missing some relevant references due to performing a manual search process, selecting only three databases for the search, and selecting the articles written only in the English language. Accordingly, for future work, it is recommended to perform an automated search instead of a manual search, to include more databases for the search, and to search for articles in languages other than the English language.

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