Process Mining and Intelligence Project

Emotion Based Music Selection

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Contents

1 BPMN modeling

1.1 Process landscape

[*Ettore Ricci, Paolo Palumbo, Francesco Boldrini, Zahra Omrani*]

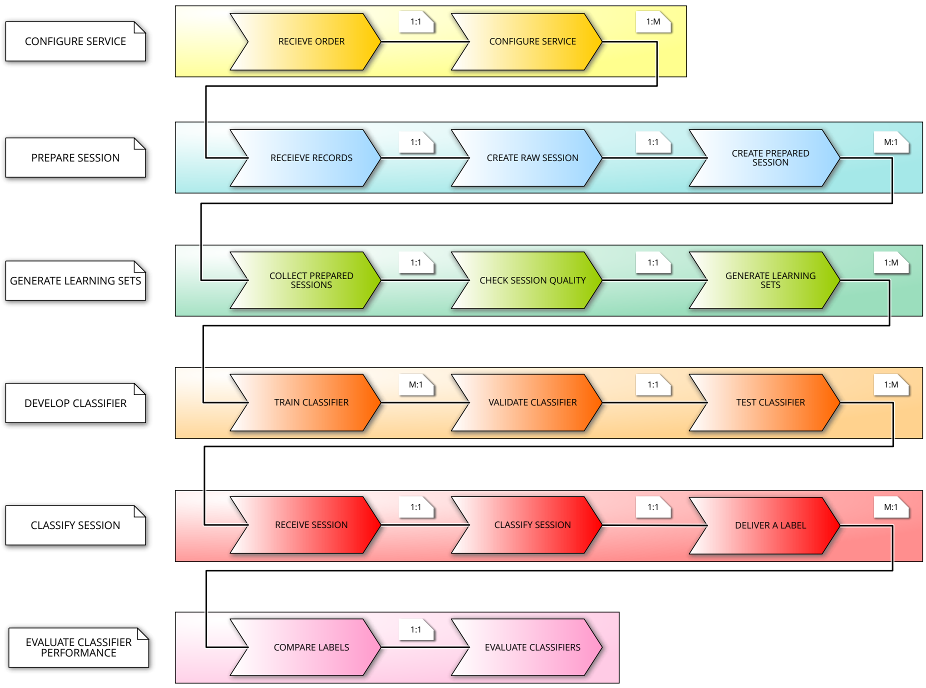

Figure 1: Process landscape

1.2 Process model

1.2.1 Prepare session

[*Ettore Ricci, Paolo Palumbo*]

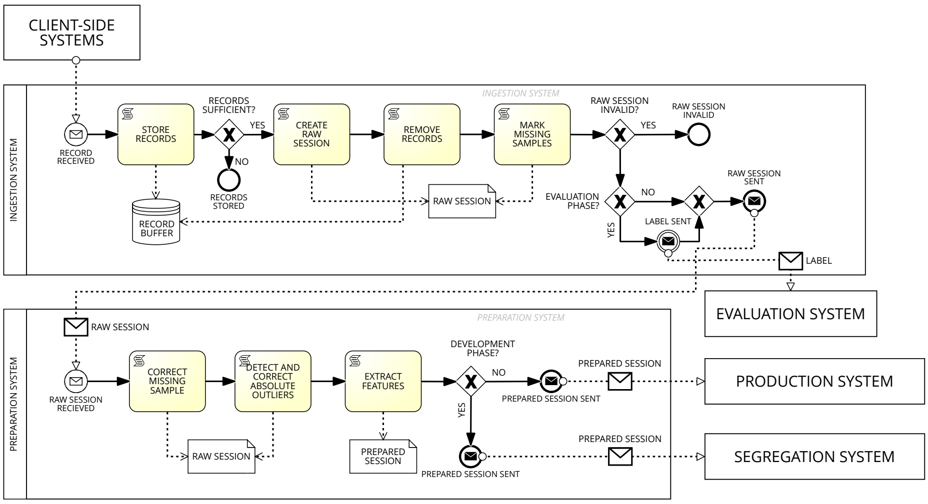

Figure 2: Business Diagram of the "Prepare session" process

1.2.2 Generate learning sets

[*Ettore Ricci, Paolo Palumbo*]

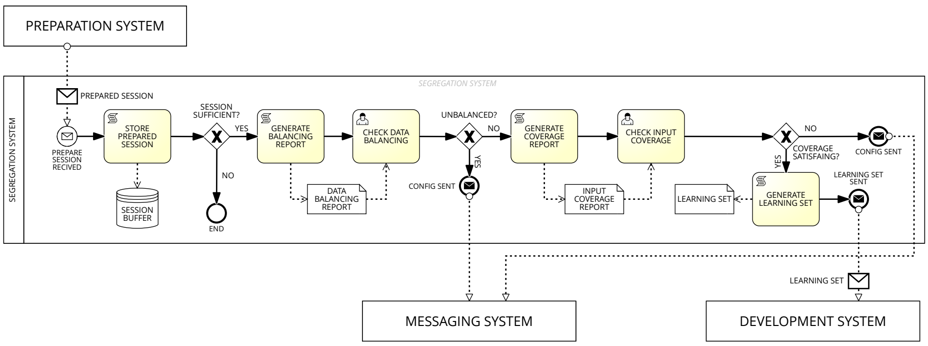

Figure 3: Business Diagram of the "Generate learning sets" process

1.2.3 Develop classifier

[*Ettore Ricci, Paolo Palumbo*]

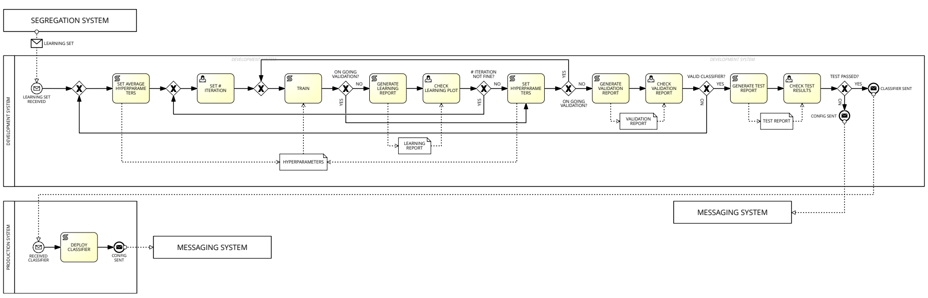

Figure 4: Business Diagram of the "Develop classifier" process

1.2.4 Classify session

[*Ettore Ricci, Paolo Palumbo*]

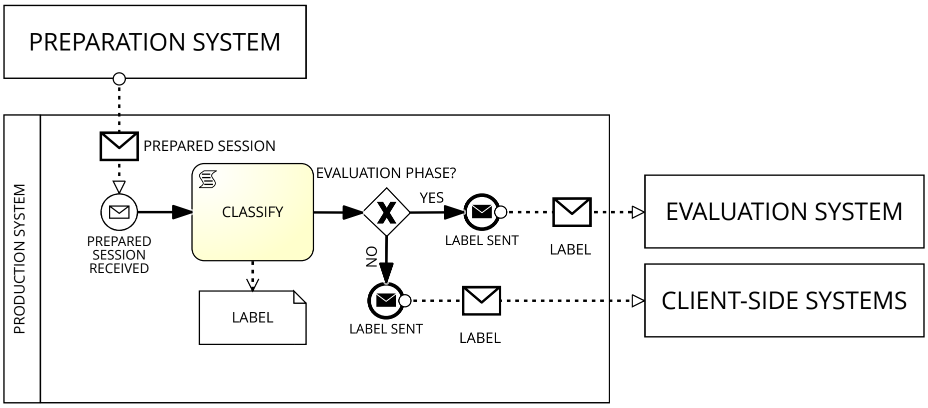

Figure 5: Business Diagram of the "Classify session" process

1.2.5 Evaluate classifier performance

[*Ettore Ricci, Paolo Palumbo*]

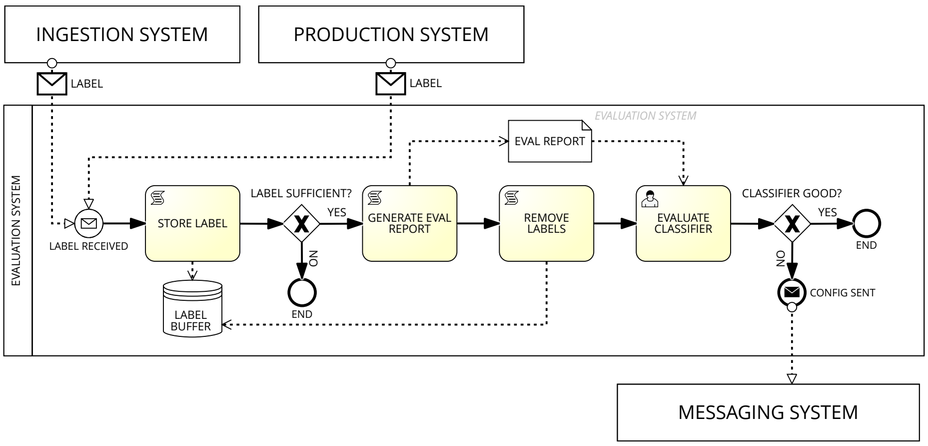

Figure 6: Business Diagram of the "Evaluate classifier performance" process

1.2.6 Configure systems

[*Ettore Ricci, Paolo Palumbo*]

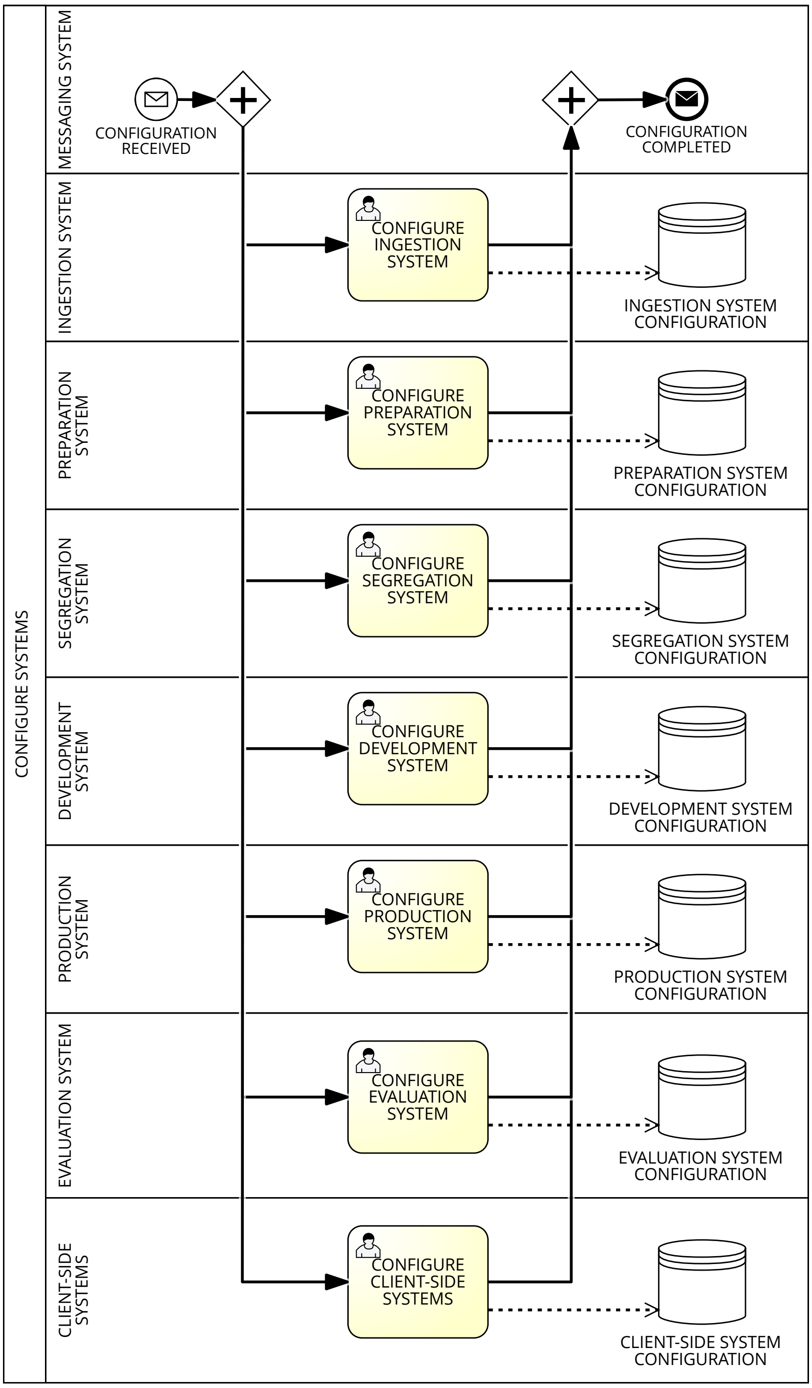

Figure 7: Business Diagram of the "Configure systems" process

2 Data modeling

2.1 Process model

2.1.1 Prepare session

[*Ettore Ricci*]

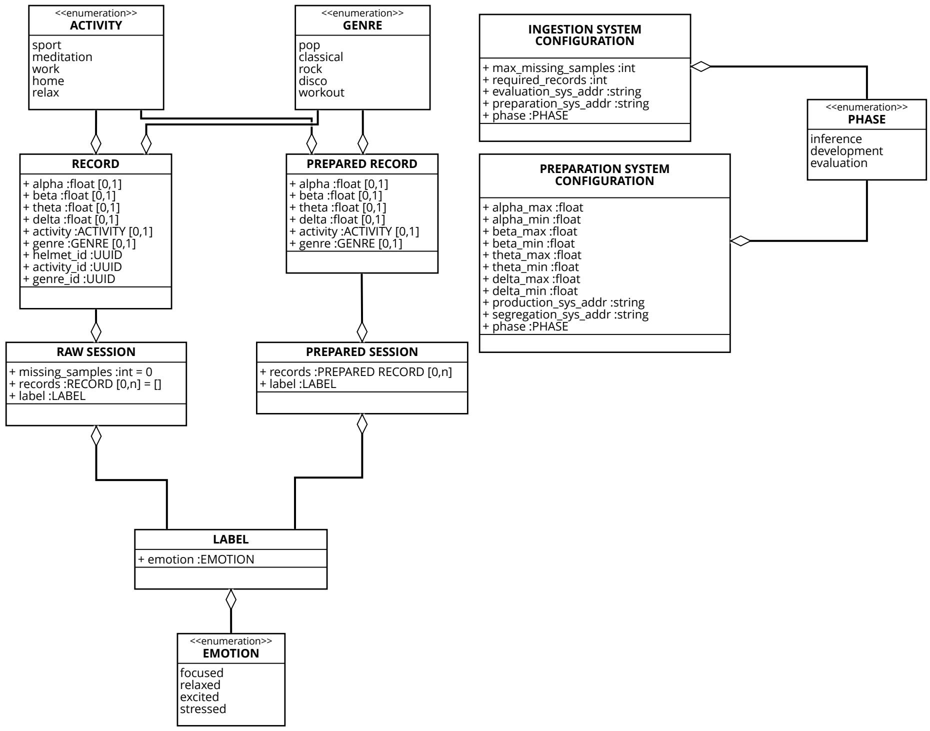

Figure 8: Data Model of the "Prepare session" process

2.1.2 Generate learning sets

[*Paolo Palumbo*]

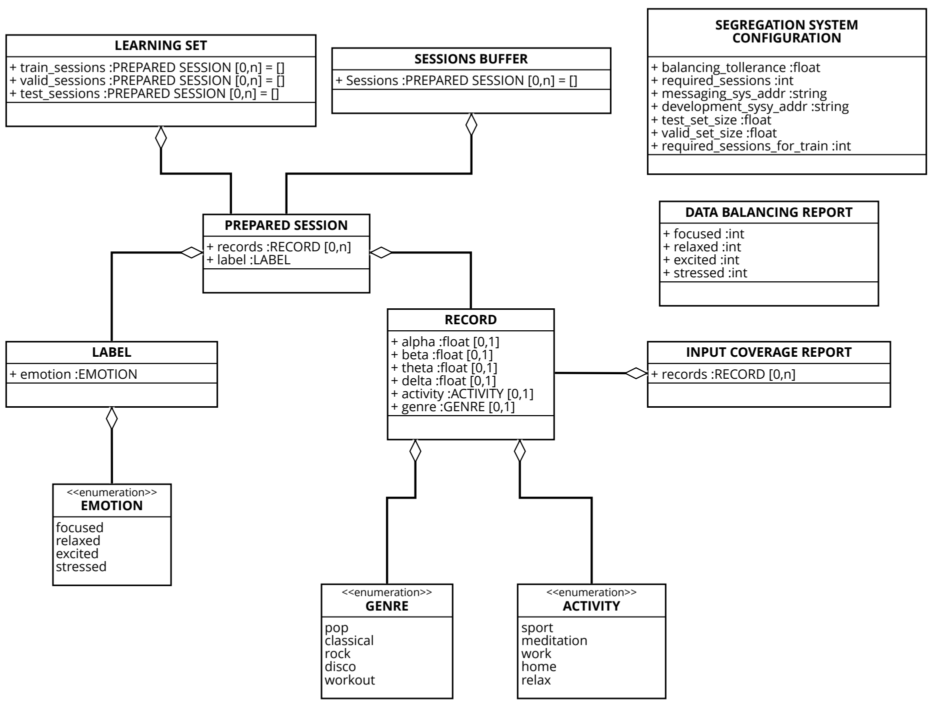

Figure 9: Data Model of the "Generate learning sets" process

2.1.3 Develop classifier

[*Paolo Palumbo*]

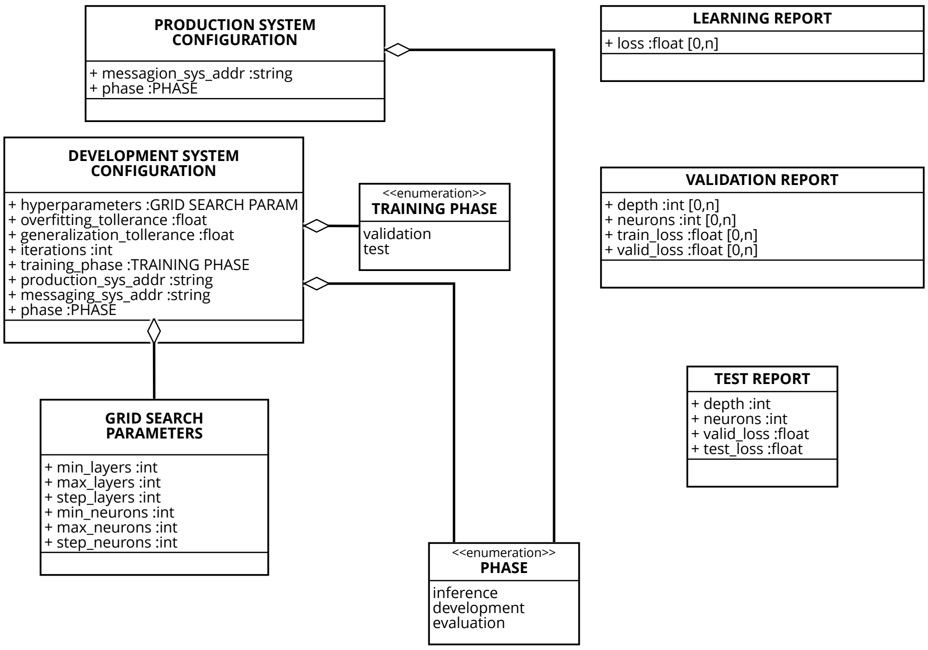

Figure 10: Data Model of the "Develop classifier" process

2.1.4 Classify session

[*Francesco Boldrini*]

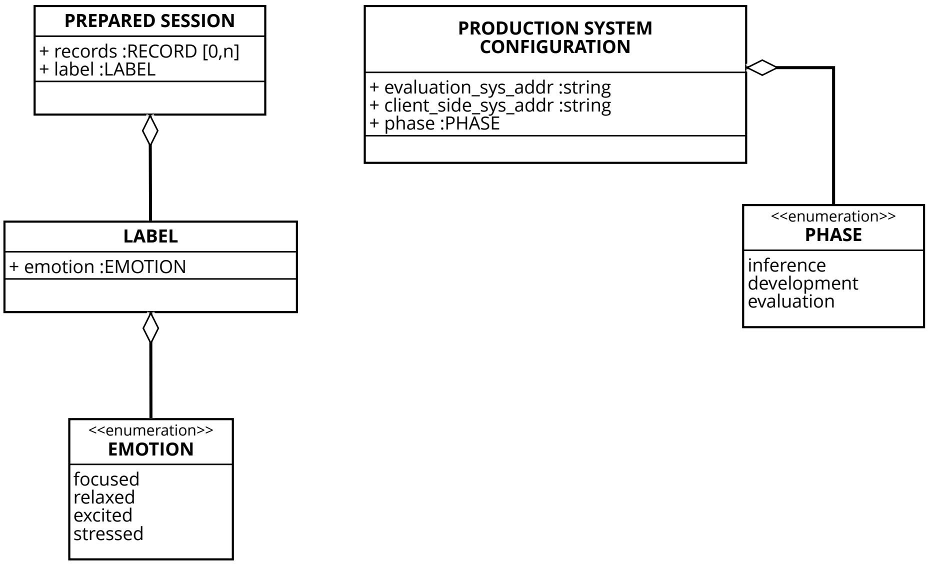

Figure 11: Data Model of the "Classify session" process

2.1.5 Evaluate classifier performance

[*Zahra Omrani*]

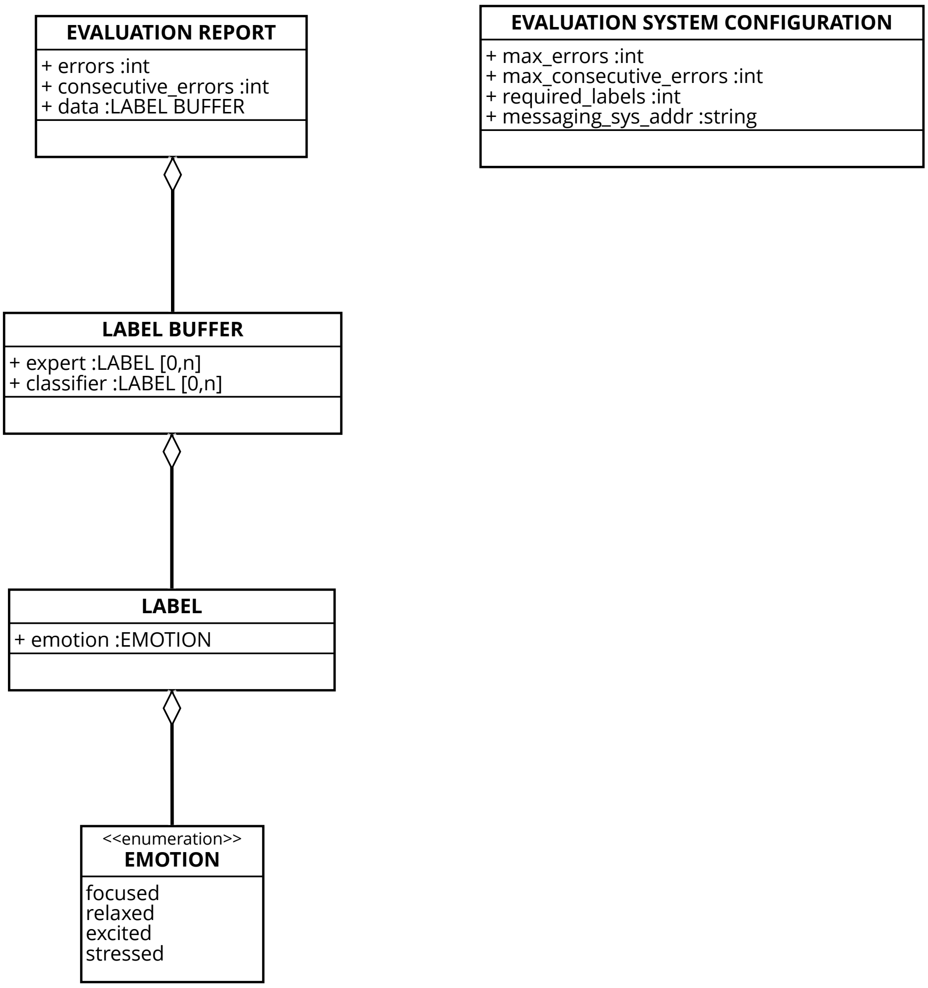

Figure 12: Data Model of the "Evaluate classifier performance" process

3 Task level modeling

3.1 Roles and salaries

[*Ettore Ricci, Paolo Palumbo*]

Position	Description	Salary	Normalized Salary
Clerk	Handles administrative tasks, organizes documentation, and assists with data entry and labeling. Ensures smooth operations by coordinating communication and managing resources.	$52,000.00	1.00
Data analyst	Prepares, analyzes, and visualizes data to extract insights. Collaborates on cleaning datasets, identifying trends, and supporting model validation.	$60,000.00	1.15
ML engineer	Builds, tests, and deploys machine learning models, optimizing performance and scalability. Integrates AI solutions into production systems with a focus on efficiency.	$130,000.00	2.50
Data scientist	Designs and experiments with AI models, applying advanced techniques to solve project challenges. Collaborates with experts to integrate domain knowledge and refine outputs.	$123,000.00	2.37
Domain expert (Neurologist)	Provides medical expertise to guide AI development and validate results. Ensures solutions align with clinical standards and address neurological challenges.	$267,000.00	5.13
Minimum		$52,000.00	1.00

Table 1: Salary and normalized salary for each position

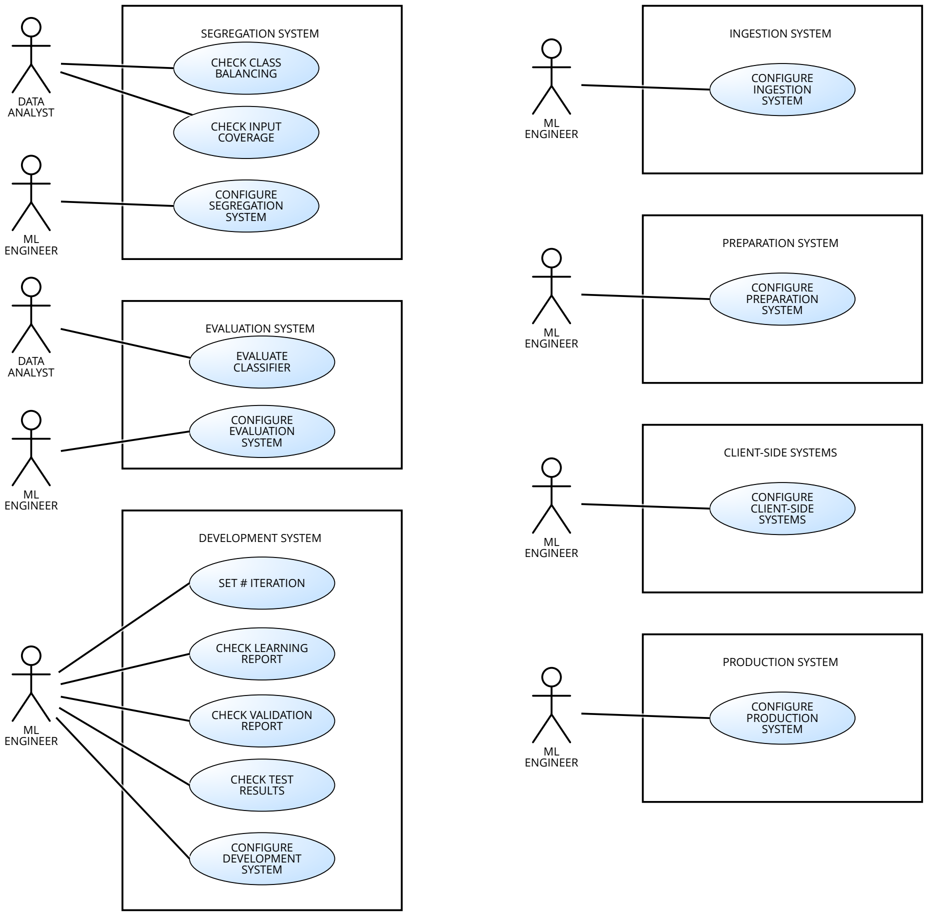

Figure 13: Use case diagram

3.2 Segregation system

3.2.1 Check data balancing

[*Ettore Ricci, Paolo Palumbo*]

The task is performed by a Data Analyst.

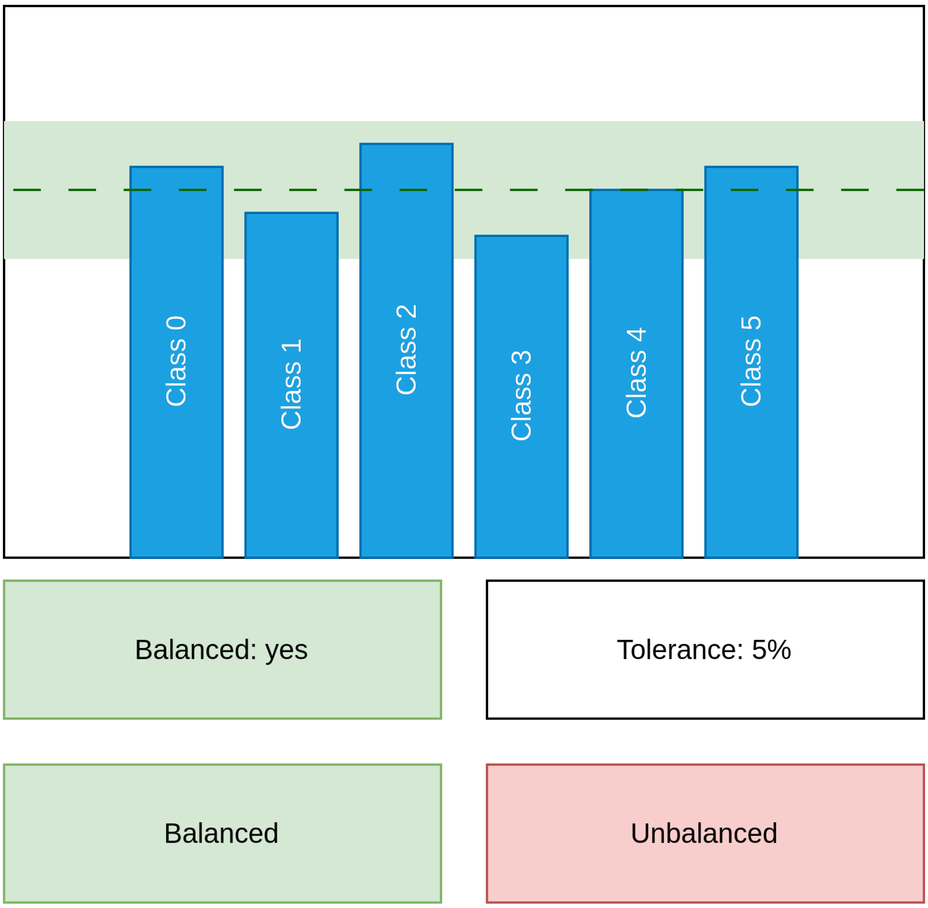

Figure 14: "Check data balancing" mock-up form

Step	O	CL	S	SC
1 ACTOR opens "Check data balancing" form.	1	1	1.15	1.15
2 SYSTEM shows the report.				
3 SYSTEM shows a hint whether the data is balanced or not.				
4 ACTOR checks the hint to see if the data is balanced or not.	1	2	1.15	2.30
5.1 IF the data is balanced.	0.2			
5.1.1 ACTOR clicks "Balanced" button.	0.2	1	1.15	0.23
5.2 ELSE	0.8			
5.2.1 ACTOR clicks "Unbalanced" button.	0.8	1	1.15	0.92
7 SYSTEM shows a confirmation dialog.				
8 ACTOR closes the form.	1	1	1.15	1.15
		Human task cost		5.74

Table 2: Detailed use case for "Check data balancing" task
O - Occurrence, CL - Cognitive Level, S - Normalized Salary, SC - Step Cost

3.2.2 Check input coverage

[*Ettore Ricci, Paolo Palumbo*]

The task is performed by a Data Analyst.

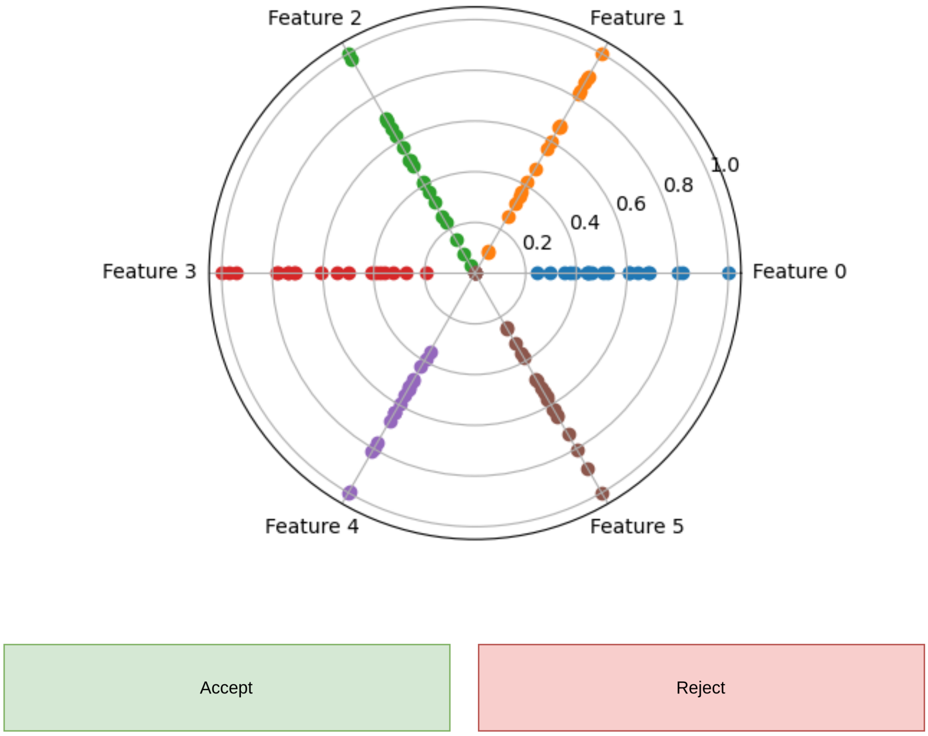

Figure 15: "Check input coverage" mock-up form

Step	**O**	**CL**	**S**	**SC**
1 ACTOR opens "Check input coverage" form.	1	1	1.15	1.15
2 SYSTEM shows a radar scatter plot of the input distribution.				
3 FOR EACH radius in the radar scatter plot:	6			
3.1 ACTOR checks if the distribution is uniform on the radius.	6	4	1.15	27.6
3.1.1 IF the distribution is not uniform as expected.	4			
3.1.1.1 THEN the input coverage is not satisfied.	4			
4.1 IF the input coverage is satisfied.	0.33			
4.1.1 ACTOR clicks "Accept" button.	0.33	1	1.15	0.38
4.2 ELSE	0.66			
4.2.1 ACTOR clicks "Reject" button.	0.66	1	1.15	0.76
5 SYSTEM shows a confirmation dialog.				
6 ACTOR closes the form.	1	1	1.15	1.15
		Human task cost		31.04

Table 3: Detailed use case for "Check input coverage" task
O - Occurrence, CL - Cognitive Level, S - Normalized Salary, SC - Step Cost

3.2.3 Configure Segregation System

[*Francesco Boldrini, Zahra Omrani*]
This task is performed by a ML Engineer.

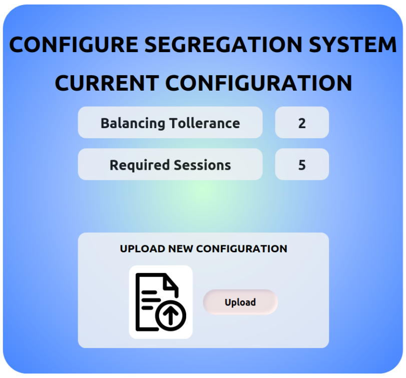

Figure 16: "Configure Segregation System" mock-up form

Step	O	CL	S	SC
1 ACTOR opens the "Configure Segregation System" form.	1	1	2.50	2.50
2 SYSTEM displays current configuration and "Upload" button.				
3 ACTOR checks parameters against previous iterations on file	1	3	2.50	7.50
4 ACTOR adjusts file based on current parameters	1	3	2.50	7.50
5 ACTOR pushes "Upload" button and uploads configuration file	1	1	2.50	2.50
6.1 SYSTEM IF config is correct and correctly formatted				
6.1.1 SYSTEM shows a confirmation message.				
6.2 ELSE				
6.2.1 SYSTEM shows error message and aborts				
7 ACTOR closes the form.	1	1	2.50	2.50
		Human task cost		22.50

Table 4: Detailed use case for "Configure Segregation" task
O - Occurrence, CL - Cognitive Level, S - Normalized Salary, SC - Step Cost

3.3 Development system

3.3.1 Set iteration number

[*Zahra Omrani*]

The task is performed by a ML engineer.

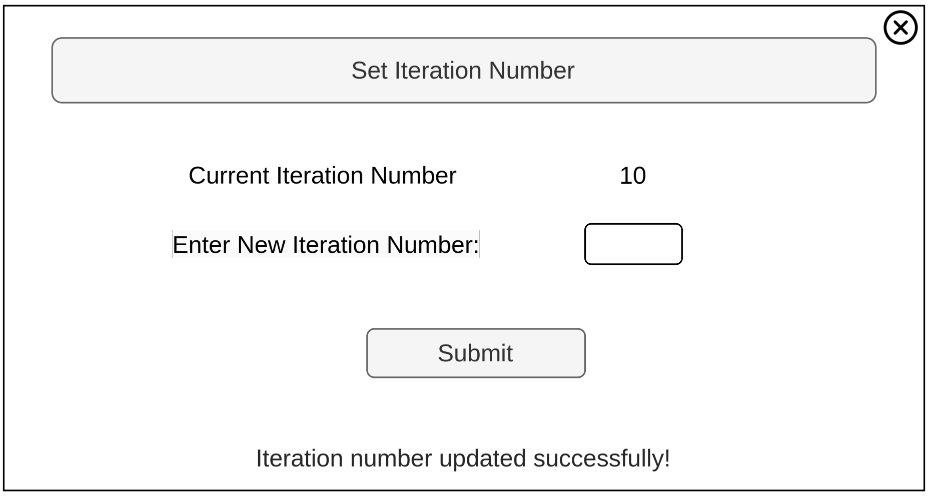

Figure 17: "Set iteration number" mock-up form

Step	**O**	**CL**	**S**	**SC**
1 ACTOR opens "Set Iteration Number" form.	1	1	2.5	2.5
2 SYSTEM displays the current iteration number.				
3.1 IF it's the first configuration:				
3.1.1 ACTOR inputs the desired number of iterations based on task complexity and previous experience.	0.2	3	2.5	1.5
3.2 ELSE (subsequent configurations):				
3.2.1 ACTOR inputs the number based on the established learning curve.	0.8	1	2.5	2
4 ACTOR clicks "Submit" button to confirm the iteration number.	1	1	2.5	2.5
5 SYSTEM shows a confirmation dialog.				
6 ACTOR closes the form.	1	1	2.5	2.5
Human task cost				11

Table 5: Detailed use case for "Set iteration number" task
O - Occurrence, CL - Cognitive Level, S - Normalized Salary, SC - Step Cost

3.3.2 Check learning report

[*Paolo Palumbo*]
The task is performed by a ML engineer.

Figure 18: "Check learning report" mock-up form

Step	O	CL	S	SC
1 ACTOR opens "Check training report" form.	1	1	2.50	2.50
2 SYSTEM shows the training loss curve.				
3 ACTOR checks the learning curve.	1	3	2.50	7.50
3.1 IF the loss is flat for at least half of the iterations:	0.4			
3.1.1 THEN ACTOR clicks "Overfit" button.	0.4	1	2.50	1.00
3.2 IF the loss is not flat at the end of the iterations:	0.4			
3.2.1 THEN ACTOR clicks "Underfit" button.	0.4	1	2.50	1.00
3.3 ELSE	0.2			
3.3.1 ACTOR clicks "Approved" button.	0.2	1	2.50	0.50
4 SYSTEM shows a confirmation dialog.				
5 ACTOR closes the form.	1	1	2.50	2.50
	Human task cost			15

Table 6: Detailed use case for "Check training report" task
O - Occurrence, CL - Cognitive Level, S - Normalized Salary, SC - Step Cost

3.3.3 Check validation report

[*Ettore Ricci*]
This task is performed by a ML engineer.

	ID	Depth	Neurons	Train MSE	Valid MSE	Delta MSE
1	954	3	4000	0.13	0.14	0.01
2	321	4	3000	0.23	0.24	0.01
3	5	3	1000	0.35	0.35	0.00
4	764	2	2000	0.24	0.45	0.21
5	202	3	2500	0.20	0.47	0.27

Reject

Overfitting Tolerance:	0.10

Figure 19: "Check validation report" mock-up form

Step	**O**	**CL**	**S**	**SC**
1 ACTOR opens "Check validation report" form.	1	1	2.5	2.5
2 SYSTEM shows the best 5 models sorted by increasing Validation Loss.				
3 FOR EACH model in the list:	5			
3.1 IF the model Validation Loss minus the Training Loss is less than the Overfitting Tolerance and the Best Model is not selected.	1	2	2.5	5
3.1.1 THEN select the model as the Best Model.	1	1	2.5	2.5
4 FOR EACH model in the list:	4			
4.1 IF the model is not the Best Model and the Validation Loss minus the Training Loss is less than the Overfitting Tolerance and the Second Best Model is not selected.	1	2	2.5	5
4.1.1 THEN select the model as the Second Best Model.	1	1	2.5	2.5
5.1 IF the Best Model is not selected.	0.05	1	2.5	0.125
5.1.1 ACTOR clicks "Reject" button.	0.05	1	2.5	0.125
5.2 ELSE IF the Second Best Model is not selected or the Validation Loss of the Second Best Model is one order of magnitude greater than the Validation Loss of the Best Model.	0.3	3	2.5	2.25
5.2.1 ACTOR clicks on the Best Model.	0.3	1	2.5	0.75
5.3 ELSE	0.65	3	2.5	4.875
5.3.1 ACTOR clicks on the least complex model among the Best Model and the Second Best Model.	0.65	3	2.5	4.875
6 SYSTEM shows a confirmation dialog.				
7 ACTOR closes the form.	1	1	2.5	2.5
	Human task cost			32.91

Table 7: Detailed use case for "Check validation report" task
O - Occurrence, CL - Cognitive Level, S - Normalized Salary, SC - Step Cost

3.3.4 Check test results

[*Ettore Ricci*]

This task is performed by a ML engineer.

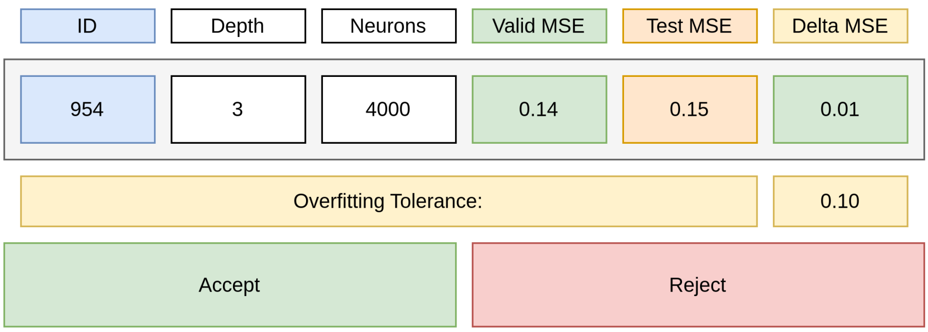

Figure 20: "Check test results" mock-up form

Step	O	CL	S	SC
1 ACTOR opens ”Check test results” form.	1	1	2.5	2.5
2 SYSTEM shows the test results.				
3 ACTOR checks if the difference between the test results and the validation results is within overfitting tolerance.	1	2	2.5	5
4.1 IF the test results is not satisfactory.	0.01			
4.1.1 ACTOR clicks ”Reject” button.	0.01	1	2.5	0.025
4.2 ELSE	0.99			
4.2.1 ACTOR clicks ”Approve” button.	0.99	1	2.5	2.475
5 SYSTEM shows a confirmation dialog.				
6 ACTOR closes the form.	1	1	2.5	2.5
	Human task cost			12.5

Table 8: Detailed use case for ”Check test results” task
O - Occurrence, CL - Cognitive Level, S - Normalized Salary, SC - Step Cost

3.3.5 Configure Development System

[*Francesco Boldrini, Zahra Omrani*]
This task is performed by a ML Engineer.

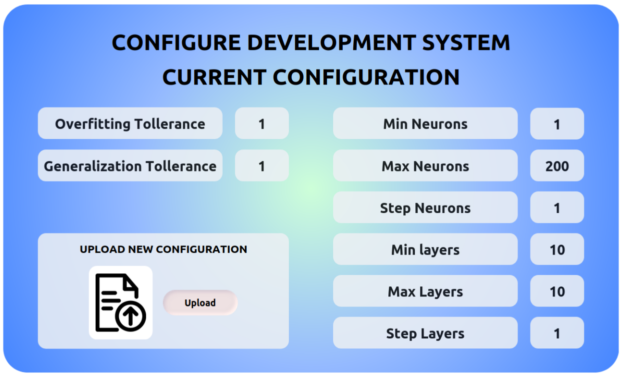

Figure 21: ”Configure Development System” mock-up form

Step	O	CL	S	SC
1 ACTOR opens the "Configure Development System" form.	1	1	2.50	2.50
2 SYSTEM displays current configuration and "Upload" button.				
3 ACTOR checks parameters against previous iterations on file	1	3	2.50	7.50
4 ACTOR adjusts file based on current parameters	1	3	2.50	7.50
5 ACTOR pushes "Upload" button and uploads configuration file	1	1	2.50	2.50
6.1 SYSTEM IF config is correct and correctly formatted				
6.1.1 SYSTEM shows a confirmation message.				
6.2 ELSE				
6.2.1 SYSTEM shows error message and aborts				
7 ACTOR closes the form.	1	1	2.50	2.50
			Human task cost	22.50

Table 9: Detailed use case for "Configure Development" task
O - Occurrence, CL - Cognitive Level, S - Normalized Salary, SC - Step Cost

3.4 Evaluation system

3.4.1 Evaluate classifier performance

[*Zahra Omrani*]

This task is performed by a Data Analyst.

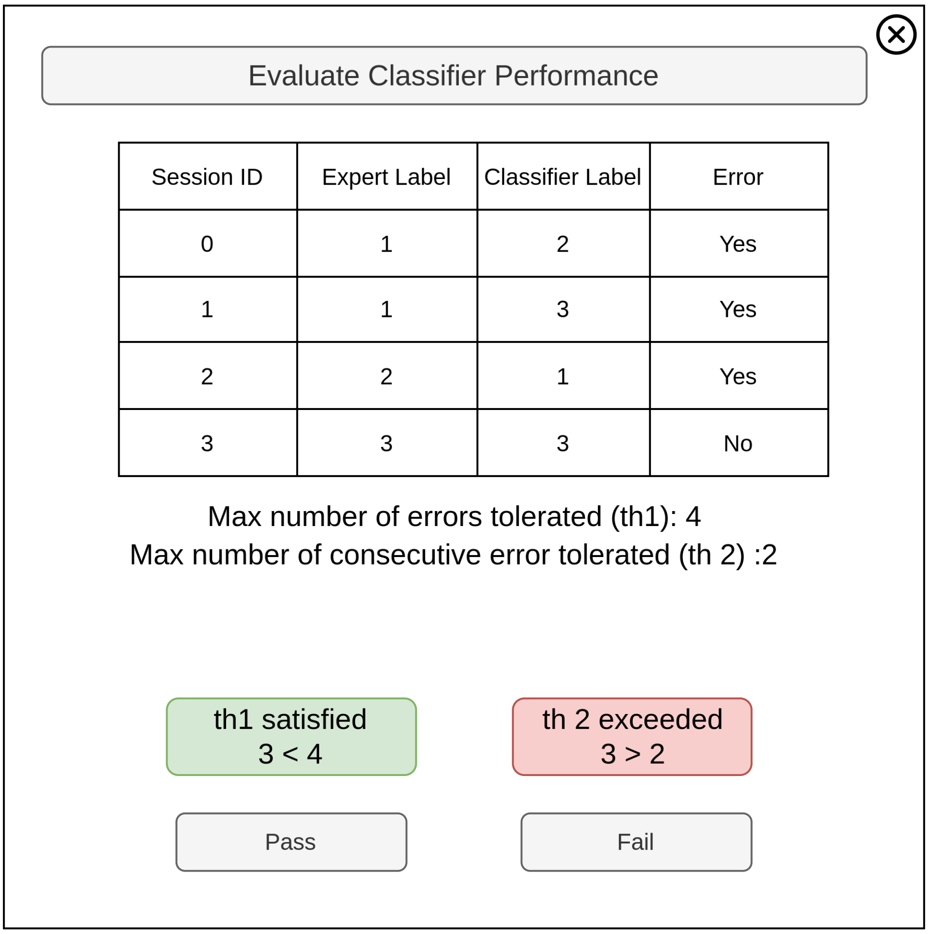

Figure 22: "Evaluate Classifier Performance" mock-up form

Step	O	CL	S	SC
1 ACTOR opens the "Evaluate Classifier Performance" form.	1	1	1.15	1.15
2 SYSTEM displays a table of sessions with Expert Label (ground truth) and Classifier Label (predicted label). The difference between the labels (if any) represents an error.				
3.1 ACTOR checks the total errors threshold color.	1	2	1.15	2.30
3.2 ACTOR checks the consecutive errors threshold color	1	2	1.15	2.30
3.3 IF at least one threshold is red				
3.3.1 ACTOR clicks the "Fail" button.	0.4	1	1.15	0.46
3.4 ELSE				
3.4.1 ACTOR clicks the "Pass" button.	0.6	1	1.15	0.65
4 SYSTEM shows a confirmation dialog.				
5 ACTOR closes the form.	1	1	1.15	1.15
			Human task cost	8.05

Table 10: Detailed use case for "Evaluate Classifier Performance" task
O - Occurrence, CL - Cognitive Level, S - Normalized Salary, SC - Step Cost

3.4.2 Configure Evaluation System

[*Francesco Boldrini, Zahra Omrani*]

This task is performed by a ML Engineer.

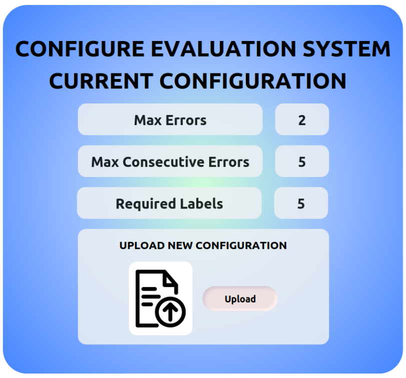

Figure 23: "Configure Evaluation System" mock-up form

Step	O	CL	S	SC
1 ACTOR opens the ”Configure Evaluation System” form.	1	1	2.50	2.50
2 SYSTEM displays current configuration and ”Upload” button.				
3 ACTOR checks parameters against previous iterations on file	1	3	2.50	7.50
4 ACTOR adjusts file based on current parameters	1	3	2.50	7.50
5 ACTOR pushes ”Upload” button and uploads configuration file	1	1	2.50	2.50
6.1 SYSTEM IF config is correct and correctly formatted				
6.1.1 SYSTEM shows a confirmation message.				
6.2 ELSE				
6.2.1 SYSTEM shows error message and aborts				
7 ACTOR closes the form.	1	1	2.50	2.50
			Human task cost	22.50

Table 11: Detailed use case for ”Configure Evaluation” task
O - Occurrence, CL - Cognitive Level, S - Normalized Salary, SC - Step Cost

3.5 Client-Side Systems

3.5.1 Configure Client-Side Systems

[*Francesco Boldrini, Zahra Omrani*]
This task is performed by a ML Engineer.

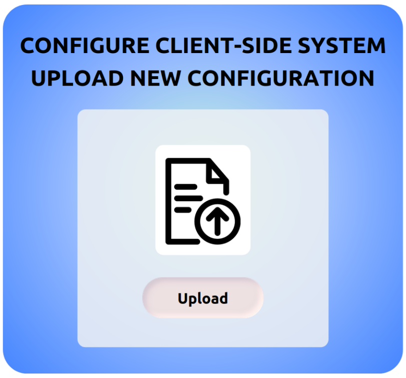

Figure 24: ”Configure Client-Side Systems” mock-up form

Step	O	CL	S	SC
1 ACTOR opens the ”Configure Client-Side System” form.	1	1	2.50	
2 SYSTEM displays the ”Upload” button.				
3 ACTOR push the ”Upload” button and upload the configuration file.	1	1	2.50	2.50
4 SYSTEM shows a confirmation message.				
5 ACTOR closes the form.	1	1	2.50	2.50
			Human task cost	7.50

Table 12: Detailed use case for ”Configure Client-Side Systems” task
O - Occurrence, CL - Cognitive Level, S - Normalized Salary, SC - Step Cost

3.6 Production System

3.6.1 Configure Production Systems

[*Francesco Boldrini, Zahra Omrani*]
This task is performed by a ML Engineer.

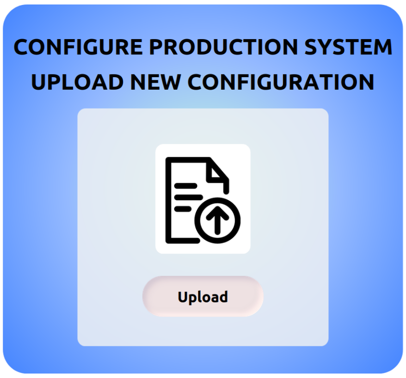

Figure 25: "Configure Production System" mock-up form

Step	O	CL	S	SC
1 ACTOR opens the "Configure Production System" form.	1	1	2.50	2.50
2 SYSTEM displays the "Upload" button.				
3 ACTOR push the "Upload" button and upload the configuration file.	1	1	2.50	2.50
4 SYSTEM shows a confirmation message.				
5 ACTOR closes the form.	1	1	2.50	2.50
			Human task cost	7.50

Table 13: Detailed use case for "Configure Production" task
O - Occurrence, CL - Cognitive Level, S - Normalized Salary, SC - Step Cost

3.7 Ingestion System

3.7.1 Configure Ingestion System

[*Francesco Boldrini, Zahra Omrani*]
This task is performed by a ML Engineer.

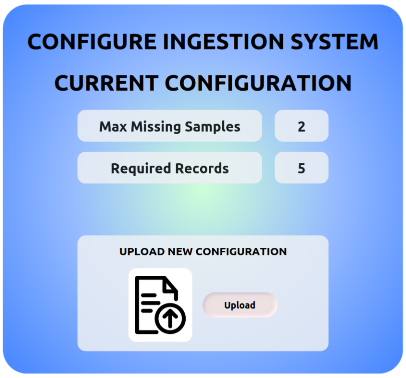

Figure 26: "Configure Ingestion System" mock-up form

Step	**O**	**CL**	**S**	**SC**
1 ACTOR opens the "Configure Ingestion System" form.			2.50	
2 SYSTEM displays current configuration and "Upload" button.				
3 ACTOR checks parameters against previous iterations on file	1	3	2.50	7.50
4 ACTOR adjusts file based on current parameters	1	3	2.50	7.50
5 ACTOR pushes "Upload" button and uploads configuration file	1	1	2.50	2.50
6.1 SYSTEM IF config is correct and correctly formatted				
6.1.1 SYSTEM shows a confirmation message.				
6.2 ELSE				
6.2.1 SYSTEM shows error message and aborts				
7 ACTOR closes the form.	1	1	2.50	2.50
		Human task cost		22.50

Table 14: Detailed use case for "Configure Ingestion" task
O - Occurrence, CL - Cognitive Level, S - Normalized Salary, SC - Step Cost

3.8 Preparation System

3.8.1 Configure Preparation System

[*Francesco Boldrini, Zahra Omrani*]
This task is performed by a ML Engineer.

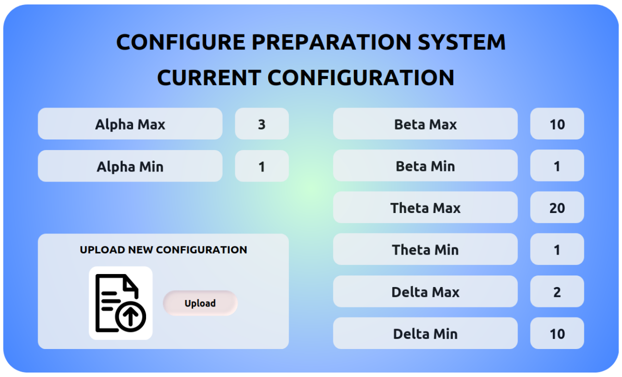

Figure 27: "Configure Preparation System" mock-up form

Step	**O**	**CL**	**S**	**SC**
1 ACTOR opens the "Configure Preparation System" form.			2.50	
2 SYSTEM displays current configuration and "Upload" button.				
3 ACTOR checks parameters against previous iterations on file	1	3	2.50	7.50
4 ACTOR adjusts file based on current parameters	1	3	2.50	7.50
5 ACTOR pushes "Upload" button and uploads configuration file	1	1	2.50	2.50
6.1 SYSTEM IF config is correct and correctly formatted				
6.1.1 SYSTEM shows a confirmation message.				
6.2 ELSE				
6.2.1 SYSTEM shows error message and aborts				
7 ACTOR closes the form.	1	1	2.50	2.50
		Human task cost		22.50

Table 15: Detailed use case for "Configure Preparation" task
O - Occurrence, CL - Cognitive Level, S - Normalized Salary, SC - Step Cost

4 Simulation

4.1 Collapsed workflow

[*Ettore Ricci, Paolo Palumbo, Francesco Boldrini*]

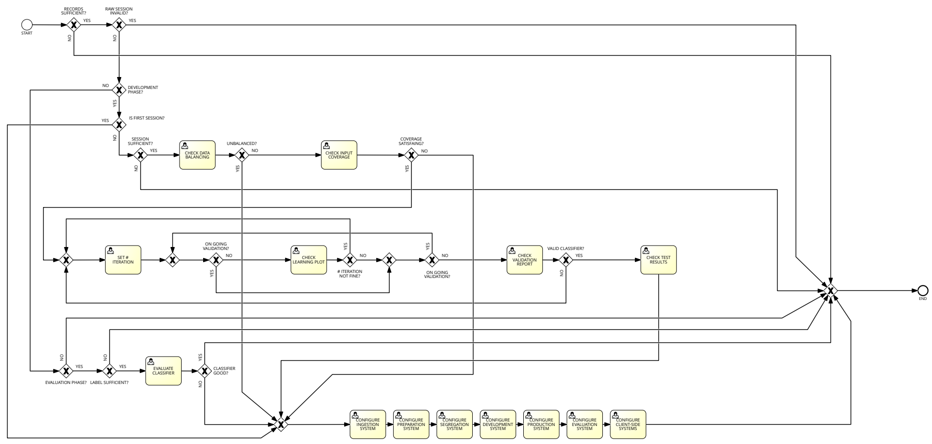

Figure 28: Collapsed workflow

5 Process mining

We mined the logs generated by the simulation of the collapsed workflow.

We modified the simulation configuration to make the 100 tokens flow through every path of the workflow. The most important gateways that we changed are listed in the following table.

Gateway	**Yes**	**No**
RAW SESSION INVALID	5%	95%
RECORD SUFFICIENT	95%	5%
SESSION SUFFICIENT	95%	5%
IS FIRST SESSION	20%	80%
COVERAGE SATISFYING	70%	30%
DEVELOPMENT PHASE	70%	30%

Table 16: Gateways configuration

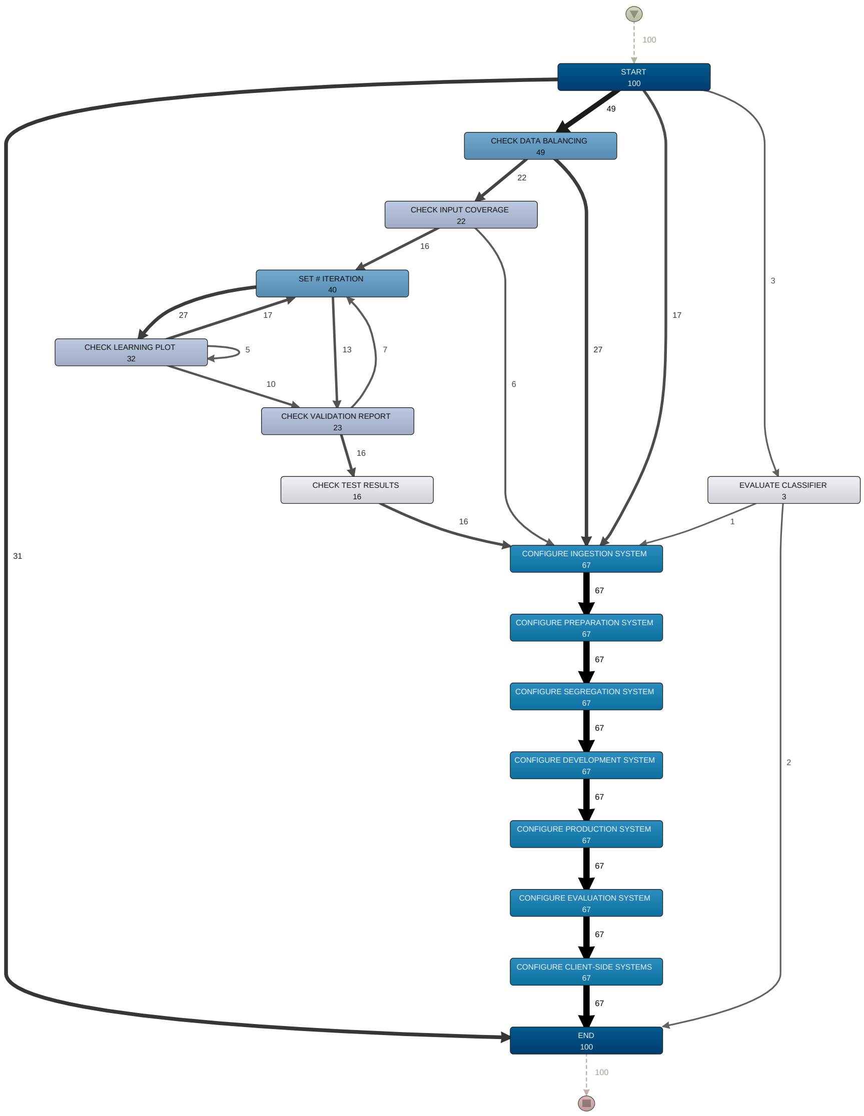

Figure 29: Disco analysis

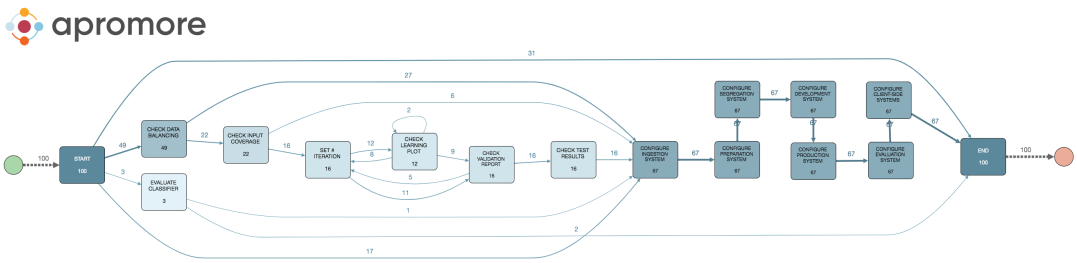

Figure 30: Apromore analysis

As we can see, the two transition maps mined from Disco and from Apromore are identical. The only difference stays in the frequencies because in Disco the frequencies are calculated as the total number of times a transition is executed, even on the same token; while in Apromore the frequencies are calculated as the number of individual tokens that execute a transition. This behavior can be changed with a setting in both tools.

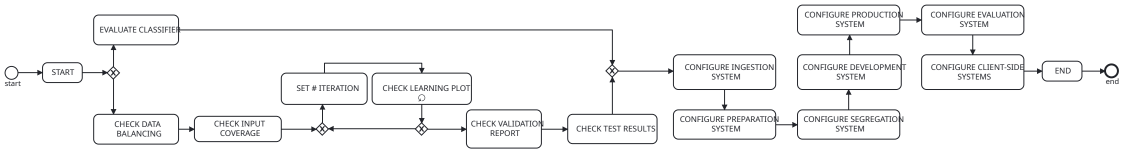

Figure 31: ProM mined BPMN model

We mined the logs using the "Heuristics Miner ProM6" mining algorithm.

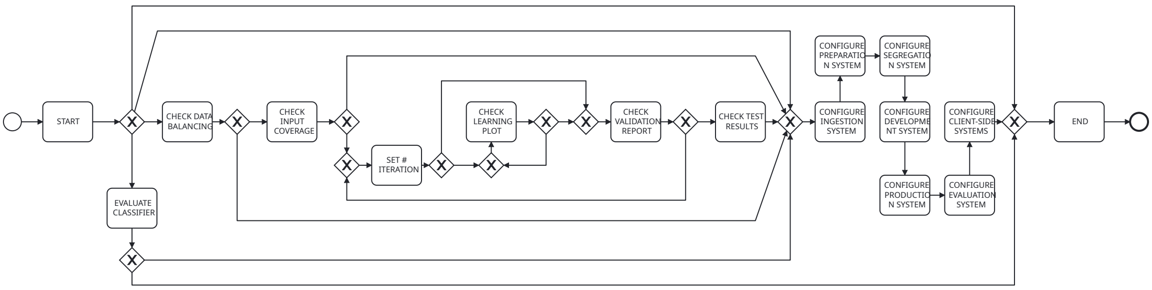

Figure 32: Apromore mined BPMN model

The BPMN model mined from Apromore is more detailed and covers more cases than the one mined from ProM. The key differences between the ProM model and the Apromore one are that the ProM model is missing the paths that skip the training and the configuration as well as one of the two paths that skip only the training. Furthermore, the training loop is much simpler in the ProM model, as it is missing every path that restarts the training after "CHECK VALIDATION REPORT".

Tool	Fitness	Generalization	Precision	Simplicity
Apromore	0.9928	0.9837	0.8199	62
ProM	0.7313	0.9902	0.8653	39

Table 17: Comparison of the process mining tools

5.1 Violations

We modified the logs to introduce 3 violations in the workflow. The violations are the following:

1. Skipping the dataset creation ("CHECK DATA BALANCING" and "CHECK INPUT COVERAGE") using data from another user.
2. Skipping "SET # ITERATIONS" and "CHECK LEARNING PLOT" by using early stopping.
3. Skipping "CHECK DATA BALANCING" by using a resampling technique.

Each violation is introduced 3 times in the logs.
These 3 violations can be beneficial in terms of time and resources:

- The first violation can make the costs of the training significantly lower for the client, because using an old dataset allows us to skip the labeling of the new data and it usually is very expensive. Also the manual check of the dataset is skipped saving additional time and resources. It must be noted that this violation can be a problem for the privacy of the clients and also result in worse models if the data of the new user has different characteristics from the old one.

- The second violation can make the training faster, because we do not need anymore to check the learning plot manually and we can train each model only once instead of trying multiple times with different number of iterations. Also, the method previously used to determine the number of iterations was based on an heuristic and it can be prone to errors.
- The third violation can reduce the time and costs of the dataset creation, also making the training possible with unbalanced datasets.

CaseID	**Violation**	**Fitness ProM**	**Fitness Apromore**
10	1	0.91	0.87
20	1	0.85	0.84
47	1	0.86	0.86
53	2	0.91	0.93
63	2	0.84	0.82
88	2	0.91	0.93
6	3	0.91	0.93
72	3	0.91	0.85
81	3	0.94	0.87

Table 18: Cases, violations and fitness on models generated by ProM and Apromore

Tool	**Fitness**
Apromore	0.9875
ProM	0.7256

Table 19: New fitness with violations included in the logs

Figure 33: Violations in the Apromore model visualized with ProM

Figure 34: Violations in the ProM model visualized with ProM