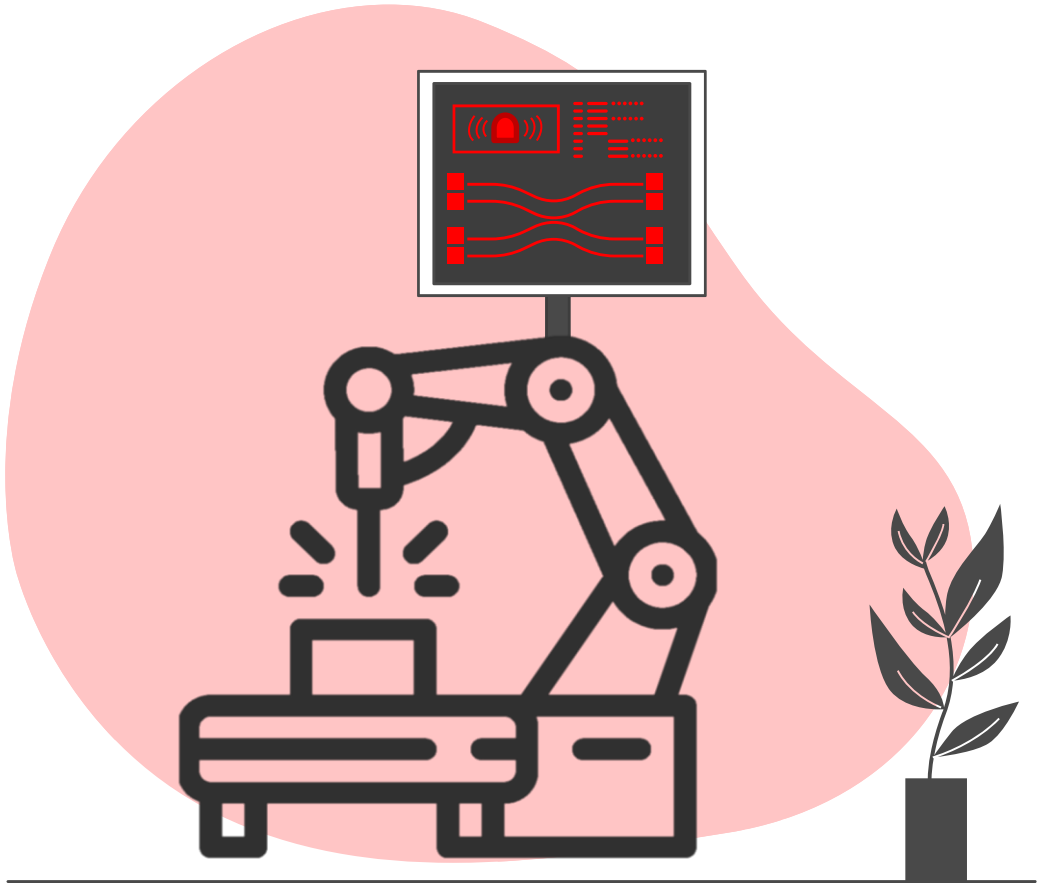


Predictive Maintenance

Objective

01

Flow Process

ป้องกันการพังของเครื่องจักรซึ่งทำให้การผลิตหยุดชะงักและไม่สามารถไปต่อที่ขั้นตอนถัดไปได้

02

Reduce cost of Maintenance

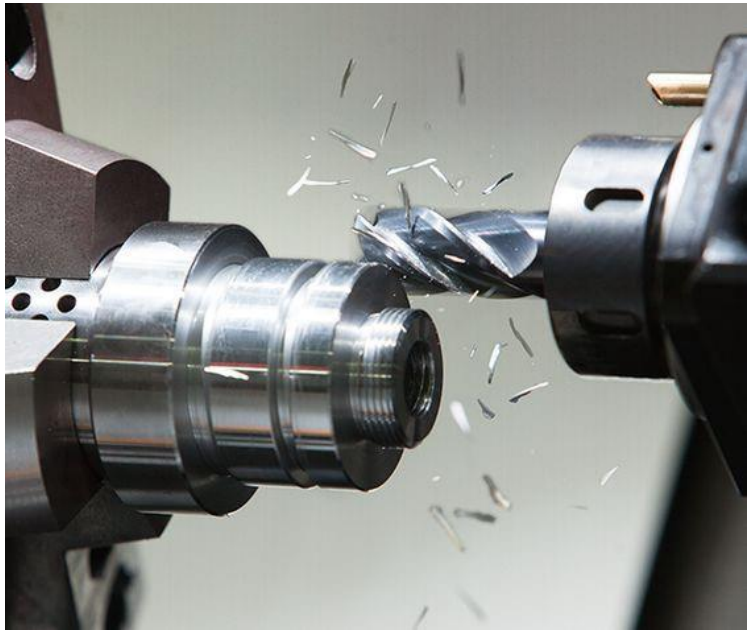
ลดค่าใช้จ่ายในการบำรุงรักษาทั้งที่เครื่องยังสามารถทำงานได้ดีอยู่

03

Improve Performance

เมื่อเราติดตามการทำงานของเครื่องจักรและทำนายได้ว่า Performance ต่ำและมีเกณฑ์ที่จะเสียหาย ให้เข้ามาบำรุงรักษาเพื่อให้มีประสิทธิภาพทำงานได้ดีต่อเนื่อง

Machine Data



Air Temperature [K] ความร้อนของอากาศโดยรอบ

Process Temperature [K] ความร้อนของเครื่องในขณะทำงาน

Rotational Speed [rpm] ความเร็วในการหมุน

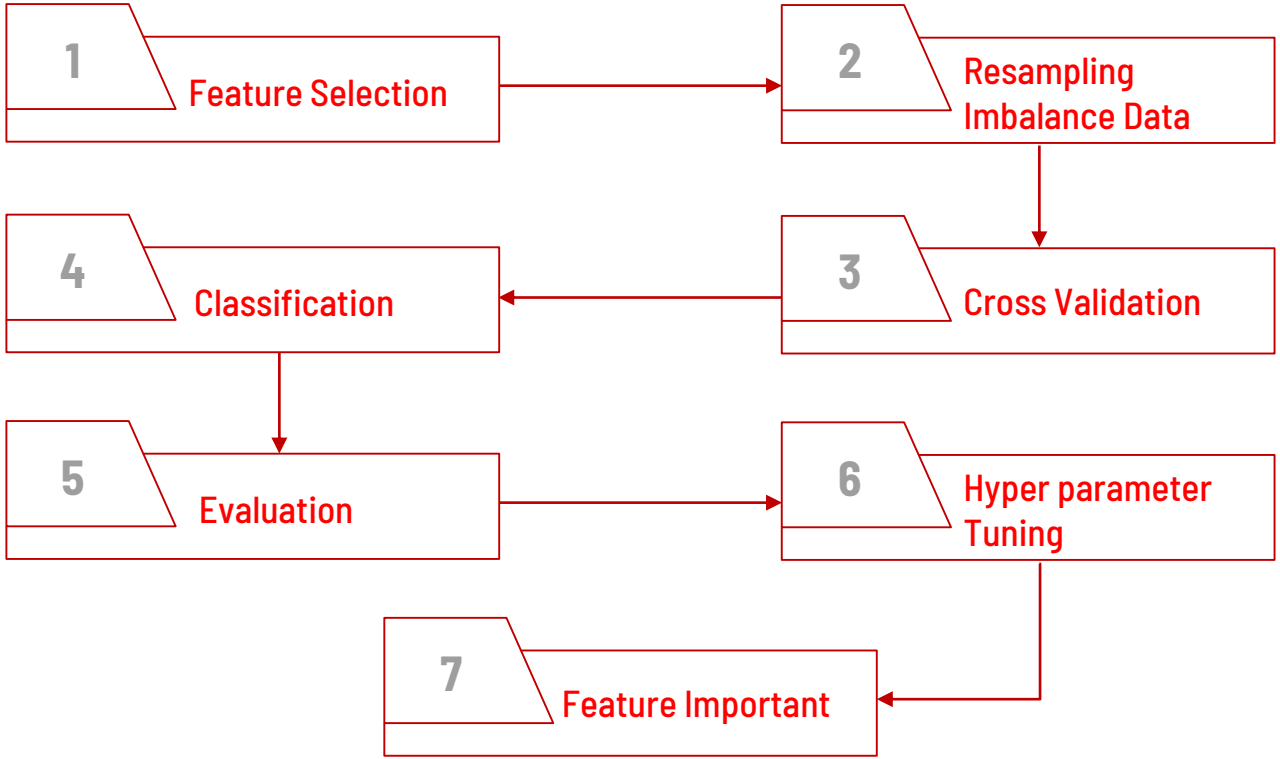
Torque [Nm] แรงที่พยายามจะหมุนมวลหรือแรงบิด

Tool Wear [min] การสึกหรอของเม็ดมีดตัดในกระบวนการ

01

Let do it!
1st draft

Model Flow


1
Feature Selection
2
Resampling
Imbalance Data
3
Cross Validation
4
Classification
5
Evaluation
6
Hyper parameter
Tuning
7
Feature Important

Feature Selection

Recursive Feature Elimination (RFE)
- จะทำงานโดยค่อยตัด **Feature** ออกไปทีละตัว จนเหลือจำนวน **Feature** ตามที่ต้องการ
- XGBoost
- LightGBM

Tree Based
- ใช้หลักการคำนวน **Impurity** ที่ลดลง เมื่อใส่ **Combination** ของ **Feature** เข้าไป ถ้ายิ่งลดลงมากแสดงว่า **Feature** นั้นยิ่งมีความสำคัญมาก
- AdaBoost selector
- RandomForest selector
- ExtraTrees selector
- GradientBoosting selector
- XGBoost selector
- lightGBM selector

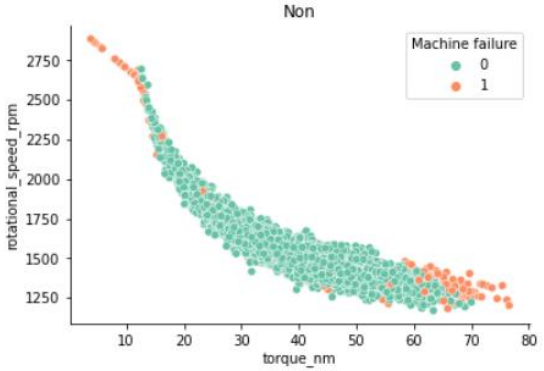
Lasso
- เลือกตัวแปรโดยการ ปรับค่าสัมประสิทธิ์ของ **Feature** เพื่อที่จะทำให้ **Cost Function** ซึ่งก็คือ **MSE** ต่ำสุด ถ้าค่าสัมประสิทธิ์ของ **Feature** นั้นเป็น **0** ก็คือ **Feature** นั้นถูกคัดออกไป

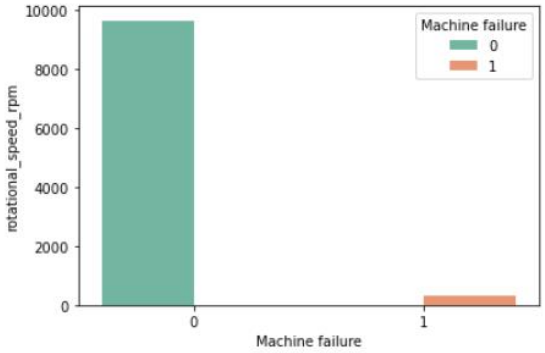
Feature Selection (2)

feature	RFE-XGB	RFE-LGB	Lasso	RandomForest	AdaBoost	ExtraTrees	GradientBoosting	XGBoost	LightGBM	Total
rotational_speed_rpm	True	True	True	True	True	True	True	True	True	9
torque_nm	True	True	True	True	True	True	True	True	True	9
tool_wear_min	True	True	True	True	True	True	True	True	True	9
air_temperature_k	True	True	True	True	False	True	True	False	True	7
process_temperature_k	True	True	True	False	False	True	True	False	True	6
H	True	True	True	False	False	False	False	False	False	3
L	True	True	True	False	False	False	False	False	False	3
M	True	True	False	False	False	False	False	False	False	2

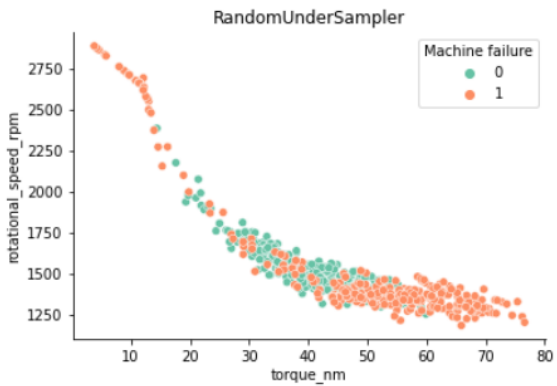
Resampling Imbalance Data

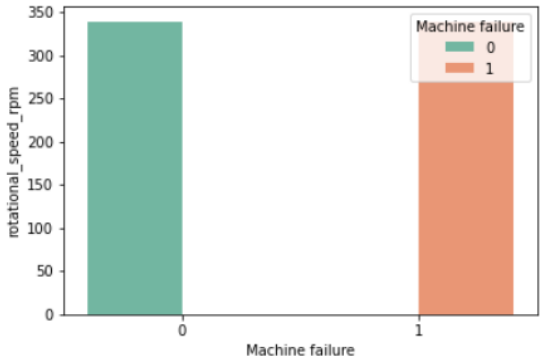
No Sampling



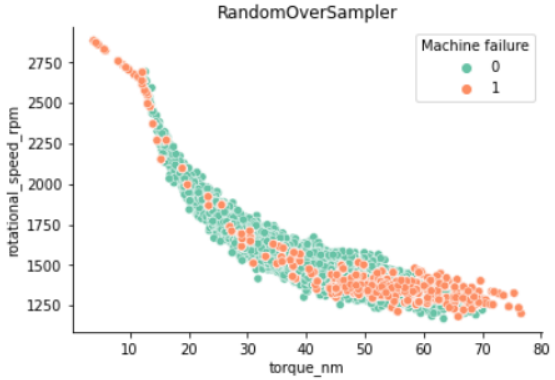


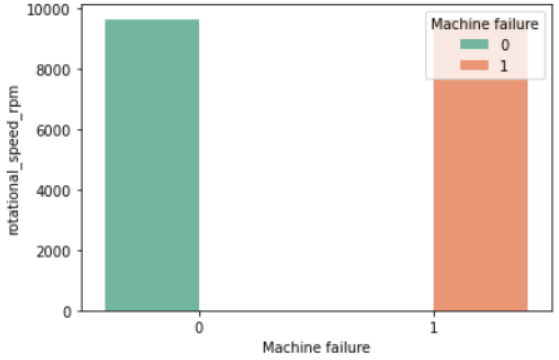
Undersampling





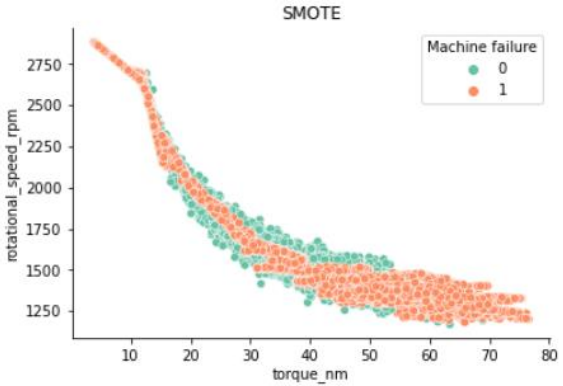
Oversampling

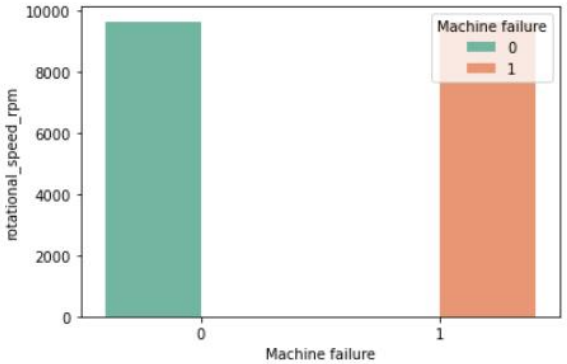




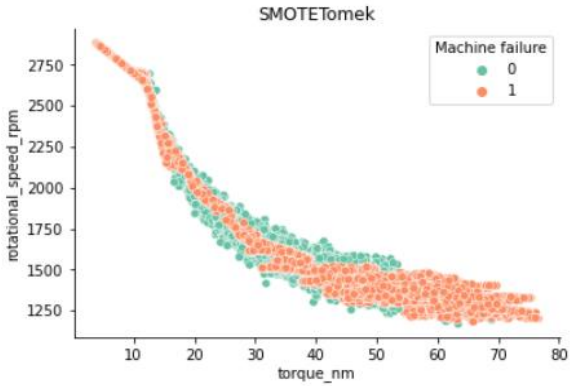
Resampling Imbalance Data

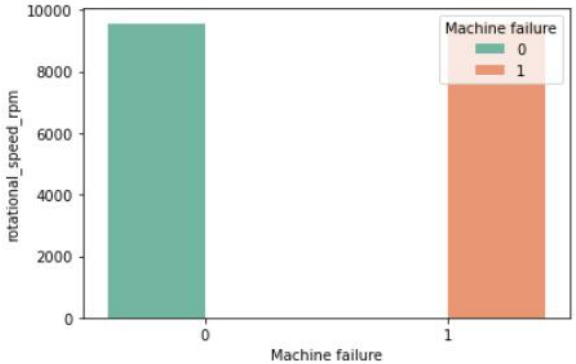
SMOTE



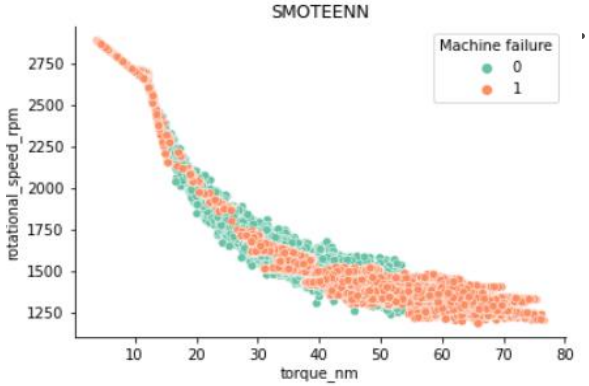


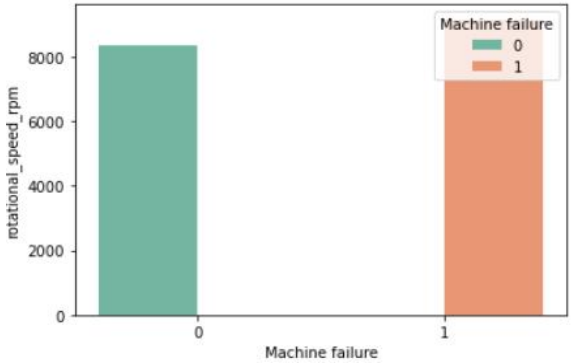
SMOTE+TOMEK Links





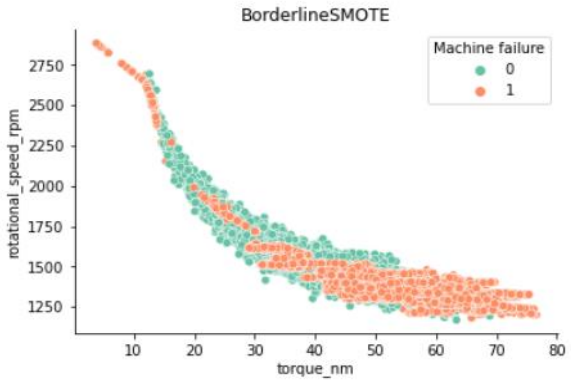
SMOTE+ENN

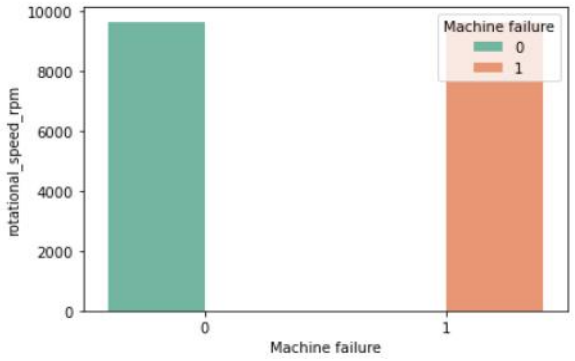




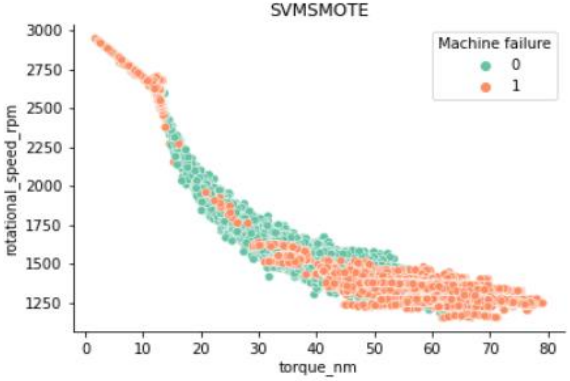
Resampling Imbalance Data

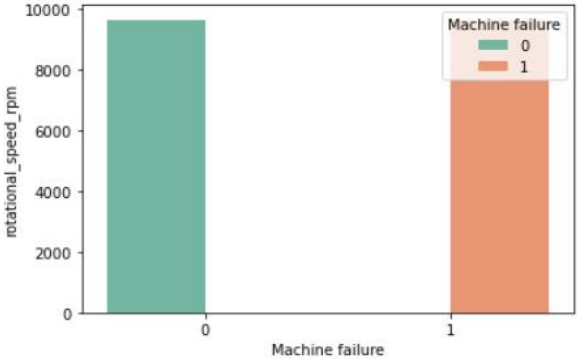
Borderline SMOTE



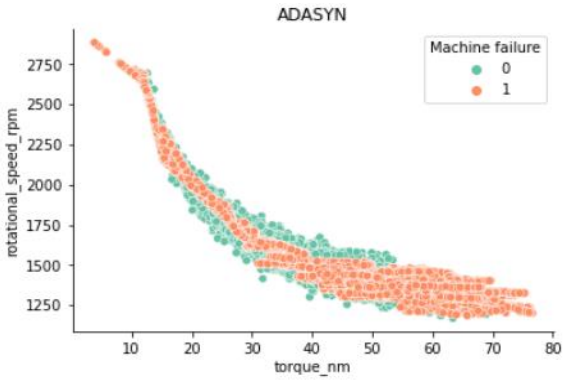


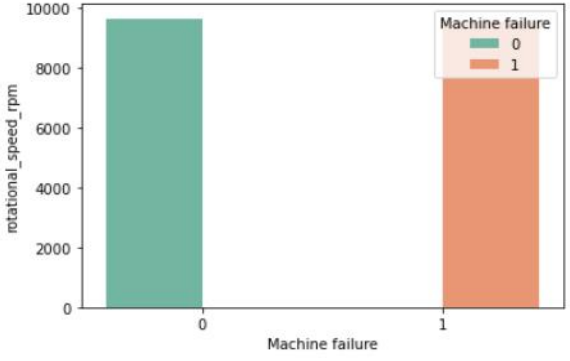
Borderline-SMOTE SVM





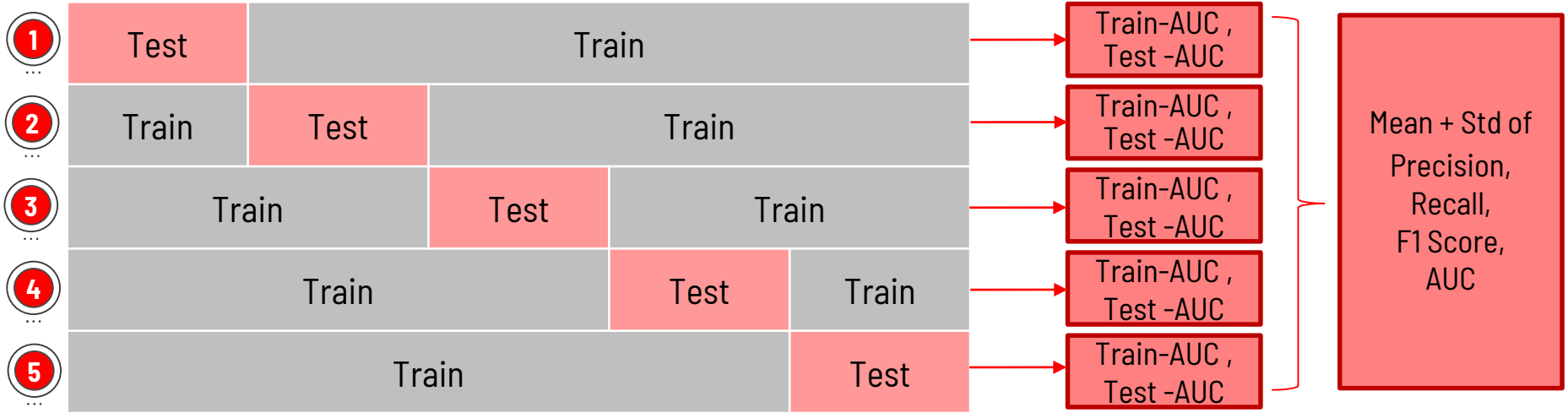
ADASYN





Cross Validation

- Stratified K Fold (K=5)
- Each round define dataset Train 80% and Test 20%
- Positive value ratio in test and train dataset is equal



Classification Model

1. K-Nearest Neighbor
2. Logistic Regression
3. Decision Tree
4. Random Forest
5. XGBoost
6. LightGBM

Evaluation

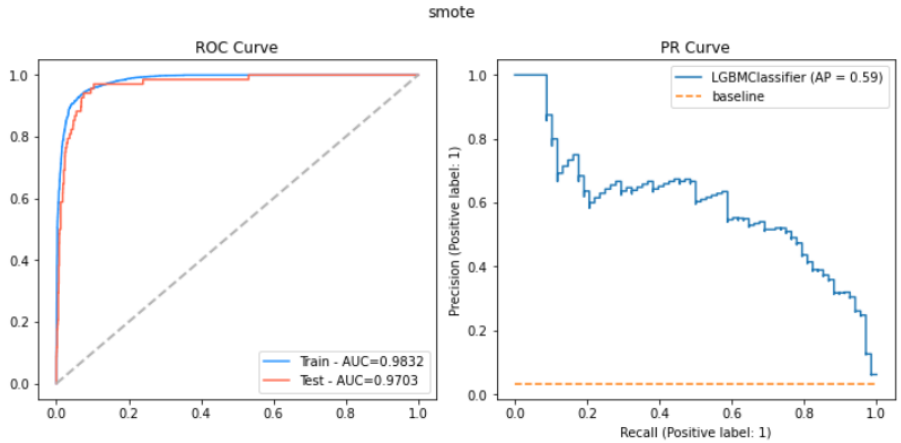
- Top 10 Model Performance

	model	resampler	accuracy_mean	accuracy_std	precision_mean	precision_std	recall_mean	recall_std	f1-score_mean	f1-score_std	auc_train_mean	auc_train_std	auc_test_mean	auc_test_std
48	LightGBM	smote	90.37%	0.74%	25.31%	1.18%	93.78%	3.95%	39.83%	1.39%	98.32%	0.10%	97.03%	0.58%
49	LightGBM	smote_tomek	90.09%	0.69%	24.74%	0.92%	93.78%	3.84%	39.13%	1.04%	98.40%	0.07%	97.00%	0.59%
47	LightGBM	oversampler	92.11%	0.50%	29.14%	0.85%	92.31%	4.07%	44.26%	0.78%	98.78%	0.05%	96.83%	0.69%
53	LightGBM	adasyn	89.43%	0.64%	23.72%	0.93%	95.26%	3.58%	37.96%	1.22%	98.01%	0.10%	96.81%	0.76%
45	LightGBM	no resampler	96.76%	0.10%	72.67%	37.26%	5.31%	4.01%	9.66%	6.97%	98.21%	0.09%	96.49%	0.88%
50	LightGBM	smote_enn	87.75%	1.27%	21.33%	1.60%	96.15%	2.78%	34.87%	2.12%	99.30%	0.08%	96.41%	0.73%
36	XGBoost	no resampler	90.61%	0.37%	25.66%	0.84%	93.20%	3.50%	40.23%	1.20%	97.88%	0.11%	96.39%	0.93%
38	XGBoost	oversampler	90.86%	0.57%	26.23%	0.92%	93.20%	3.50%	40.91%	1.07%	97.90%	0.12%	96.37%	0.96%
39	XGBoost	smote	90.02%	0.61%	24.36%	0.70%	92.02%	3.49%	38.50%	0.66%	97.69%	0.14%	96.22%	0.95%
40	XGBoost	smote_tomek	90.07%	0.66%	24.50%	0.76%	92.31%	3.59%	38.70%	0.69%	97.84%	0.14%	96.17%	0.98%

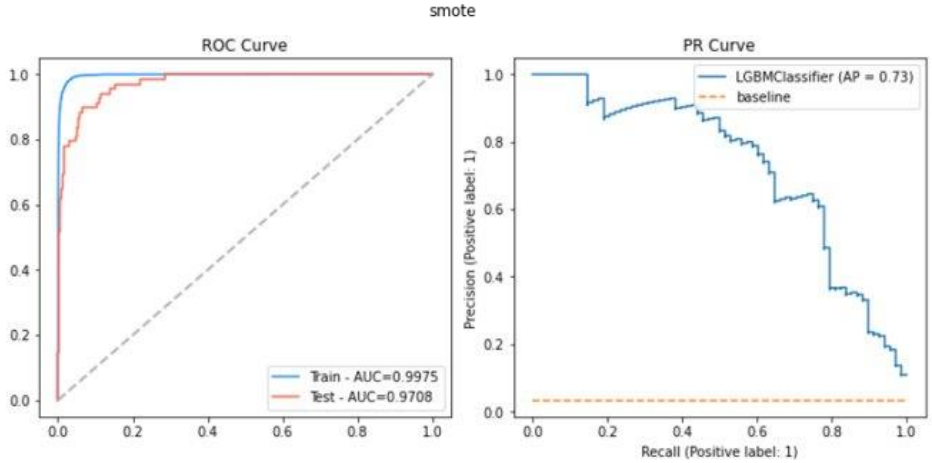
- LightGBM+SMOTE
  - Accuracy = 90.37 %
  - Precision = 25.31 %
  - Recall = 93.78 %
  - F1-Score = 38.83 %
  - AUC Test = 97.03 %

Hyper parameter tuning

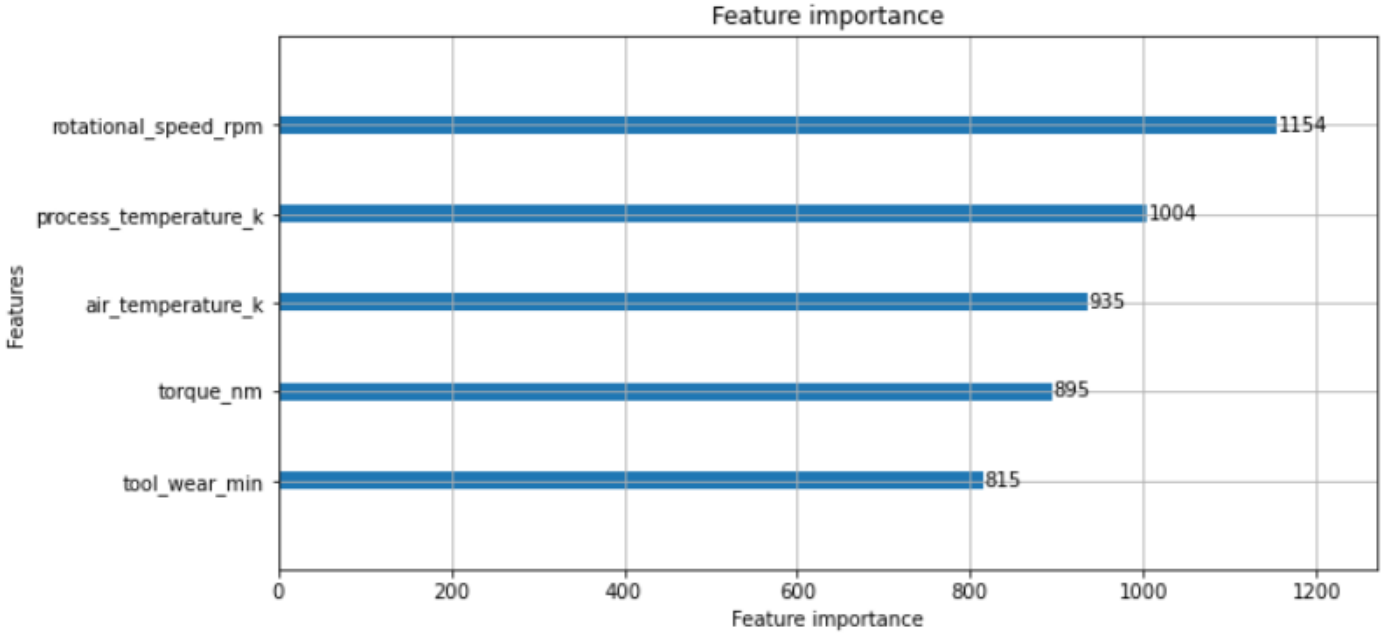
- Before Tuning



- Optuna



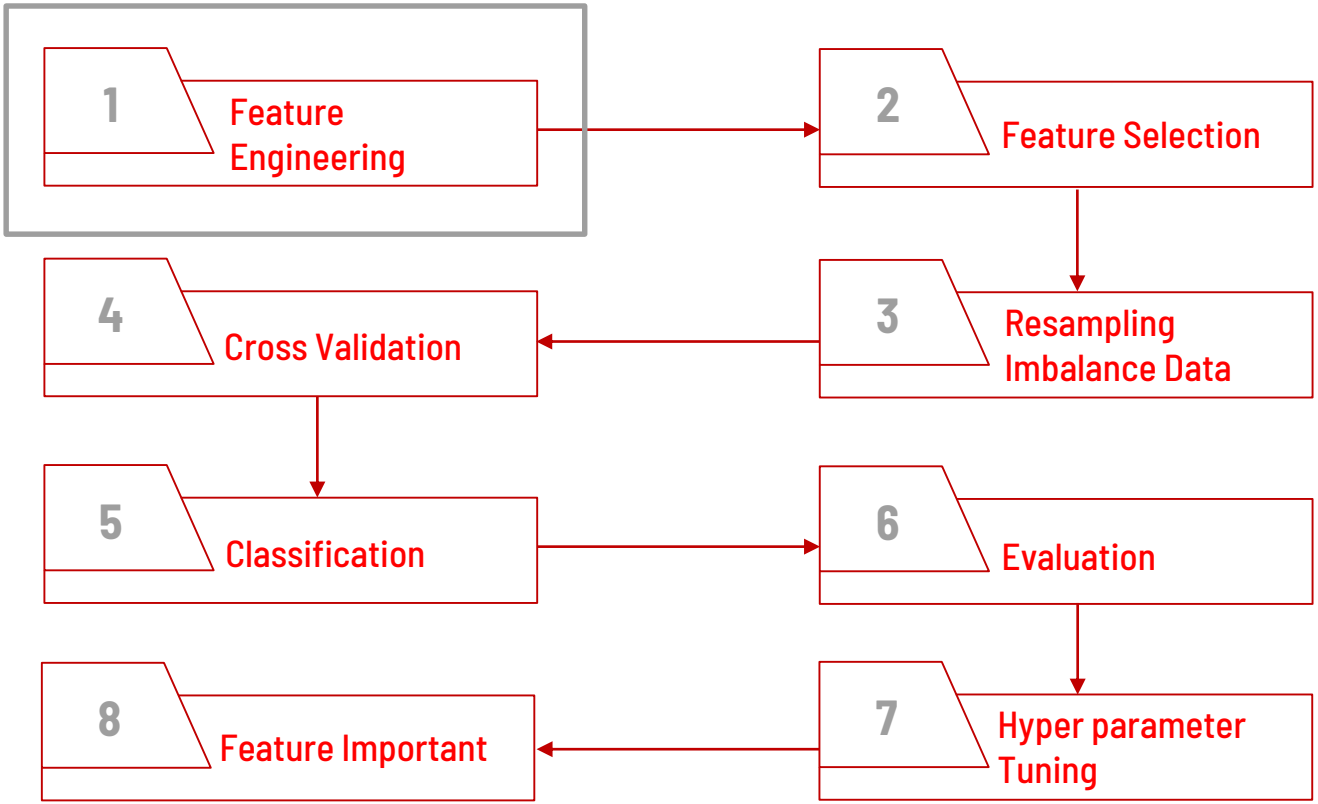
Feature Importance



02

Improve it!

Model Flow


1
Feature Engineering
2
Feature Selection
3
Resampling Imbalance Data
4
Cross Validation
5
Classification
6
Evaluation
7
Hyper parameter Tuning
8
Feature Important

2nd (Feature Engineering)

1. Air Temperature * Process Temperature
2. Air Temperature * Rotation Speed
3. Air Temperature * Torque
4. Air Temperature * Tool Wear
5. Process Temperature * Rotation Speed
6. Process Temperature * Torque
7. Process Temperature * Tool Wear
8. Rotation Speed * Torque
9. Rotation Speed * Tool Wear
10. Torque * Tool Wear

11. Air Temperature - Process Temperature
12. (Air Temperature - Process Temperature) * Rotation Speed
13. (Air Temperature - Process Temperature) * Torque
14. (Air Temperature - Process Temperature) * Tool Wear

2nd (Feature Engineering)

- Feature Selection

feature	RFE-XGB	RFE-LGB	Lasso	RandomForest	AdaBoost	ExtraTrees	GradientBoosting	XGBoost	LightGBM	Total
rotational_speed_rpm_X_torque_nm	True	True	True	True	True	True	True	True	True	9
diff_temperature_X_rotational_speed_rpm	True	True	True	True	True	True	True	False	True	8
diff_temperature	True	True	True	True	True	True	True	False	True	8
torque_nm_X_tool_wear_min	True	True	True	True	True	True	True	False	True	8
rotational_speed_rpm	True	True	True	True	True	True	True	False	True	8
air_temperature_k_X_torque_nm	True	True	True	True	True	True	False	False	True	7
process_temperature_k_X_rotational_speed_rpm	True	True	True	True	True	True	False	True	False	7
torque_nm	True	True	True	True	False	True	False	True	False	6
diff_temperature_X_torque_nm	True	True	True	False	True	True	False	False	True	6
air_temperature_k_X_rotational_speed_rpm	True	True	True	True	True	True	False	False	False	6
process_temperature_k_X_torque_nm	True	True	True	True	True	True	False	False	False	6
tool_wear_min	True	True	True	False	False	False	False	True	True	5
diff_temperature_X_tool_wear_min	True	True	True	False	True	False	False	False	True	5
rotational_speed_rpm_X_tool_wear_min	True	True	True	False	True	False	False	False	False	4
air_temperature_k_X_process_temperature_k	True	True	False	False	True	False	False	False	True	4
process_temperature_k	True	True	False	False	True	False	False	False	True	4
air_temperature_k	True	True	True	False	False	False	False	False	False	3
process_temperature_k_X_tool_wear_min	True	True	False	False	False	False	False	False	False	2
L	False	True	True	False	False	False	False	False	False	2
air_temperature_k_X_tool_wear_min	True	True	False	False	False	False	False	False	False	2
M	False	False	True	False	False	False	False	False	False	1
H	True	False	False	False	False	False	False	False	False	1

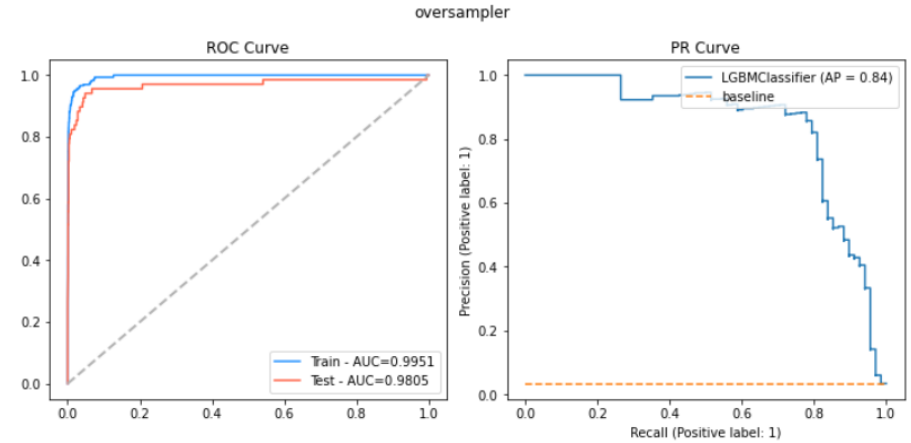
Evaluation

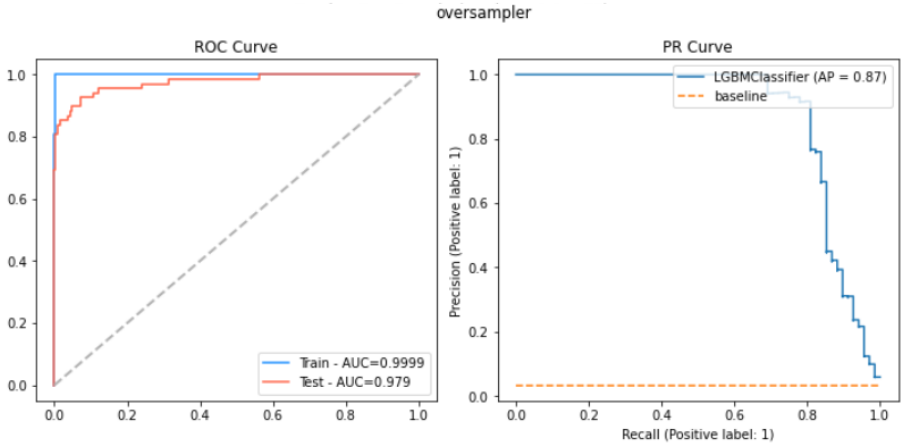
- Top 10 Model Performance

	model	resampler	accuracy_mean	accuracy_std	precision_mean	precision_std	recall_mean	recall_std	f1-score_mean	f1-score_std	auc_train_mean	auc_train_std	auc_test_mean	auc_test_std
47	LightGBM	oversampler	95.22%	0.52%	41.15%	2.67%	92.60%	3.81%	56.89%	2.44%	99.51%	0.03%	98.05%	0.94%
36	XGBoost	no resampler	94.53%	0.36%	37.59%	2.06%	92.61%	4.30%	53.46%	2.66%	98.66%	0.45%	98.00%	1.14%
38	XGBoost	oversampler	94.42%	0.45%	37.18%	2.21%	92.90%	4.26%	53.07%	2.64%	98.84%	0.27%	98.00%	1.07%
49	LightGBM	smote_tomek	93.81%	0.62%	34.72%	1.88%	92.31%	4.93%	50.36%	1.68%	99.12%	0.05%	97.99%	0.82%
39	XGBoost	smote	93.78%	0.70%	34.60%	2.37%	92.01%	4.49%	50.20%	2.49%	98.27%	0.52%	97.99%	1.03%
40	XGBoost	smote_tomek	93.70%	0.74%	34.35%	2.61%	92.31%	4.57%	49.98%	2.76%	98.37%	0.48%	97.96%	1.05%
48	LightGBM	smote	93.98%	0.71%	35.44%	2.51%	92.31%	4.75%	51.11%	2.42%	99.07%	0.04%	97.93%	1.06%
44	XGBoost	adasyn	92.45%	0.58%	30.28%	1.33%	93.50%	2.44%	45.71%	1.37%	98.05%	0.34%	97.90%	0.97%
53	LightGBM	adasyn	92.30%	0.75%	30.10%	1.77%	94.97%	2.76%	45.65%	1.85%	98.72%	0.04%	97.89%	0.83%
45	LightGBM	no resampler	96.79%	0.08%	76.67%	38.87%	5.59%	3.00%	10.39%	5.53%	99.27%	0.06%	97.69%	1.02%

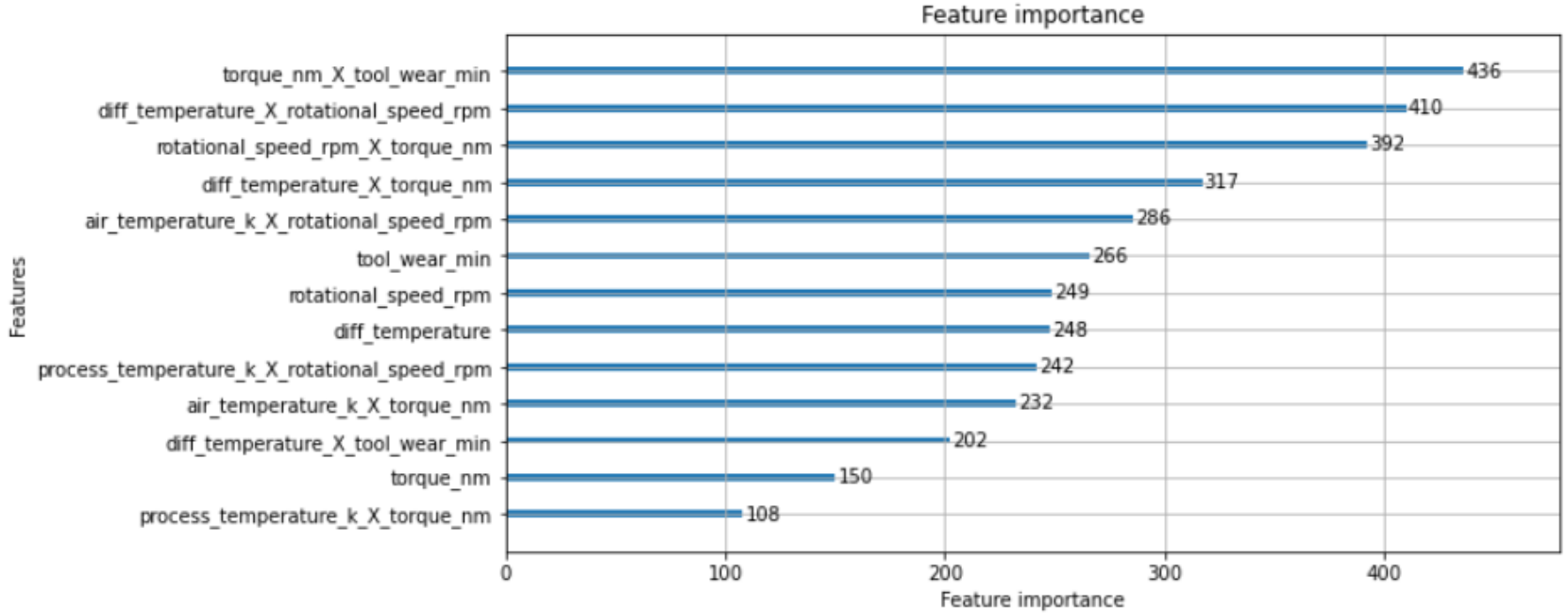
- LightGBM+Oversampler
  - Accuracy = 95.22 %
  - Precision = 41.15 %
  - Recall = 92.60 %
  - F1-Score = 56.89 %
  - AUC Test = 98.05 %

Hyper parameter tuning



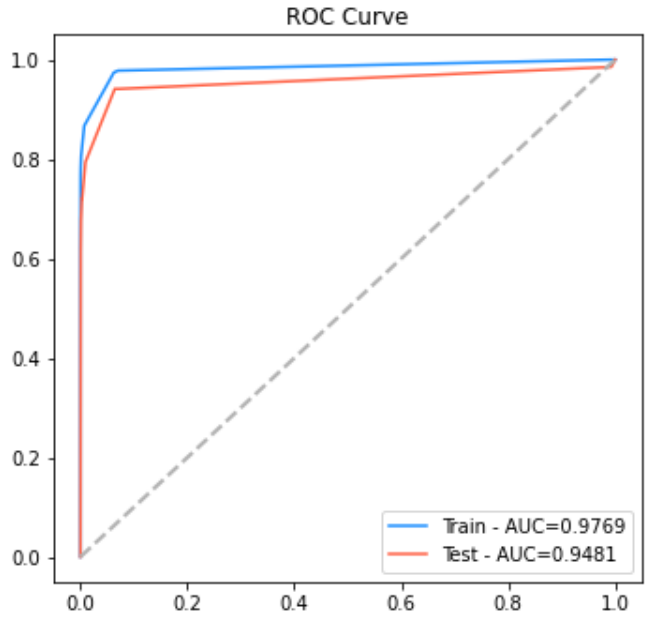


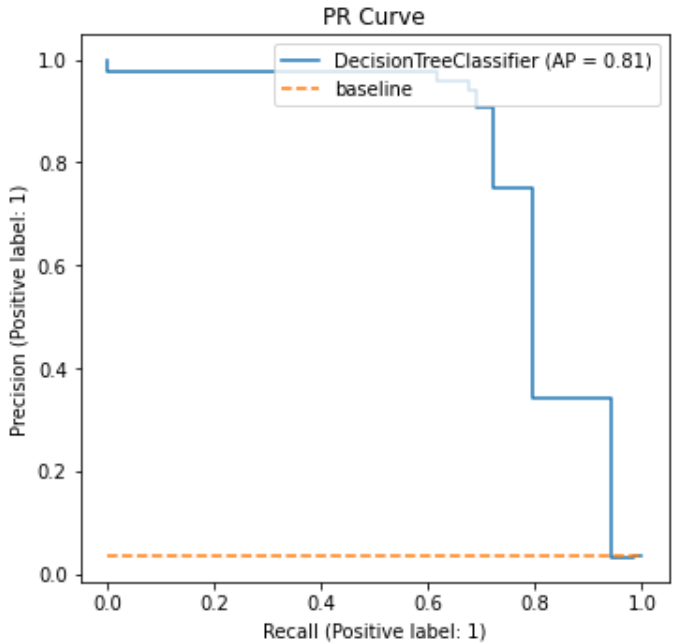
Feature Importance



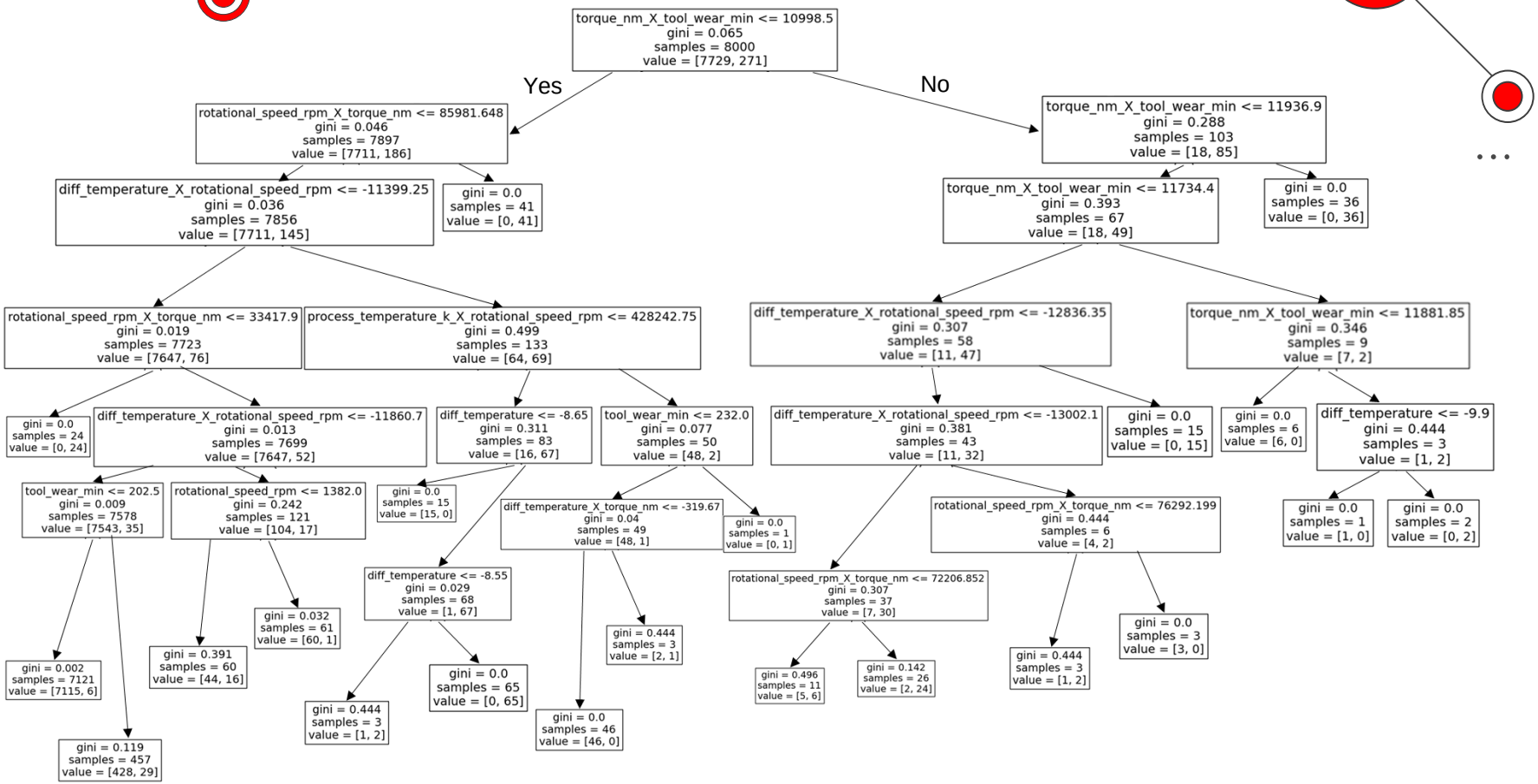
Interpret

- Interpret rule based by Decision Tree (max depth = 6)





Interpret


torque_nm_X_tool_wear_min <= 10998.5
gini = 0.065
samples = 8000
value = [7729, 271]
Yes
No
rotational_speed_rpm_X_torque_nm <= 85981.648
gini = 0.046
samples = 7897
value = [7711, 186]
torque_nm_X_tool_wear_min <= 11936.9
gini = 0.288
samples = 103
value = [18, 85]
diff_temperature_X_rotational_speed_rpm <= -11399.25
gini = 0.036
samples = 7856
value = [7711, 145]
gini = 0.0
samples = 41
value = [0, 41]
torque_nm_X_tool_wear_min <= 11734.4
gini = 0.393
samples = 67
value = [18, 49]
gini = 0.0
samples = 36
value = [0, 36]
rotational_speed_rpm_X_torque_nm <= 33417.9
gini = 0.019
samples = 7723
value = [7647, 76]
process_temperature_k_X_rotational_speed_rpm <= 428242.75
gini = 0.499
samples = 133
value = [64, 69]
diff_temperature_X_rotational_speed_rpm <= -12836.35
gini = 0.307
samples = 58
value = [11, 47]
torque_nm_X_tool_wear_min <= 11881.85
gini = 0.346
samples = 9
value = [7, 2]
gini = 0.0
samples = 24
value = [0, 24]
diff_temperature_X_rotational_speed_rpm <= -11860.7
gini = 0.013
samples = 7699
value = [7647, 52]
diff_temperature <= -8.65
gini = 0.311
samples = 83
value = [16, 67]
tool_wear_min <= 232.0
gini = 0.077
samples = 50
value = [48, 2]
diff_temperature_X_rotational_speed_rpm <= -13002.1
gini = 0.381
samples = 43
value = [11, 32]
gini = 0.0
samples = 15
value = [0, 15]
gini = 0.0
samples = 6
value = [6, 0]
diff_temperature <= -9.9
gini = 0.444
samples = 3
value = [1, 2]
tool_wear_min <= 202.5
gini = 0.009
samples = 7578
value = [7543, 35]
rotational_speed_rpm <= 1382.0
gini = 0.242
samples = 121
value = [104, 17]
gini = 0.0
samples = 15
value = [15, 0]
diff_temperature_X_torque_nm <= -319.67
gini = 0.04
samples = 49
value = [48, 1]
gini = 0.0
samples = 1
value = [0, 1]
rotational_speed_rpm_X_torque_nm <= 76292.199
gini = 0.444
samples = 6
value = [4, 2]
gini = 0.0
samples = 1
value = [0, 1]
gini = 0.0
samples = 2
value = [0, 2]
gini = 0.002
samples = 7121
value = [7115, 6]
gini = 0.119
samples = 457
value = [428, 29]
gini = 0.391
samples = 60
value = [44, 16]
gini = 0.032
samples = 61
value = [60, 1]
diff_temperature <= -8.55
gini = 0.029
samples = 68
value = [1, 67]
gini = 0.444
samples = 3
value = [2, 1]
rotational_speed_rpm_X_torque_nm <= 72206.852
gini = 0.307
samples = 37
value = [7, 30]
gini = 0.0
samples = 3
value = [3, 0]
gini = 0.444
samples = 3
value = [1, 2]
gini = 0.0
samples = 65
value = [0, 65]
gini = 0.0
samples = 46
value = [46, 0]
gini = 0.496
samples = 11
value = [5, 6]
gini = 0.142
samples = 26
value = [2, 24]
gini = 0.444
samples = 3
value = [1, 2]

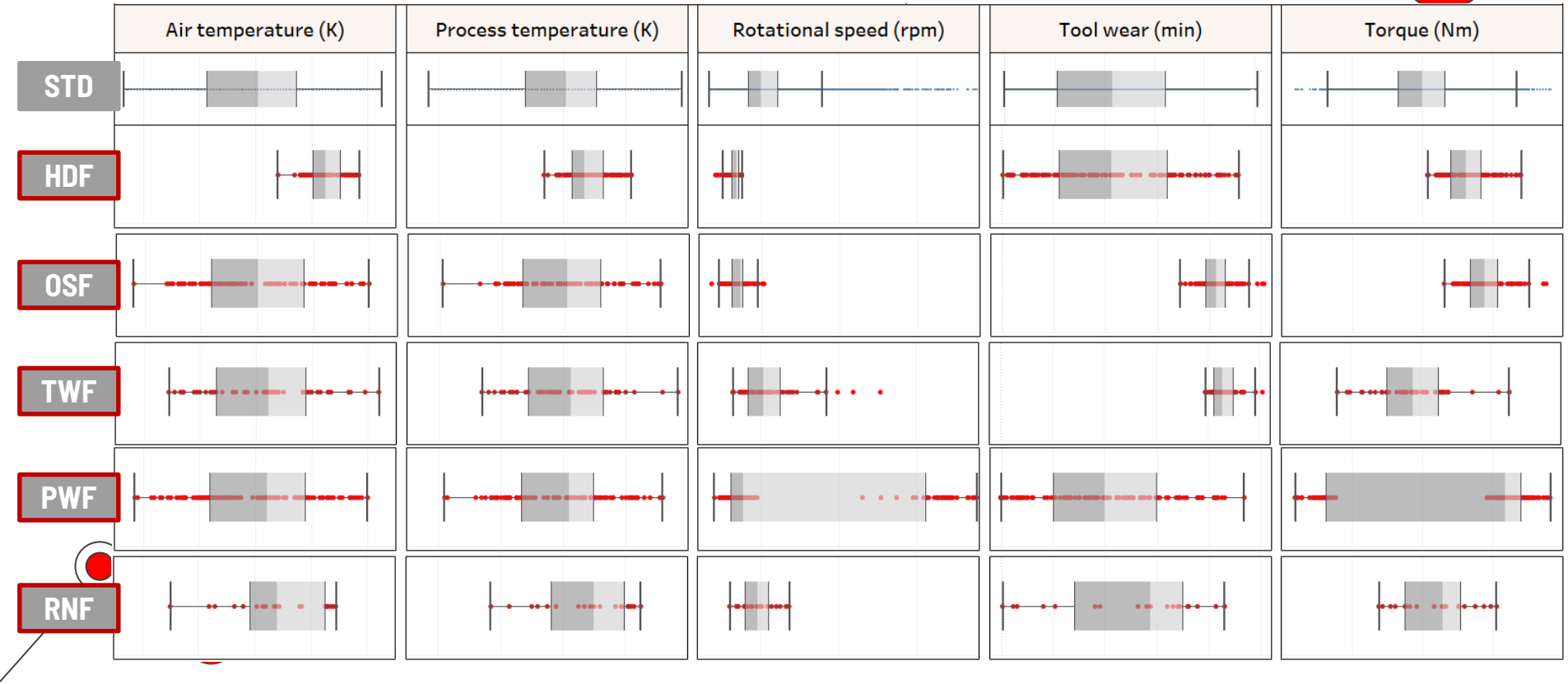
03

Let try! Each Failure

Failure Type

1. Heat dissipation failure (HDF)
2. Overstrain failure (OSF)
3. Tool wear failure (TWF)
4. Power failure (PWF)
5. Random failures (RNF)

Feature Analysis



Feature selection for each type

1 Heat dissipation failure (HDF)

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.033713981	0.229114847	-0.147148826	0.88301752	-0.482825221	0.415397259	-0.482825221	0.415397259
Air temperature [K]	0.020213357	0.001074071	18.81938923	1.14318E-77	0.018107962	0.022318752	0.018107962	0.022318752
Process temperature [K]	-0.019637918	0.001447781	-13.56414925	1.5219E-41	-0.02247586	-0.016799976	-0.02247586	-0.016799976
Rotational speed [rpm]	3.60839E-06	1.19361E-05	0.302308885	0.762422896	-1.97888E-05	2.70056E-05	-1.97888E-05	2.70056E-05
Torque [Nm]	0.001596808	0.00021463	7.439810916	1.09129E-13	0.001176089	0.002017526	0.001176089	0.002017526
Tool wear [min]	-4.01042E-06	1.62708E-05	-0.246479804	0.805315899	-3.59045E-05	2.78836E-05	-3.59045E-05	2.78836E-05

2 Overstrain failure (OSF)

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.488611819	0.210053304	-2.326132506	0.020031381	-0.900358596	-0.076865042	-0.900358596	-0.076865042
Air temperature [K]	-0.000664672	0.000984712	-0.67499139	0.49969685	-0.002594906	0.001265562	-0.002594906	0.001265562
Process temperature [K]	0.001007084	0.001327331	0.75872841	0.448032931	-0.001594752	0.003608919	-0.001594752	0.003608919
Rotational speed [rpm]	0.00013223	1.09431E-05	12.08340349	2.20781E-33	0.000110779	0.00015368	0.000110779	0.00015368
Torque [Nm]	0.003898941	0.000196774	19.81433931	9.78208E-86	0.003513225	0.004284657	0.003513225	0.004284657
Tool wear [min]	0.000243045	1.49171E-05	16.29303095	6.33524E-59	0.000213805	0.000272286	0.000213805	0.000272286

Feature selection for each type

3 Tool wear failure (TWF)

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.044352859	0.14873082	-0.298208931	0.765549905	-0.335895218	0.2471895	-0.335895218	0.2471895
Air temperature [K]	0.000485104	0.000697237	0.695752184	0.486600217	-0.000881621	0.00185183	-0.000881621	0.00185183
Process temperature [K]	-0.000316485	0.000939833	-0.336746457	0.73631511	-0.002158747	0.001525776	-0.002158747	0.001525776
Rotational speed [rpm]	-3.63548E-06	7.74838E-06	-0.469192284	0.638942435	-1.88239E-05	1.15529E-05	-1.88239E-05	1.15529E-05
Torque [Nm]	-0.00015363	0.000139328	-1.102646854	0.270207106	-0.000426741	0.000119481	-0.000426741	0.000119481
Tool wear [min]	0.000122914	1.05623E-05	11.63713247	4.23265E-31	0.00010221	0.000143618	0.00010221	0.000143618

4 Power failure (PWF)

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.805802292	0.195396051	-4.123943584	3.75454E-05	-1.188817901	-0.422786682	-1.188817901	-0.422786682
Air temperature [K]	0.000578074	0.000916	0.631085406	0.527999115	-0.00121747	0.002373619	-0.00121747	0.002373619
Process temperature [K]	-0.001201054	0.001234711	-0.972740864	0.330705653	-0.003621337	0.001219229	-0.003621337	0.001219229
Rotational speed [rpm]	0.000453309	1.01795E-05	44.53167914	0	0.000433355	0.000473263	0.000433355	0.000473263
Torque [Nm]	0.007947764	0.000183043	43.42018553	0	0.007588963	0.008306566	0.007588963	0.008306566
Tool wear [min]	-1.05349E-05	1.38762E-05	-0.759207288	0.447746473	-3.77351E-05	1.66653E-05	-3.77351E-05	1.66653E-05

Feature selection for each type

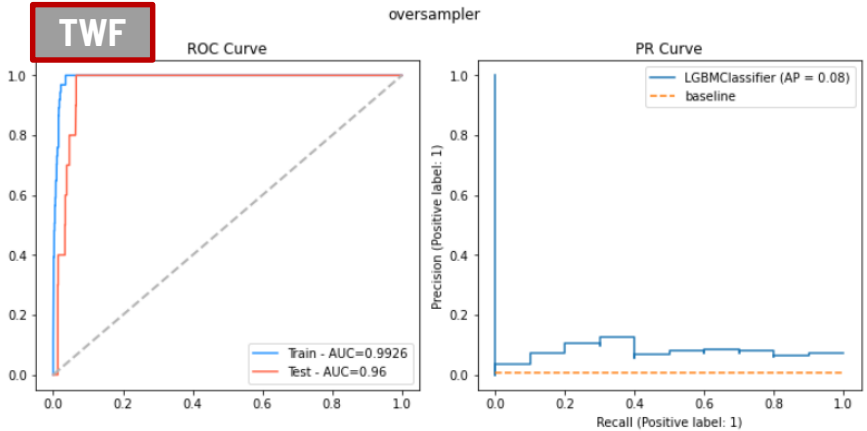
5

Random failures (RNF)

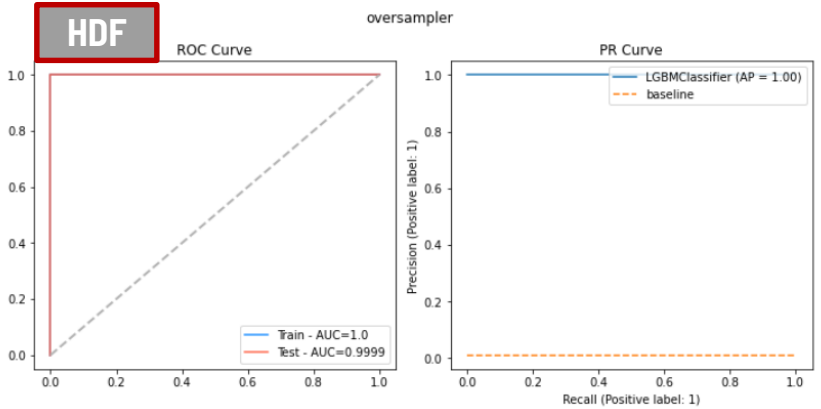
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.218566382	0.096335836	-2.268796245	0.023301949	-0.407404021	-0.029728744	-0.407404021	-0.029728744
Air temperature [K]	-0.00017307	0.000451614	-0.383225573	0.701560669	-0.001058325	0.000712185	-0.001058325	0.000712185
Process temperature [K]	0.000859914	0.000608748	1.41259513	0.157805941	-0.000333354	0.002053183	-0.000333354	0.002053183
Rotational speed [rpm]	9.74372E-07	5.01877E-06	0.194145502	0.8460659	-8.86343E-06	1.08122E-05	-8.86343E-06	1.08122E-05
Torque [Nm]	8.72976E-05	9.02455E-05	0.967334606	0.333400197	-8.96017E-05	0.000264197	-8.96017E-05	0.000264197
Tool wear [min]	7.59528E-06	6.84138E-06	1.110198242	0.266940321	-5.81519E-06	2.10058E-05	-5.81519E-06	2.10058E-05

Result

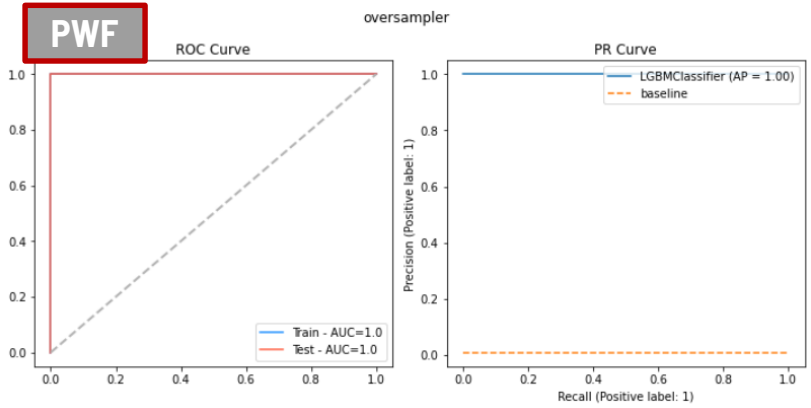
TWF



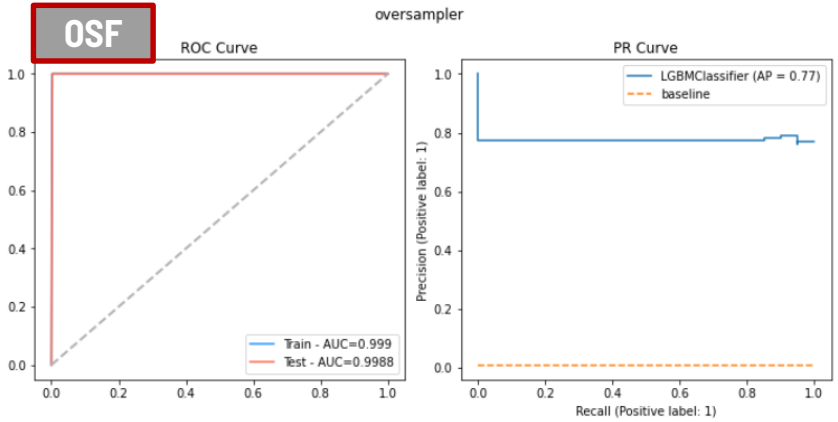
HDF



PWF



OSF



Summary

	Model	AUC	PR-Curve
All 1st	LightGBM+Smote+Optuna	0.9708	0.7300
All 2nd	Feature En+ LightGBM+Oversampler	0.9805	0.8400
All 2nd	Feature En+ LightGBM+Oversampler+Optuna	0.9790	0.8700
HDF	Feature En+ LightGBM+Oversampler	0.9999	1.0000
OSF	Feature En+ LightGBM+Oversampler	0.9988	0.7700
TWF	Feature En+ LightGBM+Oversampler	0.9600	0.0800
PWF	Feature En+ LightGBM+Oversampler	1.0000	1.0000

Our Team

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Thanks!