UNIVERSITY OF TARTU
Institute of Computer Science
Software Engineering Curriculum

Kostiantyn Popov

Comparative Evaluation of Log-Based Process Performance Analysis Techniques

Master's Thesis (30 ECTS)

Supervisor: Fabrizio Maggi, PHD
Supervisor: Payman Fredrik Milani, PHD

Tartu 2017

Acknowledgements

I would like to express my sincere gratitude to my supervisors Dr. Payman Fredrik Milani and Dr. Fabrizio Maggi who provided guidance and huge support, also big thanks to the lecturers of the Computer Science faculty for the knowledge I got during my studies.

I wish to thank my friends and colleagues at Adcash ÖU for support and flexible working hours.

Finally, I would like to thank my family and friends for being with me on every step of the way.

Comparative Evaluation of Log-Based Process Performance Analysis Techniques

Abstract:

This paper gives a comparative overview of process mining performance studies and clusters them based on proposed metrics: time, quality and resources. This thesis provides an explanation of reasons for using process mining performance techniques and shows what value they can bring. We provide common metrics and unit of measurement that can be used to evaluate process performance analysis methods. Also, the paper describes tools and algorithms that have been implemented in the literature.

Keywords: process mining, performance analysis, performance mining.

CERCS: P170 Computer science, numerical analysis, systems, control

Logipõhiste protsessi tulemuslikkuse analüüsimeetodite võrdlev hindamine

Lühikokkuvõte:

Käesolev väitekiri võrdleb erinevaid protsessikaeve uurimustöid ning liigitab neid järgnevate näitajate põhjal: aeg, kvaliteet ja ressursikasutus. Magistritöö põhjendab protsessikaeve meetodite kasutamist ja nende pakutavat lisandväärtust. Pakume ühiseid mõõtühikuid ja parameetreid, mida saab kasutada protsessi tulemuslikkuse analüüsimeetodite hindamiseks. Lisaks eelnevale kirjeldab väitekiri kirjanduses esinevaid tarkvaralahendusi ja algoritme.

Võtmesõnad: protsessikaeve, jõudluse analüüs, jõudluskaeve.

CERCS: P170 Arvutiteadus, arvutusmeetodid, süsteemid, juhtimine (automaatjuhtimisteooria)

Table of Contents

1 Introduction

Process mining is a field of science that helps to understand business processes. Process mining includes multiple analysis methods.

This thesis focuses on performance analysis techniques. Process performance is one of the vital parts in business process analysis because based on the performance analysis further investigation of the process becomes possible (for example, process optimization). Performance analysis techniques give an overview of the current process from quantitative and qualitative perspectives. They can give a better understanding of the “as-is” business process (find bottlenecks, etc.) [34].

1.1 Problem statement

Performance analysis is not new and such kind of analysis has already been done for academic and industrial purposes. Process performance analysis is quite a broad topic; therefore multiple studies with different approaches and algorithms have been conducted. Multiple methods and approaches in process performance make it harder to identify the suitable one for the specific cases, as in most of the studies process performance analysis approaches highly depend on the context of a log data. In the light of the above context, it is relevant to survey and investigate what are the reasons for doing performance analysis, how and what the analyst can measure in terms of process performance. Also, it is important to discover the main approaches and techniques that can be used for process performance analysis.

1.2 The aim of the thesis

The aim of the current thesis is to provide a literature review of the existing process performance techniques. By evaluating all the relevant studies this thesis will be able to bring a better understanding of researches that have been done so far in the process performance field. In order to be able to make a meaningful conclusion in the current research a set of points should be discovered, based on which gathered information could be systematized and presented.

First action point to focus on will be to why process mining techniques for performance analysis re needed. According to [34], the main process performance dimensions are time, resources, costs, and quality. Therefore the main goal of performance analysis techniques is to analyse a business process from this perspectives using execution data.

Second action point of focus addresses the evaluation of the process performance. Finding units of measurement that give the ability to calculate performance is substantial in order to better understanding the current state of researched studies.

Third and final action point of focus will be to identify main approaches and algorithms for dealing with process performance. A number of studies have done such analysis and this thesis will cluster and summarize the effort that was done so far.

All action points will be summarized and presented in a framework at the end of the thesis. The aim of the framework is to find most optimal and flexible way of doing process performance analysis. Framework will include action points defined above and will have certain process flow that will be discovered during current research.

1.3 Structure of the thesis

Section 2 presents the methodology of the literature review. Also, it describes the research questions that current research is trying to answer. In Section 3 gives a summary of each of identified paper. Discussion of the research questions is given in Section 4, an answer to each of the research questions is given. In Section 5 provides an evaluation evaluation, where a framework for the classification of process performance analysis techniques is given. Section 6 concludes the thesis.

2 Methodology for the Literature Review

In this part of the thesis, the literature review follows the main guidelines as outlined by Kitchenman (2004). In the following sections we discuss the aim of the literature review. The data gathered would give the summary of what has been done in process performance analysis field so far.

In the following sections we describe: research questions formulation (3.1), search strings (3.2), data source selection (3.3), inclusion and exclusion criteria (3.4), study selection (3.5), data extraction strategy (3.6), data analysis (3.7).

2.1 Research Questions Formulation

The literature review has been developed and described to bring the understanding of process performance analysis value in the industry and academic world. In order to understand its value we decided to observe the current use of process performance and classify it. In order to reach this aim 5 research questions were formulated:

1. What is the value that business process performance analysis can deliver? (**RQ1**)

The answer to this question will explain the reasons for applying performance based on existing use in industry.

2. What can process performance measure? (**RQ2**)

The answer to this question will describe units of measurement available in the existing process performance analysis techniques.

3. How can process performance can be measured? (**RQ3**)

The answer to this question will clarify how to deal with data from a log in order to be able to do performance calculations.

4. What are the existing approaches for performance analysis? (**RQ4**)

The answer to this question will explain how to use the data in order to obtain the meaningful outputs from performance analysis techniques.

5. What algorithms/tools are available for performance analysis? (**RQ5**)

The answer to this question will show algorithms and tools that have been already used in performance analysis.

2.2 Search Strings

Performance analysis is mostly used in pair with other process mining techniques (discovery, optimization, conformance, etc.). Thus, it is very important to make proper data selection and solve the main problem on this step: extract all the relevant data without information leaks. In order to make a proper data selection, it was decided to search by heading ("process mining" AND "performance") only to avoid missing information, so the query was as general as possible. The extracted data contained a lot of duplicated papers. After removing duplicated papers it became possible to start doing manual filtering by title and abstract.

2.3 Data Source Selection

Filtering by publication year was not applied because the topic has appeared recently. Web of Science (WOS) and Scopus were chosen as data sources.

2.4 Inclusion and Exclusion Criteria

The strategy of inclusion and exclusion criteria was formulated based on research questions and the aim of the thesis (Kitchenham 2004). Based on the inclusion criteria, there were found out what papers that are relevant or irrelevant.

Inclusion criteria:

- The paper describes the performance analysis of a business process (not performance of an algorithm, a tool, etc.).
- The paper describes an existing approach for dealing with process performance analysis.
- The paper describes a new approach for dealing with process performance analysis.
- The paper uses at least one of the main process performance metrics (time, quality, resources, costs).
- The paper includes a description of the units of measurement of at least one of metrics defined in the previous inclusion criteria.

Exclusion criteria:

- The paper is not in English.
- The paper's length is less than 5 pages (as it was discovered during papers' review that articles with less than 5 pages are not descriptive).
- No access for paper's full content.
- Non-peer reviewed article.

2.5 Study Selection

After the first data extraction, there were 319 papers from Scopus and 160 papers from Web of Science (WOS). The data was taken from two different sources so it can have duplicates.

Using Excel all duplicated papers were removed and the primary search ended up with 330 papers.

The literature research screening has been inspired by (Kitchenham 2004). In order to identify the article and choose the correct category the title, abstract and introduction, by reading full paper. Full copies of the papers were downloaded and obtained by the reviewer. If the exclusion criteria were met or inclusion criteria were not met the analysis was stopped and no further research of the paper was done. If the paper's relevance could be not specified the paper was reviewed by another reviewer and resolved by consensus. Steps of systematic papers' review:

- by title, where the main idea was to exclude all papers that were out of the scope of the current thesis (for example, the paper is about algorithm's performance or not about performance at all, etc.). At the end of this stage there were 114 relevant papers left.

- by abstract and introduction, where further investigation was done after passing the previous step and was in understanding how relevant was the paper in the scope of current research. In this part inclusion and exclusion criteria were applied and not relevant papers were excluded (for example, paper stands for a performance of a new algorithm, etc.). At the end of this stage, there were 70 relevant papers left.
- by the context of the paper, where was applied the same methodology as in the previous step but based on the full text of the paper.

Stages of the each step of literature review are shown of Figure 1. After final review stage 32 papers were left from both data sources. All those papers were analyzed and categorized based on a set of clusters that will be described in next section.

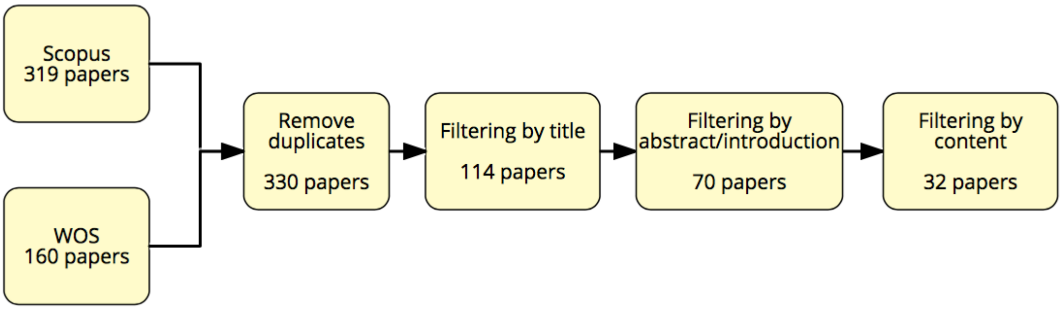

Figure 1. Literature review process

The search was done in April 2017 and includes all relevant papers that were published till that time.

2.6 Data Extraction

In order to answer the research questions defined in Section 2.1 from 32 papers that have passed the secondary search in Section 2.5 was extracted the following information: general information about the paper, algorithm, metric, units of measurement, experiment, aim of the paper, input data, output data and tool. Each of the categories will be described in following sections.

2.6.1 General information

General information consists of paper title, authors and year of publishing. This information is used to find researched papers.

2.6.2 Algorithm

This column consists of algorithm related information which is used in the paper, and this information is used as part of the answer for RQ 5.

2.6.3 Metric

Common metric types are Time, Quality, Resources and Costs. In order to understand what metric authors used it was necessary to identify the main focus of the approach used in an article. For example, if the authors are trying to solve the issue with processes taking too much time then the metric value was Time. This is the information that is needed to answer the RQ 2.

2.6.4 Measurement

This column consists of units that authors used to measure performance. Unit metrics in process performance are referred to as Key Performance Indicators (KPI). In order to get this data, it is necessary to understand what input and output data were required to perform the research. For example, if authors calculated the duration of activities in order to see what activities are the most time consuming than the measurement value was Activity time. This information helps answer the RQ 3.

2.6.5 Validation/Experiment

All extracted papers include experiment, the difference is in the type of data the authors have used. In current paper types we propose three categories for clusterization input data type (log type): synthetic data, real case data, and artificial data. This data is needed for better understanding the answer of RQ 1.

Synthetic data – means that log was generated based on real data (in some cases it is prohibited to disclose the company's data and this type of log consists synthetic data which has same characteristics as the real data).

Real case data – authors used log from real life case(s).

Artificial data – artificially generated data.

2.6.6 Aim/Objective

This column consists of information that describes the purpose of the research and problems a paper is trying to solve. For better understanding the reasons behind applying process performance analysis techniques it is highly beneficial to see in which industries this technique have already been applied, what results industries got and how valuable it was. Traditionally the most popular field for applying process mining techniques is healthcare, additionally, performance algorithms have been applied in other industries like shipbuilding and banking. All of the fields of usage will be clustered and presented in an understandable way in Section 4. This information relates to the answer to the RQ 1.

2.6.7 Output

This column describes the data/the type of the data that authors got at the end of the experiments. Information is needed for answering RQ 2.

2.6.8 Input

This column describes the data/the type of the data that authors have as input of performance analysis. This information is needed for answering RQ 2.

2.6.9 Tool(s)

To answer RQ 5 it is important to know what tool(s) authors used for performance analysis. In the process mining field the most popular standalone tools are Prom and Disco Fluxicon.

ProM - is the most popular framework for implementing process mining algorithms and techniques. It is an open source framework that has huge support from community and has several of plugins and add-ons. Also, it is free and mostly used for academic purposes.

Disco – tool for operating process mining techniques that was developed by Fluxicon company. Disco has very good and clear documentation and it is mainly used in industry and has a free trial version.

3 Results of the Literature Review

This section presents the results of the literature review categorization. In Figure 2 it is visible that most of the process performance analysis techniques have been developed very recently. The first relevant papers appeared in 2006. However, the amount of papers in 2015 - 2016 is bigger than in previous years.

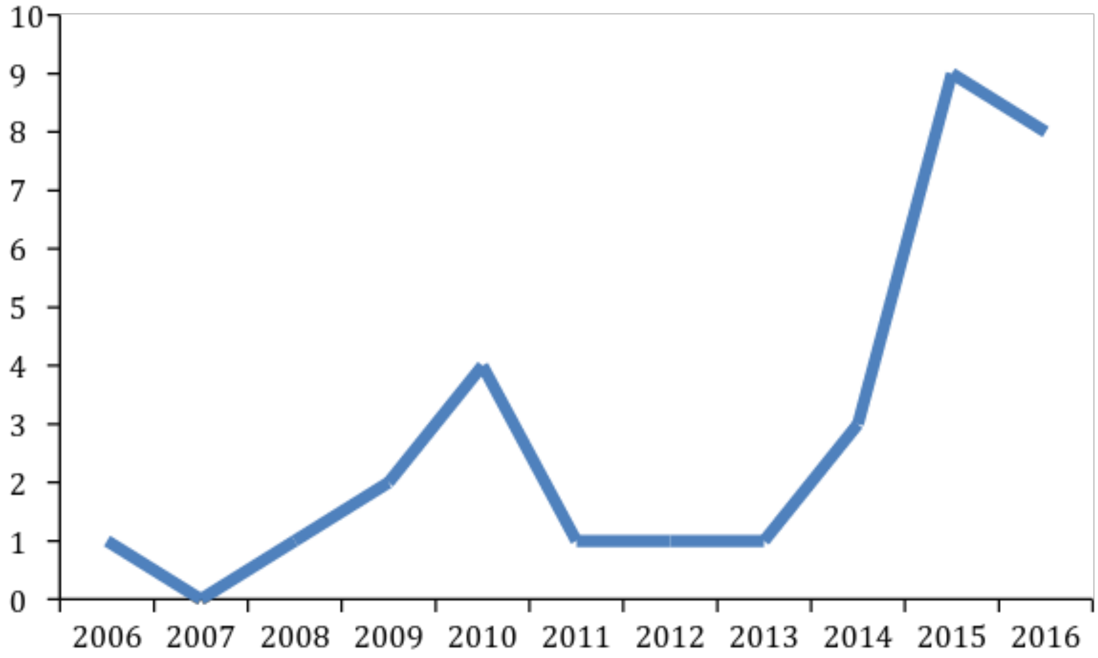

Figure 2. Distribution of relevant papers by year of publishing

All 32 papers are classified by measurement metric they use (Figure 3). In order to generalize researched papers they were classified by metrics defined in each paper. Each category has a number of sub-categories:

1. Time
   - Waiting time
   - Activity duration
   - Certain period duration
   - Process duration
2. Quality
   - Number of defects
   - Number of complaints
3. Resources

Resource metric is not divided into sections because the amount of papers is small (four) therefore it was decided to describe these approaches together.

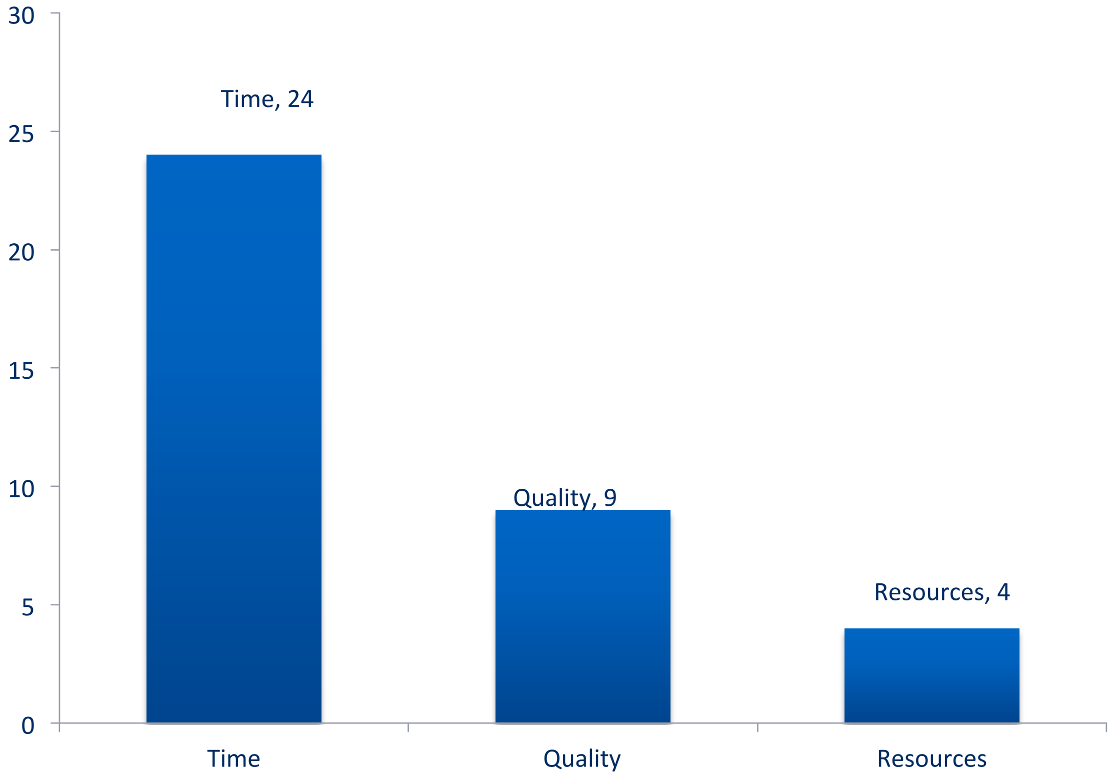

Figure 3. Distribution of papers by metric

3.1 Time

In this section papers with metric “time” will be categorized and described. Each paper belongs to at least one sub-category that are described in further sections (4.1.1, 4.1.2, 4.1.3, 4.1.4). Some of papers describe two or three sub-categories. In these papers authors were focused on several aspects of process performance, like activity time and waiting time between activities. Figure 4 is showing the amount approaches per sub-category. The total amount of approaches is different from the amount of papers in current metric what can be justified by statement above.

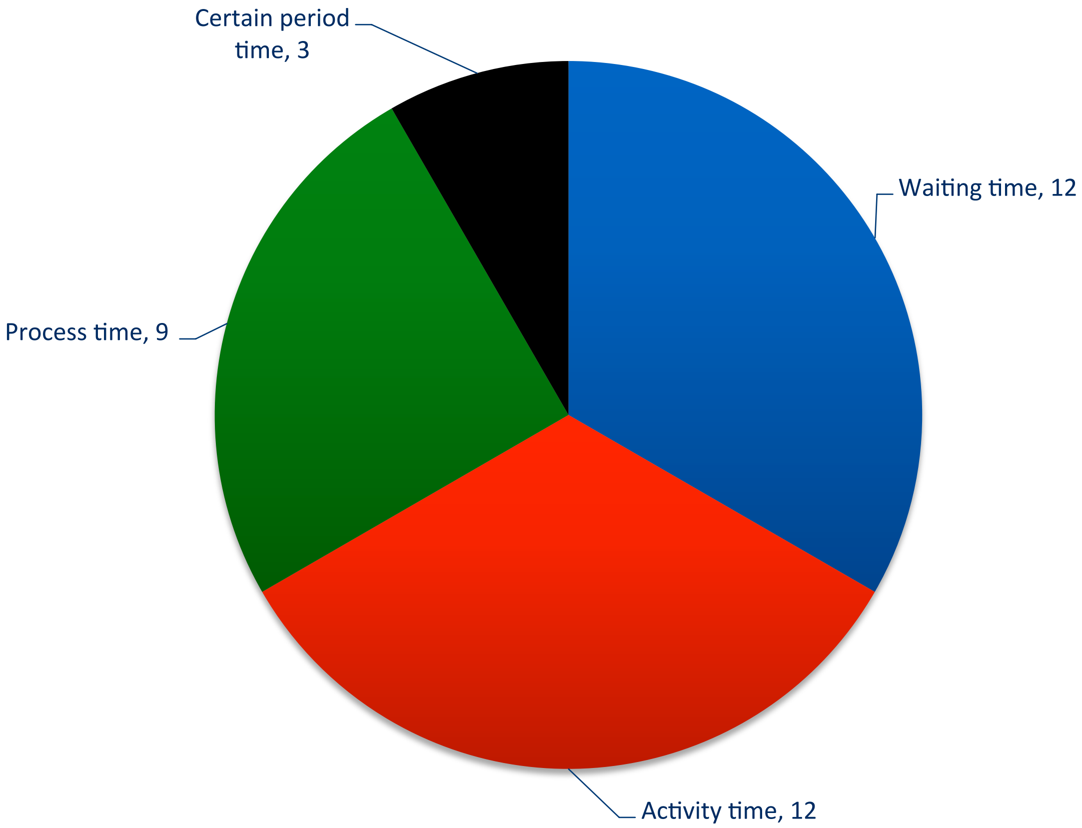

Figure 4. Amount approaches per sub-category

In Figure 5 is shown graphical representation of the time sub-categories. It includes 4 sub-categories. The definition for each category is given in the corresponding subsection.

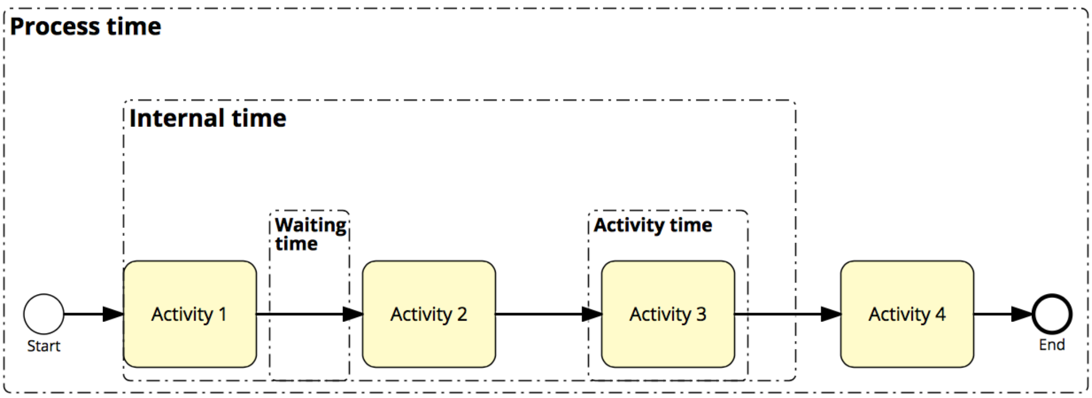

Figure 5. Graphical representation for 4 definitions: waiting time, activity time, internal time, process time.

3.1.1 Waiting time

In the current section we present approaches that were used across papers with measurement metric "waiting time". Waiting time is the name that was used to define papers that are focused on the measurement of time between activities in a process (Figure 5).

In the [1] authors' aim is to implement a process mining technique to improve health service quality via decreasing the queue waiting time. In order to achieve the aim of the research the method that is proposed in the paper calculates the average waiting time per person, the average number of persons per hour and the average length of each of medical procedures. Based on the calculated data the authors propose few scenarios that can lead to improvement.

In [2] the authors evaluate data quality of process performance time metrics. Using control-flow perspective authors are trying to find abnormal activities (activities with most deviated waiting time). The aim is achieved by using Disco build-in functionality and the results are presented as a table with the most frequent abnormal delays. Authors do not make any suggestion of possible improvement based on the results of the experiment, but highlight the bottlenecks (Figure 6) in an emergency department processes.

Time-based performance reporting	Data fields used
Elapsed time between triage and nurse seen	'Triage Date/Time' and 'Nurse Seen Date/Time'
Elapsed time between triage and doctor seen	'Triage Date/Time' and 'Doctor Seen Date/Time'
Elapsed time between triage and time seen	'Triage Date/Time' and 'Doctor Seen Date/Time' or 'Nurse Seen Date/Time' (*if both times are recorded, the earlier time is used*)
Elapsed time between time seen and ED Disposition (*for those not admitted*)	'Doctor Seen Date/Time' or 'Nurse Seen Date/ Time' (*if both times are recorded, the earlier time is used*) and 'ED Departure Date/Time'
Elapsed time between ED Disposition and departing ED (*for those admitted only*)	'ED Departure Date/Time' and 'Ward Date/ Time' (*the first ward the patient was moved*)

Figure 6. Abnormal activities [2]

and present them in a human understandable way.

[3] aims to describe a novel approach for dealing with latent waiting time and latent activity time of the process. As in [1] authors use average time values. These values are found to get three unobservable indicators: latent waiting time, latent service time and latent activity duration that are calculated in order to apply EM algorithm [11] and give the estimation to latent metrics. The proposed approach can be used for predicting sets of connected in the future activities that are not covered with existing data and can estimate hidden performance indicators (example: waiting time for set of independent activities and dependent ones).

The main idea of [4] is to apply process mining techniques (discovery, conformance, performance, etc.) on hospital data. The performance part of this research is to analyze the average time spent by a patient in a hospital for all services including delays in the process. The analysis is made using Performance build-in feature (Duration of Time Analysis) in Disco Fluxicon, so the results are presented as a set of statistical data with assumptions from authors that could help to decrease time that patients spend in the hospital. Similar statistical approach is used in [1].

In the [5] authors are not focused on process performance but use more general approach in workflow simulation for decision support. The performance factor in this article is in calculating delays each pair of activities in banking operations. The idea is to simulate a set of models based on the data extracted previously. These models will be able to combine most suitable and least time consuming sequence of activities according to the time delays between each of them that was found in the previous step. As an output of the performance analysis authors get a matrix of delays that is used in the further analysis.

[6] is describes problems that Volvo office in Belgium faced with technology management and shows how the approach is used to reduce customer waiting time by reducing the

time needed for departments cooperation inside the company. The ping pong issue is well known for large companies and authors of current article are focusing on ping pong activities that is performed by each team in the process. The ping pong results are shown in Figure 7 (number of transfers – number of interactions with customer). Ping pong behavior usually appears in repeated cases and is characterized as "unwanted case" [6]. After all of

	# of Transfers	# of Ping Pongs	Ping Pong Frequency	Function	Org Line
Service Line 1 (total = 231)	11,113	2,107	0.19		
D4	546	**336**	**0.62**	A2_1	A2
G97	1,233	**236**	0.19	V3_2	C
D5	408	**210**	**0.51**	A2_1	C
D8	402	**170**	**0.42**	A2_1	A2
D2	346	**162**	**0.47**	A2_1	C
D7	205	**106**	**0.52**	A2_1	A2
D1	181	**103**	**0.57**	A2_1	B
G96	1,686	**69**	0.04	V3_2	C
D6	124	**61**	**0.49**	A2_1	C
G92	226	**58**	0.26	E_5	C
S49	148	**58**	0.39	V3_2	C

Figure 7. "Pin pong"ing inside of support team [6]

pre-performance analysis authors grouped cases by categories and calculated number of ping pongs cases, their frequency for each department and based on these results came up with suggestions (concentrate more attention on most frequently ping ponging teams) and calculated the possible amount of time that can be saved. Improvements that are done directly concern resource allocation and user waiting time via root cause of ping pong between divisions of the company.

[7] focuses on analysis of emergency call service and proposes a new approach that will be able to improve waiting time for the user to interact with system. In order to achieve the aim authors calculated minimum, maximum and mean vales for each type of calls with the respect to the average amount of daily calls and came up with an "as-is" model using Disco tool (fuzzy miner build-in algorithm). Types of calls are: Emergent, Urgent and not Urgent. The approach for performance improvement was in prioritization based on the call type. Authors decide that the service center should make a threshold for maximum waiting time for Emergent type as most important should not be more than 1,29 min (in "as-is" same variable equals to 5,13 min). As a result of proposed improvements the average values for Urgent and not Urgent types become smaller as well.

The research [8] is done in order to perform the described approach on three real case scenarios from gas industry, government institution and agriculture. The used approach is about the comparison of "as-is" and "to-be" models, based on KPI (key performance indicators). In order to create a "to-be" model researchers are mining KPI's and based on them changing the process model. In [8] KPI's are time-based metrics: activity time, process time and waiting time between activities. In order to see the differences between models authors used Petri net representation in ProM tool. The chosen representation highlighted bottlenecks. Each of them is able to show KPI information (values on each KPI). On later stage authors are focusing on process mining redesign as a main research focus.

In [9] authors were comparing workflows of several hospitals in the context of the same procedure that patient is doing. Authors calculated the average time needed for each procedure (activity time) and time that patient needs to wait (waiting time) and came up with conclusion about each of observed procedures. The model comparison step is

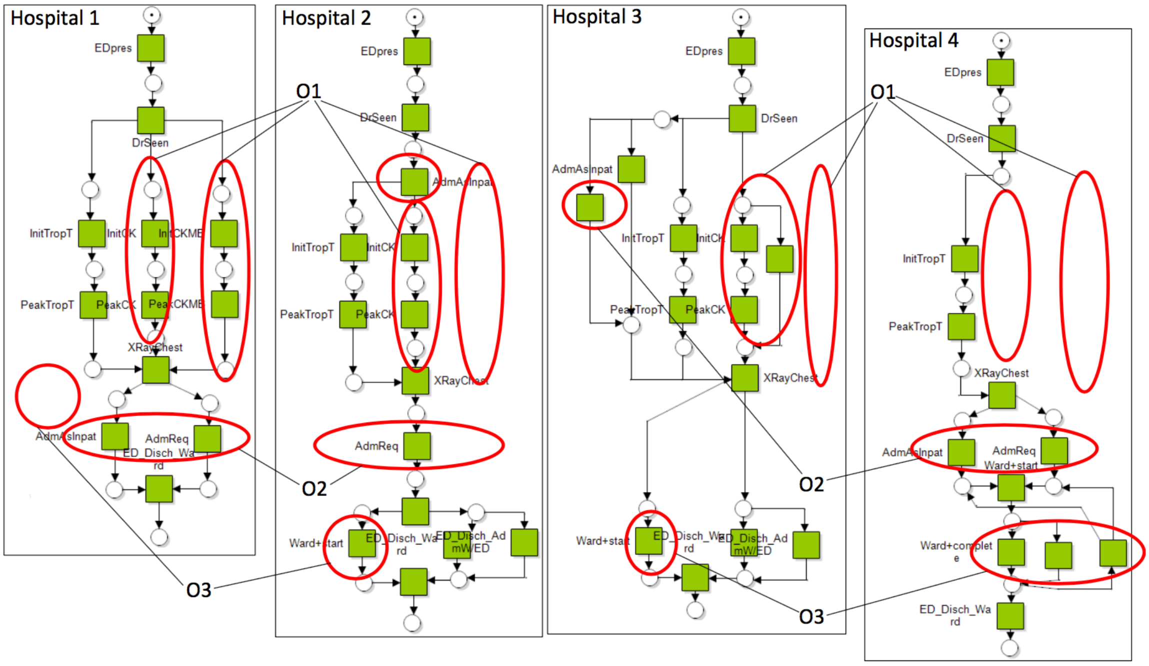

Figure 8. Comparison of the models from 4 different hospitals [9]

shown on Figure 8. The main bottleneck was waiting time, which can be explained different ordering of activities and worse recourses' allocation (the queue for the device for example).

3.1.2 Activity time

In current section we present approaches that were used across papers with measurement metric "activity time". Activity time – is the name that was used to define papers that are focused on performance of time per activity (Figure 5).

[10] focuses on process mining performance of business processes and proposes the theory that stands for better analysis of KPI (key performance indicators) by understanding of the type of the process (Figure 9).

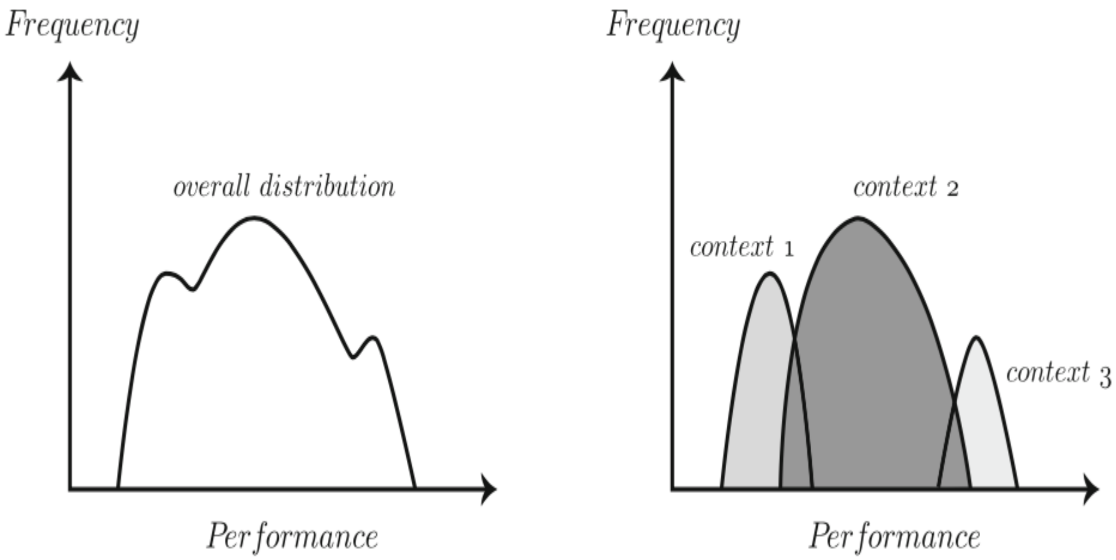

Figure 9. Overall distribution (left) and performance based on the context (right) [10]

Based on this theory the authors present a framework that calculates performance indicators in different scopes. Then statistical approach is used in order to compare the obtained results. In the example from [10] the authors explain the meaning of context: they focus on activity N, which uses amount of resources K during time T, after they find activity N1, resources K1 and time T1. After all values were mined the framework makes calculations and comparisons of each set or sequence of sets. Proposed approach can give more information on each activity (not the department or full company) and show possible way for process improvement.
In [11] the authors try to find ways to decrease the time needed for reviewing seminar and conference papers after online submission. To succeed in this, the authors decided to compare the process gained from event log and model gained from the conversations with reviewers and staff. This approach helps to identify the deviation and bottlenecks on the process based on data mismatch. In order to see the results the authors used Performance Analysis with Petri Net, which showed the severity of each deviation (Figure 10). The output of the experiment was a suggestion for conference organizers to pay attention to

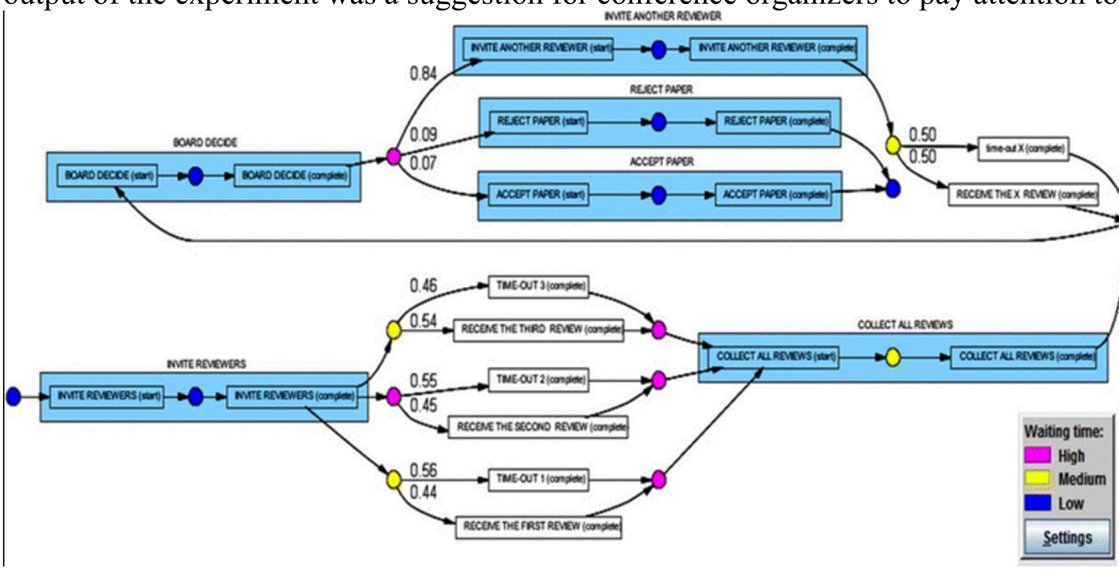

Figure 10. Petri net model for paper review system [11]

activity differences between the model that was generated from the log and the one generated from conversations with employees of the conference.
In [12] an approach similar to the one presented in [10] is introduced. The aim of [12] is to identify how the scope of the process can influence key performance indicators. In Figure 11 is shown the division of the process by scopes, where the data log can be separated based on three contexts: process in the morning, process during day and process in the evening. Similar approach was used in [31] but authors separated performance indicators into functional and non-functional.

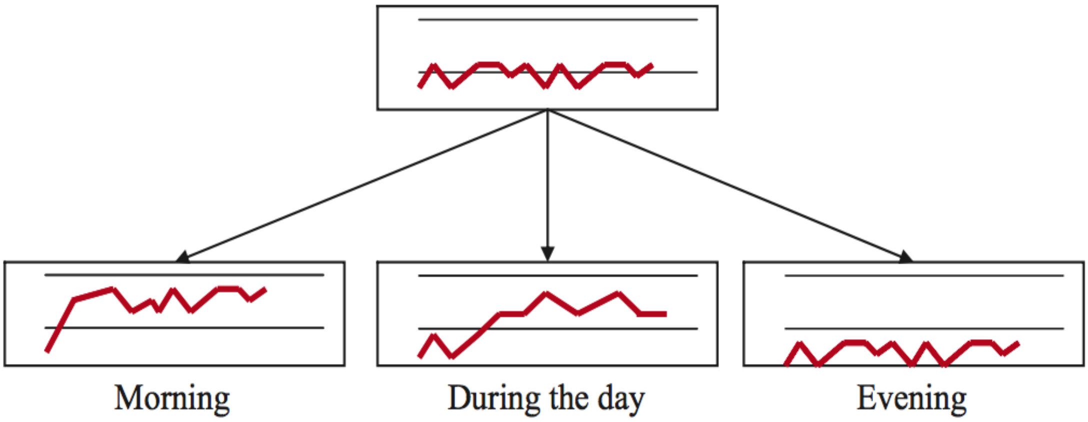

Figure 11. Separation the process based on the context [12].

In the case study the authors applied the "scope approach" on German bank data and they divided log into sub logs. The division is based on type of load, level of approval and weekday. After this division, the average activity times and the percentage of successful events are calculated. Based on the acquired the data authors are able to point out abnormal patterns that can help to improve process performance.
[13] focuses on a more general approach rather than on process performance. The authors are apply process mining techniques on construction, shipbuilding and aviation real life logs to show how process mining can bring improvements into processes. A method is used for calculating delay based on activity completion time and delay based on previous activities (how previous activities completion times influenced the chosen activity's completion time in terms of the whole process). After it, the authors get the top most frequent activities with the calculated values and based on that can see most delayed activities that should be improved in the future.
[14] is aiming to improve performance based on similarity of key measures of the process. In the case study the main indicator is tardiness of the process with root cause in activity's tardiness. The approach used is the implementation scheduling policy based on resource availability, historical success rate (time needed for activity by each of performers). Units that were taken into account: tardiness, general flow time, and completion time for process and for activities. As an output of proposed approach authors achieved significant average process time decreasing in the whole log.
In [15] is shown a way of process performance improvement via better performance visualization. In order to understand how process can be improved it should be obvious where are the bottlenecks and clear graphical representation will improve the quality of the analysis. Figure 12 presents the running example from [15] where the size of each activity depends on its importance (frequency of the activity in the process). The same pattern is applicable for arrows, the thinner the arrow the less frequent the connection is happening.

The color of arrows and activities indicate the time needed for the action (red – relatively high, green - low).

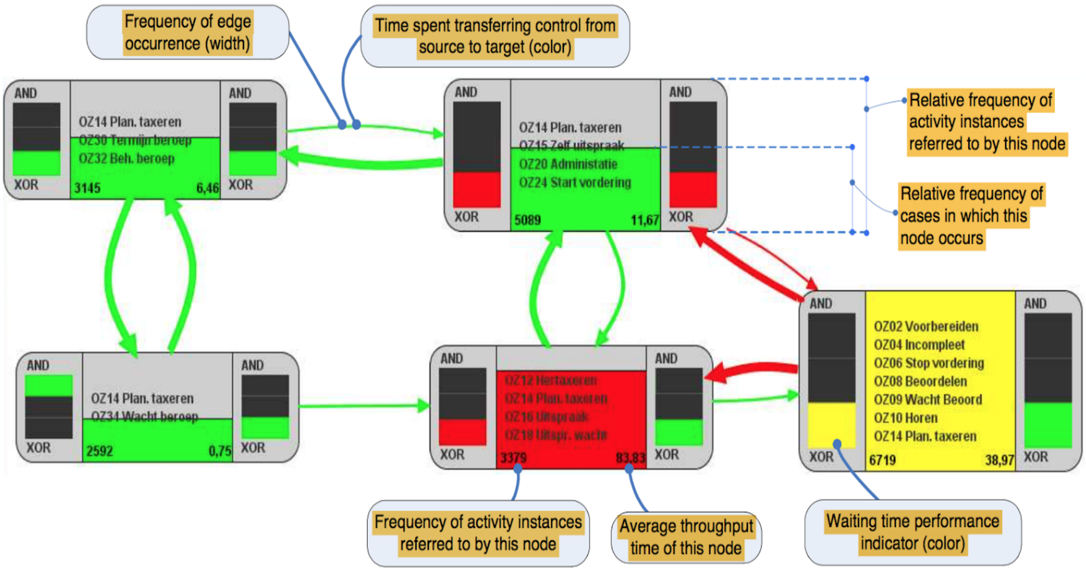

Figure 12. Fuzzy performance diagram [15]

From the initial analysis the analyst can easily identify activities that require more attention and based on given visualization further analysis can be done.

3.1.3 Process time

In this section are presented approaches that were used across papers with measurement metric “process time”. Process time – is the name that was used to define papers that are focused on performance time spent on a full process (Figure 5).
In [16] the authors are finding the way of customer integration into the companies process that will cause less time loss. The problem they are trying to solve is the decreasing quality of process performance. The approach used stands for identifying key points that can be involved along certain customer integration and building model. In order to find key activities authors are asking several questions: which processes have a connection to the customer, which types of employees are involved, how often is customer integration happening and what is the impact of average cycle time [16].
[17] presents a framework for analyzing related processes via different cases in order to be able to improve each of analyzed cases as separate instance. The approach used best case scenarios based on KPI (key performance indicators) as an example of best workflow for all other cases (cases with worse KPI’s). KPI’s that are being measured are: average activity time, average waiting time, average process time, internal time. As the output authors get the table with discovered KPI’s and their deviations. After this approach is applied each of the cases can be checked with respect to other process mining techniques.
In [18] the authors propose the way for better managing process flow of software projects. The main measurement metric is relative working together metric per each performer. They calculated the number of cases that each performer worked with each other. Thus it becomes easier to find the performers for future tasks, if performer A used to work more with performer B than with performers C or D then this pair will spend less time working upcoming on the task. And at the same time if the performer B is unavailable then performer C or D can be chosen based on the same decision criteria.

[19] proposes a tool for performance analysis and visualization. The units that are taken are split into 3 categories: Net (entire process metrics), Tasks (one activity time) and Flows (time between activities). Each category has the following units of measurement: Net – average throughput time (per process) and amount of cancelled tasks; Tasks – average throughput time (per activity), average number of completed activities, performer that cancelled the activity; Flows – average waiting time between activities, average amount of task's cancellation. In Figure 13 is shown the example of the process using extracted and visualized data with YAWL Performance Diagrams.

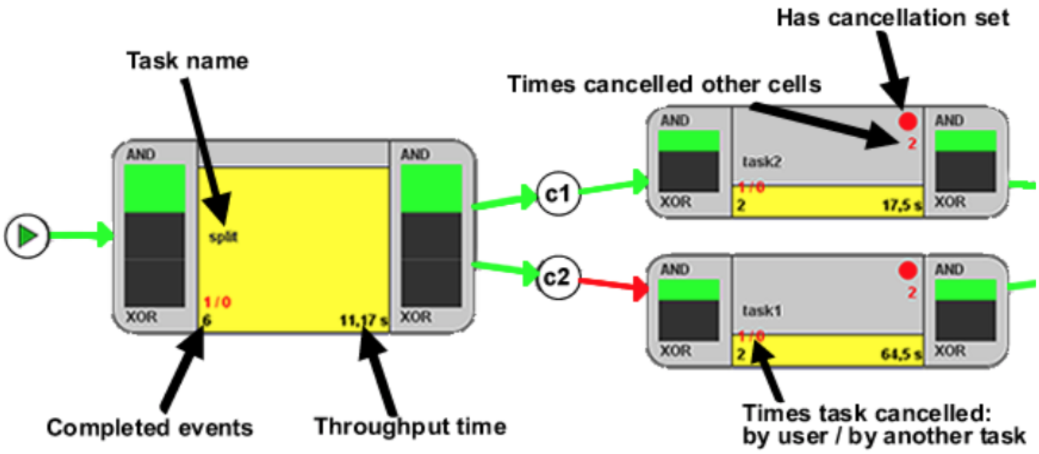

Figure 13. YAWL Performance Diagrams [19]

3.1.4 Internal time

In this section are presented approaches that were used across papers with measurement metric "internal time". Internal time – is the name that was used to define papers that are focused on performance time per sub process, meaning that authors are focusing on certain sequence of activities including waiting time between chosen activities (Figure 5).

In [20] authors apply process mining techniques in the logistics area proving the proposed concepts on Chinese bulk port. Performance analysis includes identifying bottlenecks and certain period's duration comparison. Using process mining discovery techniques authors identified the most time consuming periods in the process and came up with a table with the amount of cases per each time interval (up to 10 days, 10-20 days, etc.). This analysis is able to help on focusing on problematic cases (most time consuming cases) and its impact on the full process time.

[21] focuses on similar activities that are performed by performers from different locations and what impact on a workflow location can have. The research was done using performance sequence diagrams in ProM plugin. Performance sequence diagrams show KPI (key performance indicators) such as: average throughput time, average transfer time, average time per set of activities, etc. In the log there are different types of tasks, but activities of the task are being repeated in scopes of other tasks, meaning that the same activity can be part of different tasks. Authors found out that activities of the task with less amount of different locations are performed faster than similar activities of the task, which requires more locations.

In [22] authors focus on certain period for set of patients from a Dutch hospital. Performance perspective is in doing analysis with dotted chart that displays all the relevant information about the process. The main difference from similar visualization technics is that dotted chart is easy to check certain period data by checking two dots on the same line depending on the activities the analyst is interested in. The chart provides information about timestamp (and calculation the time of the period that can be chosen manually), activity duration (Figure 14). The graph does not show the average information but about each of processes per patient, so this vitalization brings more value to small log analysis or deeper analysis of problematic process instances.

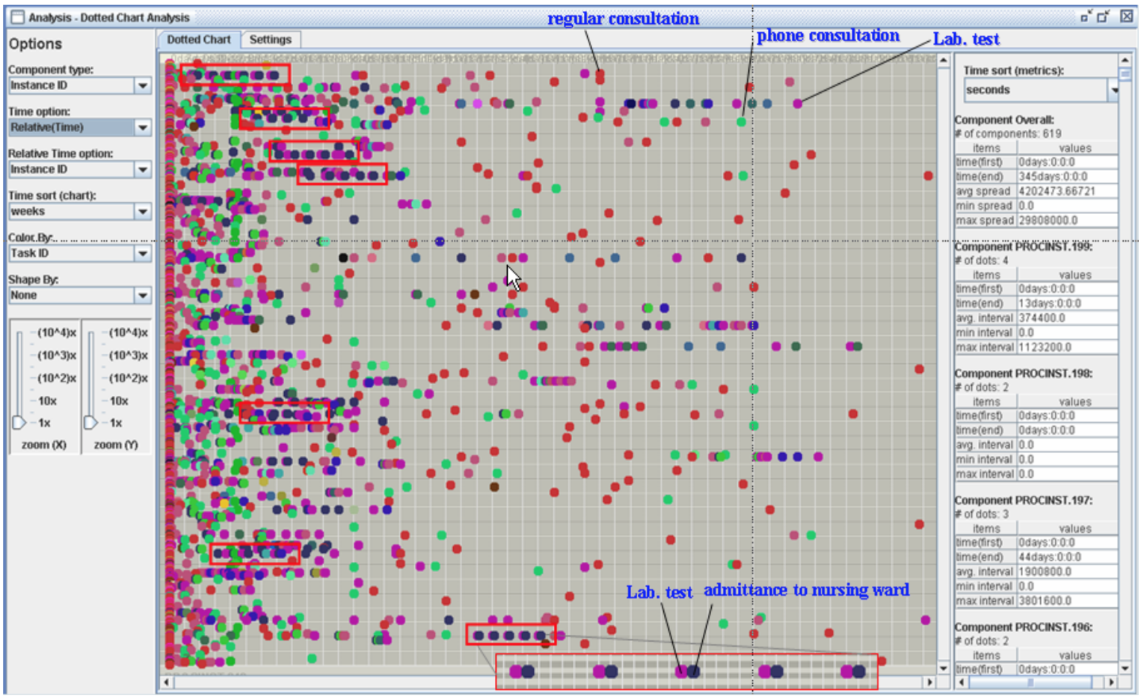

Figure 14. Dotted chart [22]

3.2 Quality

In this section papers with metric "quality" will be categorized and described. Each paper in this metric has at least one sub-category that are described in further sections (4.2.1, 4.2.2). Some of papers describe two of three sub-categories or presented in the previous section (Section 4.1). It can be explained that in one paper authors were focused on several aspects of process performance, like activity time and number of complains per activity. The total amount of approaches is different from the amount of papers in current metric what can be justified by the statement above.

3.2.1 Number of defects

In this section are presented approaches that were used across papers with measurement metric "number of defects". Number of defects – is the name that was used to define papers that are focused on performance based on the amount of defect in the end product of the production process.

In [22] the authors are finding reasons for quality bottlenecks via mining association rules. The reason for appearing defects during the process can be tracked and linked with specific differences between successful and failed processes. Based on the comparison of the

processes' values an algorithm can find which KPI's (key performance indicators) have most influence on the quality of the end product. The algorithm for mining association rules is an iterative process mining (i-PM) algorithm [32], [33] and based on its implementation on real case scenarios there were 3 rules found. The first rule indicates that most dependent values in terms of quality are suppliers' lead time, size of material ordered and fixture angle of the machine. The second rule suggests that low material orders will lead to smaller amount of defects (also, same rule stands for not taking too many orders in parallel). Third rule says that suppliers' lead time is the main factor for defects appearing.
[24] investigates a call center in Thailand's bank from the process quality point. From the full log there were extracted only calls with "failed" and "not responded" type to investigate the reasons of failed processes. The used approach showed statistical data about reasons, the most frequent reason was client reaching card limit (the problem that was not solved in 30% of cases after second attempt). The second reason was with card number that is already activated (meaning that customers were not able to use the card after activation) and this reason was not solved after second attempt in 10% of cases. The third reason was about customer's missing data, that was not solved in more than 50% cases after the second call. The authors used Disco Fluxion build-in functionality (Figure 15).

Activity	▲ Frequency	Relative fr
DAS_BALANCE_INQUIRY_VIA_VOICE-10211\\NA	239755	38.31 %
BALANCE_INQUIRY_VIA_VOICE-10621\\NA	146949	23.48 %
STATEMENT_VIA_FAX-10251\\NA	62363	9.97 %
LIMIT_CHANGE-10472\\NA	55383	8.85 %
CREDIT_CARD_ACTIVATION-10584\\NA	28287	4.52 %
CREDIT_CARD_UPFRONT_BALANCE-1058\\NA	19230	3.07 %
LIMIT_CHECK-10471\\NA	16213	2.59 %
BALANCE_INQUIRY_VIA_VOICE_KEC-117821\\NA	15035	2.4 %
LIMIT_CHANGE-10472\\OVER CARD LIMIT	4667	0.75 %
INQUIRY_PRIMARY_ACCOUNT_BALANCE-10211A\\NA	3994	0.64 %
INQUIRY_SECONDARY_ACCOUNT_BALANCE-10211B\\NA	3849	0.62 %
C20_Campaign - โครงการ ""บัตรเดียว เที่ยวเหมาลำ"-123520\\NA	3807	0.61 %
C30_Campaign - จ่ายบิลด่วนแลกของวิเศษโดราเอมอน 2014-123530\\NA	3152	0.5 %
REWARDS_POINT_INQUIRY_VIA_VOICE-10623\\NA	2972	0.47 %
CREDIT_CARD_ACTIVATION-10584\\KB1B720 "CARD NUMBER IS ALREADY ACTIVAT...	2068	0.33 %
LAST_CYCLE-10771\\NA	1650	0.26 %
C10_Campaign -บริการแจ้งรายการเดินบัญชีเงินฝากผ่าน SMS (SMS ขยันบอก)-123510\\NA	1534	0.25 %
BRANCH_CODE_INFORMATION-12433\\NA	1242	0.2 %
C50_Campaign - บริการเงินสดทันใจโทรสั่งได้ (Call for Express Cash)-123550\\NA	877	0.14 %
CHEQUE_SUSPENSION-10124\\NA	842	0.13 %
CREDIT_CARD_PAYMENT_CREDIT_CARDS-10625\\NA	658	0.11 %
FUNDS_TRANSFER-10822\\NA	655	0.1 %

Figure 15. Reason for failed calls sorted by frequency [24]

3.2.2 Number of complains

In this section are presented approaches that were used across papers with measurement metric "number of complains". Number of complains – is the name that was used to define papers that are focused on performance based on the amount of complains that came from the customers.
[25] analyses information about a call center in Thailand telecommunication company. The performance aspect in the article is in calculating the total amount of complains that each team got. As a conclusion the authors came up with top 3 teams that got most com-

plains (percentage ration of all calls per team and calls with complains). Similar approach was used in [24] but in current research main focus was not on process performance.

[26] provides the description for 7 step process improvement for delivery services via process mining techniques. The performance approach used in the article is in decreasing amount of complains after production. 7 step approach includes: “a must” measurement metrics of the process, “nice to have” measurement metrics of the process, gathering the data, processing the data, analyzing the data, presentation and usage of the data, and implementation. The approach was used in real case log from a German telecommunication company.

[27] describes the implementation of a continuous process improving in SÜWAG company. The tool used is ARIS PPM (Process Performance Manager). Given tool calculated KPI’s (key performance indicators), but in the article they are not specified. As an example of process analysis based on performance indicators can be Figure 16, where there are shown processes that customer integrates with. Based on this data it is easy to track the changes in behavior (for example, when integration with some services become less than month before).

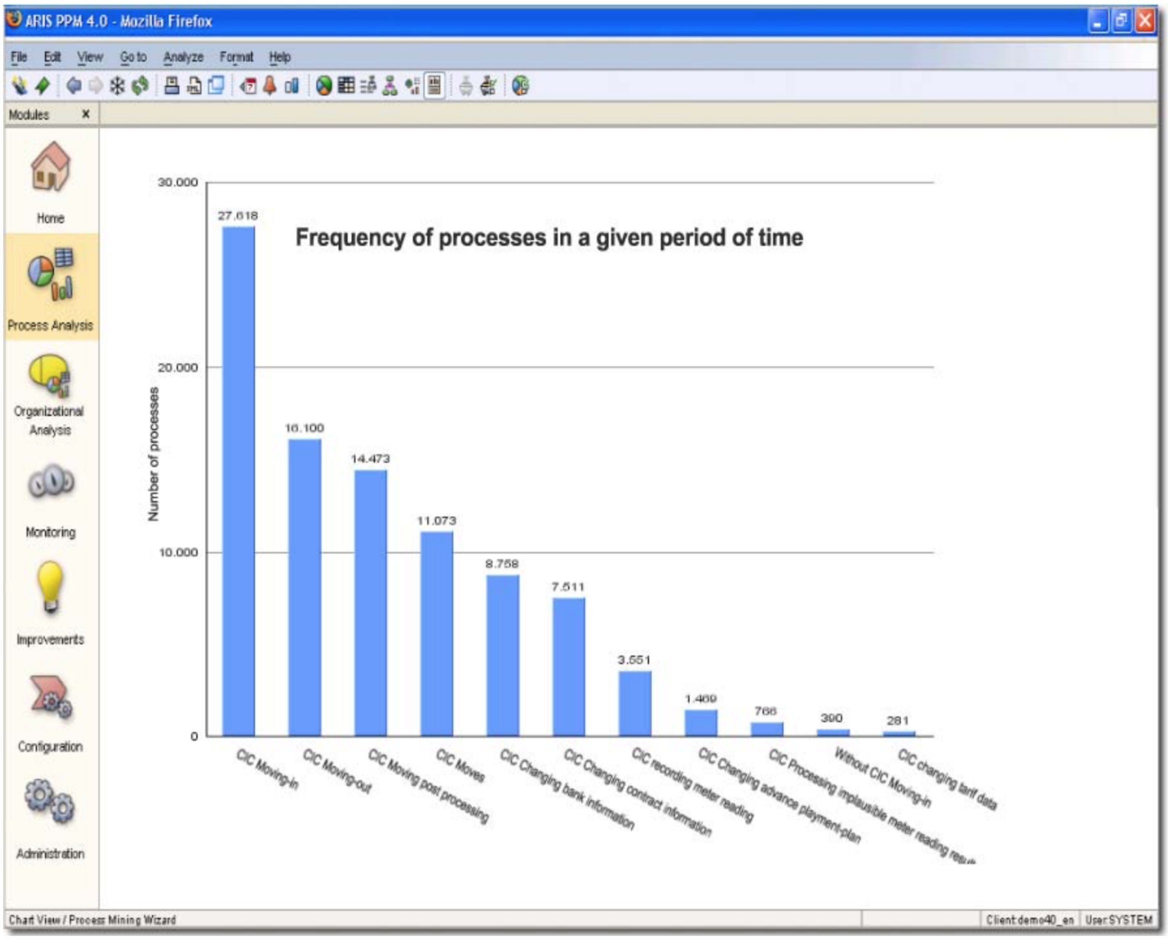

Figure 16. Number of processes that participate in customer integration and their frequency [27]

3.3 Resources

In these sections papers with metric “resources” will be presented and described. This category has 4 papers in terms of current research. Two of the articles were discussed in pre-

vious sections. This section will be focused on 2 remaining papers that propose different approaches in process performance context.
[28] aims to describe the framework that uses resource allocation recommendations. In order to implement the approach, the framework looks for similar requests in the past before request reaches the activity. Also, the framework takes into account not only activity division but sequence of activities as well. The performer that spent less time in the past on similar actions or the performer with more experience can manage upcoming request better and the process will spend less resources (human resources, costs, time, etc.). Authors propose 6 characteristics for better request evaluation: frequency of similar requests, performance of the past execution (time that performer spent), quality of the output (customer complains count, defect, etc.), execution costs, level at which the performer was able to execute the activity and workload (number of cases when performer was busy at the moment of similar request was coming). Part of performance analysis based on proposed criteria is presented in Figure 17. Similar approach was used in [30].

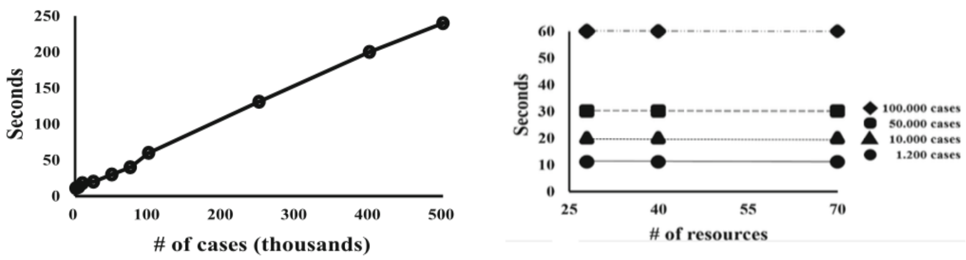

Figure 17. Part of the performance analysis output [28]

Authors in [29] describes the usage of Resource Behavior Analyzer (RBA) [29] on real case example and shows the resources load decrease by 59% by finding which activity should be performed next in the queue. The idea behind the proposed approach is in finding the optimal resource load using the time taken by performer for activity and resources used. A schema for better understanding of process flow is presented on Figure 18 (dotted line shows the path of the workflow).

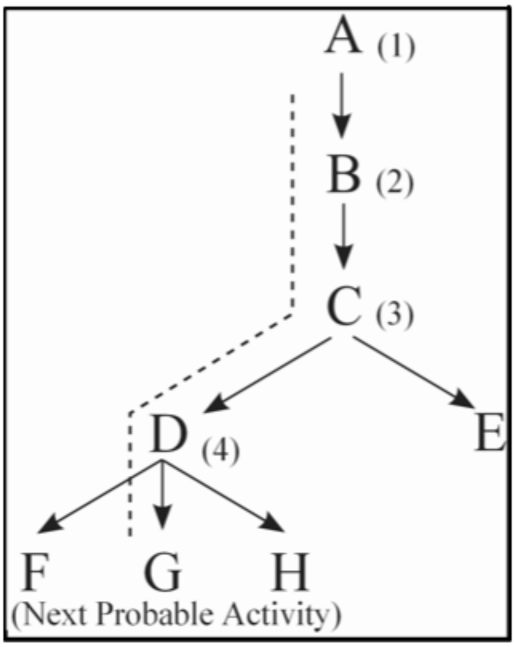

Figure 18. Graphical presentation of RBA's approach [29]

3.4 Summary

The purpose of the study is to make an overview of existing ways for doing process performance analysis. All of 32 researched papers were analyzed in order to find similarities among them. There were discovered 24 papers with time-based metrics, with 9 quality-based metrics and 4 resource-based metrics. In some cases single paper could include several metrics. There were no papers that perfectly matched each other according to subcategories that were observed, so categorization was mainly done based on the main direction of the used approach. The main idea behind comparative evaluation is in comparing papers between each other, finding a common pattern and finalizing the research with the framework.

According to [34] there are four main indicators of process performance: Time, Quality, Costs and Resources. In the current research, there were found three of proposed indicators (Time, Quality and Resources) because it this thesis we were focusing on the units of measurement based on the data that could be obtained from the log. None of the researched papers included the units of measurement related to Costs metrics.

4 Discussion of RQs

In this section are given answers to the research questions that were outlined in section 3.1. Papers' comparison was done based on the data extracted from each of them (defined in Section 2.6).

4.1 RQ1

- What is the value that business process performance analysis can deliver? (**RQ1**)

This section will give the understanding of purposes and motivation for using process performance analysis, involving the information about types of experiments described and the output of the researches in the observed papers. Most of the 32 papers had process performance section as part of the more global research, however in current section there will be described only performance analysis part of papers. Among all the discovered studies, there can be highlighted several reasons behind using process performance analysis.

The **first** reason is based on the analysis of an basic process performance – the category where authors are doing analysis based on already known methodologies and contribution is to be able to deal with different input data (for example, analysis on real life log from shipbuilding industry). The motivation behind such kind of researches is in applying already known techniques on the data coming from different context [1] [8] [11]. In Figure 19 authors use heuristic net model for mining a gas industry log.

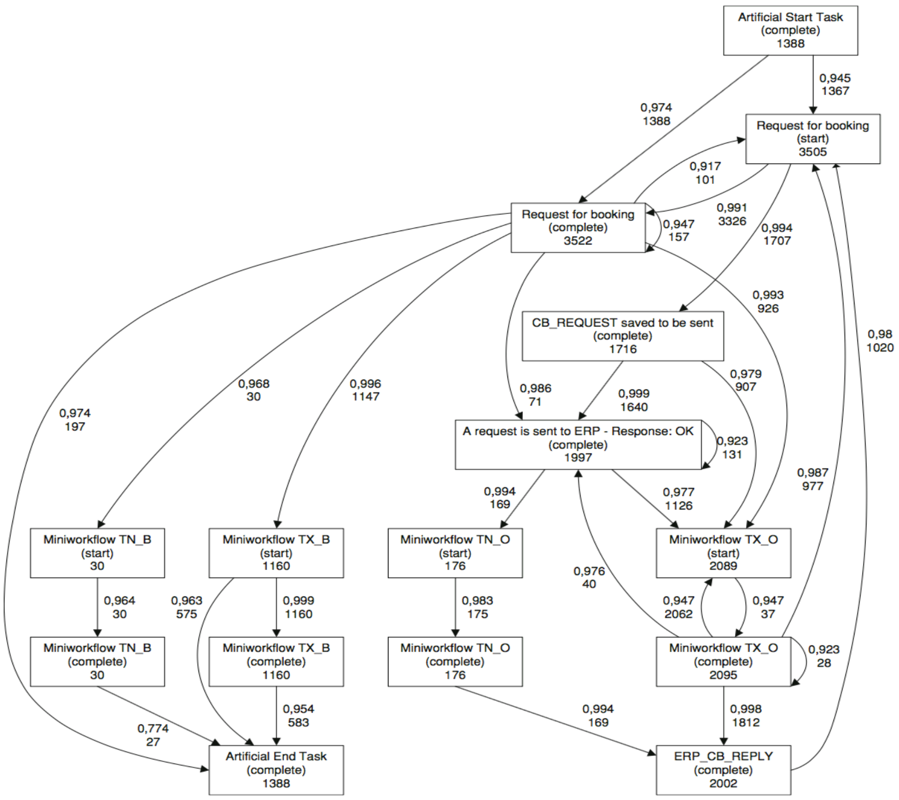

Figure 19. Heuristic net for gas industry log. [8]

Second category is implementing novel analysis methods where authors are focusing on a new method for evaluating performance and test it with experiments. The aim of papers from this category is in proving the concept that was developed by authors and implemented. Example of this approach can be [12] where authors are doing analysis after dividing the data based on its content (day time in Figure 11). Also, paper [7] describes the new way of dealing with incoming calls in call service depending on the reason of the call. There are two figures shown – "as is" (Figure 20) and "to be" (Figure 21), where authors have come up with idea of setting limits for calls that are less urgent which will bring more time for more important calls.

		Severity Index			
		Level 1 Resuscitation - Emergent	Level 2 Urgent - Less Urgent	Level 3 Non Urgent	All
Number of calls answered by AO		82	90	66	238
Call duration by AO	Mean	00:01:21	00:01:01	00:03:00	00:01:41
	Min	00:00:42	00:00:45	00:02:26	00:00:42
	Max	00:05:56	00:01:18	00:03:35	00:05:56
Speed to answer by AO	Mean	00:00:37	00:00:58	00:00:50	00:00:48
	Min	00:00:00	00:00:00	00:00:00	00:00:00
	Max	00:05:13	00:05:48	00:07:45	00:07:45

Figure 20. "As-is" time limits for call center. [7]

		Severity Index			
		Level 1 Resuscitation - Emergent	Level 2 Urgent - Less Urgent	Level 3 Non Urgent	All
Number of calls answered by AO		82	90	66	238
Call duration by AO	Mean	00:01:34	00:01:20	00:04:34	00:02:19
	Min	00:00:42	00:00:45	00:02:35	00:00:42
	Max	00:05:56	00:04:37	00:11:38	00:11:38
Speed to answer by AO	Mean	00:00:07	00:00:17	00:00:17	00:00:14
	Min	00:00:00	00:00:00	00:00:00	00:00:00
	Max	00:01:29	00:05:31	00:05:26	00:05:31

Figure 21. "To-be" time limits for call center. [7]

The **third** cluster is about finding hidden key performance indicators, the indicators that are not observed in the industry before. The root aim of the third approach is to highlight the hidden indicators that have an influence on the process flow. Good example for this case can be paper [3], where authors are calculating waiting time for set of independent activities and dependent ones as a part of calculation. Figure 22 shows graphical presentation of finding latent time units of measurement from [3].

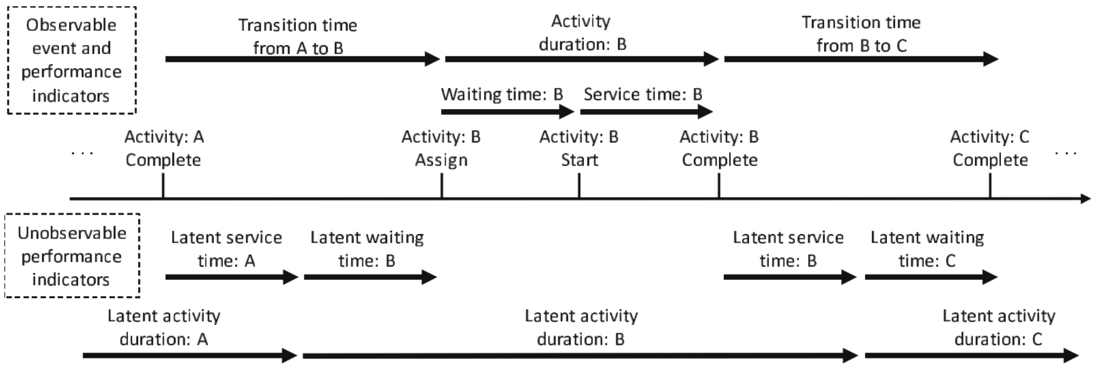

Figure 22. Finding latent time unit of measurement [3]

The **fourth** reason of several papers is in presenting and describing a new tool and its abilities to evaluate process performance and present it in a most understandable way to the user. Papers [15] and [19] are proposing tools that bring better understanding of "as-is" business process performance via visualization.
To sum up the approaches Table 1 presents the overview of the discovered categorization of the reasons for doing process performance analysis.

Table 1. Main reasons for doing process performance analysis.

Reason	**Description**	**References**
Applying known techniques	Analyst applies known techniques on logs of different content.	[1] [8] [11]
Novel method	Analyst proposes novel approach for process performance analysis.	[7] [12]
Identifying hidden indicators	Analyst is calculating hidden key performance indicators.	[3]
New tool	Analyst presents and describes new tool for doing process performance analysis.	[15] [19]

Above main reasons for conducting performance analysis and thereby delivering value to the business, have been verified on real life logs. This matters, as synthetic logs might not reflect the complexity of industry logs. Thus it is extremely important as it shows the real value that process performance analysis can bring into an industry. In order to show the overview of observed papers by the data they used the categorization was created. Categorization of log types was proposed in Section 3.7.2 and Section 3.7.3 and the results can be captured in Figure 23 (the type of experiments) and Figure 24 (application domain of the experiment). From Figure 23 it becomes clear that most of the experiments have been performed on real life data, which means that most of the process performance analysis papers in the scope of the current research can have real value in the industry (banking, shipbuilding, healthcare, call center, manufactory, etc.).

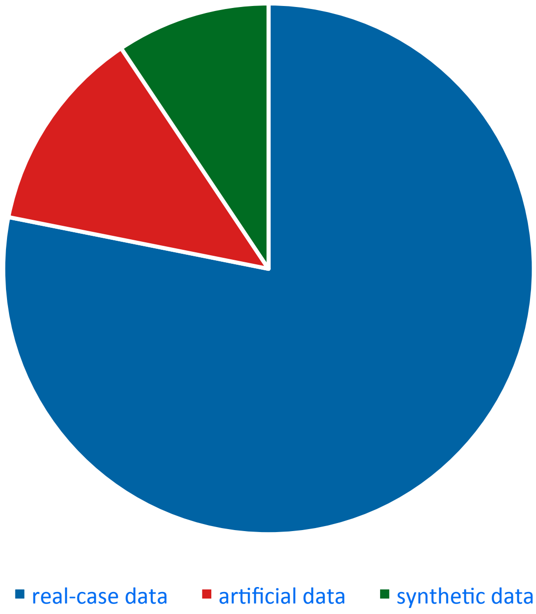

Figure 23. The ratio of papers per each type of data

In the Figure 24 it is shown some ratio of experiments' fields, where the healthcare has approximately 25% of total share, which means that healthcare is one of main directions for applying existing and testing new process performance analysis approaches.

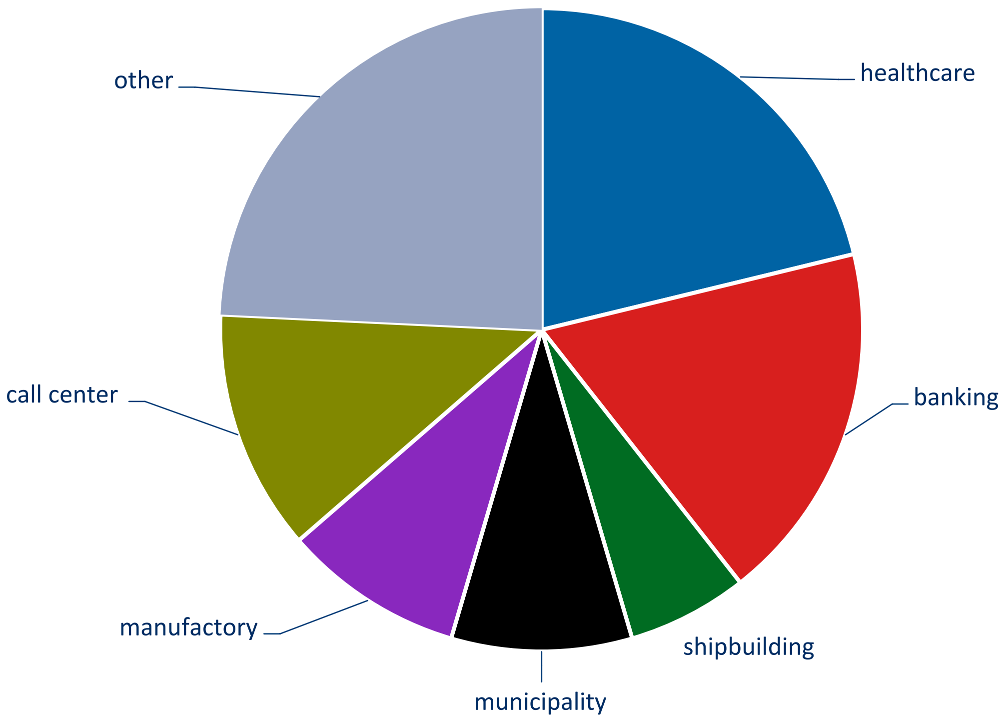

Figure 24. The ratio of papers per field of the experiment

4.2 RQ2

- What can process performance measure? (**RQ2**)

This section will give an understanding of metrics that are used for evaluation the business process performance. This step in business process performance analysis comes after defining the aim for doing the analysis (RQ1).
According to Section 3, there are 3 metrics (time, quality and resources) that were clustered by their root units of measurement in the same section. The answer for RQ2 can be separated into two parts:
- the first part stands for values that are presenting only one metric and can be calculated using same type of measurement (maximum waiting time, average activity time);
- the second part present units that are calculated using different types of measurement units (average time spend for producing product with defect – meaning that time and quality metrics can produce mixed type of measurement). In Figures 25, 26, 27 are shown typical measurements per metric that are combined from all papers of current research.

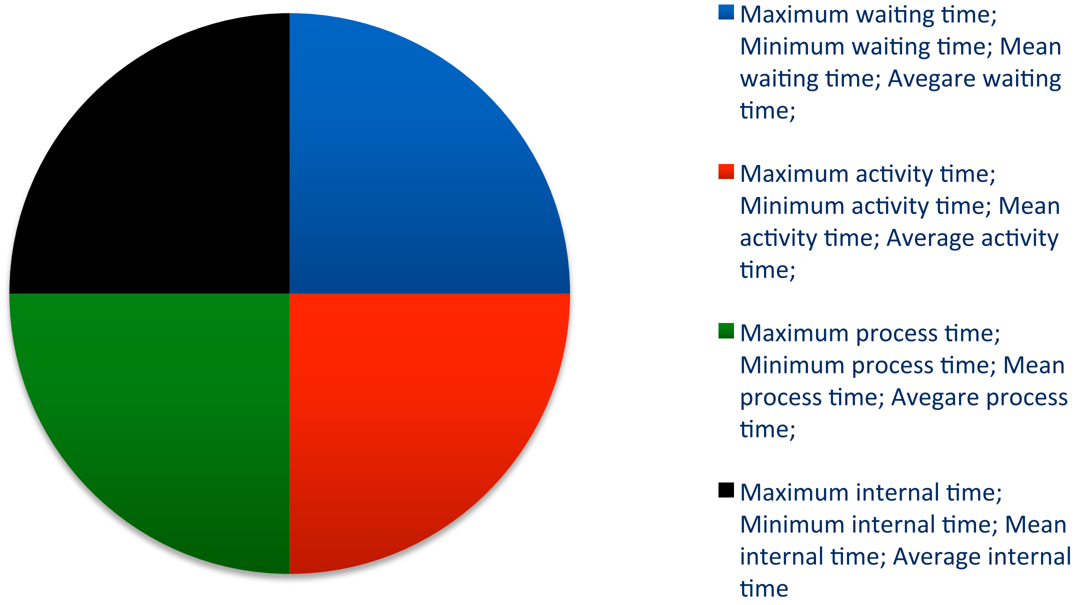

Figure 25. Time-based units of measurement

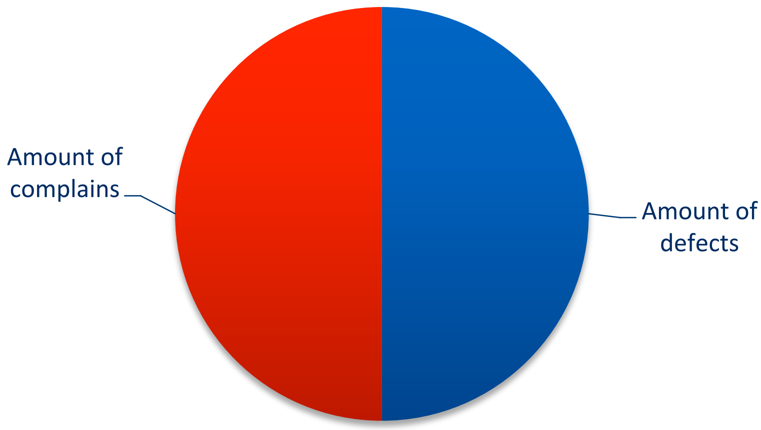

Figure 26. Quality-based units of measurement.

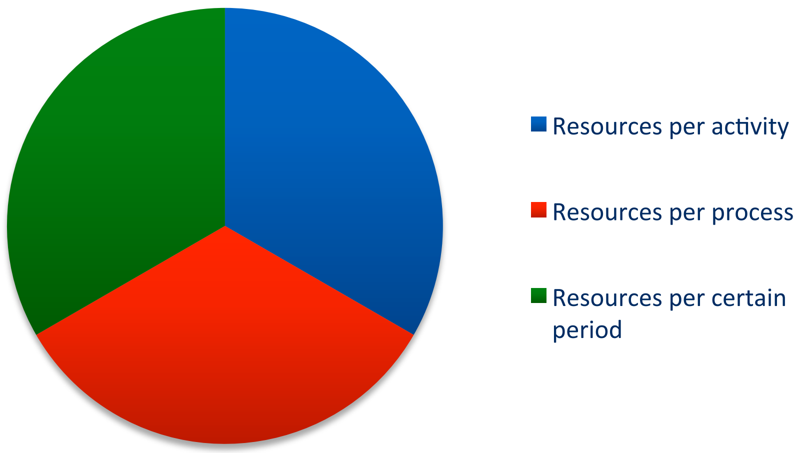

Figure 27. Resource-based units of measurement.

Table 2 shows units of measurement based on the relation between metrics. There can be found and calculated other units of measurement (for example, latent KPI's,), but it mainly depends on the content of the input data. Proposed units of measurement are the basic ones and constitute the minimum basis for every performance analysis.

Table 2. Units of measurement based on relation between metrics

	Quality	**Resources**
Time	Amount of defects/complains per process time Amount of defects/complains per activity time	Resource per activity time Resource per process time Resource per certain period time
Quality		Defect/complains items per resource

4.3 RQ3

- How can process performance can be measured? (**RQ3**)

This section will give an understanding of methods for evaluation the business process performance. In the previous RQ we have identified the set of basic units of measurement for common performance analysis. In this section we will discuss how units of measurement can be calculated from the raw log data. In order to answer this question the process mining performer needs to have certain data in the log. For more clear description it was decided to split log information by used in previous sections metrics. In Table 3 there is shown a log template for calculating time based units of measurement, where

- A1, A2, A3, An – "Activity name";
- sT1,..., sTn – timestamp of activity "Start time";
- eT1,..., eTn – timestamp of activity "End time";

Table 3. Log template for time based metric

Activity name	Start time	End time
A1	sT1	eT1
A2	sT2	eT2
A3	sT3	eT3
…	…	…
An	sTn	eTn

For calculating time based units we need activity start and end time, and based on this data the performer can calculate all the key performance indicators that are related to time metric (for example, for waiting time between A1 and A2: eT1 – sT2, etc.). Table 4 stands for quality

Table 4. Log template for quality based metric

Full process					
Activity name	Activity name	…	Activity name	Complain (yes/no)	Defect (yes/no)
A1	A2	…	An		

based log template, where the analyst is able to see the set of activities of the full process with quality outcome, that show how successful was production process (based of "Complain" and "Defect" columns). Table 5 is used to describe the log template for resource

Table 5. Log template for resource based metric

Activity name	Performer	Resources used
A1	P1	R1
A2	P2	R2
A3	P3	R3
…	…	…
An	Pn	Rn

metric. Based on the Table 6 the information can be obtained from:

- "Activity name" column (values were described above),
- "Performer" column, where P1, …, Pn – is the human resource representation
- "Resources used" column, where R1, …, Rn – is the amount of resources used for performing corresponding activity (for example, materials that are needed for production).

4.4 RQ4

- What are the existing approaches for performance analysis? (**RQ4**)

All approaches along papers included in the current thesis are classified in order to give a broad understanding of performance field in business processes. Methods from papers are different by their aim, industry or other factors but can be clustered by similarity in their approach.

The **first** approach stands for calculating units of measurement and based on the given data authors are giving suggestions. Different papers are calculating corresponding units depending on the initial aim of the paper. In Table 1 are presented values that can be calculated with this method, but at the same time in this method, latent units can be discovered. Authors were calculating units for some particular (problematic/abnormal) cases or single process instance. This approach does not give any certain conclusion and in other approaches units' calculation is only one of steps in the performance analysis. Examples of such approach are presented in [2] [16].

The **second** approach is more advanced than the previous one. It can be called statistical approach. Authors have the big amount of data and they are calculating deviations of the same values across all same kind of processes. In the scope of statistical approach process, bottlenecks can be identified and presented as Petri Net model that will highlight weak points of the process with the most relevant unit of measurement (for example, values from Table 1). Also, this way of doing performance analysis can include splitting input data based on the context of the data, as in [12] where authors were calculating performance after splitting data into activities that were performed in the morning, during the day and evening.

Third proposed approach describes that for performance measurement/improvement can be used models' comparison. The idea behind comparing the models stands for using the data from companies of the same business industry/field that have differences in their processes. In this case, a model comparison can be applied in order to highlight ways for improving processes (finding redundant processes, performers' ranking, etc.). An example can be [9]. Authors have compared similar processes from 4 hospitals.

The **last** approach is in finding regularities in the process. As in [23] authors have applied association rules algorithm (i-PM) in order to find general patterns and concentrate on bottlenecks based on the output rules. Association rules are calculating all if/then options and trying to find most interesting regularities in the process log. In the example from one of the used papers [23] authors came up with several correlations that analyst can focus on for further investigation.
Table 6 shows an overview of described above approaches.

Table 6. Main approaches of process performance analysis.

Approach	Description	References
Calculating units of measurement	Analyst calculates units of measurement based of the data from the log.	[12 [16]
Statistical approach	Analyst presents statistical overview of the process performance.	[12]
Models' comparison	Analyst compares different models of same type of the process.	[9]
Finding regularities	Analyst applies algorithm to find association rules.	[23] [32]

4.5 RQ5

- What algorithms/tools are available for performance analysis? (**RQ5**)

In section 3.7.1 were discussed two main tools that are used in process mining (ProM and DISCO). Figure 28 shows that these tools were mainly used in observed papers. **Other** section means that authors used some custom tool(s) for achieving the results of the experiment and **No data** means that authors did not mention anything about the tool(s) they used in the paper. For most of process performance analyses it is not enough to use only one a tool, usually the analysis requires using some specific plugins and/or algorithms.

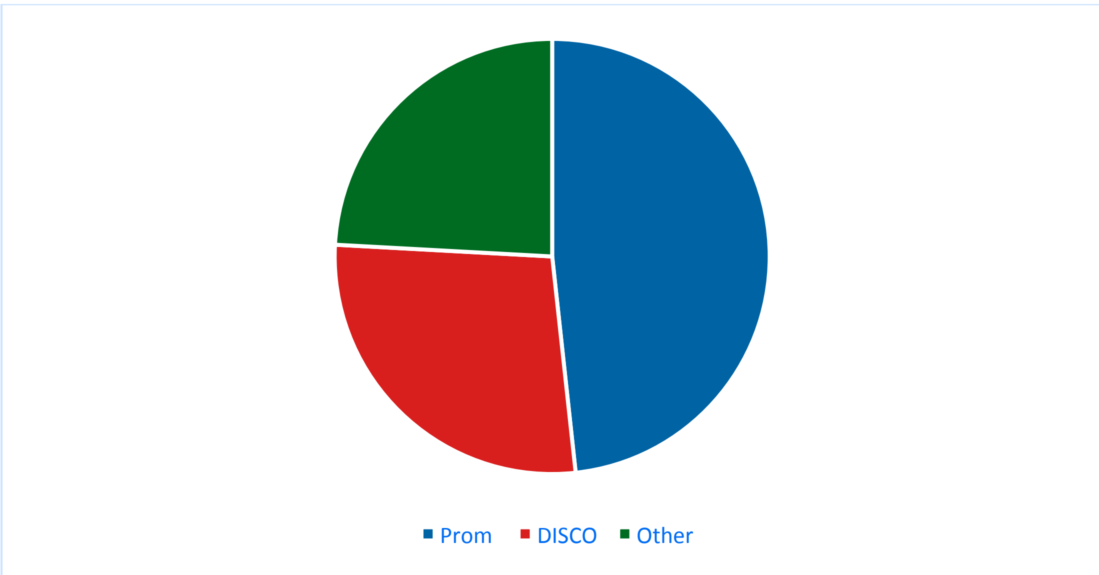

Figure 28. The ratio of tools used in extracted papers.

Here is a table of existing plugins and algorithms that were used among papers of current research (Table 7).

Table 7. Main algorithms/plugins for process performance analysis.

Plugin/algorithm	Description	References
Heuristics Miner	Shows a heuristic net model with performance indicators as an output.	[20]
Dotted Chart	Shows an output as a dotted chart with all activities according to the time (end/start).	[22]
Fuzzy Miner plugin	Gives and ability to change units of measurement and see the reflection of the other process indicators.	[4]
i-PM Algorithm	Mines association rules.	[23]
RBA Miner	Recommends optimal resource for performing the activity.	[29]
BPA Algorithm	Mines best resource for the activity based on the previously defined custom metrics.	[28]
Role Hierarchy Miner	Improves comprehensibility of mined models.	[25]
Basic Performance Analysis plugin	Presents units of measurement statistics in understandable way and gives a possibility to configure the data in order to see only relevant results.	[22]

However, most of authors were using custom algorithms that are described in Section 3 for preprocessing the data or for the whole research based on the approaches they have used.

5 Framework

Evaluation part of the thesis will be presented as a framework for doing business process performance analysis based on the analysis that was done in this paper. In previous section we have discussed each step for doing performance analysis. Figure 29 shows the flow for basic performance analysis. From the Figure 29 we can see that after “Identifying aim of the analysis” step flow goes in two ways: one way skips “Calculating unit of measurement”, that can be justified that some of the algorithms include the calculations by their build it functionality.

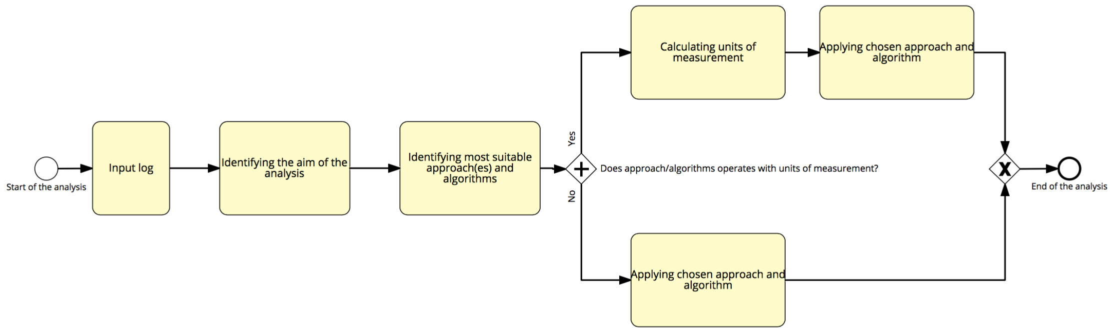

Figure 29. The process flow for performance analysis

Input log

In this part of the analysis we will describe what data should be in the log. According to the observed papers input logs were different in most of papers. However, in most of business cases it is possible to add data to the log. As it was described in Section 4 units of measurement and metrics depend on the aim of the study and the data that log consists of. In our case we have an artificial log that we can fulfill with desired data. Table 8 shows log sample that was combined based on the information from Section 4.

Table 8. Log description

Activity name	Start time	End time	Performer	Resources used	Complain (yes/no)	Defect (yes/no)
A1	sT1	eT1	P1	R1	No	No
A2	sT2	eT2	P2	R2	Yes	No
A3	sT3	eT3	P3	R3	Yes	Yes
…	…	…	…	…	…	…
An	sTn	eTn	Pn	Rn	No	No

Identifying the aim of the analysis

The aim of the analysis is to receive as much useful information about current process performance as possible. We are proposing the framework based of the collaborative analysis of 32 observed paper and describing the algorithm of action needed to perform the analysis. Based on this statement we can use the classification that was defined in Section 4.1 and aim of the framework is to present the novel approach for dealing with business process performance.

Calculating units of measurement

This step presents the calculating and adopting the data for further analysis. Based on the data from the artificial log from Table 8 we are able to calculate the all of unit of measurement from Figures 25, 26, 27.

Identifying most suitable approaches

Based on the previous step we have identified the aim of the whole analysis and based on the received data we can proceed. Considering that the analysis already has necessary knowledge analyst is able to pick the needed option. The question that the analyst has to answer is "Does approach/algorithms operate with units of measurement?". But in the scope of the designed framework we will describe each option.

Calculating units of measurement and Applying chosen approach and algorithm

If the answer to the question ("Does approach/algorithms operate with units of measurement?") is **Yes**, than we do "**Calculating units of measurement**" step the most suitable approach is statistical one. The data from the log can be used for calculation main units of measurement (Section 4) for each of defined in current thesis metrics. "**Applying chosen approach and algorithm**" step starts Using Basic Performance plugin (implemented in ProM) we can insert custom values (units of measurement that we have already calculated) and get different visualization with bottlenecks highlighted. This basic analysis with Petri will be able to show the overall picture of the process. Additionally, analyst can use the approach from [7] where authors changed some of key units of measurement in order to see how the rest of the process will react on this change.

If the answer to the question ("Does approach/algorithms operate with units of measurement?") is **NO**, than we skip "**Calculating units of measurement**" step and do "**Applying chosen approach and algorithm**" step, we can use association rules algorithm (i-PM). But in this case it would be highly beneficial to know the context of the business process that we are analyzing. For better understanding of benefits for using context of the business process we can discuss two separate cases from different fields: healthcare process and shipbuilding factory. The reason behind adopting proposed framework on range of industries is the differences between bottlenecks' values per industry. As a prove of this statement can be an example that compares two industries: healthcare and shipbuilding. In healthcare industry the central problem is based on Time-related units of measurement – waiting time of the patient, queue length, time needed for procedure. With decreasing Time-related units of measurement as a consequence the quality and resources aspects will show better performance results (better resource allocation/reusing by time, customer satisfaction, amount of complains, etc.). On the other hand the root problem for shipbuilding industry is in quality of produced products, the business value of the mistake is higher (and the amount of items is smaller). So according to this statement it is better to focus on quality improvement and spend more time per item production.

- For the healthcare process, we can find association rules between performers in order to know which sequence of people is more productive (from resources, time or quality points of view). As far as this type of business process mainly depends on the performers' skills the information about workers is vital in calculating the overall performance.

- For the second case, with shipbuilding industry we can focus more on the end product and find out rules that lead to process delay or defects in production. Example can be the relation between waiting time between two activities and significant increase in defects. This will help to pay attention to problematic point and find out the way of decreasing the damage of the business.

Summary

The described above framework will give an output with the data visualization in human understandable way, which this will help the analyst to have better control over the business process. Also, this output type is quite simple and does not require deep knowledge, so most of all of business process stakeholders will be able to understand it. The result will highlight bottlenecks that will give an understanding of activities and nodes that need to be improved. Additionally, it will give the ability to configure parameters in real time to see what consequences it will bring to the whole process. And the conclusion, based on associations that were discovered will help to better understand insights of the process. This information will explicitly give the information about rules that the process flow and if/then cases.

6 Conclusion

In current paper main idea was to categorize items that participate in process performance analysis. Five research questions were answered based on the data from a systematic literature review. Each of extracted data column was part of the answer or fully answered one of the research questions. All 32 papers were extracted and analyzed in order to be able to find common patterns that authors were following. Research questions discussion section presents an overview of the studies that have been done so far in this researched field. The final framework includes most common approaches and algorithms that can be used for business process performance analysis.

The conclusion of current research is categorization and connection into meaningful output of several points:

- Unit of measurement of process performance
- Approaches for applying mining performance analysis
- Algorithms that can be used in process performance analysis

Based on the first key point we have discovered key reasons doing using process performance analysis. We have found out what purposes for using process performance analysis and what value it can bring to the industry. In order to apply performance techniques, there was described the way of getting data from the log, taking into account what kind of data is present in the log. After getting the data from the log it can be transformed into meaningful units of measurement that are used in the analysis.

According to the units of measurement, we have found out main existing approaches for dealing with process performance, which includes tracking the current status of the business process from performance side and shows ways for process improvement. In the current study, we have identified 3 key metrics (time, quality and resources). Each metric has set of units of measurement that help an analyst to understand the current state of the business process. Identification and calculation of units of measurement is the fundamental step for every performance analysis. Further performance analysis depends on the approach authors have chosen. The choice of the approach is usually based on the aim of the paper and the problem authors are trying to solve. Also, an important factor is the context of the input data.

Most popular visualization for business process model is Petri Net representation, which allows seeing some of the units of measurement and the business model workflow. Depending on the chosen activity Petri Net is showing data according to chosen element. Performance analysis can include ProM build-in plugins, such as Basic Performance Analysis or Performance Sequence Diagrams plugin. To find association rules there was used only i-PM Algorithm, it does not have graphical representation but the textual output is clearly showing the current performance state of the process.

As a future work, it is planned to apply designed framework on experimental data, preferable real case data. In order to be able to see if the proposed framework can bring real value to the industry. For better understanding what real value can proposed framework bring it is highly beneficial to use it on different types of industries (shipbuilding, banking, healthcare, etc.).

Also, as part of the future work can be designed technical implementation of a proposed framework as a plugin for ProM (as far as it is the most popular standalone tool in process mining community). In the evaluation framework was separated by metric, but it could be a good idea to design a framework that includes the analysis of 3 metrics in one single plugin. For example, it could be profitable to see how time-related units of measurement can change based on resource-related units changes.

7 References

[1] Yampaka T.; Chongstitvatana P. An Application of Process Mining for Queueing System in Health Service. *International Joint Conference on Computer Science and Software Engineering*, 2016, vol. 9, pp. 161-166.

[2] Perimal-Lewis, L., Teubner, D., Hakendorf, P., Horwood, C. Application of process mining to assess the data quality of routinely collected time-based performance data sourced from electronic health records by validating process conformance. *Health Informatics Journal,* 2016, vol. 22, pp. 1017-1029.

[3] Nogayama, T., Takahashi, H. Estimation of average latent waiting and service times of activities from event logs. *Lecture Notes in Computer Science*, 2015, vol. 9253, pp. 172-179.

[4] Jaisook, P., Premchaiswadi, W. Time performance analysis of medical treatment processes by using disco. *International Conference on ICT and Knowledge Engineering*, 2015, pp. 110-115

[5] Liu, Y., Zhang, H., Li, C., Jiao, R.J. Workflow simulation for operational decision support using event graph through process mining. *Decision Support Systems*, 2012, vol. 52, pp. 685-697.

[6] Bautista, A.D., Akbar, S.M.K., Alvarez, A., Metzger, T., Reaves, M.L. Process mining in information technology incident management: A case study at Volvo Belgium. *CEUR Workshop Proceedings*, vol. 1052, pp. 1-26.

[7] Lamine, E., Fontanili, F., Mascolo, M.D., Pingaud, H. Improving the management of an emergency call service by combining process mining and discrete event simulation approaches. *IFIP Advances in Information and Communication Technology*, 2015, vol. 463, pp. 535-546.

[8] Măruşter, L., Van Beest, N.R.T.P. Redesigning business processes: A methodology based on simulation and process mining techniques. *Knowledge and Information Systems*, 2009, vol. 21, pp. 267-297.

[9] Suriadi, S., Mans, R.S., Wynn, M.T., Partington, A., Karnon, J. Measuring patient flow variations: A cross-organisational process mining approach. *Lecture Notes in Business Information Processing*, 2014, vol. 181 LNCS, pp. 43-58.

[10] Hompes, B.F.A., Buijs, J.C.A.M., van der Aalst, W.M.P. A generic framework for context-aware process performance analysis. *Lecture Notes in Computer Science,* 2016, vol. 10033 LNCS, pp. 300-317.

[11] Premchaiswadi, W., Porouhan, P. Process modeling and bottleneck mining in online peer-review systems. *SpringerPlus*, 2015, vol. 4, pp. 1-18.

[12] Leyer, M. Towards a context-aware analysis of business process performance. *PACIS 2011 - 15th Pacific Asia Conference on Information Systems: Quality Research in Pacific*, 2011, vol. 4, pp. 1-14.

[13] Park, M., Song, M., Baek, T.H., Son, S.Y., Ha, S.J., Cho, S.W. Workload and de-

lay analysis in manufacturing process using process mining. *Lecture Notes in Business Information Processing*, 2015, vol. 219, pp. 138-151.

[14] Senderovich, A., Weidlich, M., Yedidsion, L., Gal, A., Mandelbaum, A., Kadish, S., Bunnell, CA. Conformance checking and performance improvement in scheduled processes: A queueing-network perspective. *27th International Conference on Advanced Information Systems Engineering*, 2015, vol. 62, pp. 185-206.

[15] Van Dongen, B.F., Adriansyah, A. Process mining: Fuzzy clustering and performance visualization. *Lecture Notes in Business Information Processing*, 2010, vol. 43 LNBIP, pp. 158-169.

[16] Leyer, M., Moormann, J. Facilitating operational control of business services: A method for analysing and structuring customer integration. *ACIS 2010 Proceedings - 21st Australasian Conference on Information Systems*, 2010, pp. 1-12.

[17] Jagadeesh Chandra Bose, R.P., Gupta, A., Chander, D., Ramanath, A., Dasgupta, K. Opportunities for process improvement: A cross-clientele analysis of event data using process mining. *Lecture Notes in Computer Science*, 2015, vol. 9435, pp. 444-460.

[18] Gupta, M., Sureka, A., Padmanabhuni, S. Process mining multiple repositories for software defect resolution from control and organizational perspective. *11th Working Conference on Mining Software Repositories*, 2014, pp. 122-131.

[19] Piessens, D., Wynn, M.T., Adams, M., van Dongen, B.F. Performance analysis of business process models with advanced constructs. *ACIS 2010 Proceedings - 21st Australasian Conference on Information Systems*, 2010, pp. 1-12.

[20] Wang, Y., Caron, F., Vanthienen, J., Huang, L., Guo, Y. Acquiring logistics process intelligence: Methodology and an application for a Chinese bulk port. *Expert Systems with Applications*, 2014, vol. 41, pp. 195-209.

[21] Reijers, H.A., Song, M., Jeong, B. Analysis of a collaborative workflow process with distributed actors. *Information Systems Frontiers*, 2009, vol. 11, pp. 307-322.

[22] Mans, R.S., Schonenberg, M.H., Song, M., Van Der Aalst, W.M.P., Bakker, P.J.M. Application of process mining in healthcare - A case study in a Dutch Hospital. *Communications in Computer and Information Science*, 2008, vol. 25 CCIS, pp. 425-438.

[22] Lau, H.C.W., Ho, G.T.S., Zhao, Y., Chung, N.S.H. Development of a process mining system for supporting knowledge discovery in a supply chain network. *International Journal of Production Economics*, 2009, vol.122, pp. 176-187.

[23] B.F. van Dongen, N. Busi, G.M. Pinna, W.M.P. van der Aalst. An Iterative Algorithm for Applying the Theory of Regions in Process Mining. *BETA publicaties: Preprints*, 2007, pp. 1-22.

[24] Arpasat, P., Porouhan, P., Premchaiswadi, W. Improvement of call center customer service in a Thai bank using disco fuzzy mining algorithm. *International Conference on ICT and Knowledge Engineering*, 2015, pp. 90-96.

[25] Wongvigran, S., Premchaiswadi, W. Analysis of call-center operational data using role hierarchy miner. *International Conference on ICT and Knowledge Engineering*,

2015, pp. 142-146.

[26] Gerke, K., Petruch, K., Tamm, G. Optimization of service delivery through continual process improvement: A case study. *Business Process and Service Science, Proceedings of ISSS and BPSC*, 2010, pp. 94-107.

[27] Dreiben, A., Heinrichs, R. Successful process and performance controlling in the power supply industry by SÜWAG energie. *Book Chapter*, 2006, pp. 65-76.

[28] Arias, M., Rojas, E., Munoz-Gama, J., Sepúlveda, M. A framework for recommending resource allocation based on process mining. *Lecture Notes in Business Information Processing*, 2016, vol. 256, pp. 458-470.

[29] Thomas, L., Manoj Kumar, M.V., Annappa, B., Vishwanath, K.P. An optimal process model for a real time process. *CEUR Workshop Proceedings*, vol. 1371, pp. 117-131.

[30] Zhao, W., Liu, H., Dai, W., Ma, J. An entropy-based clustering ensemble method to support resource allocation in business process management. *Knowledge and Information Systems*, 2016, vol. 48, pp. 305-330.

[31] Hachicha, M., Fahad, M., Moalla, N., Ouzrout, Y. Performance assessment architecture for collaborative business processes in BPM-SOA-based environment. *Data and Knowledge Engineering*, 2016, vol. 105, pp. 73-89.

[32] Lau, H.C.W., Ho, G.T.S., Zhao, Y., Chung, N.S.H. Development of a process mining system for supporting knowledge discovery in a supply chain network. *International Journal of Production Economics*, 2009, vol. 122, pp. 176-187.

[33] A. P. Dempster; N. M. Laird; D. B. Rubin. Maximum likelihood from incomplete data via the EM algorithm. *Journal of the Royal Statistical Society,* 1977, vol. 39, no. 1, pp. 1-38.

[34] Marlon Dumas, Marcello La Rosa, Jan Mendling, Hajo A. Reijers. Fundamentals of Business Process Management. *Book*, 2013, pp. 1-339.

I. License

Non-exclusive licence to reproduce thesis and make thesis public

I, **Kostiantyn Popov**,

1. herewith grant the University of Tartu a free permit (non-exclusive licence) to:

   1.1. reproduce, for the purpose of preservation and making available to the public, including for addition to the DSpace digital archives until expiry of the term of validity of the copyright, and

   1.2. make available to the public via the web environment of the University of Tartu, including via the DSpace digital archives until expiry of the term of validity of the copyright,

of my thesis

Comparative Evaluation of Log-Based Process Performance Analysis Techniques,

supervised by Fabrizio Maggi and Payman Fredrik Milani,

2. I am aware of the fact that the author retains these rights.

3. I certify that granting the non-exclusive licence does not infringe the intellectual property rights or rights arising from the Personal Data Protection Act.

Tartu, **14.08.2017**