# Equipment Maintenance Monitoring and Analysis

A Comprehensive System for Performance Analysis, and Maintenance Planning

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# Introduction

Predictive maintenance applies machine learning and sensor data to predict failures before they happen in order to improve productivity, efficiency, and cost-effectiveness. Differing from traditional methods of maintenance, PdM studies real-time data such as temperature or vibration and, having detected anomalies or foreseeing problems, precludes downtime of up to 30-50%. This sort of technology lets conduct condition-based maintenance, as schedules are optimized and the need for unnecessary interventions is prevented. The main work is done in anomaly detection, real-time reporting, and dashboard development by machine learning, but obstacles like data quality and equipment variability exist. It aims to provide its benefits to maintenance teams so that these teams can enhance their operational efficiency according to the trend of Industry 4.0.

# Objectives

- **Build and Test Machine Learning Models:** Construct many predictive models and compare them by evaluating the most accurate and efficient model for equipment failure prediction and RUL estimation.
- **Causal Analysis:** Apply causal analysis on the root causes of equipment failures to understand the dominant factors that can be leveraged for targeted maintenance and process improvement.
- **Develop an Interactive Dashboard:** Create an interactive dashboard that presents equipment health, remaining useful life, and recommended maintenance actions in real time to anticipate better decisions by the maintenance teams.
- **Support Data-Driven Maintenance:** Ideally, enable a shift to proactive, data-driven maintenance practices that can reduce downtime while also extending equipment lifespans and equate to the yardstick of achieving Industry 4.0 goals.

# Features:

Real Time Alerts:

01 **Immediate alerts** are triggered for equipment needing maintenance based on real-time data.

02 **Visual Suggestion:** An alert box example displaying "⚠️ 3 equipment units require immediate attention!"

03

## Interactive Equipment Explorer

Users can select key metrics such as Temperature Difference, Tool Wear, Power, Torque, and Rotational Speed. Adjustable time window slider for viewing recent observations.

04

## Performance Analysis

Classification report for failure prediction accuracy.
Precision-Recall curve showing model trade-offs.
Highlights which features are most impactful in predictions.

05

## Correlation Analysis

Calculates correlation between features for insights on interdependencies.
Heatmap visually represents these relationships.

06

## Maintenance Planning

Predicts next maintenance dates based on tool wear and failure risk.Prioritizes high-risk equipment for maintenance to reduce downtime. Estimated maintenance costs for budget planning.

07

## Maintenance Cost Projection

Users enter the estimated cost per maintenance task.
Total projected cost calculated by multiplying task count by unit cost. Comparison to budget to gauge any cost overruns or savings.

08

## Historical Performance Analysis

Historical Trends: Users can review past performance of key metrics to identify patterns.
Failure Patterns: Analysis of common causes for equipment failure.
Visual Suggestions: Line chart with trend lines for historical data and failure pattern metrics for each major cause.

09

## Recommendations and Best Practices

Adjust alert thresholds to align with equipment health metrics. Regular model retraining improves prediction accuracy. Contact the maintenance team for immediate issues flagged by the system.

10

## Generate and Download Maintenance Report

Create a report with maintenance data: failure risk, tool wear, maintenance priority, and next maintenance date.
Export as CSV for offline analysis and documentation.

# Methodology

## Problem Definition & Objectives

- Address equipment breakdowns in manufacturing by forecasting failures, optimizing maintenance schedules, and enabling real-time monitoring.

## Data Collection & Preprocessing

- Used a Kaggle dataset with equipment metrics. Cleaned data, handled missing values, and created features (e.g., temperature difference, rolling means) to improve model accuracy.

## Model Selection & Training

- **Random Forest Classifier:** Predicts failure risk.
- **Gradient Boosting Regressor:** Forecasts tool wear.
- Evaluated with precision-recall, RMSE, and feature importance to ensure reliability.

# Methodology

**Dashboard Development**

- Built using Streamlit with Plotly for visuals. Includes:
  - **Real-Time Monitoring:** Live metric tracking.
  - **Performance Analysis:** Model metrics and correlation heatmaps.
  - **Maintenance Planning:** Timeline for risk-based maintenance actions.

**Deployment & Usage**

- Hosted on Hugging Face Spaces with pre-trained models cached for faster load times.
- Users can adjust model settings, thresholds, and view scheduled maintenance predictions. Future enhancements include IoT data integration and real-time alerts.

  **Technology Stack**

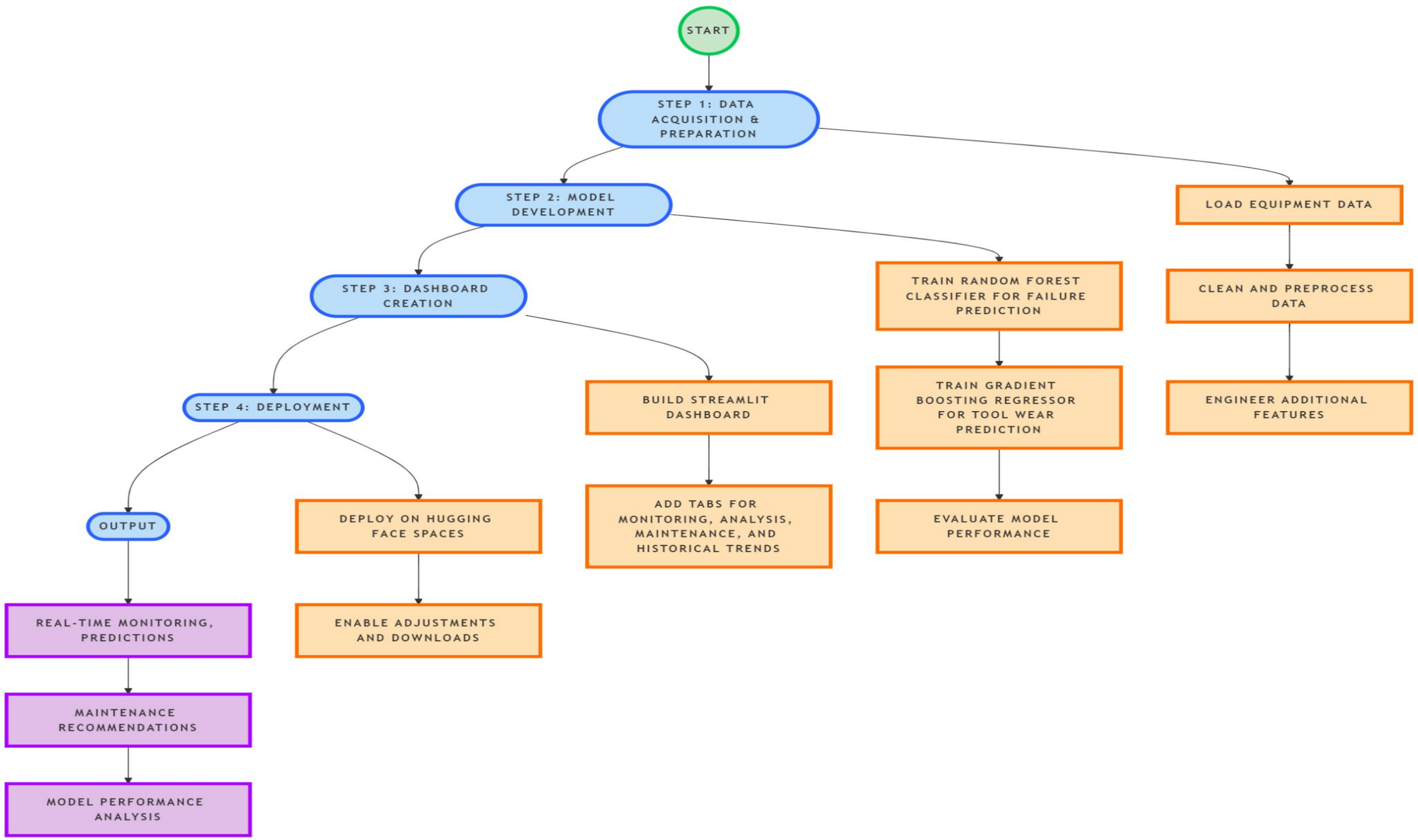
  Frontend: Streamlit for interactive dashboard UI

  Data Processing & Modeling: Scikit-learn for machine learning, Pandas for data manipulation, and NumPy for numerical operations

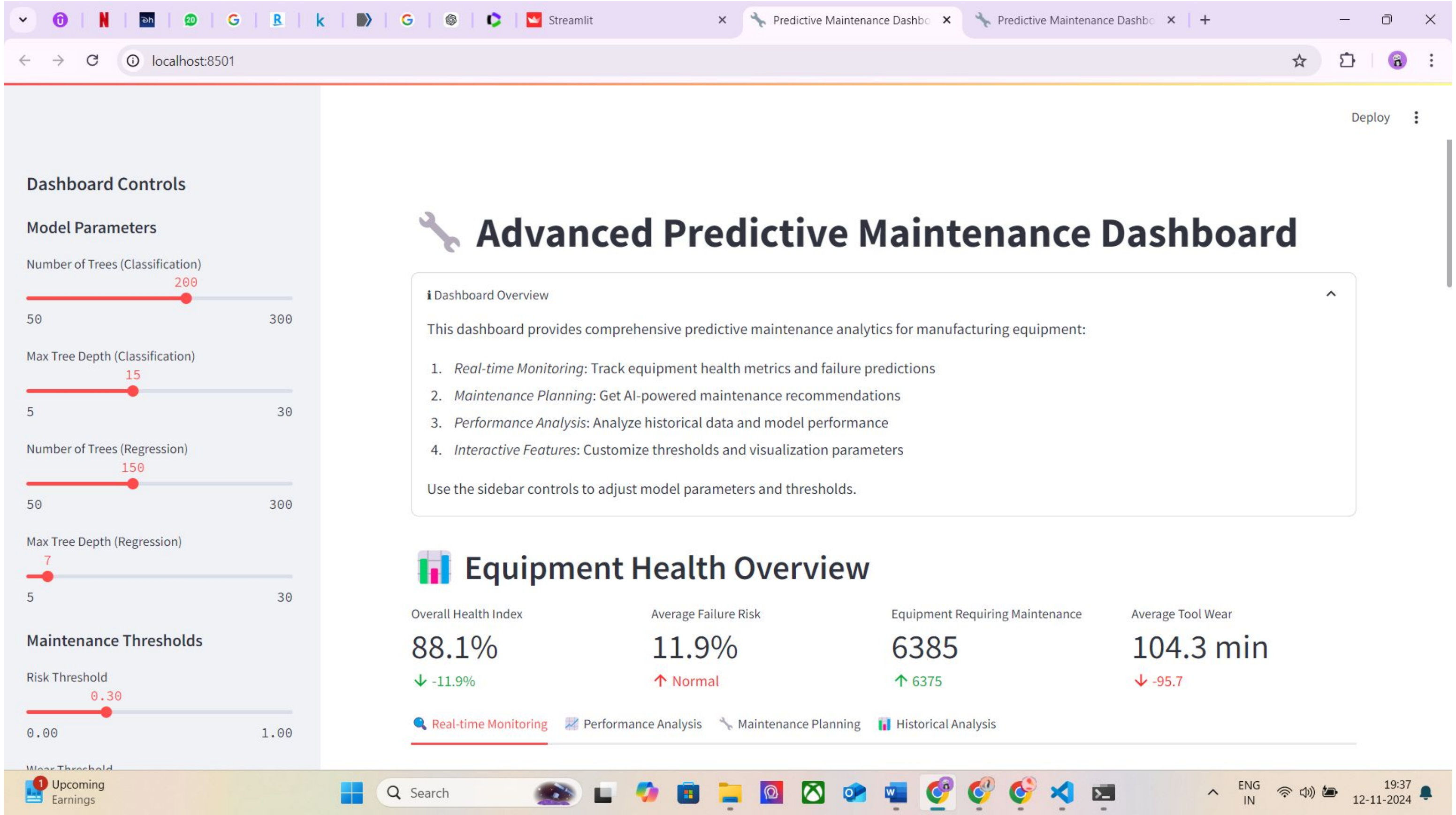
  Visualization: Plotly for interactive data visualizations and Seaborn for static plots

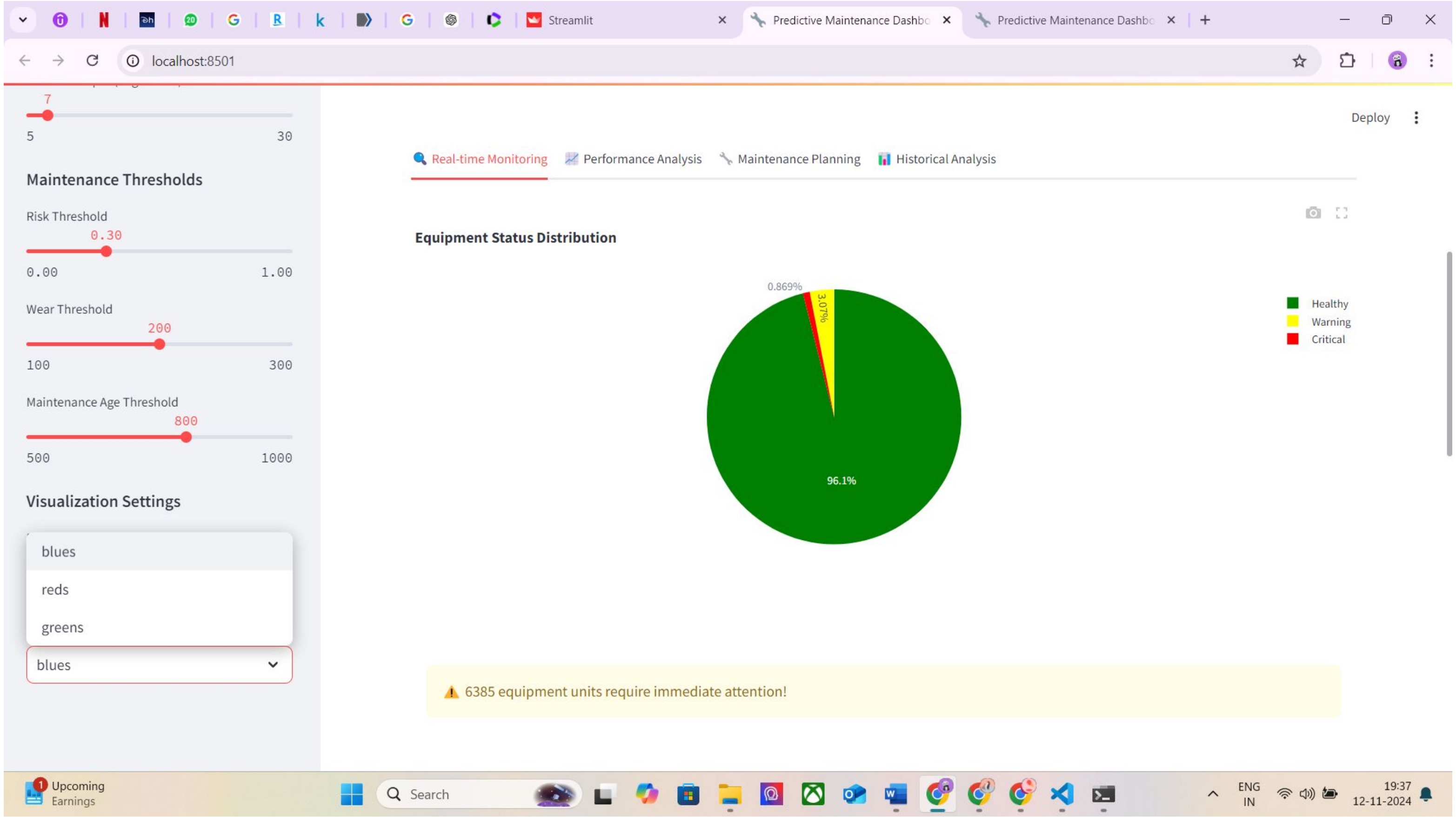
  Deployment: Hosted on Hugging Face Spaces for easy access

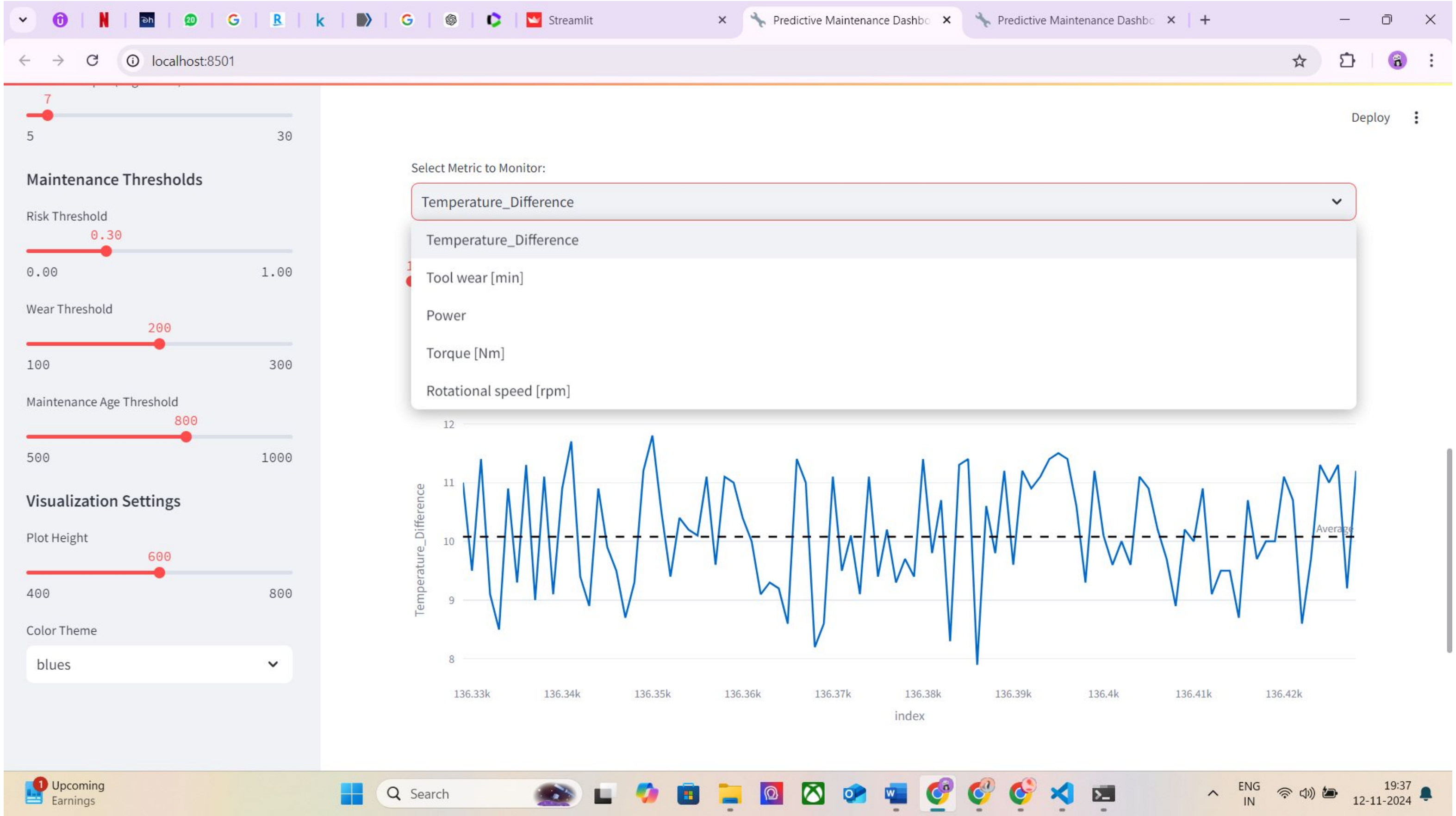
# Process Flow chart

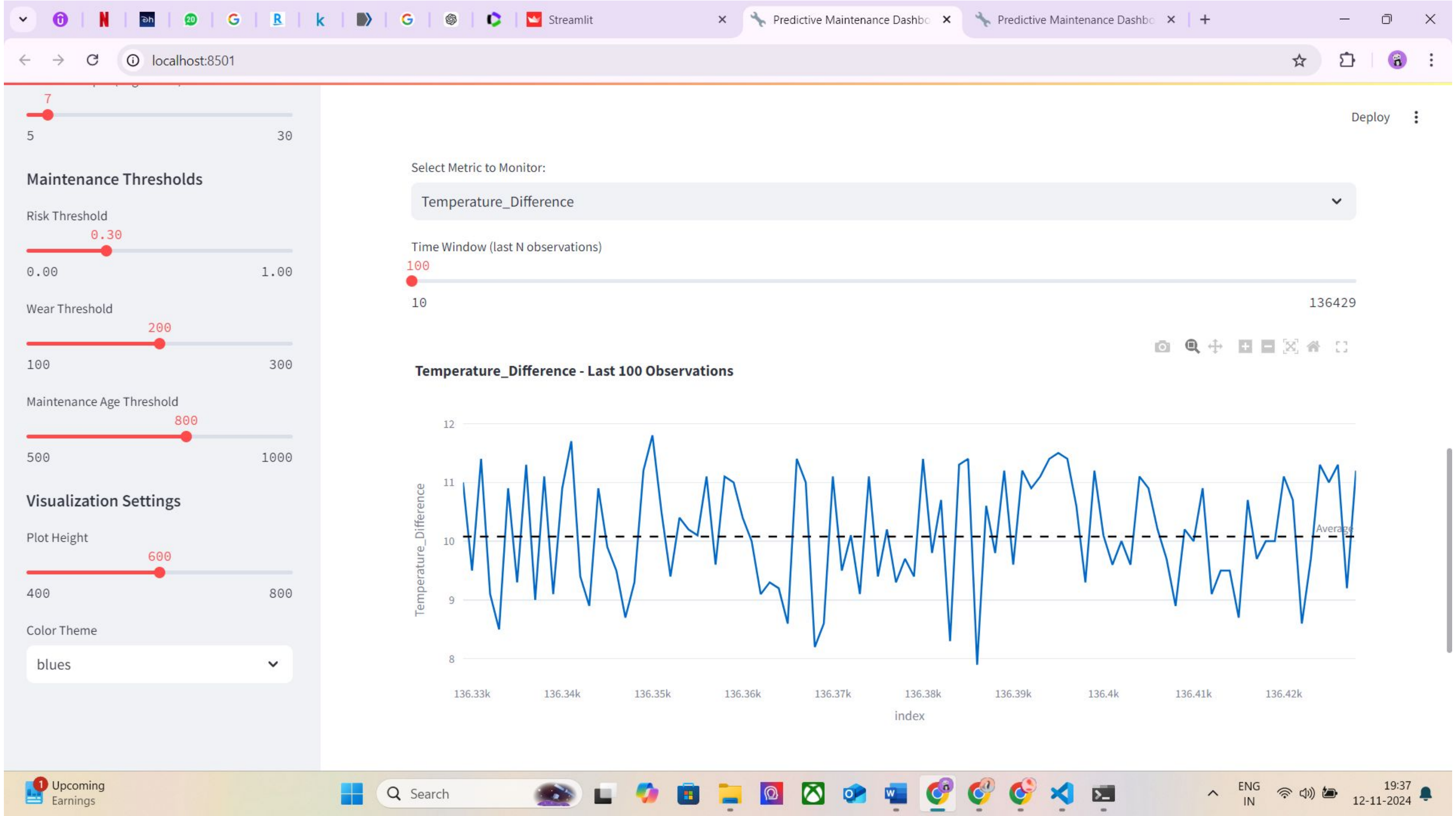


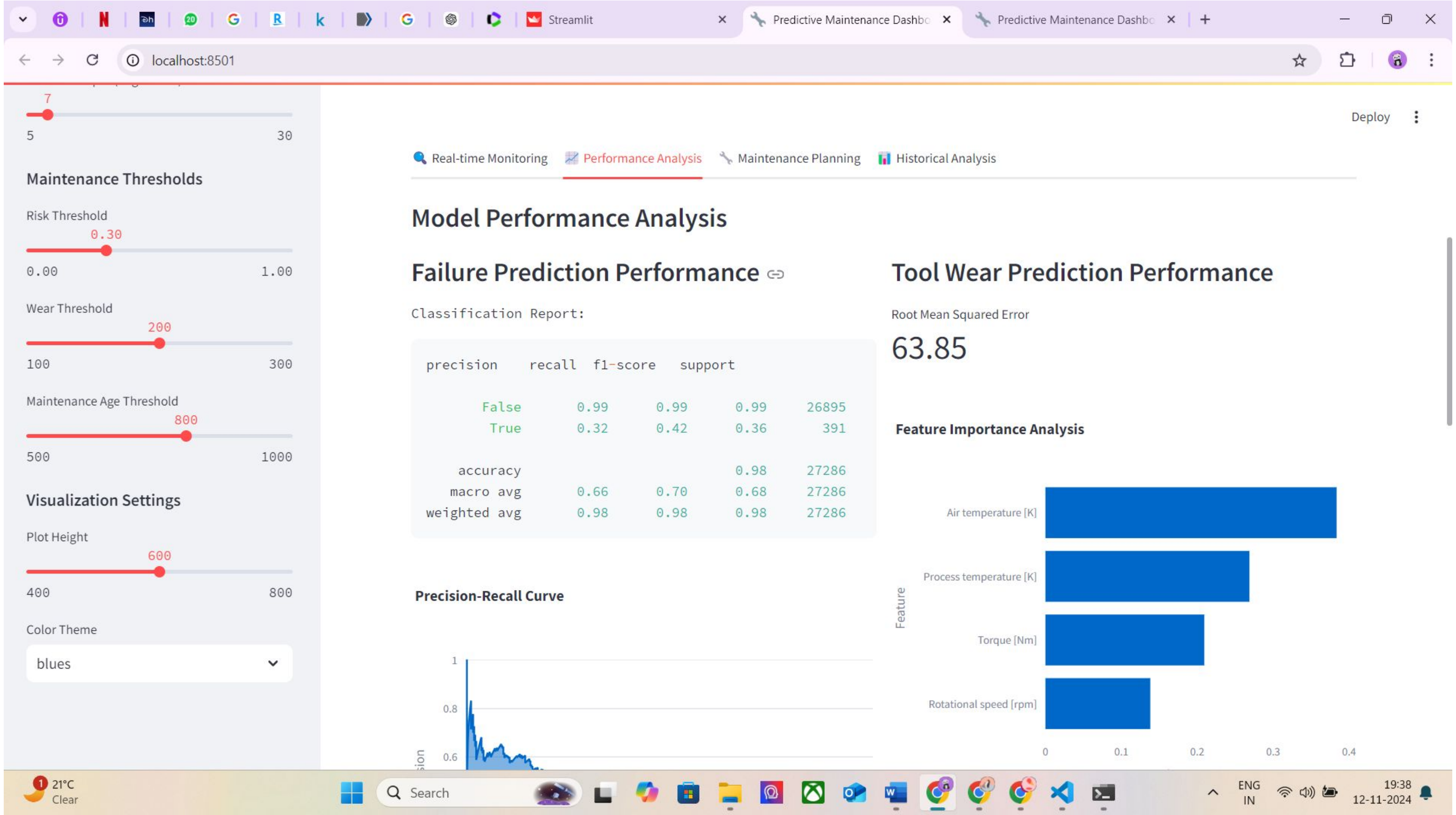
# RESULTS

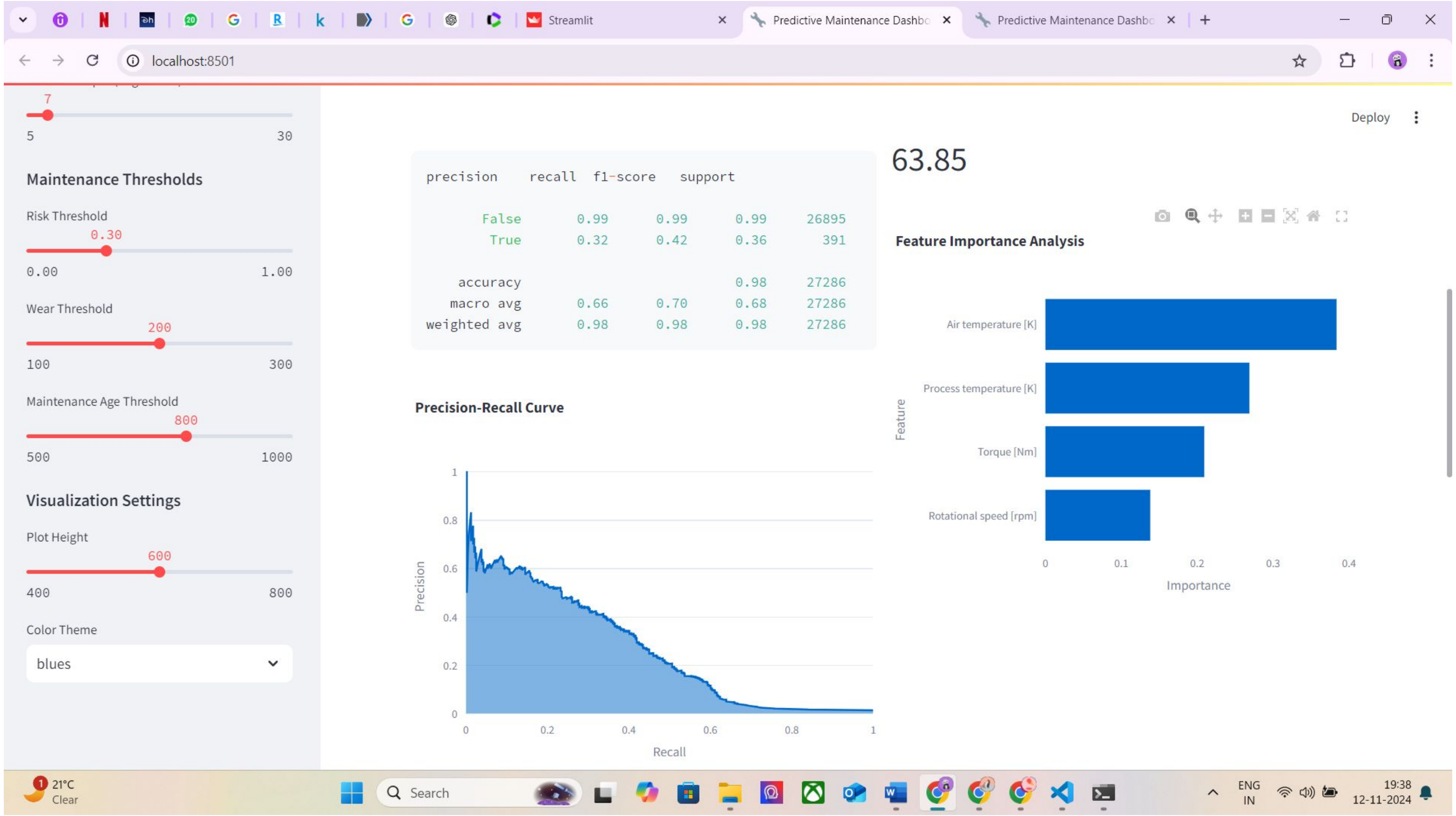

Streamlit
Predictive Maintenance Dashbo
Predictive Maintenance Dashbo
localhost:8501
Deploy
Dashboard Controls
Model Parameters
Number of Trees (Classification)
200
50
300
Max Tree Depth (Classification)
15
5
30
Number of Trees (Regression)
150
50
300
Max Tree Depth (Regression)
7
5
30
Maintenance Thresholds
Risk Threshold
0.30
0.00
1.00
Advanced Predictive Maintenance Dashboard
Dashboard Overview
This dashboard provides comprehensive predictive maintenance analytics for manufacturing equipment:
1. Real-time Monitoring: Track equipment health metrics and failure predictions
2. Maintenance Planning: Get AI-powered maintenance recommendations
3. Performance Analysis: Analyze historical data and model performance
4. Interactive Features: Customize thresholds and visualization parameters
Use the sidebar controls to adjust model parameters and thresholds.
Equipment Health Overview
Overall Health Index
88.1%
-11.9%
Average Failure Risk
11.9%
Normal
Equipment Requiring Maintenance
6385
6375
Average Tool Wear
104.3 min
-95.7
Real-time Monitoring
Performance Analysis
Maintenance Planning
Historical Analysis
Upcoming
Earnings
Search
ENG
IN
19:37
12-11-2024

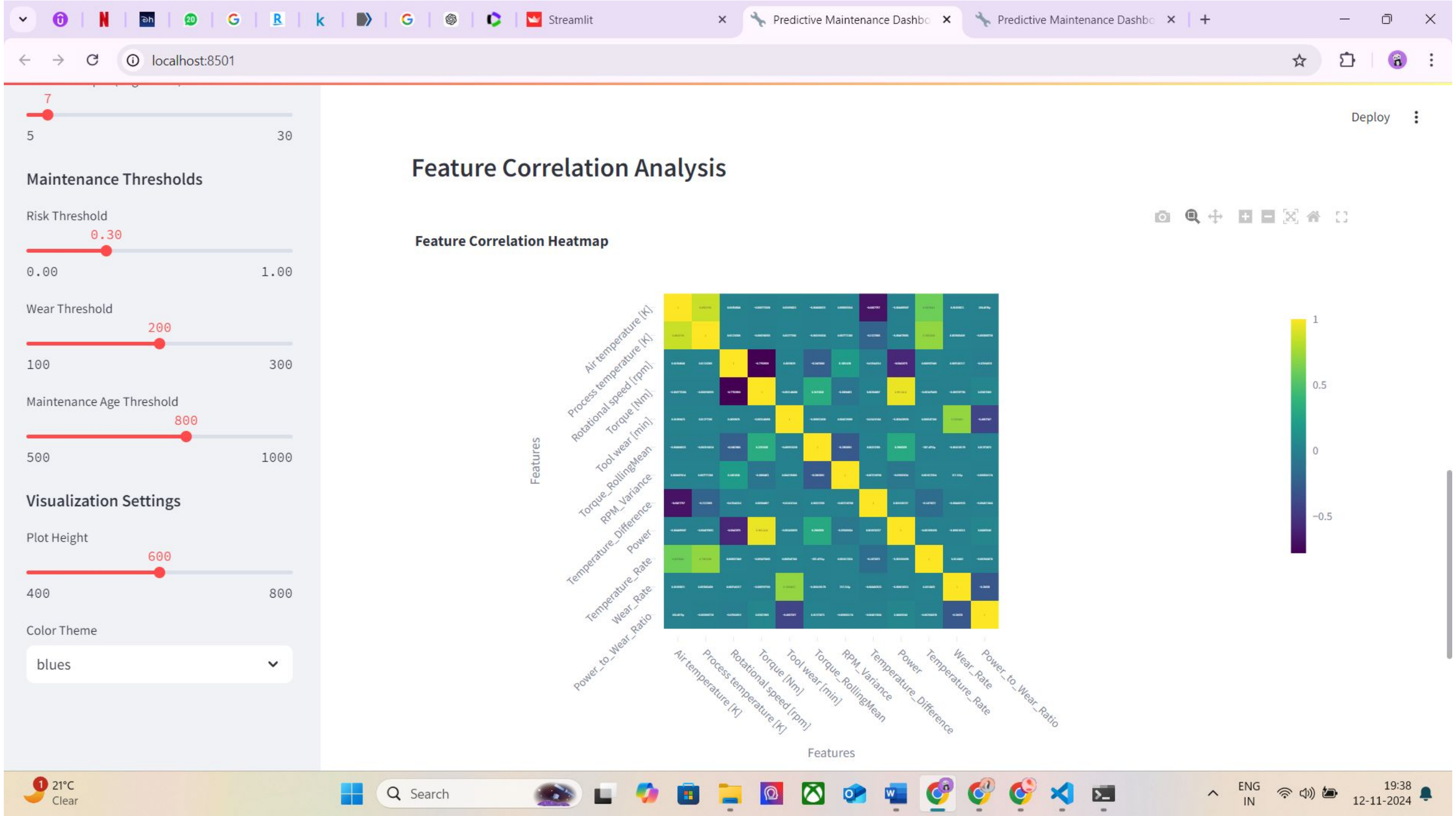

Streamlit
Predictive Maintenance Dashbo
Predictive Maintenance Dashbo
localhost:8501
7
5
30
Maintenance Thresholds
Risk Threshold
0.30
0.00
1.00
Wear Threshold
200
100
300
Maintenance Age Threshold
800
500
1000
Visualization Settings
blues
reds
greens
blues
Deploy
Real-time Monitoring
Performance Analysis
Maintenance Planning
Historical Analysis
Equipment Status Distribution
0.869%
3.07%
96.1%
Healthy
Warning
Critical
6385 equipment units require immediate attention!
Upcoming
Earnings
Search
ENG
IN
19:37
12-11-2024


Streamlit
Predictive Maintenance Dashbo
Predictive Maintenance Dashbo
localhost:8501
Deploy
7
5
30
Maintenance Thresholds
Risk Threshold
0.30
0.00
1.00
Wear Threshold
200
100
300
Maintenance Age Threshold
800
500
1000
Visualization Settings
Plot Height
600
400
800
Color Theme
blues
Select Metric to Monitor:
Temperature_Difference
Temperature_Difference
Tool wear [min]
Power
Torque [Nm]
Rotational speed [rpm]
12
11
10
9
8
Temperature_Difference
Average
136.33k
136.34k
136.35k
136.36k
136.37k
136.38k
136.39k
136.4k
136.41k
136.42k
index
Upcoming
Earnings
Search
ENG
IN
19:37
12-11-2024


Streamlit
Predictive Maintenance Dashbo
localhost:8501
Deploy
Maintenance Thresholds
Risk Threshold
0.30
0.00
1.00
Wear Threshold
200
100
300
Maintenance Age Threshold
800
500
1000
Visualization Settings
Plot Height
600
400
800
Color Theme
blues
Select Metric to Monitor:
Temperature_Difference
Time Window (last N observations)
100
10
136429
Temperature_Difference - Last 100 Observations
Temperature_Difference
Average
index
Upcoming
Earnings
Search
ENG
IN
19:37
12-11-2024


Streamlit
Predictive Maintenance Dashbo
Predictive Maintenance Dashbo
localhost:8501
7
5
30
Maintenance Thresholds
Risk Threshold
0.30
0.00
1.00
Wear Threshold
200
100
300
Maintenance Age Threshold
800
500
1000
Visualization Settings
Plot Height
600
400
800
Color Theme
blues
Deploy
Real-time Monitoring
Performance Analysis
Maintenance Planning
Historical Analysis
Model Performance Analysis
Failure Prediction Performance
Classification Report:
precision recall f1-score support
False 0.99 0.99 0.99 26895
True 0.32 0.42 0.36 391
accuracy 0.98 27286
macro avg 0.66 0.70 0.68 27286
weighted avg 0.98 0.98 0.98 27286
Precision-Recall Curve
1
0.8
0.6
Tool Wear Prediction Performance
Root Mean Squared Error
63.85
Feature Importance Analysis
Air temperature [K]
Process temperature [K]
Torque [Nm]
Rotational speed [rpm]
Feature
0
0.1
0.2
0.3
0.4
21°C
Clear
Search
ENG
IN
19:38
12-11-2024


Streamlit
Predictive Maintenance Dashbo
Predictive Maintenance Dashbo
localhost:8501
Deploy
7
5
30
Maintenance Thresholds
Risk Threshold
0.30
0.00
1.00
Wear Threshold
200
100
300
Maintenance Age Threshold
800
500
1000
Visualization Settings
Plot Height
600
400
800
Color Theme
blues
precision recall f1-score support
False 0.99 0.99 0.99 26895
True 0.32 0.42 0.36 391
accuracy 0.98 27286
macro avg 0.66 0.70 0.68 27286
weighted avg 0.98 0.98 0.98 27286
63.85
Precision-Recall Curve
Precision
Recall
Feature Importance Analysis
Air temperature [K]
Process temperature [K]
Torque [Nm]
Rotational speed [rpm]
Feature
Importance
21°C
Clear
Search
ENG
IN
19:38
12-11-2024


Streamlit
Predictive Maintenance Dashbo
Predictive Maintenance Dashbo
localhost:8501
Deploy
7
5
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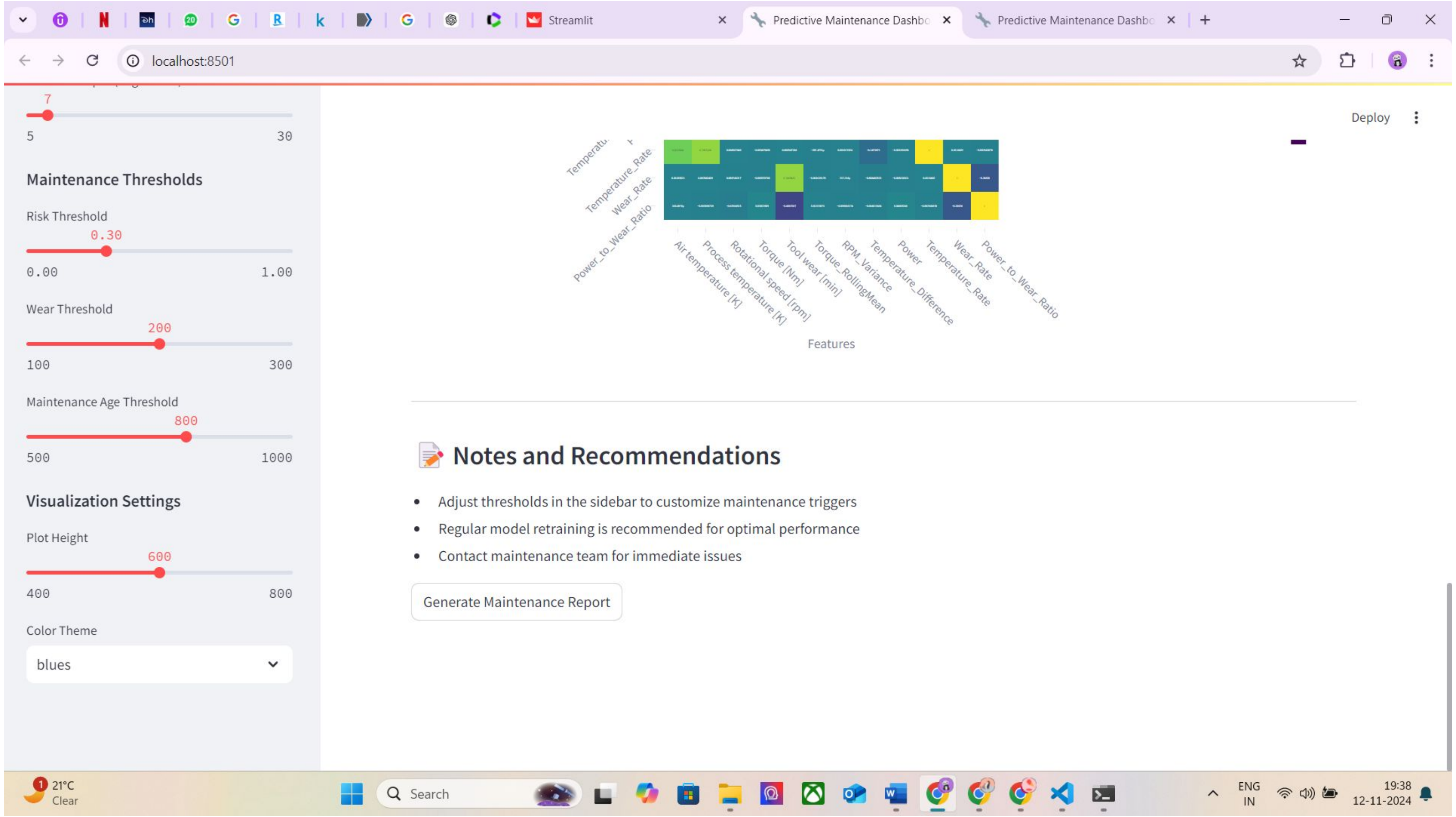
Maintenance Thresholds
Risk Threshold
0.30
0.00
1.00
Wear Threshold
200
100
300
Maintenance Age Threshold
800
500
1000
Visualization Settings
Plot Height
600
400
800
Color Theme
blues
Feature Correlation Analysis
Feature Correlation Heatmap
Features
Air temperature [K]
Process temperature [K]
Rotational speed [rpm]
Torque [Nm]
Tool wear [min]
Torque_RollingMean
RPM_Variance
Temperature_Difference
Power
Temperature_Rate
Wear_Rate
Power_to_Wear_Ratio
Features
1
0.5
0
−0.5
21°C
Clear
Search
ENG
IN
19:38
12-11-2024


Streamlit
Predictive Maintenance Dashbo
Predictive Maintenance Dashbo
localhost:8501
7
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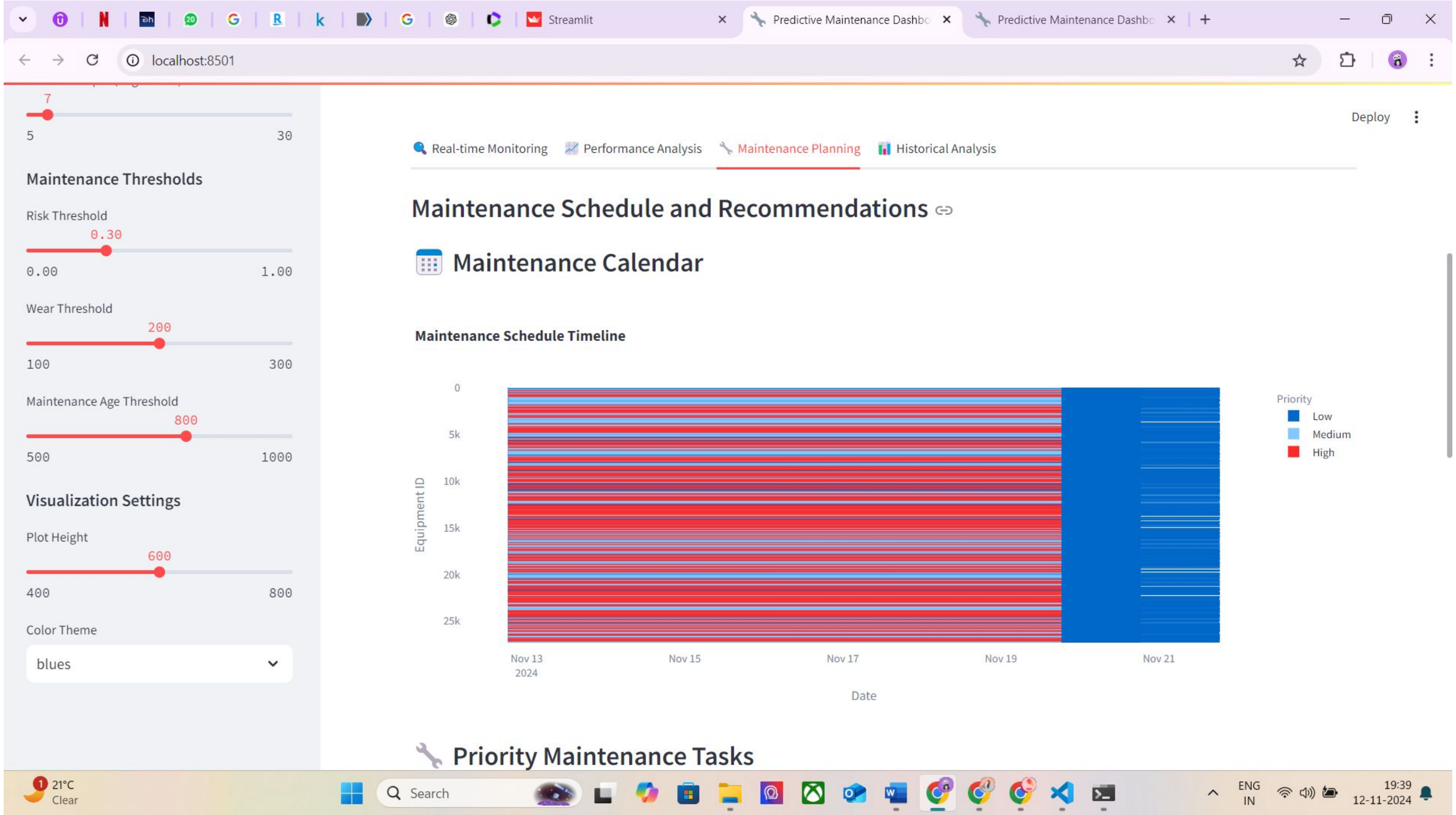
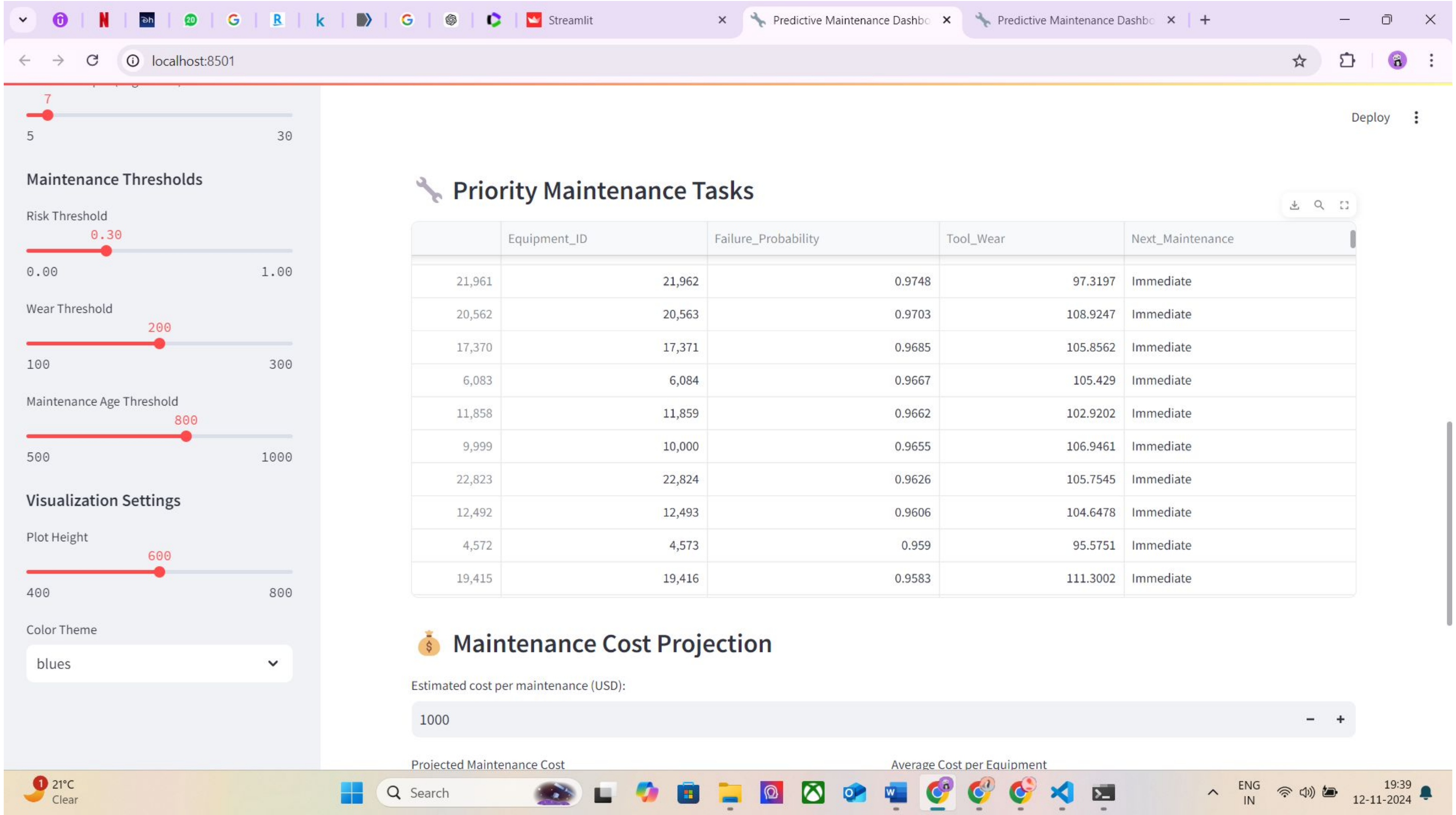
Maintenance Thresholds
Risk Threshold
0.30
0.00
1.00
Wear Threshold
200
100
300
Maintenance Age Threshold
800
500
1000
Visualization Settings
Plot Height
600
400
800
Color Theme
blues
Deploy
Temperature_Rate
Wear_Rate
Power_to_Wear_Ratio
Air temperature [K]
Process temperature [K]
Rotational speed [rpm]
Torque [Nm]
Tool wear [min]
Torque_RollingMean
RPM_Variance
Temperature_Difference
Power
Temperature_Rate
Wear_Rate
Power_to_Wear_Ratio
Features
Notes and Recommendations
Adjust thresholds in the sidebar to customize maintenance triggers
Regular model retraining is recommended for optimal performance
Contact maintenance team for immediate issues
Generate Maintenance Report
21°C
Clear
Search
ENG
IN
19:38
12-11-2024

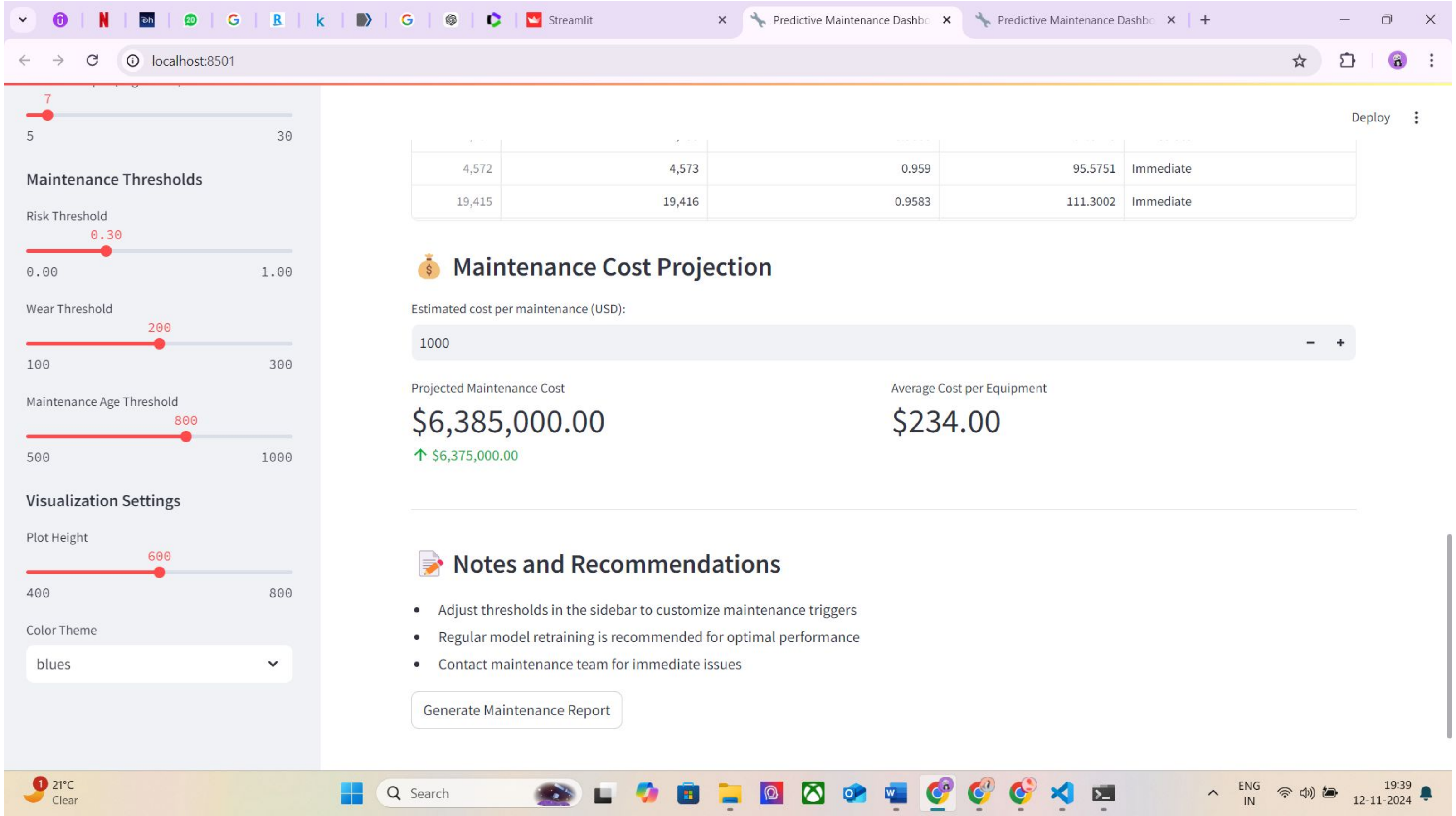


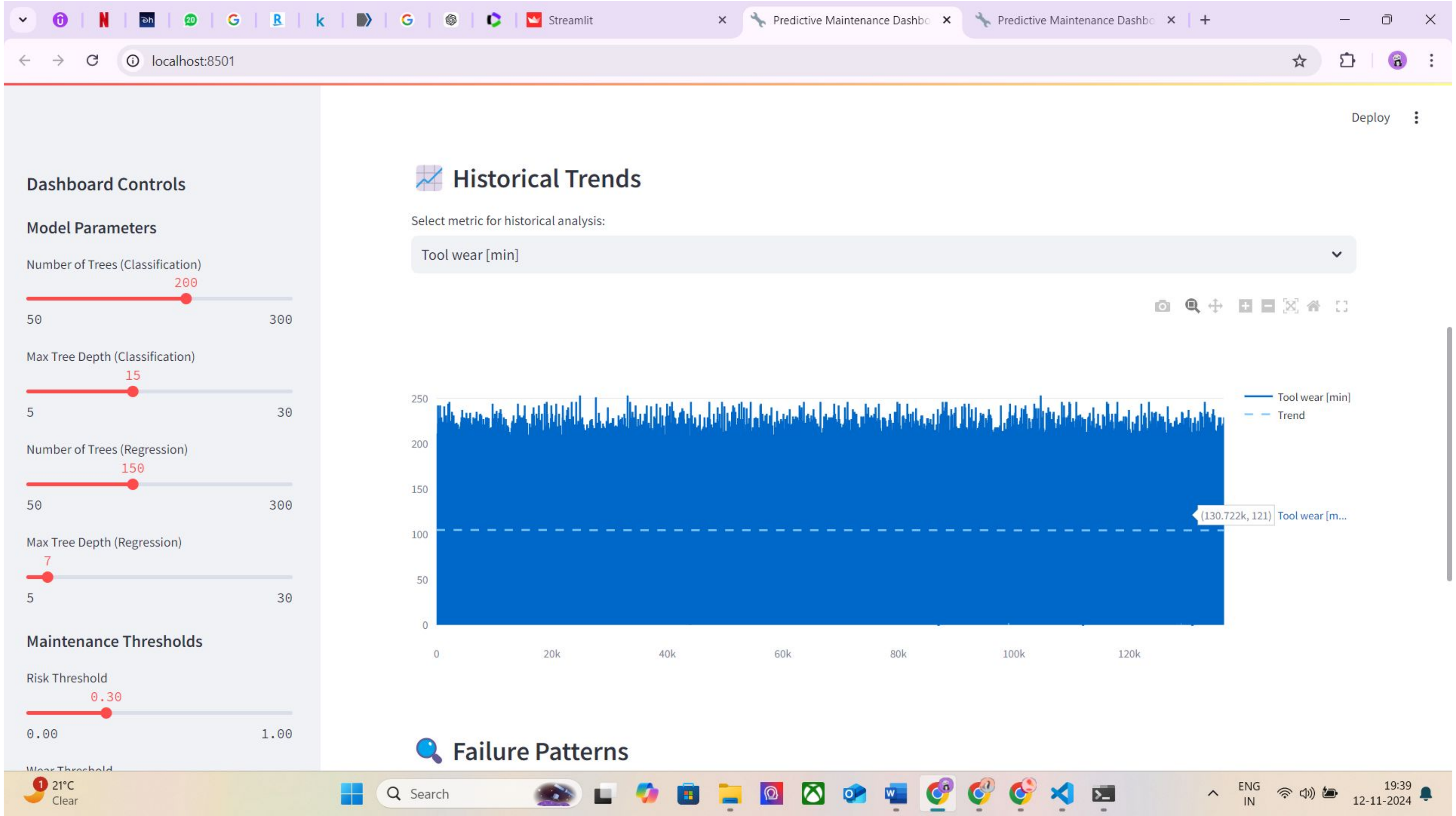
Streamlit
Predictive Maintenance Dashbo
Predictive Maintenance Dashbo
localhost:8501
7
5
30
Maintenance Thresholds
Risk Threshold
0.30
0.00
1.00
Wear Threshold
200
100
300
Maintenance Age Threshold
800
500
1000
Visualization Settings
Plot Height
600
400
800
Color Theme
blues
Deploy
Real-time Monitoring
Performance Analysis
Maintenance Planning
Historical Analysis
Maintenance Schedule and Recommendations
Maintenance Calendar
Maintenance Schedule Timeline
Equipment ID
0
5k
10k
15k
20k
25k
Nov 13
2024
Nov 15
Nov 17
Nov 19
Nov 21
Date
Priority
Low
Medium
High
Priority Maintenance Tasks
21°C
Clear
Search
ENG
IN
19:39
12-11-2024

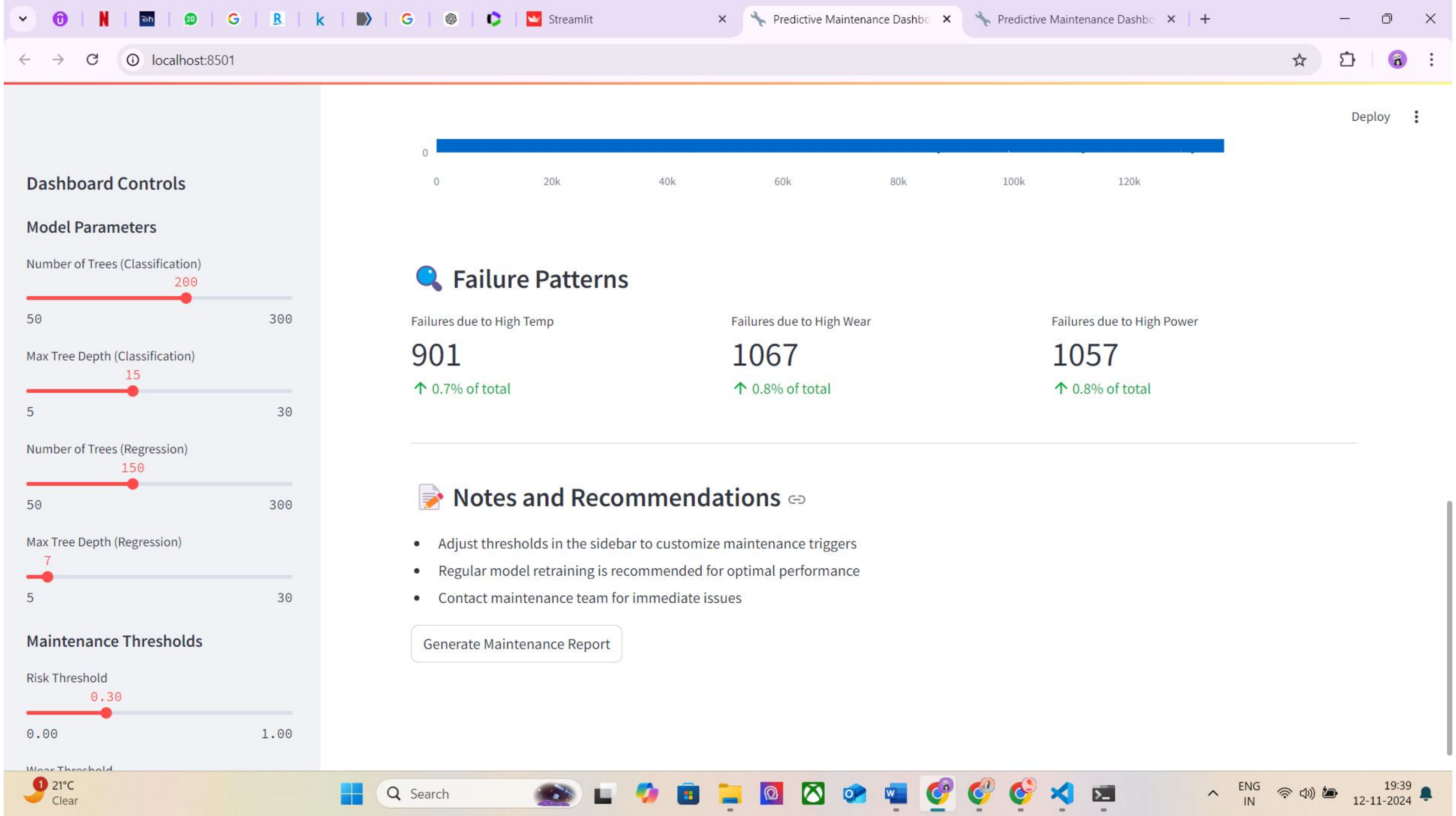

Streamlit
Predictive Maintenance Dashbo
Predictive Maintenance Dashbo
localhost:8501
7
5
30
Maintenance Thresholds
Risk Threshold
0.30
0.00
1.00
Wear Threshold
200
100
300
Maintenance Age Threshold
800
500
1000
Visualization Settings
Plot Height
600
400
800
Color Theme
blues
Deploy
Priority Maintenance Tasks

| | Equipment_ID | Failure_Probability | Tool_Wear | Next_Maintenance |
|---|---|---|---|---|
| 21,961 | 21,962 | 0.9748 | 97.3197 | Immediate |
| 20,562 | 20,563 | 0.9703 | 108.9247 | Immediate |
| 17,370 | 17,371 | 0.9685 | 105.8562 | Immediate |
| 6,083 | 6,084 | 0.9667 | 105.429 | Immediate |
| 11,858 | 11,859 | 0.9662 | 102.9202 | Immediate |
| 9,999 | 10,000 | 0.9655 | 106.9461 | Immediate |
| 22,823 | 22,824 | 0.9626 | 105.7545 | Immediate |
| 12,492 | 12,493 | 0.9606 | 104.6478 | Immediate |
| 4,572 | 4,573 | 0.959 | 95.5751 | Immediate |
| 19,415 | 19,416 | 0.9583 | 111.3002 | Immediate |

Maintenance Cost Projection
Estimated cost per maintenance (USD):
1000
Projected Maintenance Cost
Average Cost per Equipment
21°C
Clear
Search
ENG
IN
19:39
12-11-2024


Streamlit
Predictive Maintenance Dashbo
Predictive Maintenance Dashbo
localhost:8501
Deploy
7
5
30
Maintenance Thresholds
Risk Threshold
0.30
0.00
1.00
Wear Threshold
200
100
300
Maintenance Age Threshold
800
500
1000
Visualization Settings
Plot Height
600
400
800
Color Theme
blues
4,572 4,573 0.959 95.5751 Immediate
19,415 19,416 0.9583 111.3002 Immediate
Maintenance Cost Projection
Estimated cost per maintenance (USD):
1000
Projected Maintenance Cost
$6,385,000.00
$6,375,000.00
Average Cost per Equipment
$234.00
Notes and Recommendations
Adjust thresholds in the sidebar to customize maintenance triggers
Regular model retraining is recommended for optimal performance
Contact maintenance team for immediate issues
Generate Maintenance Report
21°C
Clear
Search
ENG
IN
19:39
12-11-2024


Streamlit
Predictive Maintenance Dashbo
Predictive Maintenance Dashbo
localhost:8501
Deploy
Dashboard Controls
Model Parameters
Number of Trees (Classification)
200
50
300
Max Tree Depth (Classification)
15
5
30
Number of Trees (Regression)
150
50
300
Max Tree Depth (Regression)
7
5
30
Maintenance Thresholds
Risk Threshold
0.30
0.00
1.00
Historical Trends
Select metric for historical analysis:
Tool wear [min]
Tool wear [min]
Trend
(130.722k, 121) Tool wear [m...
250
200
150
100
50
0
0
20k
40k
60k
80k
100k
120k
Failure Patterns
21°C
Clear
Search
ENG
IN
19:39
12-11-2024


Streamlit
Predictive Maintenance Dashbo
Predictive Maintenance Dashbo
localhost:8501
Deploy
0
0
20k
40k
60k
80k
100k
120k
Dashboard Controls
Model Parameters
Number of Trees (Classification)
200
50
300
Max Tree Depth (Classification)
15
5
30
Number of Trees (Regression)
150
50
300
Max Tree Depth (Regression)
7
5
30
Maintenance Thresholds
Risk Threshold
0.30
0.00
1.00
Failure Patterns
Failures due to High Temp
901
0.7% of total
Failures due to High Wear
1067
0.8% of total
Failures due to High Power
1057
0.8% of total
Notes and Recommendations
Adjust thresholds in the sidebar to customize maintenance triggers
Regular model retraining is recommended for optimal performance
Contact maintenance team for immediate issues
Generate Maintenance Report
21°C
Clear
Search
ENG
IN
19:39
12-11-2024

# Conclusion

**Challenges and Solutions:**

1.Data Quality: This has been one of the greatest challenges as incomplete, noisy, or inconsistent data is a very common phenomenon in real-world datasets. Missing values, outliers, and irrelevant features usually arise in the real dataset.

Solution: We removed irrelevant columns from data. Normalized and scaled to standardize data. The model's performance and flexibility improved by using feature selection techniques to remove redundant features.

2.Data Preprocessing: It learned very well initially on the training data but could not generalize well to the new data and was particularly bad when the dataset is small or highly unbalanced.

Solution: Since this is a categorical feature, which is the different kinds of machines, we would need to apply label encoding or one-hot encoding to make it usable by a model in the Type' column. Label encoding simply assigns unique integers to each category, and one-hot encoding adds separate binary columns for each unique type.

# Conclusion

**Lessons Learnt**

Documentation: Explicit setup and dependencies. This also is very useful for troubleshooting and team collaboration.

Model Interpretability: Ensuring stakeholders understand predictions is key for effective deployment.

Version Control & Virtual Environments: Version control through virtual environments and Git streamlined team collaboration and resolved environment issues.

Iterative Development: Successive refinement of the model based on feedback improved the performance dramatically.

# Conclusion

**Future Enhancements**

1. Integration with real-time data sources (e.g., IoT sensors)
2. Additional algorithms for failure prediction
3. Custom alerts and email notifications for critical equipment maintenance and user experience.

# Thank You