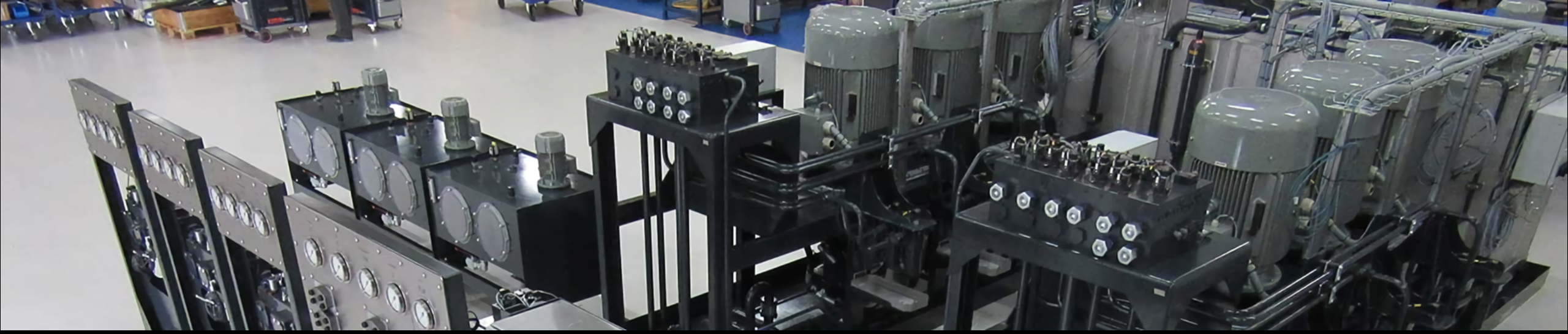
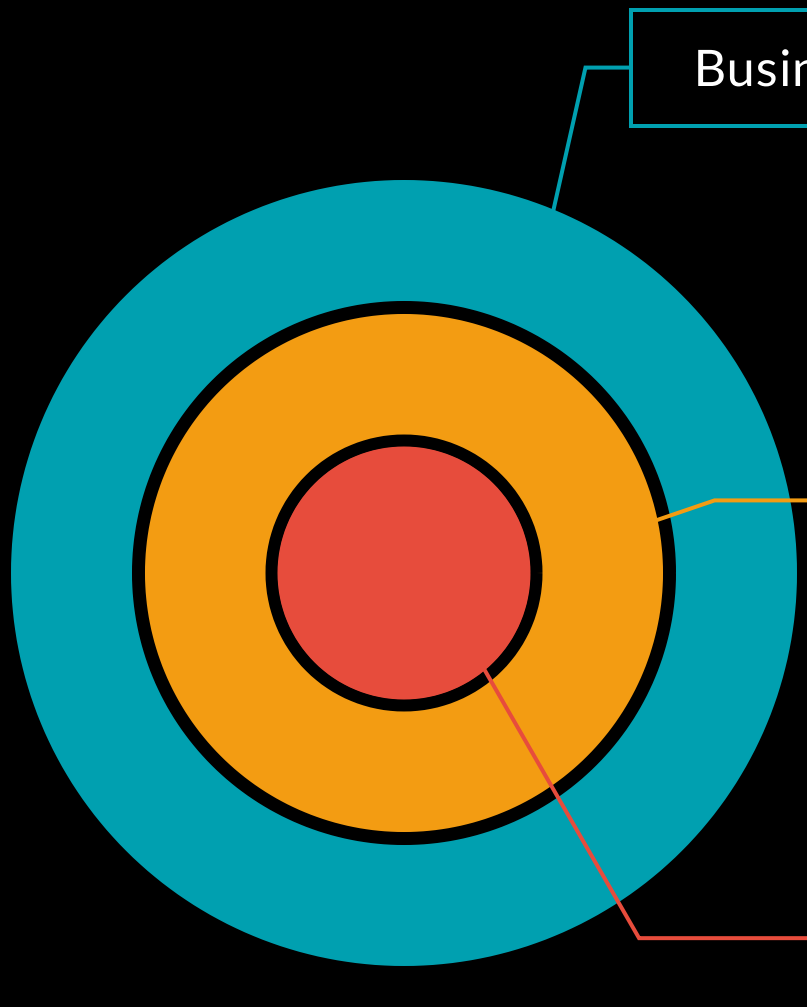


Hydraulic Systems Monitoring

Predicting system stability and process degradation

Stephen Duckers

Quick Look



1. Predict the stability of the hydraulic system
2. Determine what processes led to degradation

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1. Develop a randomforestclassifier for each degradation state.
2. Combine these predictions with the sensor data to predict the stability of the hydraulic system

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Valve condition, Efficiency Sensor, Pump Leakage are the most predictive features for determining system stability.

Business Insights & Actions

OKR:

EnergyMobil needs to focus on monitoring valve condition and Internal pump leakage because once these processes drop below optimal values the system is more likely to be unstable

Valve Condition

The valve_condition is the most significant factor affecting the stability of the hydraulic system. When the valve_condition is operating at 100%, the system is most stable. EnergyMobil should therefore focus on maintaining optimal valve conditions.

Regular inspections and maintenance of the valves could prevent potential system instabilities.

System Efficiency Sensor

The system efficiency sensor (SE) is the second greatest indicator of system stability. EnergyMobil should leverage this sensor's data to predict potential system failures or instabilities. An alert system could be put in place to notify the team when the sensor's readings drop below a certain threshold, indicating a potential decrease in stability.

Internal Pump Leakage

Internal_pump_leakage significantly affects the system stability. The system's stability begins to decrease when leakage starts to occur. Hence, it's crucial to monitor and mitigate any internal pump leakages promptly to ensure system stability.

Cooler Condition

The cooler_condition is not a significant factor in determining the system's stability. This can help EnergyMobil to prioritize its maintenance tasks and focus more on the valve condition and internal pump leakages.

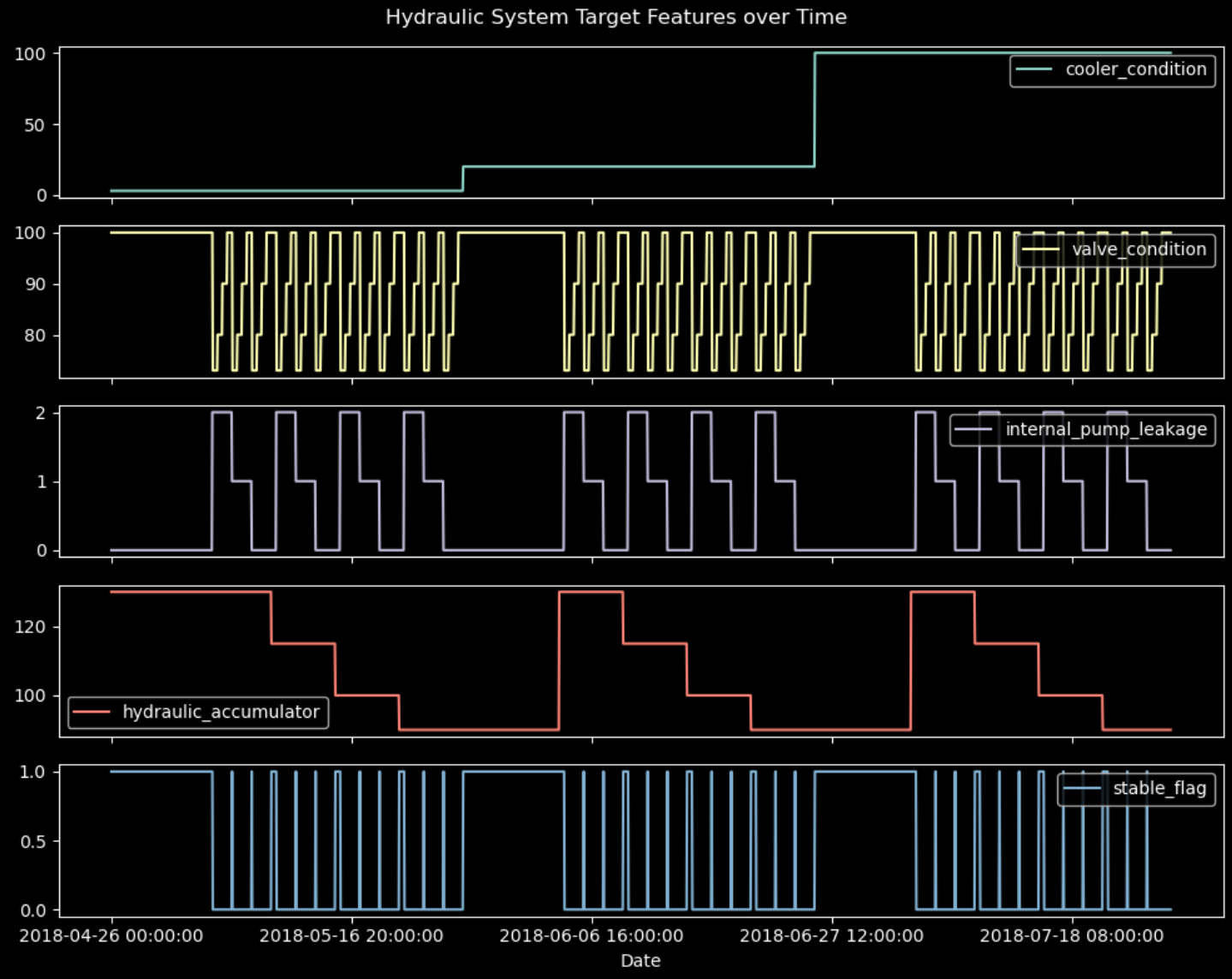
The Data

- Original Dataset
  - 17 columns corresponding sensor data
  - 4 degradation condition columns and 1 stable flag column
  - 2205 rows by 23 columns
- Multi-class Classification for Degradation Conditions
  - SMOTE for unbalanced classes
  - quantileTransformer
    - a non-linear transformation based on the ranks of the data, preserving the order of values and outliers
- Binary Classification for Stable Flag
  - Onehotencoder for degradations conditions
- Feature Importance
  - randomforestclassifier for each of the 5 targets
  - Spearman Rank Test
    - does not assume linear relationship or normally distributed data
  - Chi2 test for categorical columns
- Recall_weighted Metric
  - Prioritizes False Negatives
  - Using "weighted" averaging effectively gives higher importance to the minority classes

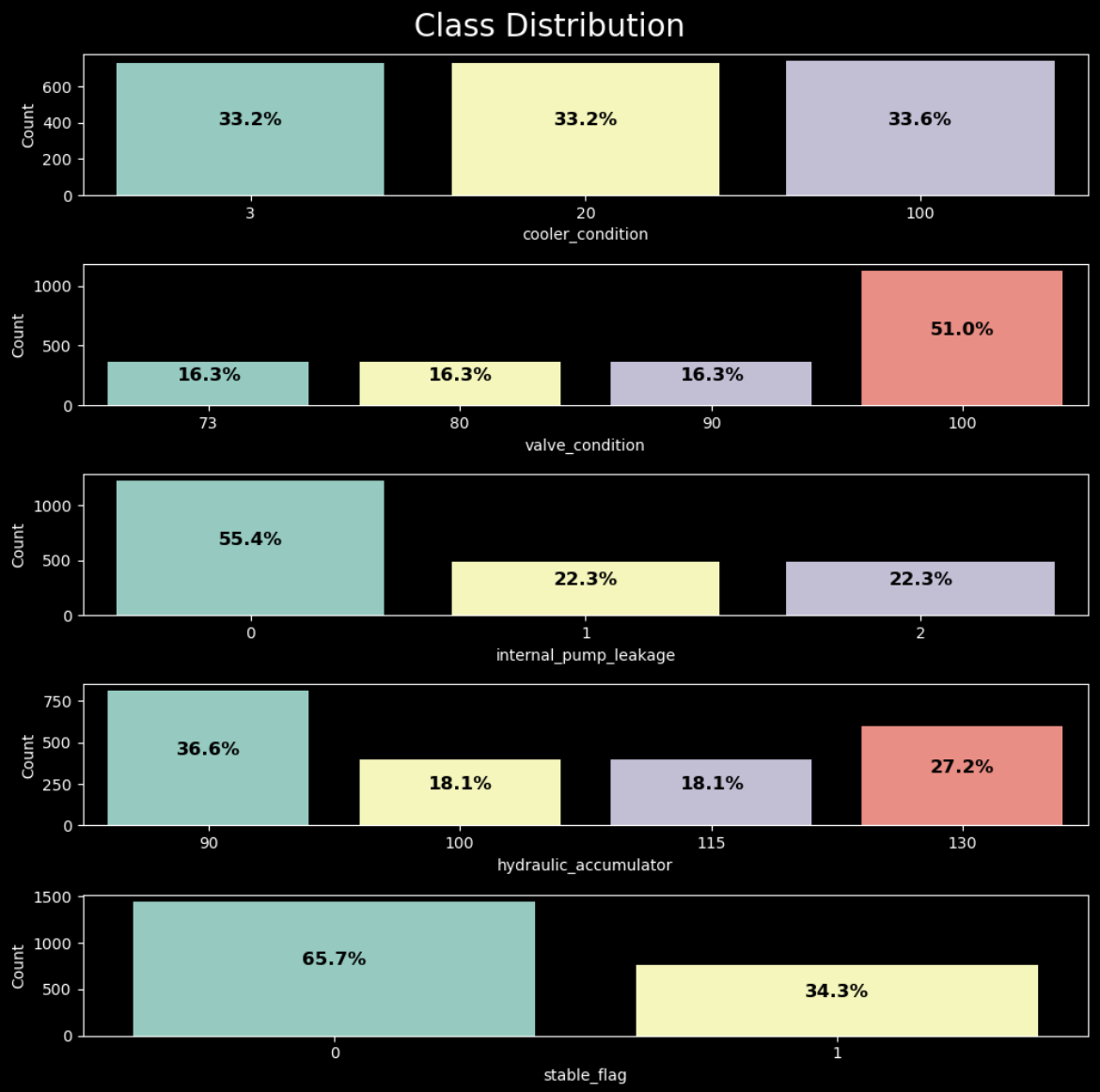
CE	CP	EPS1	FS1	FS2	PS1	PS2	PS3	PS4	PS5	PS6	SE	TS1	TS2	TS3	TS4	VS1	Date	cooler_condition	valve_condition	internal_pump_leakage	hydraulic_accumulator	stable_flag
47.202000	2.184000	2411.600000	8.990000	10.179000	151.470000	125.500000	2.305000	0.000000	9.936000	9.818000	68.039000	35.570000	40.961000	38.320000	30.363000	0.604000	2018-04-26 00:00:00	3	100	0	130	1
29.208000	1.414000	2409.600000	8.919000	10.408000	151.110000	125.060000	2.281000	0.000000	9.700000	9.592000	68.264000	36.156000	41.258000	38.680000	33.648000	0.590000	2018-04-26 01:00:00	3	100	0	130	1
23.554000	1.159000	2397.800000	9.179000	10.392000	150.810000	125.130000	2.227000	0.000000	9.606000	9.505000	68.595000	37.488000	42.129000	39.234000	35.113000	0.578000	2018-04-26 02:00:00	3	100	0	130	1
21.540000	1.101000	2383.800000	9.034000	10.329000	150.480000	124.930000	2.320000	0.000000	9.528000	9.422000	68.628000	38.633000	43.039000	40.086000	36.133000	0.565000	2018-04-26 03:00:00	3	100	0	130	1
20.460000	1.086000	2372.000000	8.729000	10.276000	150.410000	124.720000	2.250000	0.000000	9.408000	9.315000	68.868000	39.461000	44.031000	40.934000	36.992000	0.570000	2018-04-26 04:00:00	3	100	0	130	1

UCI Condition monitoring of hydraulic systems Data Set

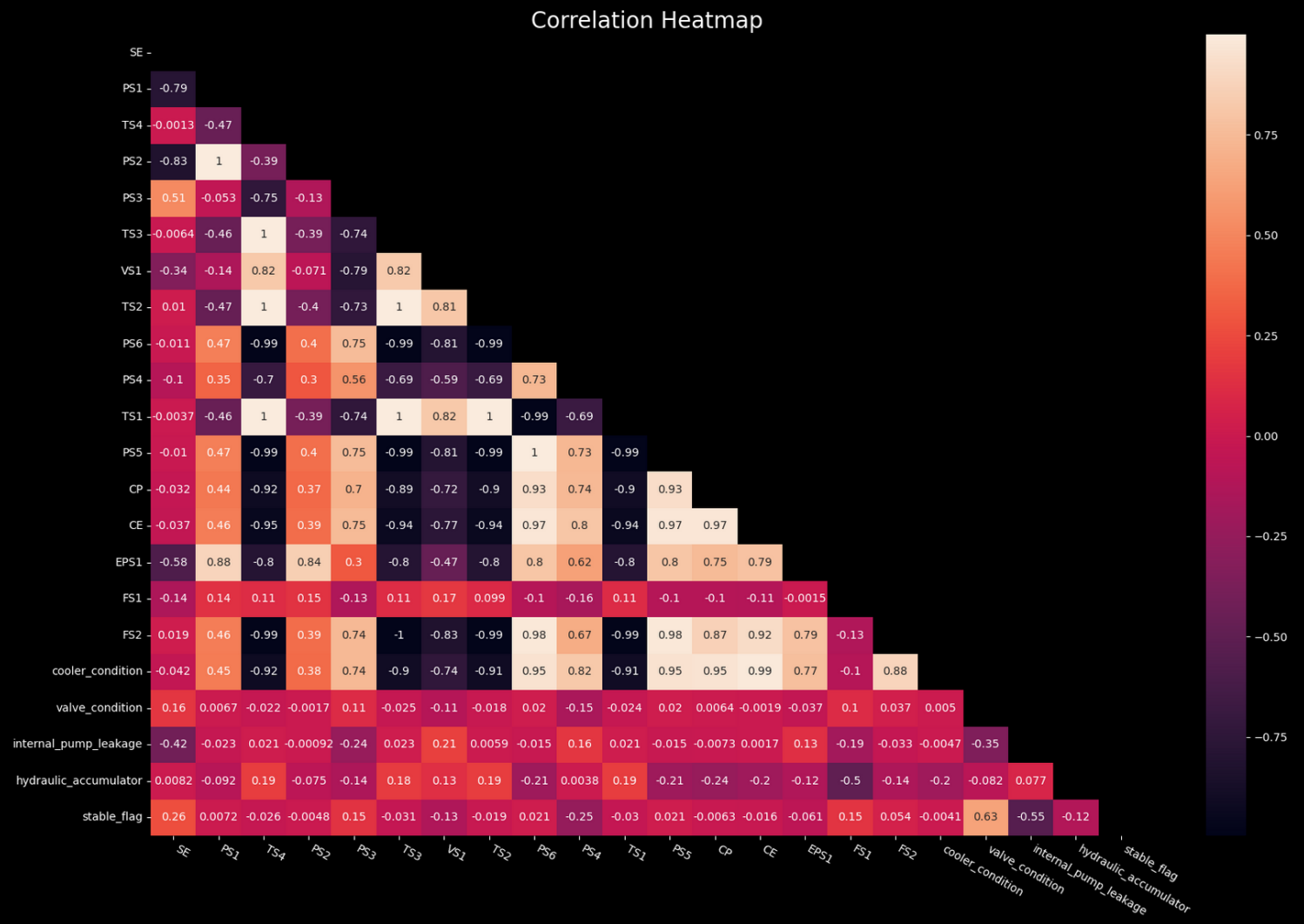
Behavior of Targets over Time



Class Distribution for each Target



Correlation between Features and Targets



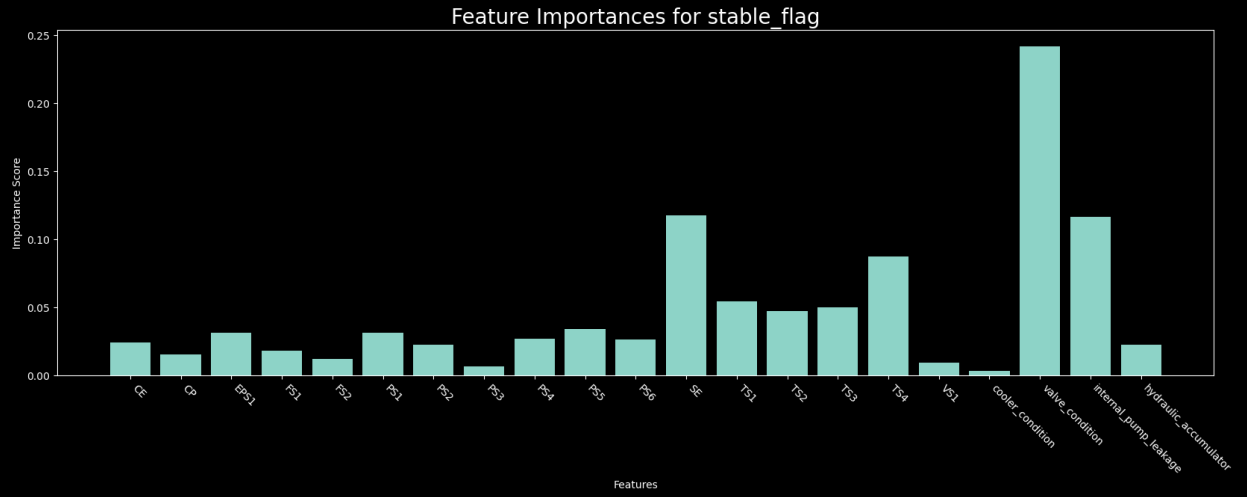
Spearman Rank Test and Chi-Squared Test

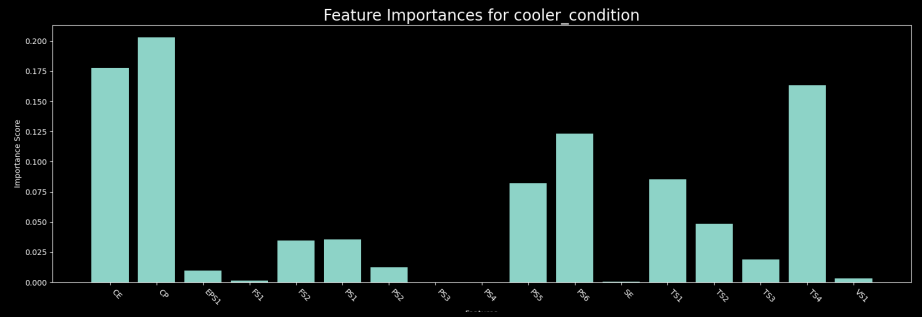
Feature	Spearman rho	p-value
FS2	0.014100	0.507200
CP	-0.024800	0.244800
TS2	-0.048700	0.022300
PS5	0.054100	0.011100
PS6	0.054100	0.011100
TS3	-0.054900	0.010000
TS4	-0.056500	0.008000
TS1	-0.056900	0.007500
PS2	0.061900	0.003700
VS1	-0.067700	0.001500
EPS1	-0.073300	0.000600
PS1	0.076500	0.000300
CE	-0.080500	0.000200
SE	0.504500	0.000000
FS1	0.165600	0.000000
PS3	0.148800	0.000000
PS4	-0.134800	0.000000

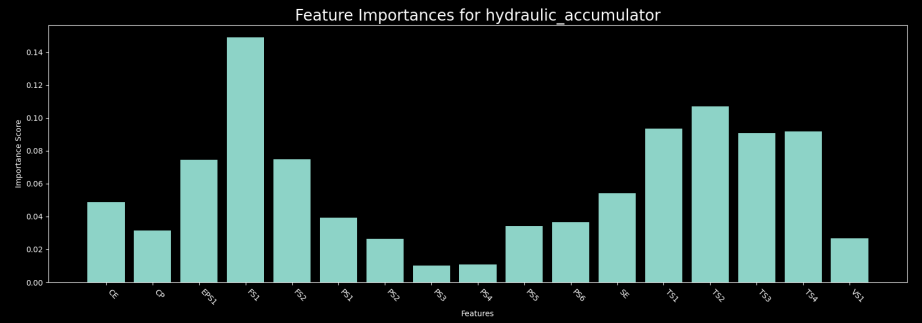
Feature	Chi-square score	p-value
cooler_condition	1.617700	0.203400
valve_condition	1098.554400	0.000000
internal_pump_leakage	664.418900	0.000000
hydraulic_accumulator	81.069400	0.000000

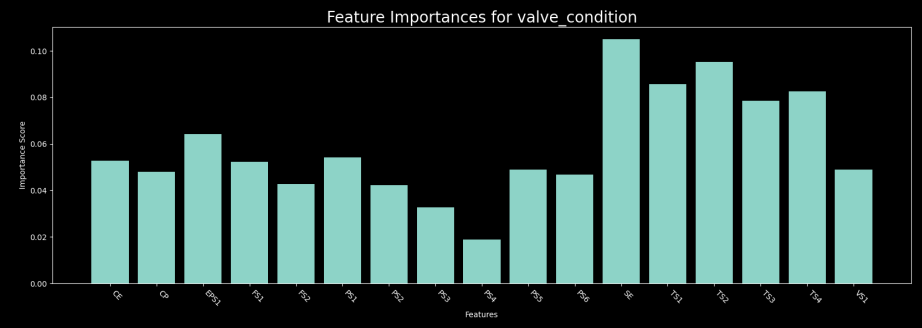
- **Strong Predictors:**
  - Based on both Spearman's rank and Chi-squared tests, 'SE' and 'FS1' from the Spearman's test, and 'valve_condition', 'internal_pump_leakage', and 'hydraulic_accumulator' from the Chi-squared test showed significant correlation or association with the target variable 'stable_flag', indicating their strong predictive power.
- **Weak Predictors:**
  - On the other hand, 'FS2' and 'CP' from the Spearman's test, and 'cooler_condition' from the Chi-squared test showed weak or no significant correlation or association with the target variable 'stable_flag', suggesting they might not be useful for prediction.
- **Significance Level:**
  - The p-values in the test results indicate the statistical significance of the results. A p-value below 0.05 (5% significance level) indicates a statistically significant result, whereas a p-value above 0.05 suggests the result could have occurred by chance.

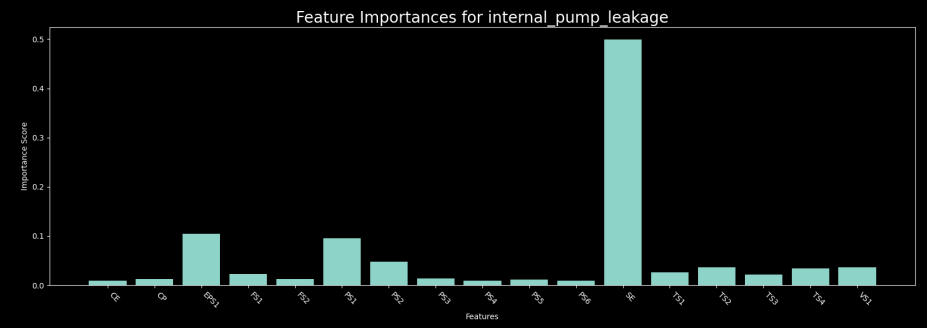
Feature Importance for Each Target











Validation Scores for Degradation States and Stable Flag

Cooler Condition Classification Report

	precision	recall	f1-score	support
3	1.000000	0.992593	0.996283	135.000000
20	0.977612	1.000000	0.988679	131.000000
100	0.994220	0.982857	0.988506	175.000000
weighted avg	0.991056	0.990930	0.990938	441.000000

Valve Condition Classification Report

	precision	recall	f1-score	support
73	0.535714	0.671642	0.596026	67.000000
80	0.365079	0.370968	0.368000	62.000000
90	0.390000	0.565217	0.461538	69.000000
100	0.953608	0.761317	0.846682	243.000000
weighted avg	0.719194	0.662132	0.681042	441.000000

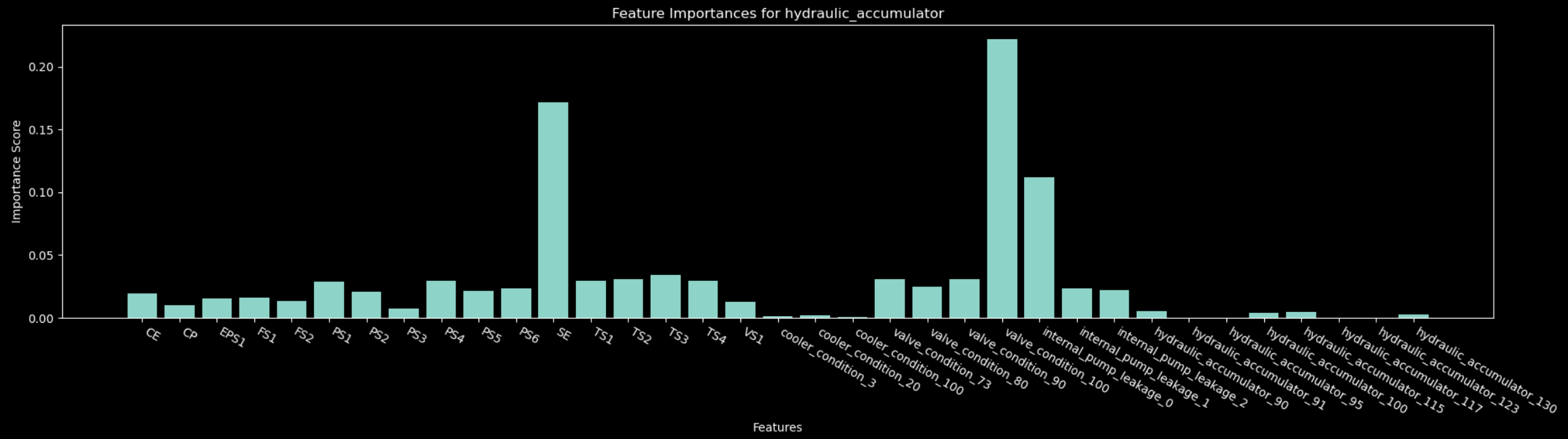
Internal Pump Leakage Classification Report

	precision	recall	f1-score	support
0	0.983122	0.978992	0.981053	238.000000
1	0.951456	0.951456	0.951456	103.000000
2	0.960396	0.970000	0.965174	100.000000
weighted avg	0.970573	0.970522	0.970540	441.000000

Hydraulic Accumulator Classification Report

	precision	recall	f1-score	support
90	0.974194	0.949686	0.961783	159.000000
100	0.783784	0.878788	0.828571	66.000000
115	0.858974	0.848101	0.853503	79.000000
130	1.000000	0.978102	0.988930	137.000000
weighted avg	0.933074	0.929705	0.930883	441.000000

Stable Flag - Validation/Test Scores & Feature Importance



Validation Set Classification Report

	precision	recall	f1-score	support
0	0.981884	0.978339	0.980108	277.000000
1	0.963636	0.969512	0.966565	164.000000
weighted avg	0.975098	0.975057	0.975072	441.000000

Test Set Classification Report

	precision	recall	f1-score	support
0	0.980000	0.970297	0.975124	303.000000
1	0.936170	0.956522	0.946237	138.000000
weighted avg	0.966285	0.965986	0.966085	441.000000