Recommendation Generation for Performance Improvement by using Cross-Organizational Process Mining

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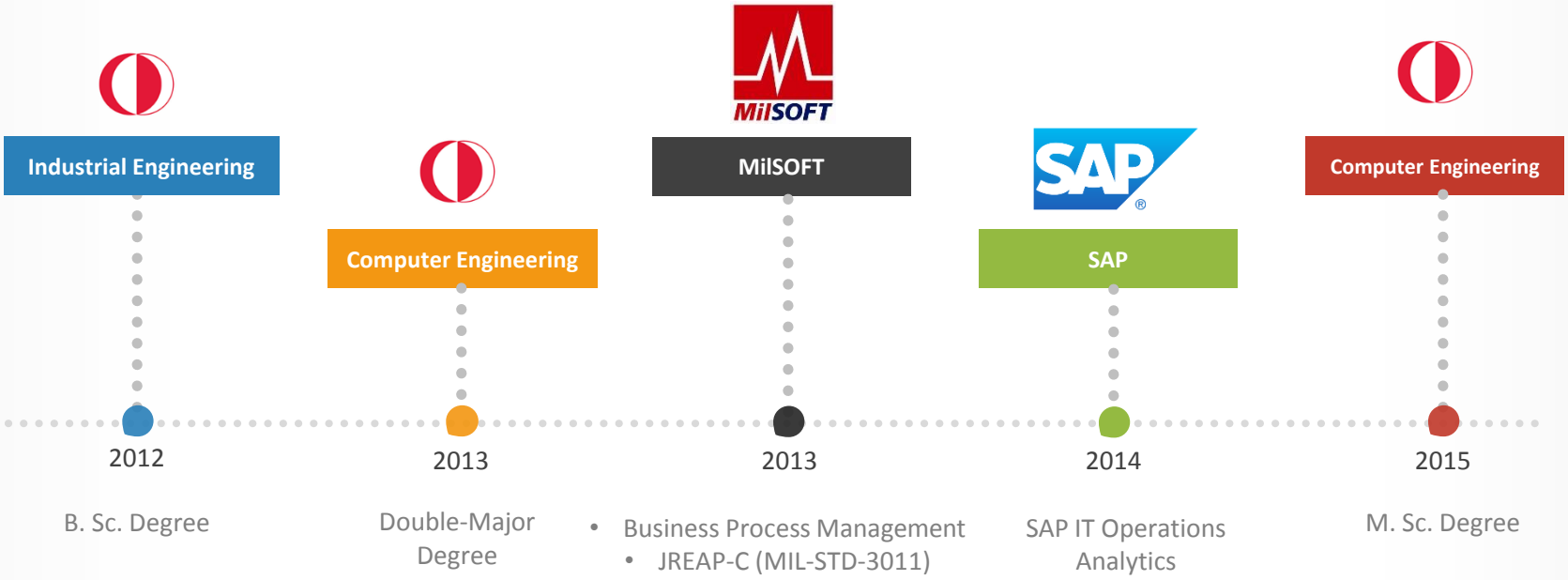

Industrial Engineering
2012
B. Sc. Degree
Computer Engineering
2013
Double-Major Degree
MilSOFT
2013
• Business Process Management
• JREAP-C (MIL-STD-3011)
SAP
2014
SAP IT Operations Analytics
Computer Engineering
2015
M. Sc. Degree

Agenda

1. Introduction
2. Related Work
3. Background
4. Methodology
5. Results & Discussions
6. Conclusion & Future Work
7. Demonstration

Introduction

Process Mining

Relatively young and developing research area and main idea is to

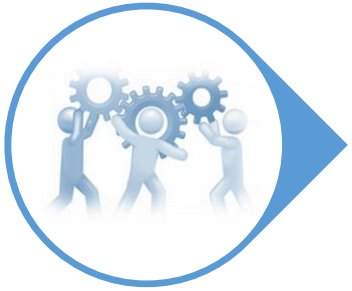
- discover,
- monitor and;
- improve processes by extracting information from event logs. [1]

Events recorded and available

Competitive business life

Introduction

Cross- Organizational Process Mining

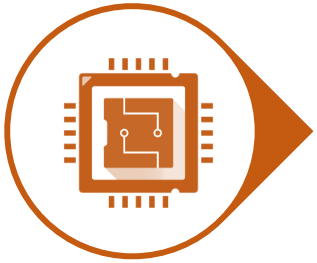


Analyze the big picture

Work together to execute the same process

Cloud computing and shared infrastructures

Event logs of multiple organizations [2]



Learn from each other

Execute the same task on shared infrastructure [3]

Introduction

Focus of this Study

- A hybrid approach
  - Using different process mining subfields to create a new point of view
- Cross-organizational process mining
  - Processes are executed on several organizations,
  - Unsupervised learning using performances of organizations

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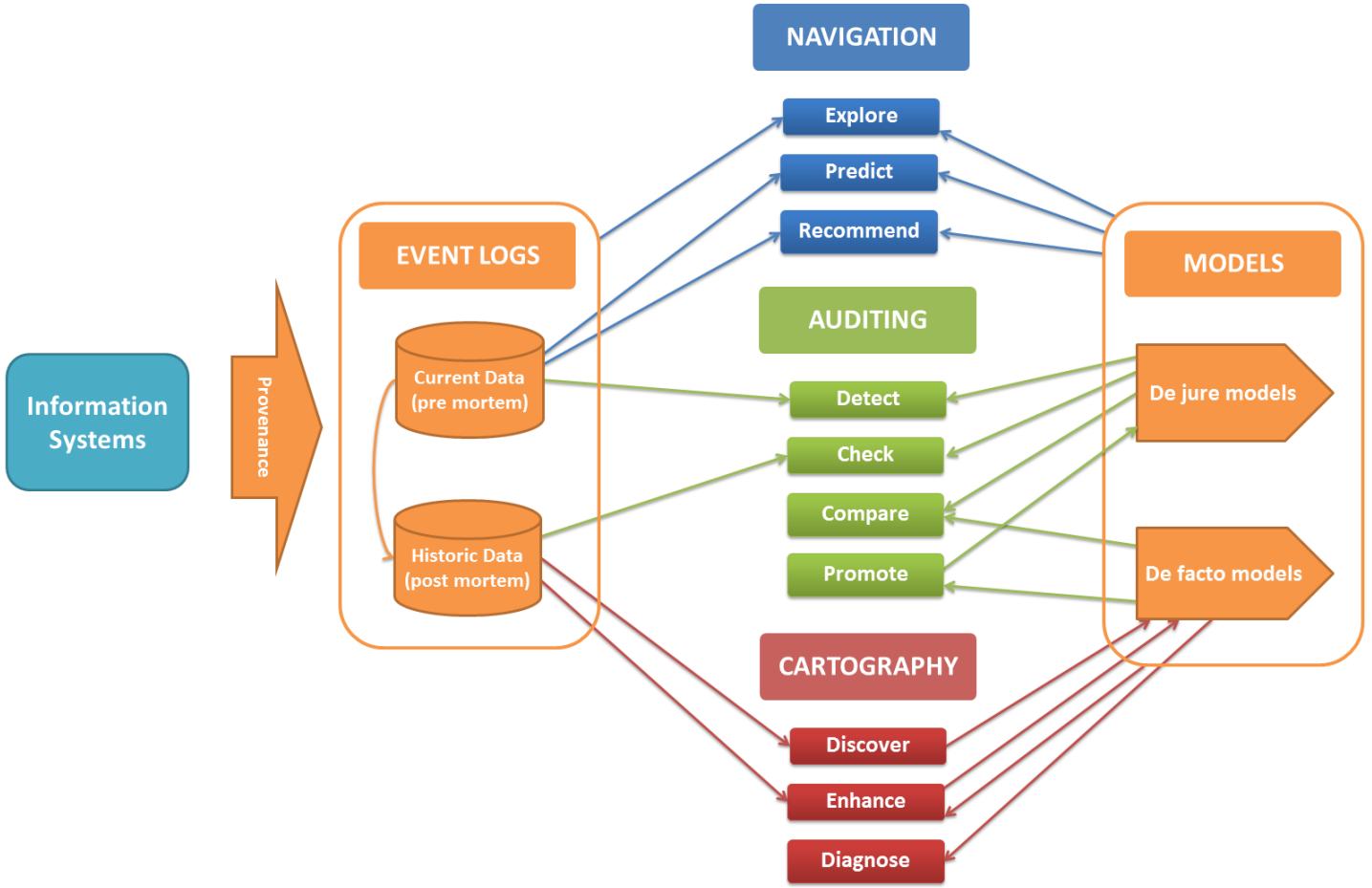
Related Work

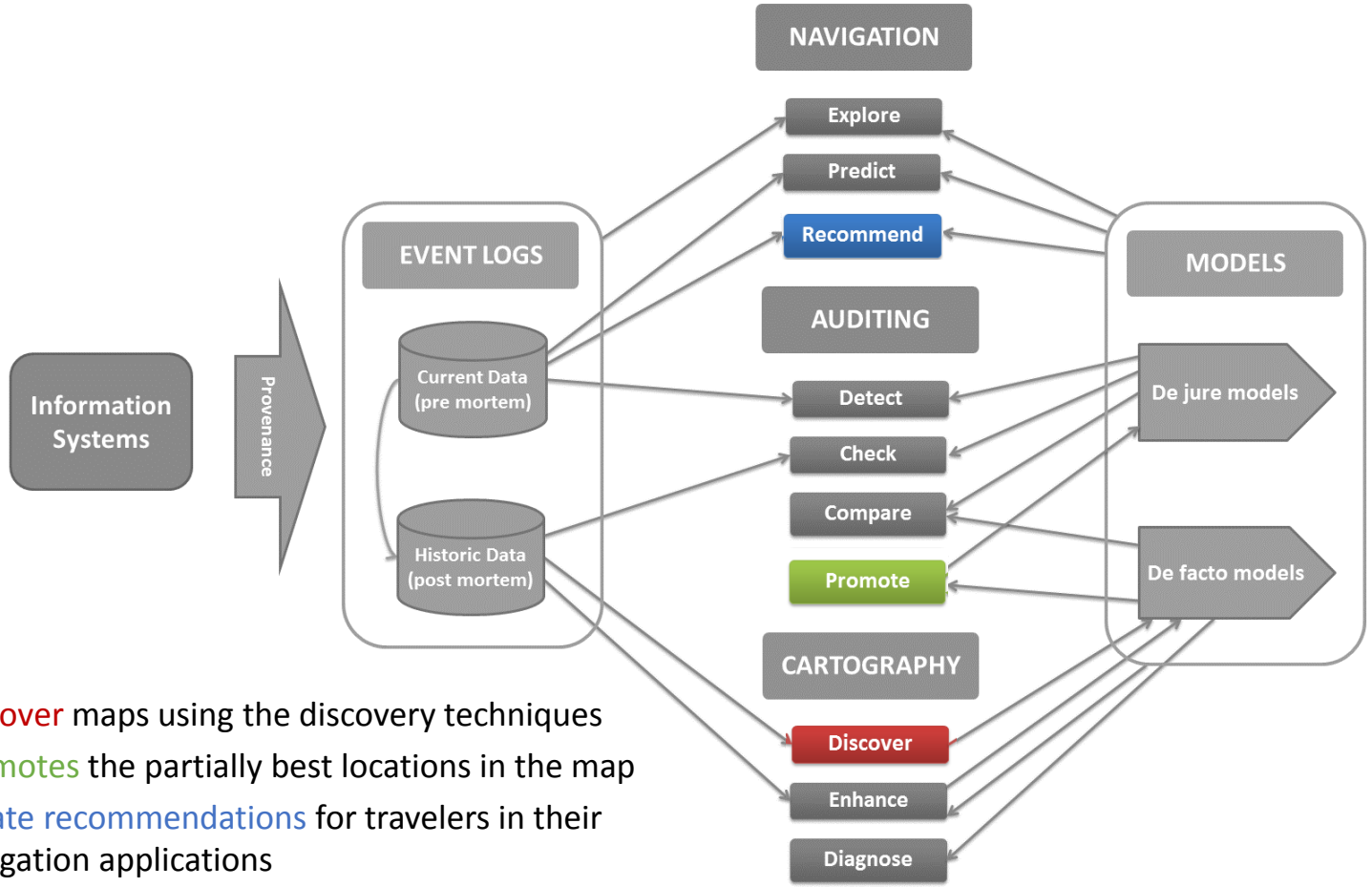
State of the Art in Process Mining



[4]

Related Work

State of the Art in Process Mining



- Discover maps using the discovery techniques
- Promotes the partially best locations in the map
- Create recommendations for travelers in their navigation applications

Related Work

Process Discovery in Process Mining

- Various different process mining algorithms for solving different challenges in the process mining area
  - Alpha Algorithm [5] [6]
  - Inductive Approach [7] [8]
  - Hierarchical Clustering [9]
  - Genetic Approach [10] [11]
  - Heuristic Approach [12]

Robust, repeatable and mature set of approaches

Related Work

Cross-organizational Process Mining

- Analyze processes of organizations in an objective manner
- Matching behaviors and process models of organizations [2]
- Configurable process models for organizations [13]
- Intra and inter-organizational process mining: [3]
  - Collaboration
  - Exploiting commonality

Learning opportunity of organizations from each other

Related Work

Process Similarity in Process Mining

- Emerging attention in business processes [2]
- Repository of process models of similar business operations [14]
- Methods in the literature
  - Similarity Metrics [15]
  - Alignment Matrix [16]
  - Delta Analysis [17] [18]
  - Mismatch Patterns [14]

Point the pattern differences between organizations

Related Work

Contributions of This Study

- Cross-organizational process mining approach for process performance improvement
- Generic, noise-capable process mining method for mining process models of different organizations
- Clustering of organizations based on their performance indicators
  - Unlike the clustering methods based on process structures in the literature [9]

Related Work

Contributions of This Study

- Mismatch analysis for spotting differences between processes of organizations
  - Formulation and implementation of patterns and analyzers
- Recommendation generation to show how organizations can learn from other organizations which perform better
- Open-source, extensible and configurable set of plugins in ProM framework

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Background

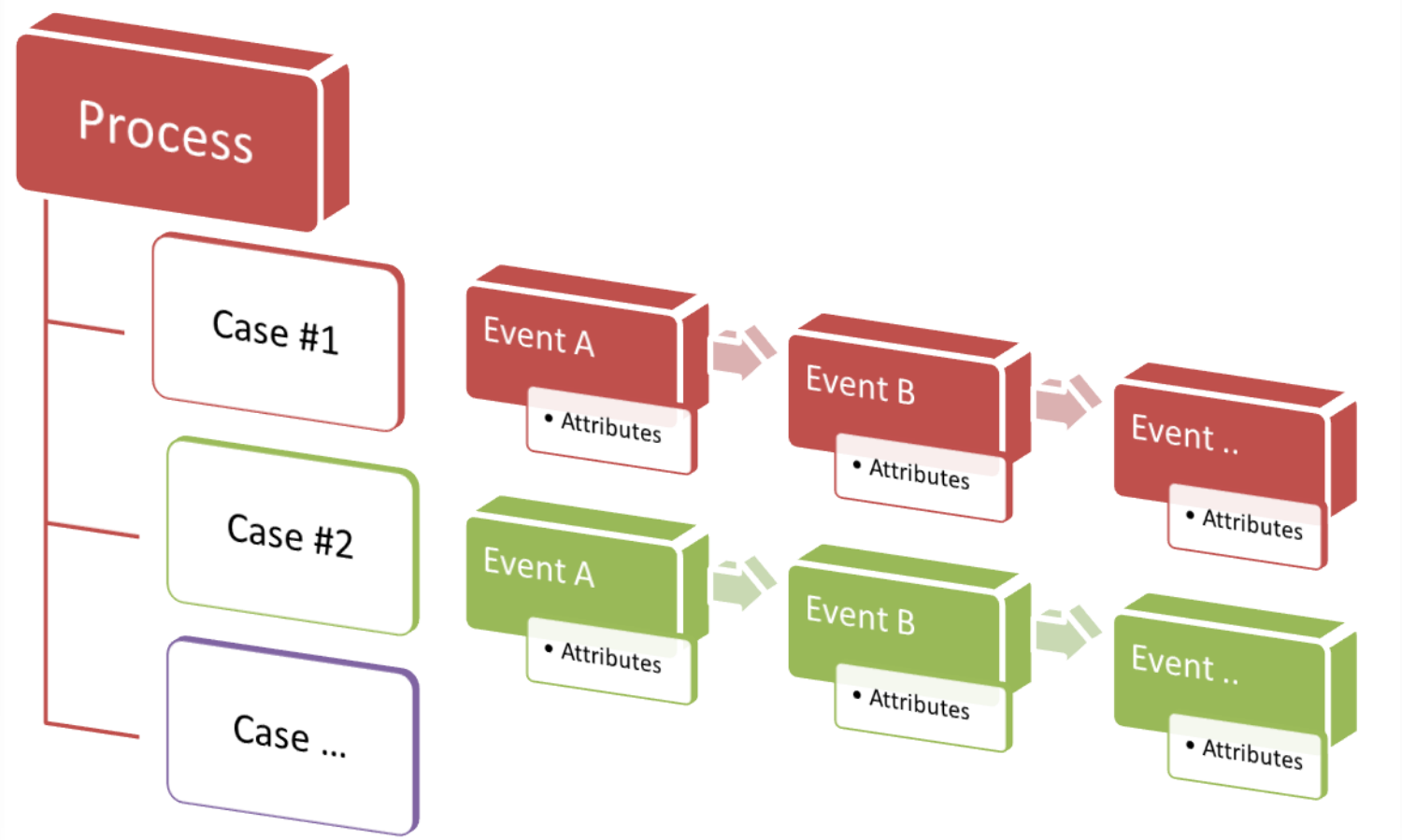
Event Log

- Outputs of the software systems like Enterprise Resource Planning (ERP) or Business Process Management (BPM)

Event Log				
		Attributes		
	Event	**Date**	**Time**	**Transition**
Case #1	Register Application	16.04.2013	14:37:27	Complete
	Check Credit	16.04.2013	14:41:19	Complete
	Check System	16.04.2013	14:47:35	Complete
	Calculate Capacity	16.04.2013	14:50:21	Complete
	Accept	16.04.2013	14:53:22	Complete
	Send decision e-mail	16.04.2013	14:55:11	Complete
Case #2	Register Application	16.04.2013	16:28:19	Complete
	Check Credit	16.04.2013	16:36:22	Complete

Background

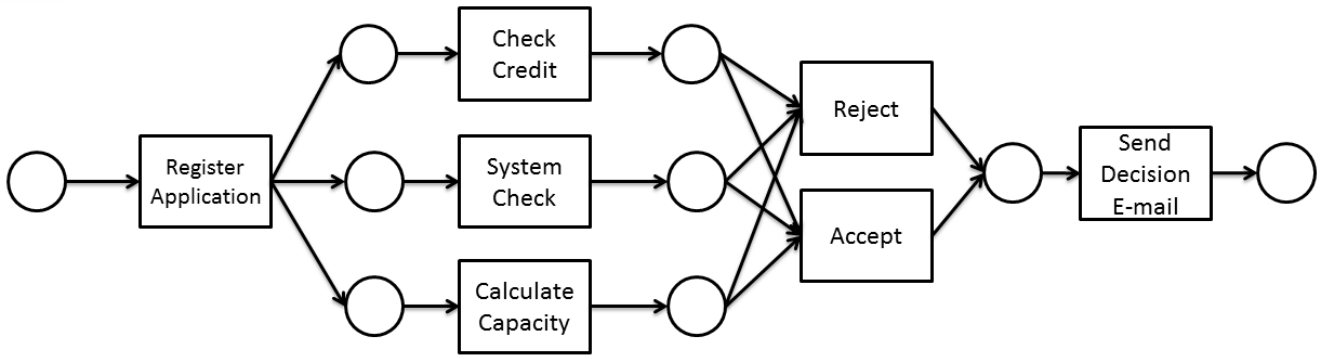
Event Log



Background

Process Modeling

- Workflow Net
  - Petri net with a start node, end node and connectedness

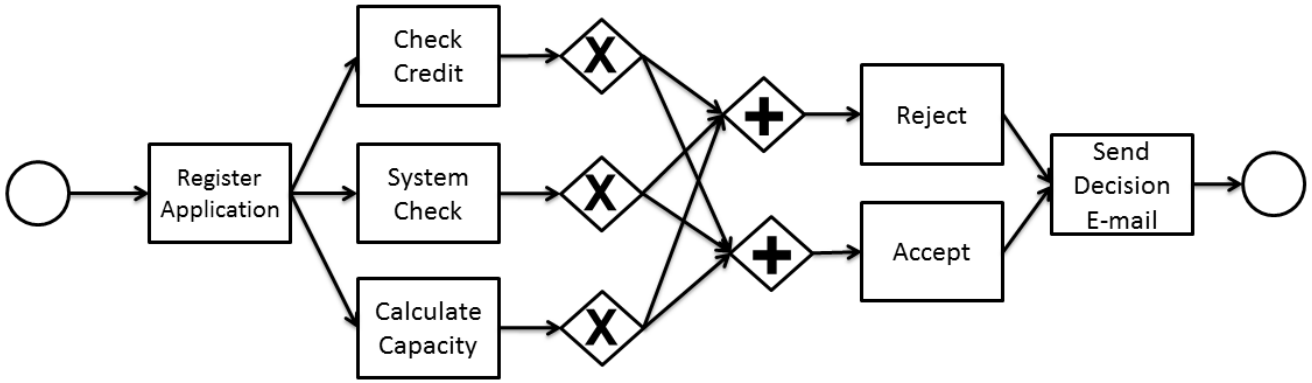


  - Mathematical background

Background

Process Modeling

- Business Process Modelling Notation (BPMN)
  - Standardized and easy to understand by stakeholders



  - Business oriented

Background

Process Discovery

- One of the most challenging tasks is to construct a process model based on the behavior in the event logs
- Inductive Process Mining is used since it is simple, highly applicable and configurable
  - Block-structured Workflow Nets
  - Rediscoverability [19]

Background

Process Discovery

- Inductive Miner Infrequent (*IMi*) is proposed as an extension to Inductive Miner to handle noise in the event logs:

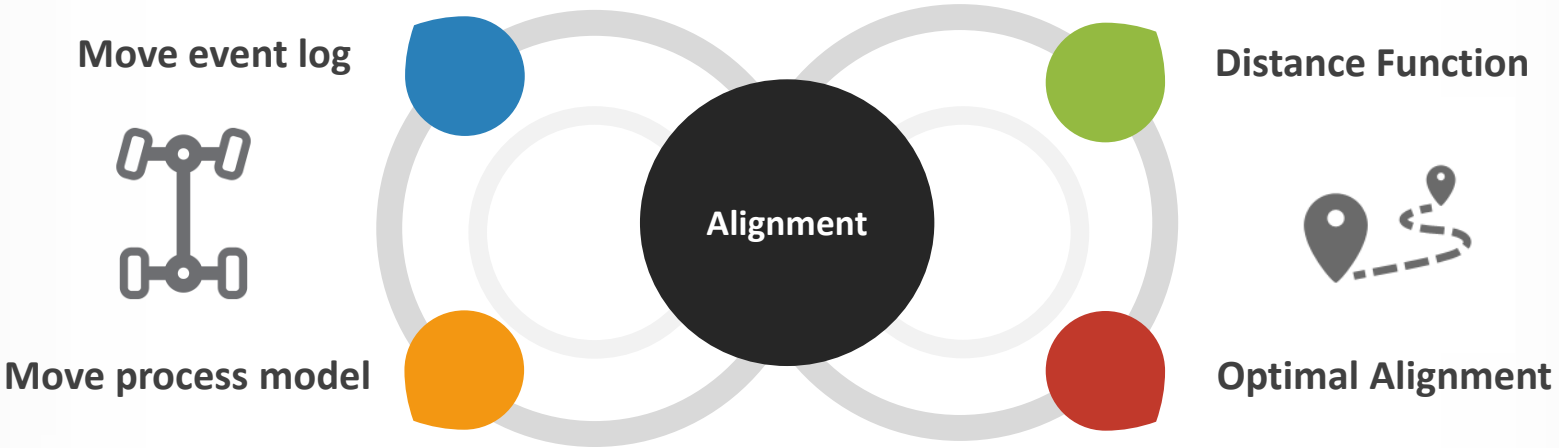
1. **Activity Sets:** Split the activities in log to disjoint sets.
2. **Sublogs:** Split the log by using activity sets.
3. **Recursive Mining:** Mine sublogs with these steps until a sublog contains only single activity. [20]

Filter infrequent behavior at every step by a user defined threshold

Background

Process Performance Analysis

- Discover relationships between event logs and process models for conformance and performance analysis [21]



Background
Clustering

- k-means algorithm (Lloyd's algorithm) and its variation based on random initialization:
  - k-means++ by Arthur and Vassilvitskii [22]
- Clustering of performance analysis results of organizations
- Implementation of k-means++ in WEKA [23]

Background

Mismatch Patterns in Process Models

- Patterns for frequent mismatches between the similar process models by Dijkman [14]

Authorization

Activity

- Skipped Activity
- Refined Activity

Control Flow

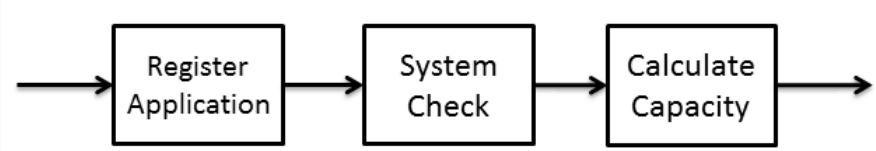
- Activities at Different Moments in Processes
- Different Conditions for Occurrence
- Different Dependencies
- Additional Dependencies

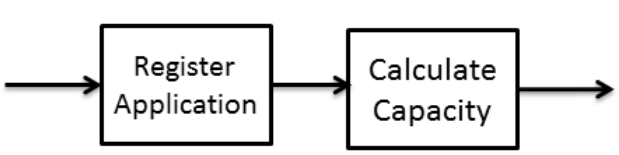
Background

Mismatch Patterns in Process Models

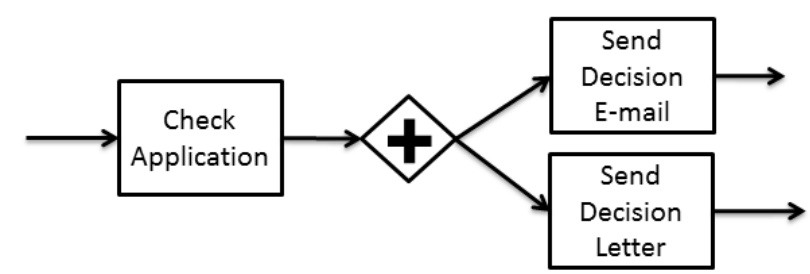
Activity Mismatch Patterns [14]

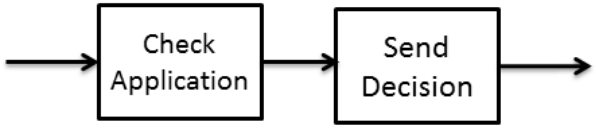
- Skipped Activity





- Refined Activity



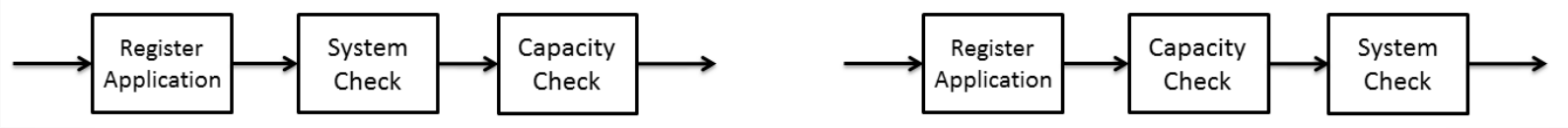


Background

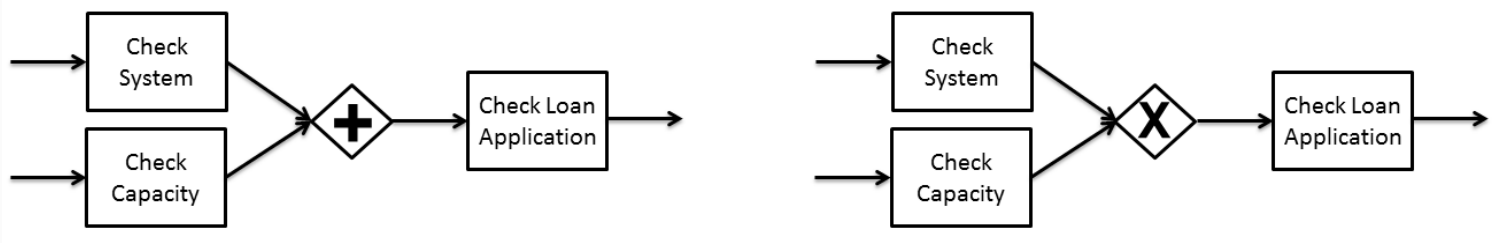
Mismatch Patterns in Process Models

Control Flow Mismatch Patterns [14]

- Activities at Different Moments in Processes



- Different Conditions for Occurrence

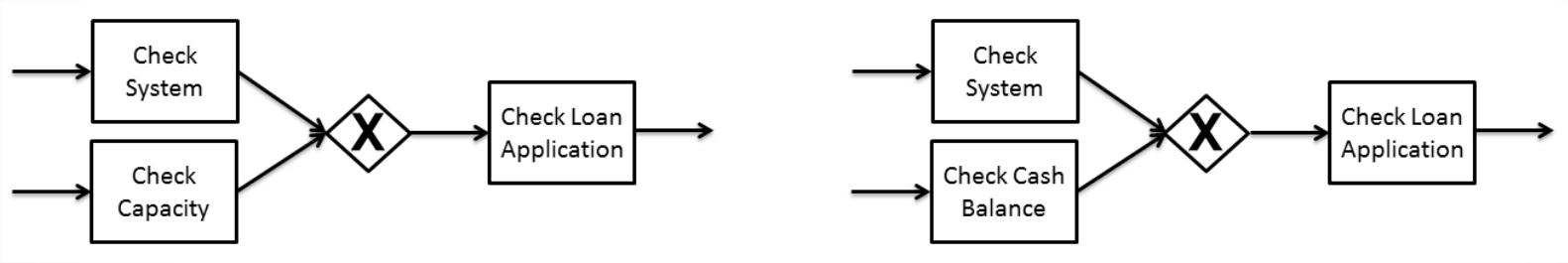


Background

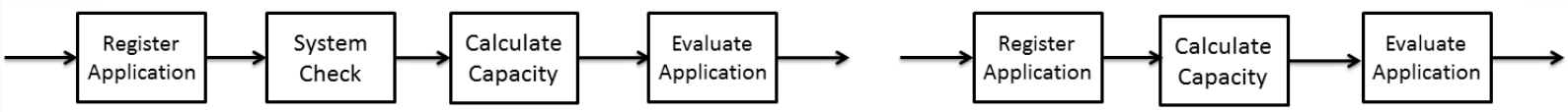
Mismatch Patterns in Process Models

Control Flow Mismatch Patterns [14]

- Different Dependencies



- Additional Dependencies



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Methodology

Approach Overview

Process Model Mining 1

- Process models from event logs for each organization

Performance Indicator Analysis 2

- Replay event logs and collect performance data
- Cluster organizations

Mismatch Pattern Analysis 3

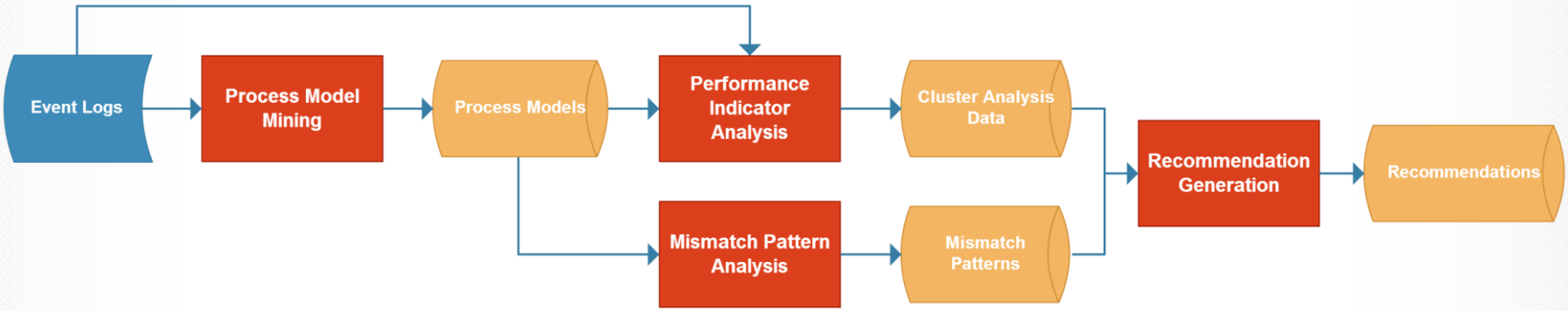
- Differences between process models of organizations

Recommendation Generation 4

- Set of recommendation for each organization using the clusters and mismatch patterns

Methodology

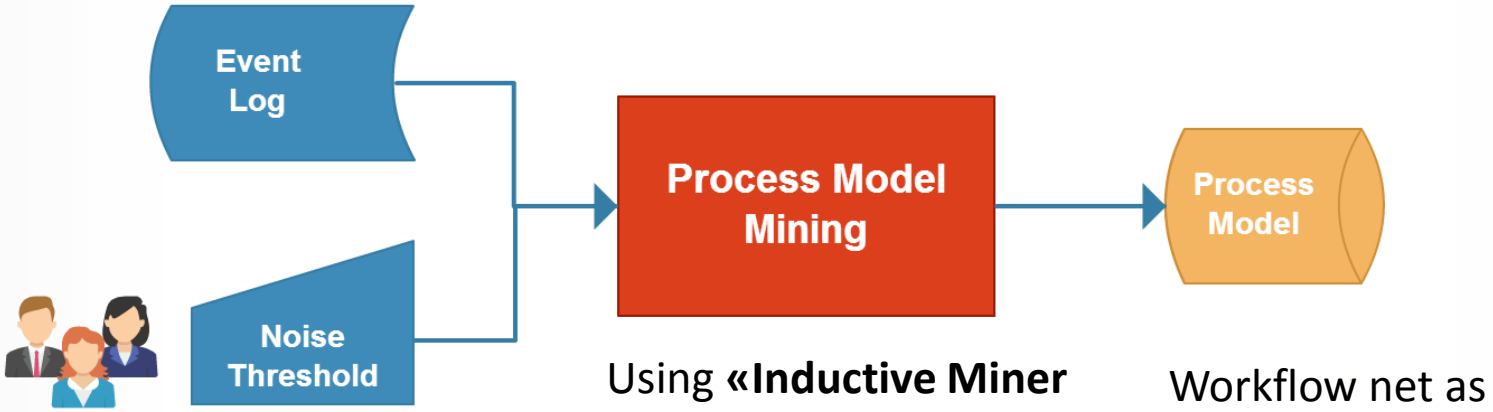
Approach Overview



Methodology

Process Model Mining

Applied for each organization:

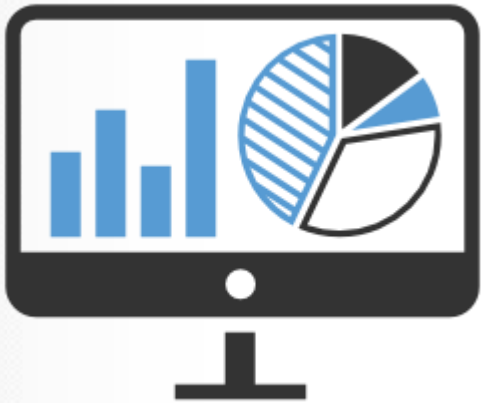


Using **«Inductive Miner Infrequent (IMi)»** method

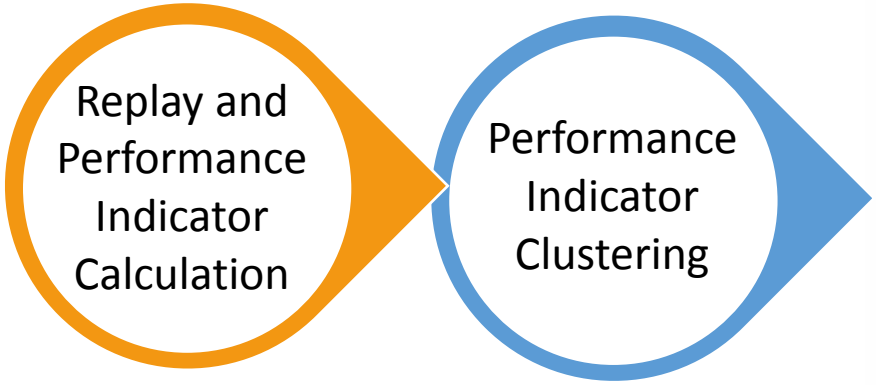
Workflow net as process model

Methodology

Performance Indicator Analysis



- Two steps:

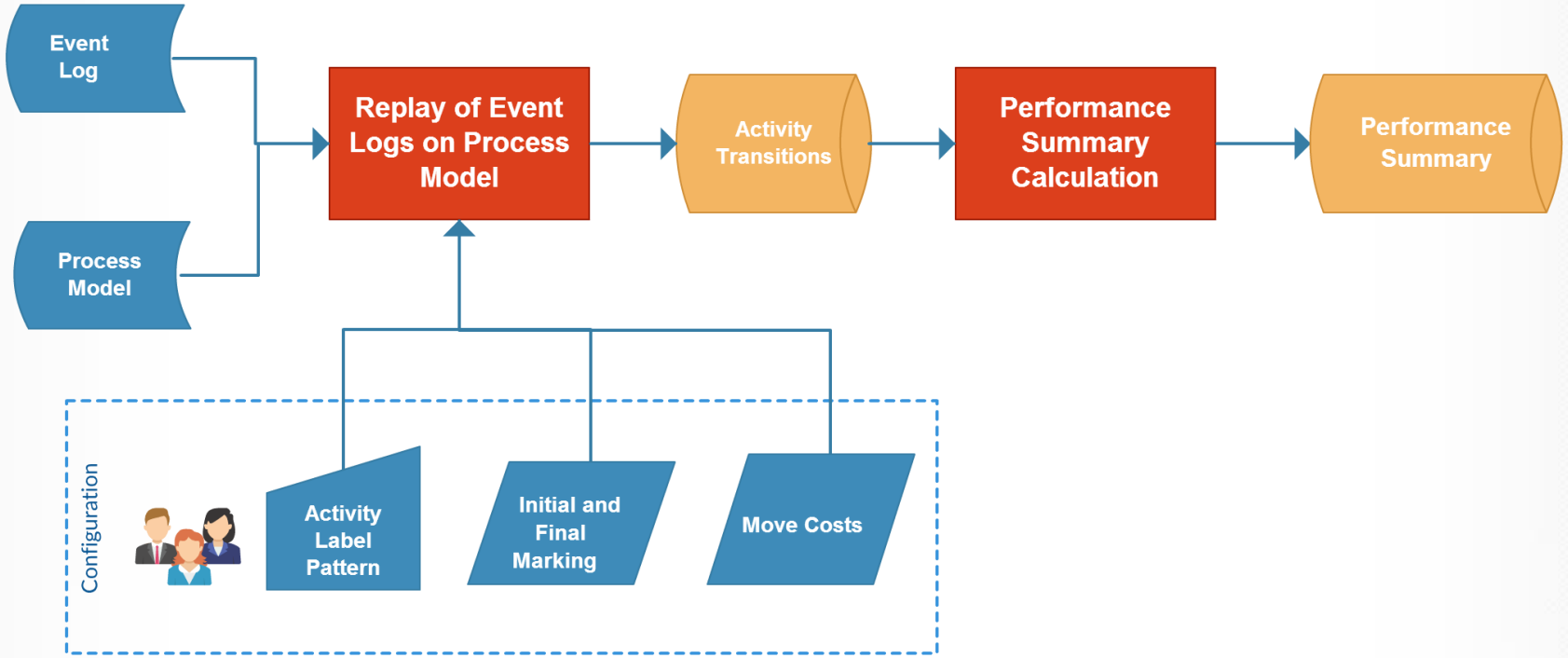


- Performance Indicators:
  - Average Time Between Activities
  - Standard Deviation of Time Between Activities

Methodology

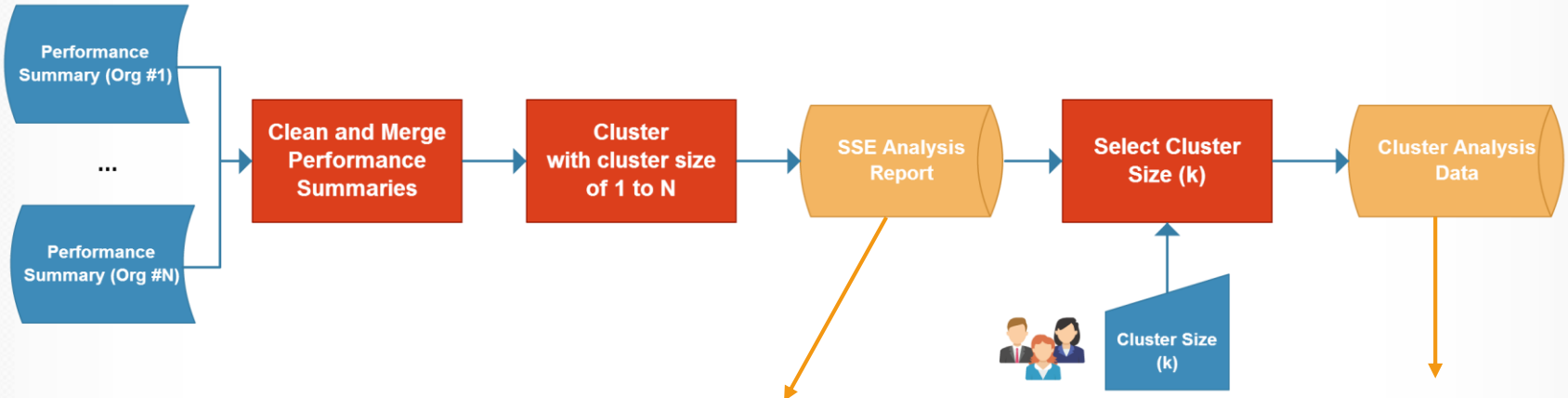
Performance Indicator Analysis - Replay and Performance Indicator Calculation

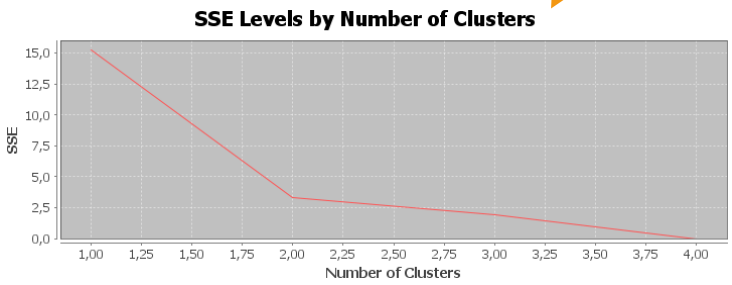
Applied for each organization:



Methodology

Performance Indicator Analysis – Performance Indicator Clustering



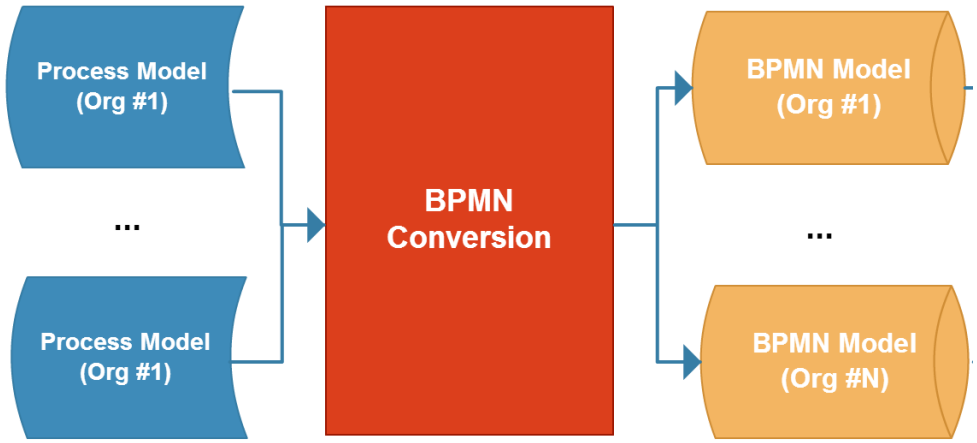


- # of Clusters
- Cluster Assignment
- Centroids (Performance Indicator Values for each cluster)

Methodology

Mismatch Pattern Analysis

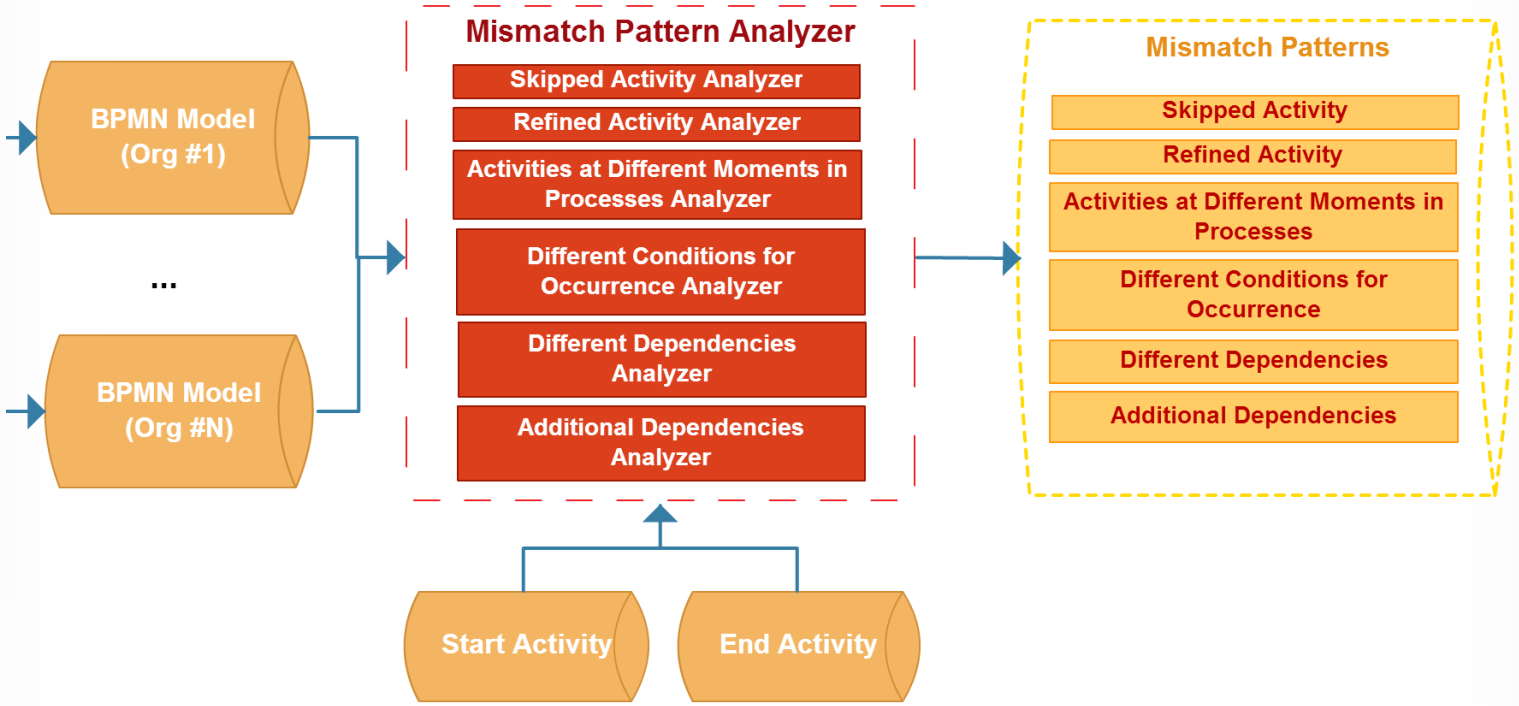
- Spot the differences between process models of different organizations as mismatch patterns
- BPMN used since notation is more appropriate to formulate mismatch patterns



Methodology

Mismatch Pattern Analysis

- Mismatch patterns and analyzers are developed



Methodology

Mismatch Pattern Analysis

- Mismatch patterns and analyzers formulated

```
input: O1 first organization, O2 second organization, Astart starting
activity, Aend ending activity
output: MismatchPatterns a set of mismatch patterns
MismatchPatterns <-- {}
MismatchPatterns <--  SkippedActivityAnalyzer(O1, Astart, Aend)
MismatchPatterns <--  RefinedActivityAnalyzer(O1, O2, Astart, Aend)
MismatchPatterns <--  DifferentMomentsAnalyzer(O1, O2, Astart, Aend)
MismatchPatterns <--  DifferentConditionsAnalyzer(O1, O2, Astart, Aend)
MismatchPatterns <--  DifferentDependencysAnalyzer(O1, O2, Astart, Aend)
MismatchPatterns <--  AdditionalDependencysAnalyzer(O1, O2, Astart, Aend)
return MismatchPatterns
```

Methodology

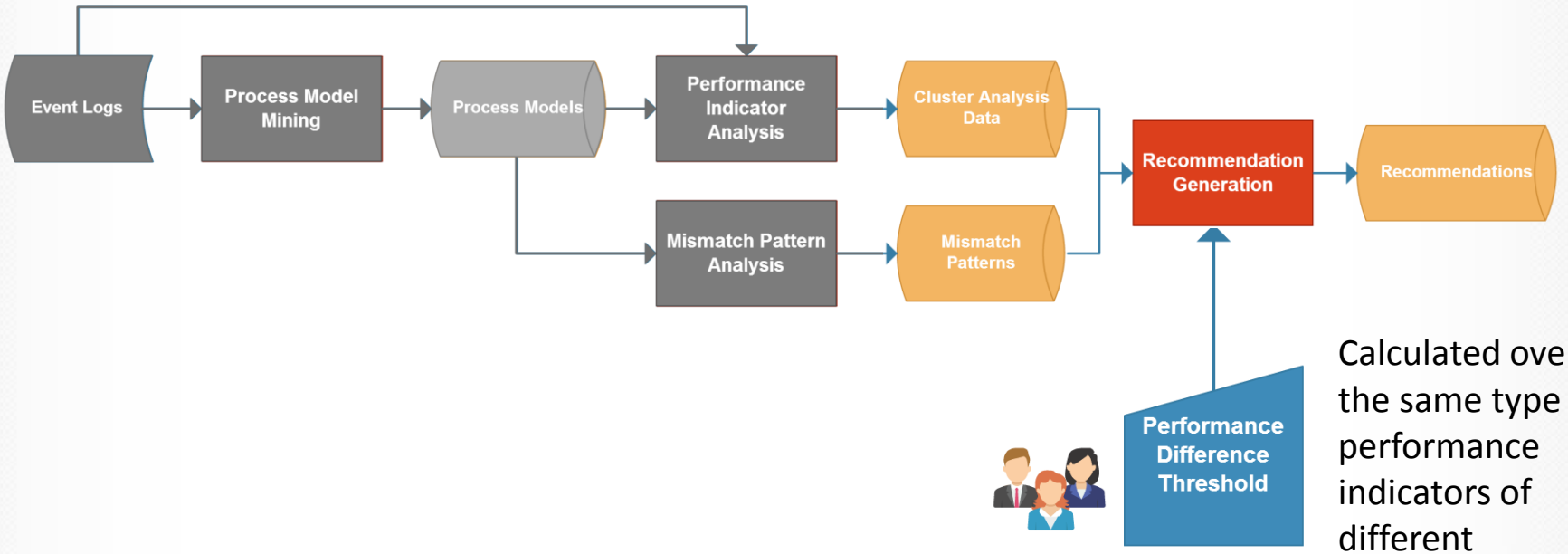
Recommendation Generation

- Providing a set of mismatch patterns for each organization to enhance their processes.
  - Mismatch patterns between organizations, which are **performing better** in terms of their performance indicator values.

$$\mathbf{Recommendation = (Organization, A_{start}, A_{end}, Mismatch\ Patterns)}$$

Methodology

Recommendation Generation



Calculated over the same type of performance indicators of different organizations

Methodology

Recommendation Generation

RecommendationGeneration
input: **O** organization, **C** Cluster Analysis Data, **P** performance difference threshold
output: **Recommendations** a set of recommendations

Recommendations ← {}
i ← Cluster of organization **O**
for each centroid for cluster **i**
  Get other cluster **j** with the centroids of A_{start} and A_{end}; and value difference larger than **P**
  for each organization **O'** in the cluster **j**
    MismatchPatterns ← Mismatch Pattern Analysis(**O**, **O'**,$\mathbf{A_{start}}$, $\mathbf{A_{end}}$)
    Recommendations ← Recommendation(**O**, $\mathbf{A_{start}}$,$\mathbf{A_{end}}$, **MismatchPatterns**)

Methodology

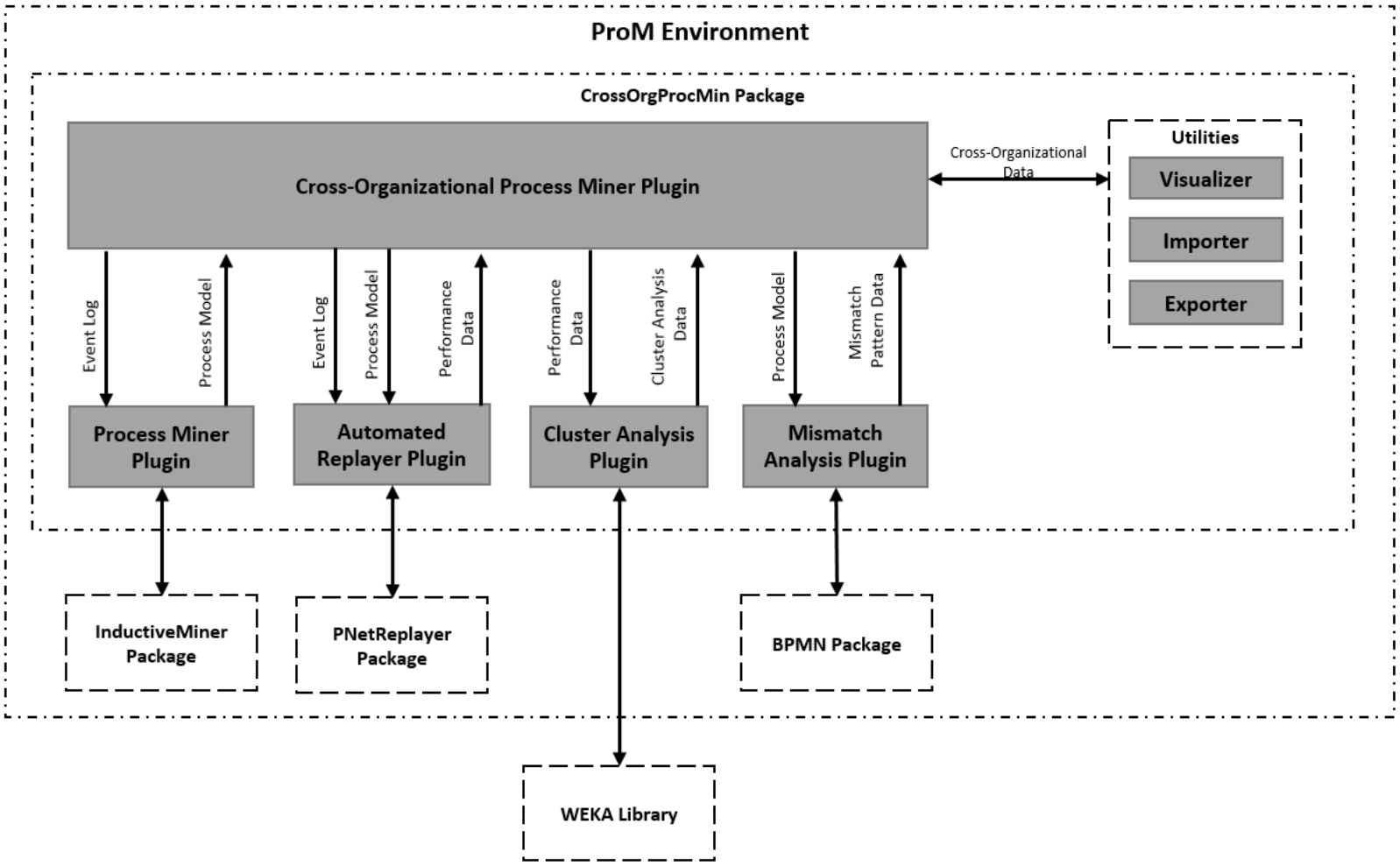
ProM Implementation

- ProM, extensible framework that supports a wide variety of process mining techniques in form of plugins [24]
- Widely accepted in industry and academia with an active community
- Developed set of plugins are packaged with the name of **«CrossOrgProcMin»** and published on Github.

onuryilmaz/cross-orc-proc-min

Methodology

ProM Implementation



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Results & Discussions

Evaluation Metrics

Process Model Mining 1

- Fitness [25]
- Appropriateness [25]
  - Structural Appropriateness
  - Behavioral Appropriateness

Mismatch Pattern Analysis 3

- Graph-edit distance similarity vs. # of Mismatch Patterns [15]

Performance Indicator Analysis 2

- Alignment costs for replay [21]
- Within-SSE values for clustering

Recommendation Generation 4

- Responsiveness with different threshold values
- Comparison with and without performance clustering

Results & Discussions

Dataset Selection

- **Loan Application Process** [26]
  - Synthetically generated
  - 4 variants of a simple loan application in a financial institute
- **Environmental Permit Application Process** [27]
  - Real-life event log from "Configurable Services for Local Governments (CoSeLoG)" project [13]
  - «Environmental Permit Application Process» of 5 municipalities in Netherlands

Results & Discussions

Loan Application Process

	Cases	Events	Percentage
Variant #1	100	590	24 %
Variant #2	70	420	17 %
Variant #3	200	800	33 %
Variant #4	105	630	26 %

Cases
475

Events
2440

- These variants are used as organizational logs

Results & Discussions

Loan Application Process – Process Model Mining

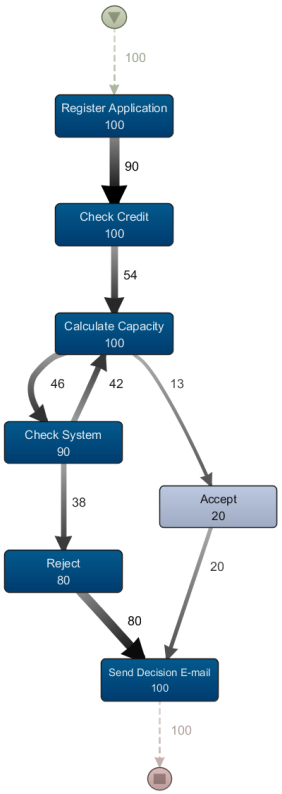
- With «0» noise threshold

	Fitness	Structural Appropriateness	Behavioral Appropriateness	Average Appropriateness
Variant #1	100 %	70 %	98.5 %	84.2 %
Variant #2	100 %	100 %	100 %	100 %
Variant #3	100 %	100 %	100 %	100 %
Variant #4	100 %	100 %	98.2 %	99.1 %
Average	**100 %**	**92.5 %**	**99.7 %**	**96.6 %**

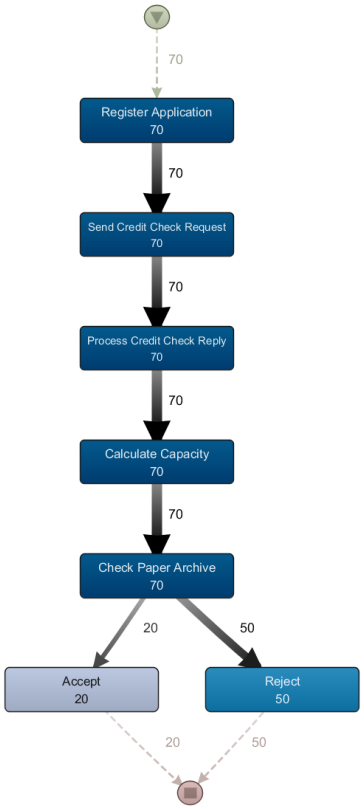
- Each process model is fitting to event log and «appropriate»

Results & Discussions

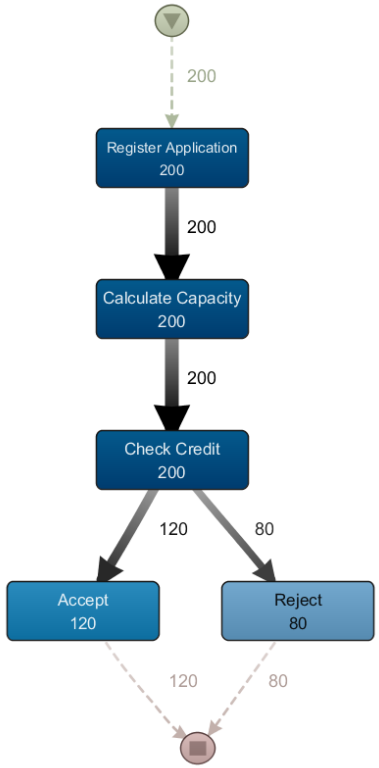
Loan Application Process – Process Model Mining



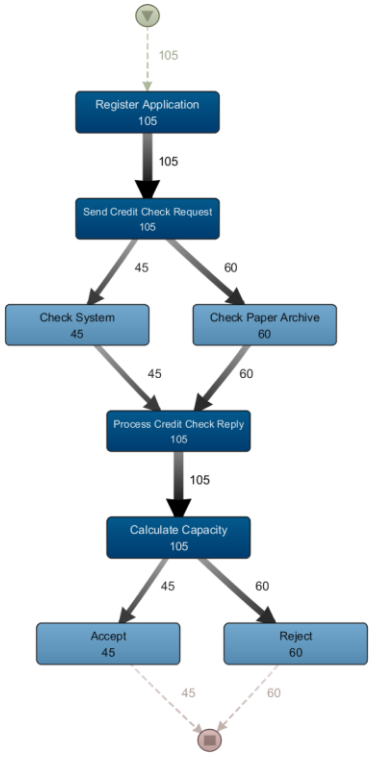
Variant #1



Variant #2



Variant #3



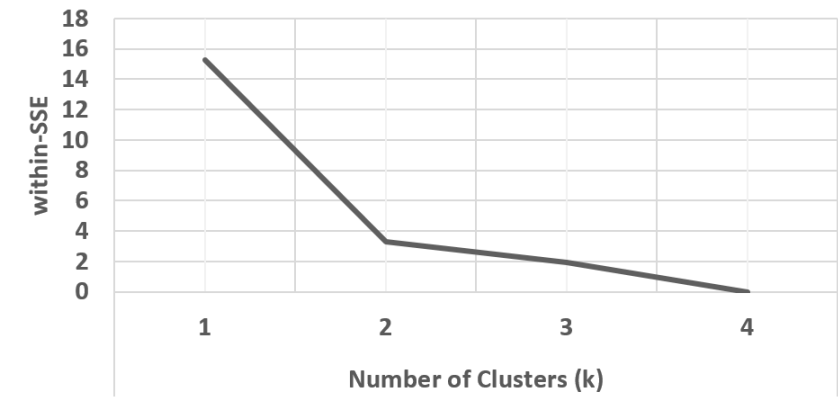
Variant #4

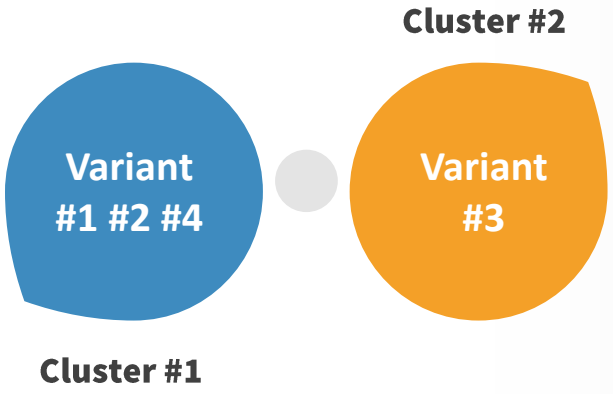
Results & Discussions

Loan Application Process – Performance Indicator Analysis

- **Performance Indicator Calculation:**
  - Replay costs are all zero since 100 % fitness is achieved

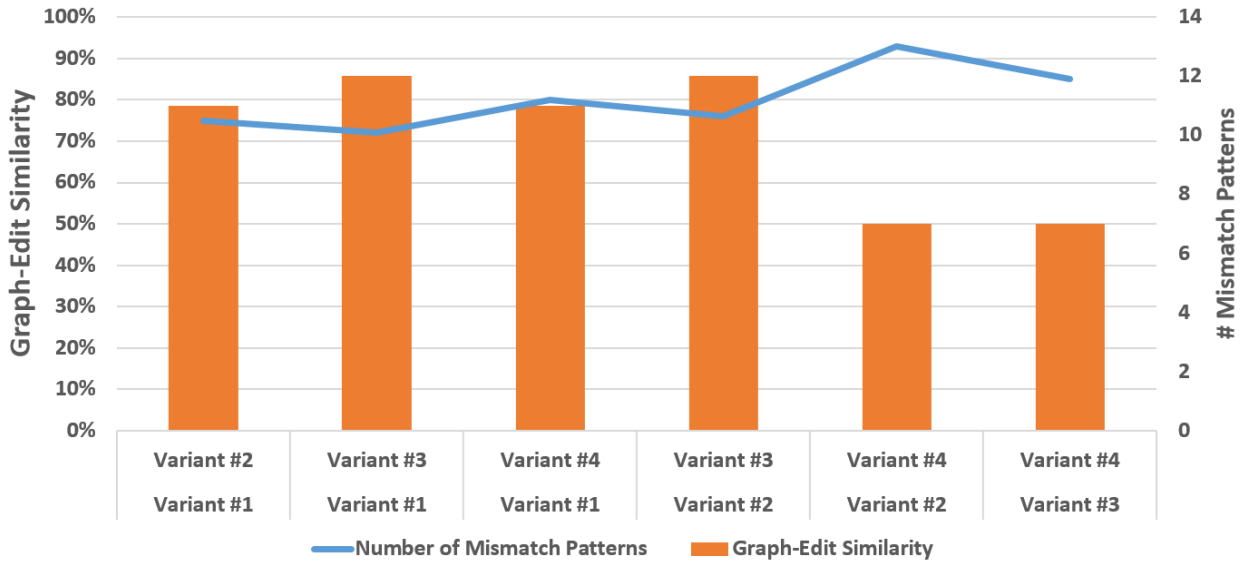
- **Clustering:**





Results & Discussions

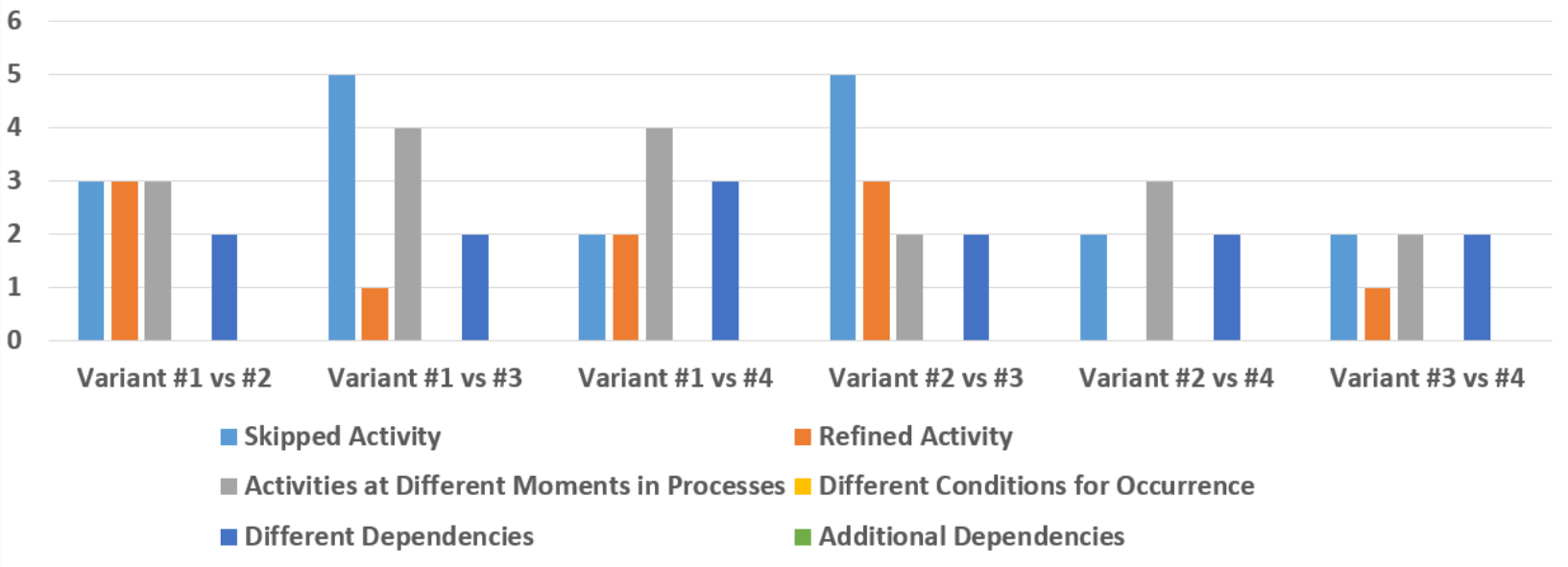
Loan Application Process – Mismatch Pattern Analysis



Correlation between graph-edit similarity and number of mismatch patterns

Results & Discussions

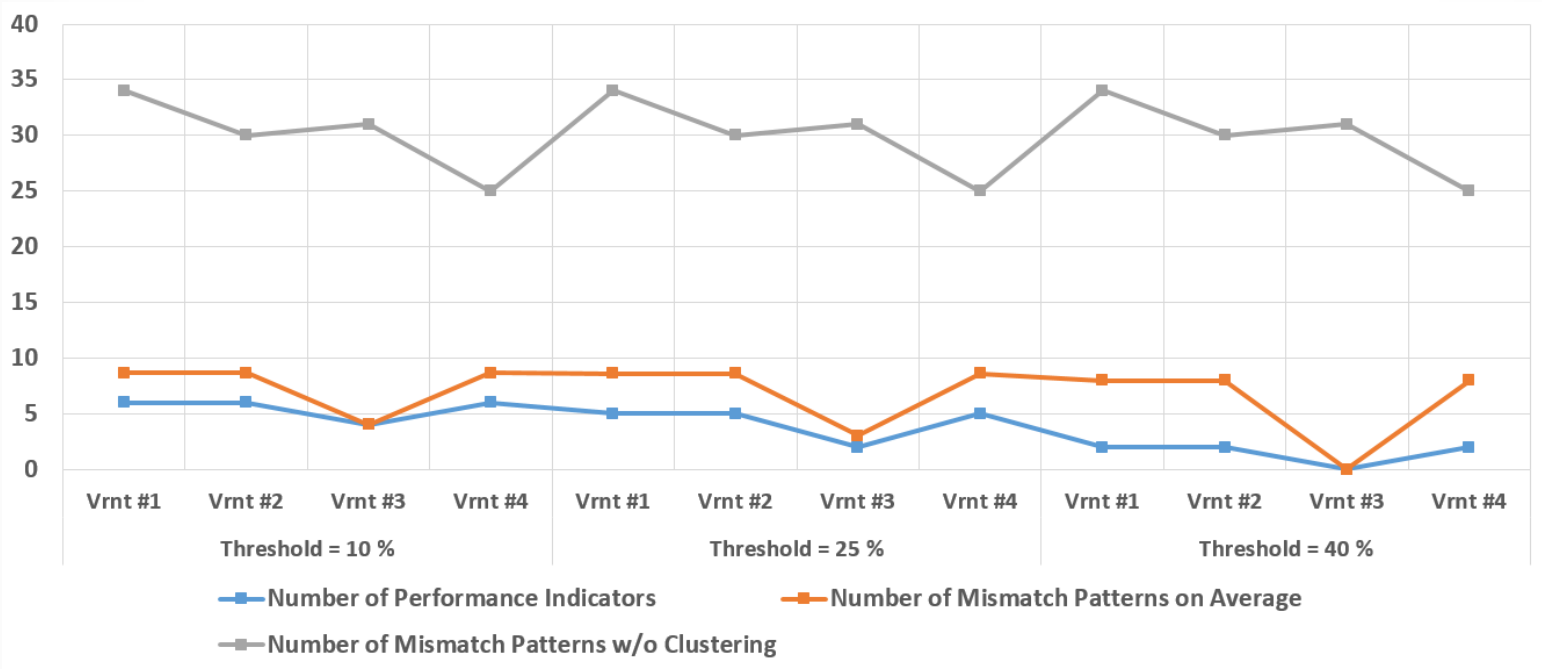
Loan Application Process – Mismatch Pattern Analysis



- "Skipped Activity" and "Activities at Different Moments" mostly
- No "Different Conditions for Occurrence" or "Additional Dependencies"

Results & Discussions

Loan Application Process – Recommendation Generation



- Responsiveness and degree of helping the user to focus on the performance improvement

Results & Discussions

Environmental Permit Application Process

	Cases	Events	Percentage
Municipality #1	54	131	6.1 %
Municipality #2	302	586	27.3 %
Municipality #3	37	73	3.4 %
Municipality #4	340	507	23.7 %
Municipality #5	481	845	39.4 %

Cases 1214 Events 2142

- Preprocessing is undertaken on the raw dataset [28]
- These municipalities are used as organizational logs

Results & Discussions

Environmental Permit Application Process – Process Model Mining

- With 10 % noise threshold

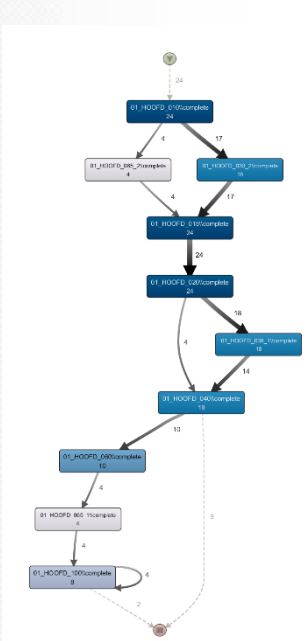
	Fitness	Structural Appropriateness	Behavioral Appropriateness	Average Appropriateness
Municipality #1	86 %	97.5 %	54.4 %	76 %
Municipality #2	100 %	100 %	100 %	100 %
Municipality #3	92.3 %	71.1 %	67.2 %	69.1 %
Municipality #4	96.8 %	65.7 %	64 %	64.9 %
Municipality #5	94.5 %	58.8 %	39.7 %	49.3 %
Average	**93.9 %**	**78.6 %**	**65.1 %**	**71.9 %**

- High fitness values except Municipality #4 and #5

Results & Discussions

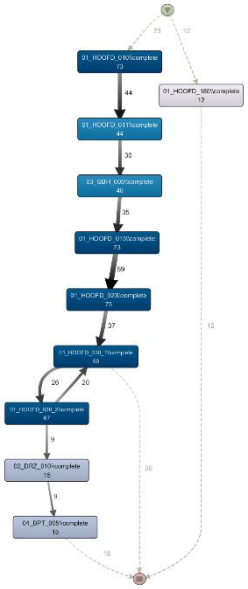
Environmental Permit Application Process – Process Model Mining

- 10 to 20 times simplified process models

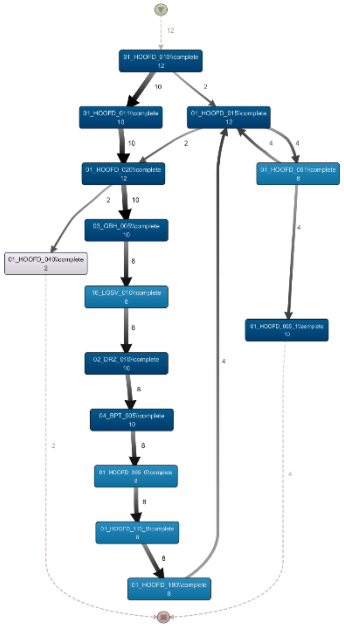


Municipality #1

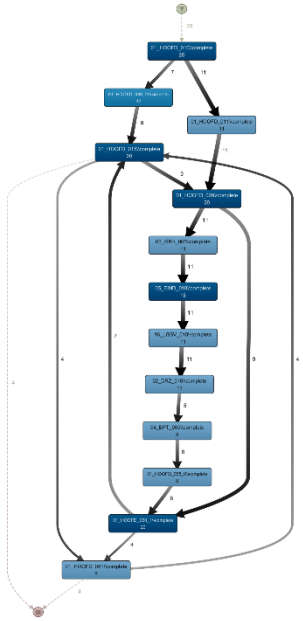
Municipality #2



Municipality #3



Municipality #4



Municipality #5

Results & Discussions

Environmental Permit Application Process – Performance Indicator Analysis

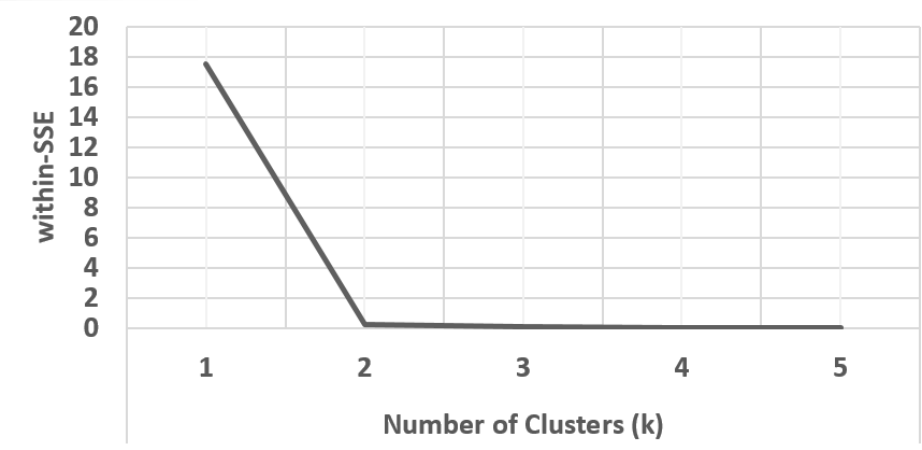
- **Performance Indicator Calculation:**
  - As appropriateness and fitness decrease; alignment costs increase for the municipalities
  - Performance indicators calculated over replay are acceptable

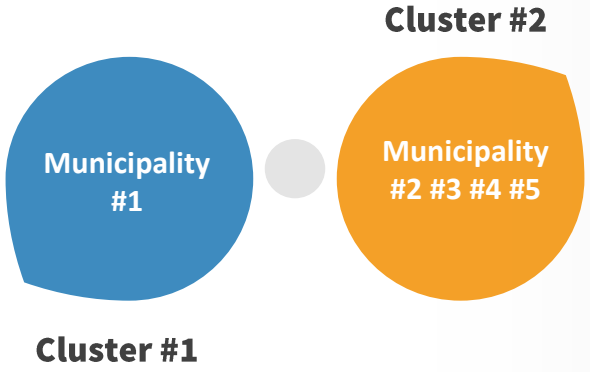
	Fitness	Average Appropriateness	Alignment Cost
Municipality #1	86 %	76 %	173.2
Municipality #2	100 %	100 %	0
Municipality #3	92.3 %	69.1 %	323.3
Municipality #4	96.8 %	64.9 %	9.1
Municipality #5	94.5 %	49.3 %	35.8

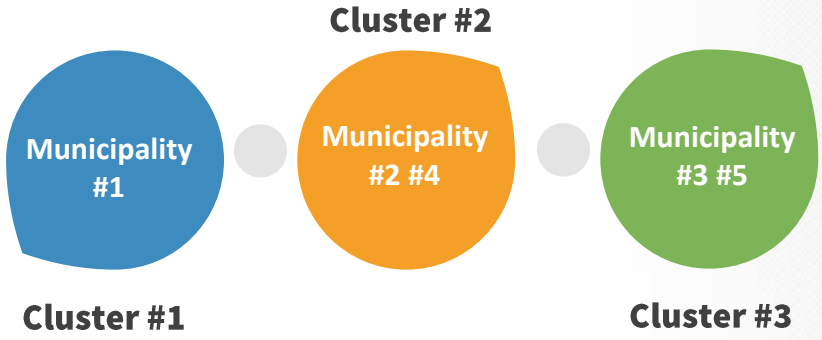
Results & Discussions

Environmental Permit Application Process – Performance Indicator Analysis

- **Clustering:**

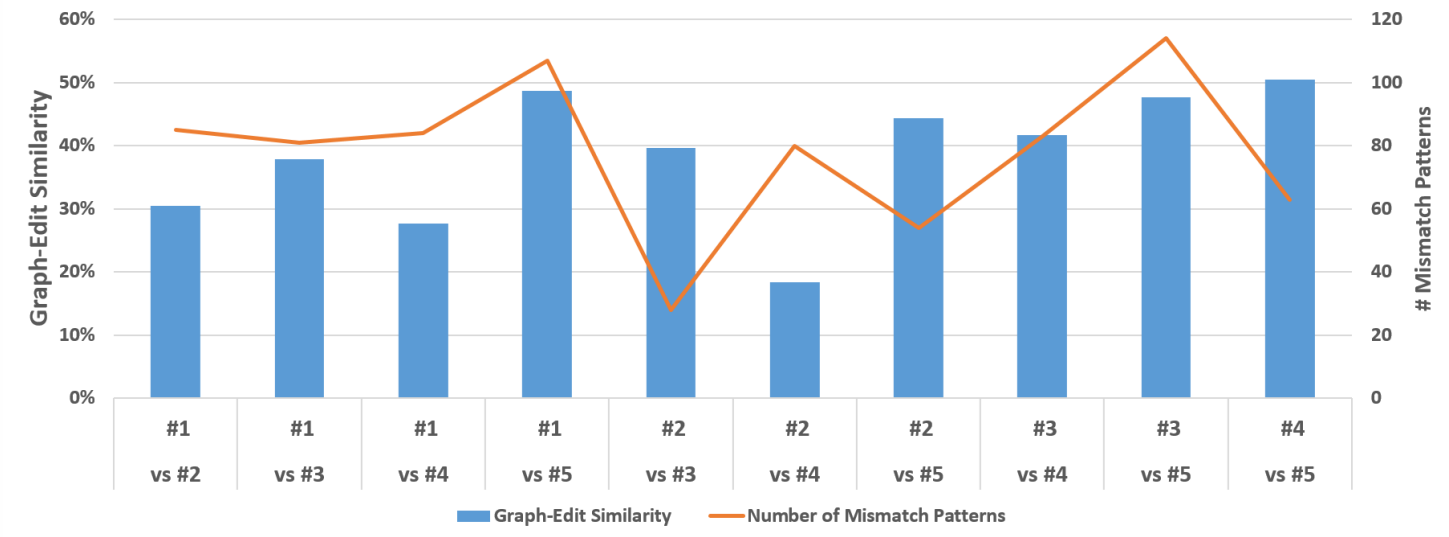






Results & Discussions

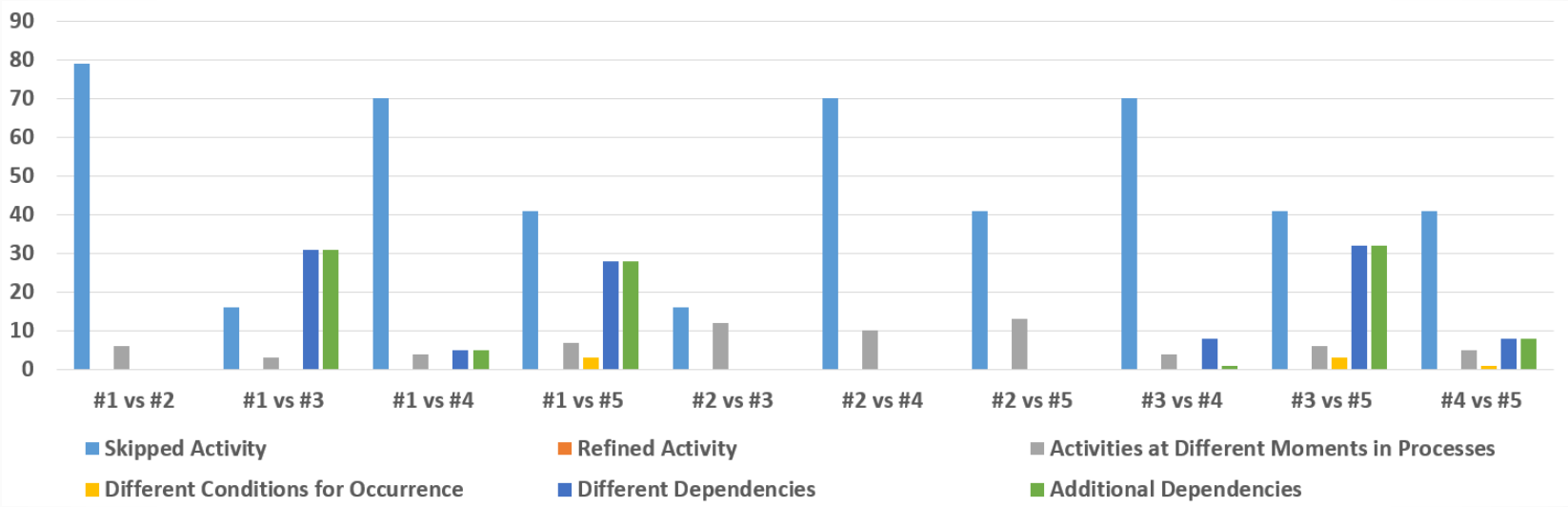
Environmental Permit Application Process – Mismatch Pattern Analysis



- Correlation between graph-edit similarity and number of mismatch patterns except Municipality #4 and #5

Results & Discussions

Environmental Permit Application Process – Mismatch Pattern Analysis

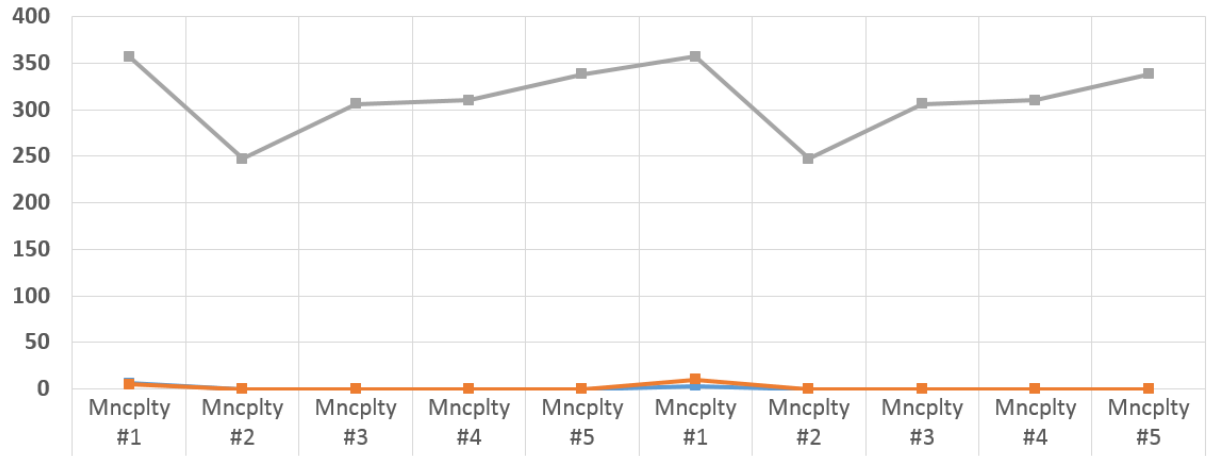


- "Skipped Activity" mostly
- "Refined Activity" is eliminated since codes are used instead of activity names

Results & Discussions

Environmental Permit Application Process – Recommendation Generation

(with 2 clusters)



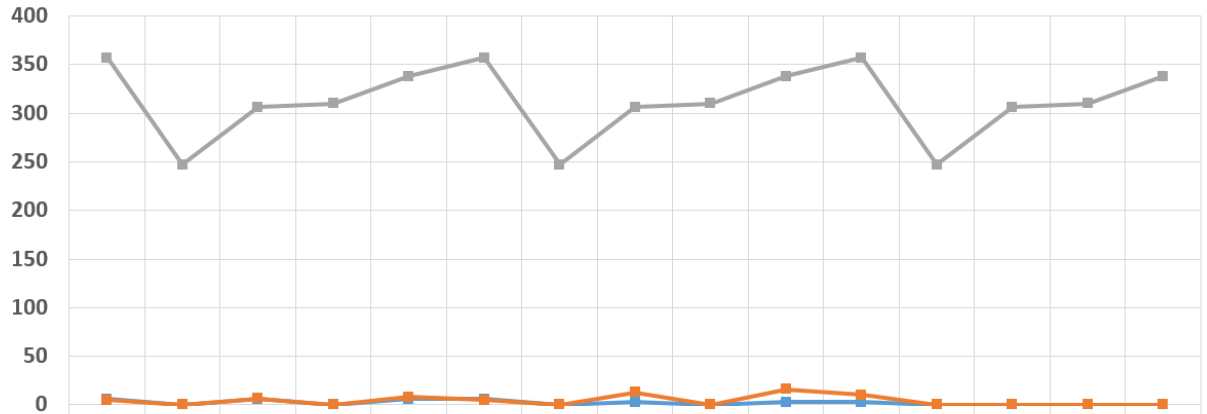
	Mncplty #1	Mncplty #2	Mncplty #3	Mncplty #4	Mncplty #5	Mncplty #1	Mncplty #2	Mncplty #3	Mncplty #4	Mncplty #5
	Threshold = 50 %					Threshold = 75 %				
Number of Performance Indicators	6	0	0	0	0	3	0	0	0	0
Number of Mismatch Patterns on Average	5	0	0	0	0	10	0	0	0	0
Number of Mismatch Patterns w/o Clustering	357	247	306	310	338	357	247	306	310	338

- Number of mismatch patterns to check significantly decreases with performance clustering

Results & Discussions

Environmental Permit Application Process – Recommendation Generation

(with 3 clusters)



	M. #1	M. #2	M. #3	M. #4	M. #5	M. #1	M. #2	M. #3	M. #4	M. #5	M. #1	M. #2	M. #3	M. #4	M. #5
	Threshold = 25 %					Threshold = 50 %					Threshold = 75 %				
Number of Performance Indicators	6	0	6	0	6	6	0	3	0	3	3	0	0	0	0
Number of Mismatch Patterns on Average	5	0	6	0	8	5	0	13	0	16	10	0	0	0	0
Number of Mismatch Patterns w/o Clustering	357	247	306	310	338	357	247	306	310	338	357	247	306	310	338

- Learning opportunities increases as number of cluster increases
- Number of mismatch patterns to check significantly decreases with performance clustering

Results & Discussions

Discussions

- Process mining stage:
  - Mines the process models with high fitness and high appropriateness from event logs
- Performance indicator calculation stage:
  - With the high quality process models, calculated performance indicators are acceptable
- Clustering stage:
  - Organizations can be clustered based on their performance indicators

Results & Discussions

Discussions

- Mismatch analysis stage:
  - It finds differences in accordance with similarity metrics
  - Not all mismatch patterns are discovered
  - Information value of mismatch patterns are not equal
- Recommendation generation stage:
  - Performance clustering helps to focus on differences
    - 3 times more in Loan Application Process
    - 100 times more in Environmental Permit Application Process

Results & Discussions

Discussions

- Business value of generated recommendations:
  - Results may be
    - important or
    - infeasible and irrelevant for business environment
  - Some insights about results can be provided but business environment and case related assessment is also required.

Results & Discussions

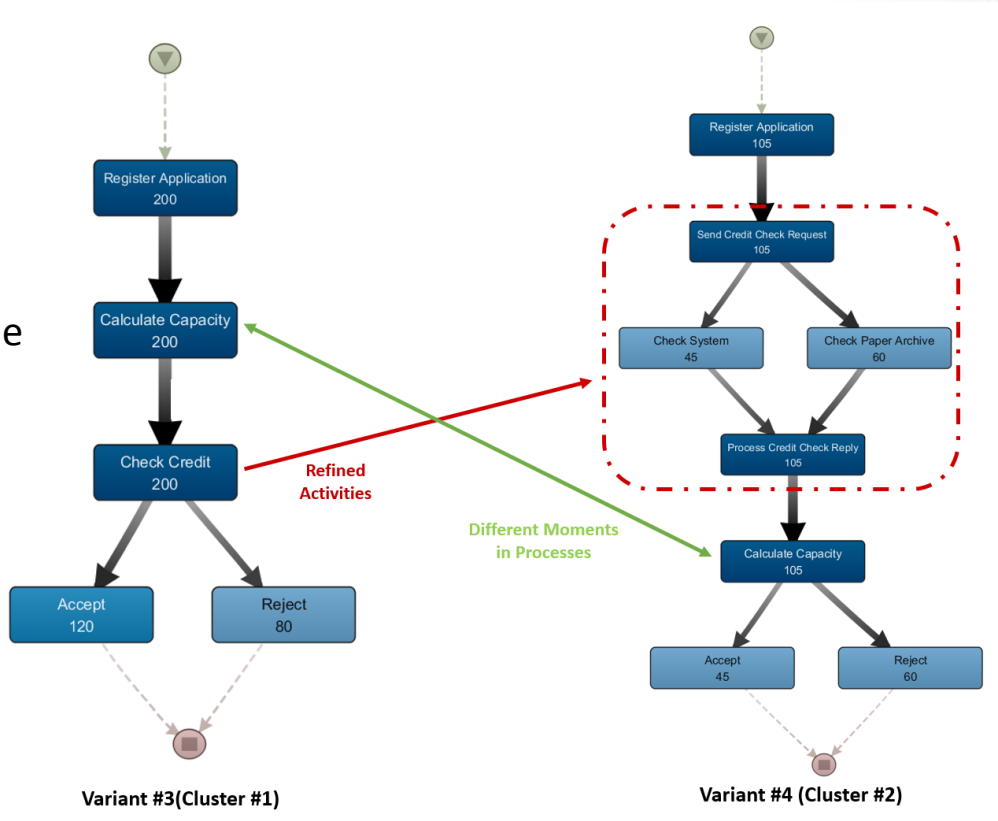
Discussions

In Loan Application Process, Variant #3 performs worse

- 27 % on average time and
- 12 % on standard deviation time

between activities

Calculate Capacity» → Accept



Results & Discussions

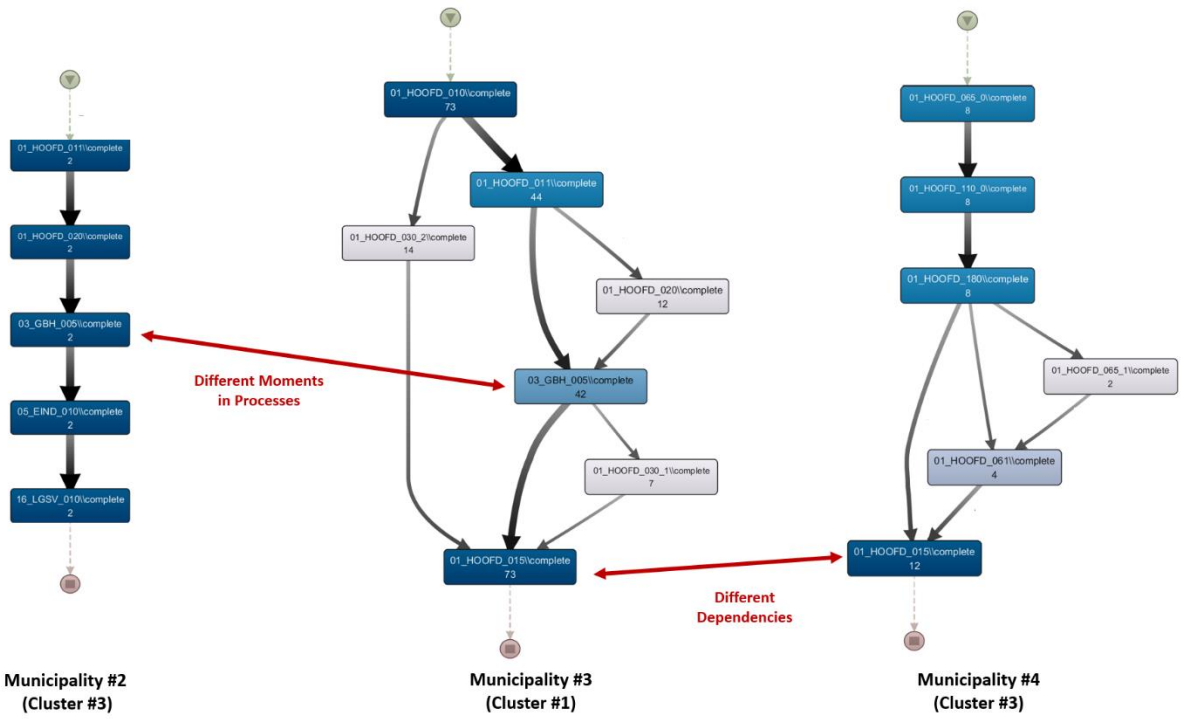
Discussions

In Environmental Permit Application Process,
Cluster #3 performs better

- 40 % on average time and
- 53% on standard deviation time

between activities

01_HOOFD_010 → 01_HOOFD_015



Agenda

1. Introduction
2. Related Work
3. Background
4. Methodology
5. Results & Discussions
6. Conclusion & Future Work
7. Demonstration

Conclusion

- Cross-organizational process mining is applied
  - Unsupervised learning with predictor variables as performances of organizations
  - In an environment where processes are executed on several organizations
- Results show that it is possible to use cross-organizational process mining and mismatch patterns for performance improvement recommendations

Conclusion

- A four-stage solution is presented and their performances are explained

Conclusion

Future Work

- Process mining stage:
  - Different techniques can be used to mine complex process models
- Performance indicator stage:
  - New indicators based on business environment
- Mismatch pattern analysis:
  - New patterns can be introduced

Conclusion

Future Work

- Recommendation generation:
  - Domain or BPM expertise to assess the quality of recommendations
- ProM implementation:
  - Visually selecting the interested area of process models

Agenda

1. Introduction
2. Related Work
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4. Methodology
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Demonstration

Also available on YouTube

https://youtu.be/T92UrRfl3r0

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Questions & Comments

Thank you for your attention!

Recommendation Generation for Performance Improvement by using Cross-Organizational Process Mining

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