

Predictive Absenteeism Model Testing

The ML_Absenteeism_MU_Grouped dataset and SQL query provide an aggregated view of absenteeism data, derived from the same data source and department used in the first analysis.

To avoid data leakage during rolling and shifting calculations, data modeling preparation is handled via SQL Server, ensuring robust feature engineering for time-series analysis.

Below is the structured review of the dataset, query, and analytical workflow:

Dataset Overview

1. Key Features:

Date Columns:

- Date: Represents the day for each record, used for grouping and trend analysis.

Categorical Features:

1. AssignedDep: Identifies the assigned department.
2. MU_Name: Management Unit name (e.g., MU_Name_1, MU_Name_2).
3. Country: Includes 'Greece' by default if missing.
4. Is_Actual: Indicates whether the data point is actual or forecasted.
5. Is_Strike: Flags if there was a strike on the date.

Numerical Features:

- Time and Effort Measures:
 - Scheduled, Worked, Overtime, Training, Vacation, Sick, and Absence.
- Performance Metrics:
 - Early, Late, and Total_Lost.

2. Derived Features:

- Waha%: Proportion of WAHA (Work-At-Home Agents).
- Strike_Participant%: Proportion of participants in strikes.

Rolling Metrics:

- Rolling calculations over the last 7 and 14 days for key metrics like:
 - Scheduled, Worked, and Absence.
- Average and lagged values for rolling windows.

Aggregates:

- HC_Weight: Weighted headcount metric based on HC.
- AVG_*: Average metrics for various measures like Scheduled and Worked.

SQL Query Analysis

1. Query Logic:

Data Preparation (prep CTE):

1. Fetches the base dataset from the `vScheduleV3_Static` table.
2. Performs initial transformations, including:
 - Generating `Is_Actual` based on date comparison.
 - Calculating derived fields like `Waha`, `Is_Strike`, and `Absence`.
 - Ensuring default values for null entries in numerical fields using `COALESCE`.

Aggregation and Rolling Calculations:

- Groups data by Date, MU_Name, and other key features.
- Computes:
 - Rolling sums and averages over 7 and 14 days for key measures.
 - Lagged metrics over 7 and 14 days to capture temporal trends.

⌚ Final Selection:

- Includes both raw and derived metrics for downstream analysis.

🔍 2. Purpose of Rolling and Lagged Metrics:

• Rolling Metrics:

Provide insight into short-term trends and variability in absenteeism and other measures.

• Lagged Metrics:

Capture delayed effects of absenteeism-related factors, improving predictability.

📈 Analytical Workflow

1. Dataset Review:

- Evaluate the aggregated dataset structure:
 - Ensure key metrics (Scheduled, Worked, Absence, etc.) align with business objectives.
 - Verify rolling and lagged values for consistency.

2. Correlation Analysis:

- Similar to the first analysis, apply Pearson and Spearman correlation coefficients to identify:
 - Strong relationships between features (e.g., Scheduled vs. Worked).
 - Associations of rolling and lagged metrics with the target variable (Absence).

3. Feature Selection:

- Assess which features (e.g., rolling averages, lagged values) improve model performance.
- Identify and remove redundant features to avoid multicollinearity.

4. Model Experimentation:

- Use the aggregated dataset for training and testing predictive models.
- Compare model performance with and without rolling and lagged metrics to validate their utility.

💡 Example Insights

1. WAHA% and Strike_Participant%:

- Understanding how WAHA and strike participation influence absenteeism can guide policy adjustments.

⌚ 2. Rolling and Lagged Metrics:

• Metrics like:

- `Rolling_Last_7_Days_Scheduled_Hours`
- `lag7_Absence_Hours`

Can reveal patterns that static features might miss.

📅 3. Seasonal Trends:

- Aggregated data helps explore seasonality in absenteeism across different management units (MU_Name).

✍️ Final Thought:

By leveraging SQL Server for data preparation, we ensure that rolling and lagged calculations are robust, reducing the risk of data leakage and enhancing the predictive power of our models. ☝

```
import pandas as pd
import numpy as np
import random
import pylab as pl
import time
import datetime
from sklearn.feature_selection import RFECV
# for plotting
```

```
import matplotlib.pyplot as plt
import seaborn as sns
import scipy.stats as stats
from scipy.stats import chi2_contingency
from statsmodels.graphics.tsaplots import plot_acf, plot_pacf
from statsmodels.tsa.seasonal import seasonal_decompose
from lightgbm import LGBMRegressor
from xgboost import XGBRegressor
import shap
# scikit learning packages
from lightgbm import LGBMRegressor, early_stopping
from xgboost import XGBClassifier
from sklearn.model_selection import TimeSeriesSplit
from sklearn.pipeline import Pipeline
from sklearn.compose import ColumnTransformer
from sklearn.feature_selection import RFE, SelectFromModel
from sklearn.neighbors import KNeighborsClassifier
from sklearn.dummy import DummyRegressor
from sklearn.base import clone, BaseEstimator, TransformerMixin
from sklearn.model_selection import (
    train_test_split,
    cross_val_score,
    cross_val_predict,
    KFold,
    StratifiedKFold,
    GridSearchCV,
    RandomizedSearchCV
)
from sklearn.ensemble import (
    RandomForestClassifier,
    RandomForestRegressor,
    GradientBoostingRegressor,
    GradientBoostingClassifier,
    AdaBoostClassifier,
    ExtraTreesClassifier,
    VotingClassifier,
    VotingRegressor
)
from sklearn.metrics import (
    confusion_matrix,
    accuracy_score,
    mean_absolute_error,
    mean_squared_error,
    r2_score,
    make_scorer,
    classification_report,
    roc_curve,
    auc
)
from sklearn.preprocessing import (
    LabelEncoder,
    MinMaxScaler,
    StandardScaler,
    OneHotEncoder,
    PolynomialFeatures,
    scale
)
from sklearn.naive_bayes import GaussianNB, BernoulliNB, MultinomialNB
from sklearn.decomposition import PCA, FactorAnalysis
from sklearn.linear_model import (
    LinearRegression,
    Ridge,
    LogisticRegressionCV,
    LogisticRegression
)
from sklearn.svm import SVC
from sklearn import svm, metrics, tree
from sklearn.tree import DecisionTreeClassifier, DecisionTreeRegressor
from sklearn.multiclass import OneVsRestClassifier
from sklearn.discriminant_analysis import LinearDiscriminantAnalysis
from sklearn.neural_network import MLPClassifier
from sklearn.utils import resample, shuffle

from collections import Counter
from pandas.api.types import is_numeric_dtype
import holidays
import warnings
from scipy.stats.mstats import mquantiles
```

```

from scipy.stats import skew
from scipy.stats import randint, uniform
import lightgbm as lgb
import logging

warnings.filterwarnings("ignore")
cmap = sns.color_palette('Blues_r')

logging.getLogger("lightgbm").setLevel(logging.CRITICAL)

#####
starting_time = time.perf_counter()
print('')
print('starting time: ', datetime.datetime.now().strftime("%H:%M:%S"))
print('')
#####

### Read the file
df_raw = pd.read_excel(r"ML_Absenteism_MU_Grouped.xlsx")
#####
ending_time = time.perf_counter()
total_in_sec = ending_time-starting_time
print("Data time in sec")
print(total_in_sec)
print("Data uploaded")

```

starting time: 16:49:15

Data time in sec

21.067719900001975

Data uploaded

```

#####
starting_time = time.perf_counter()
print('')
print('starting time: ', datetime.datetime.now().strftime("%H:%M:%S"))
print('')
#####

df = df_raw.copy()
df = df[df['Is_Actual']=='Actual']
# -----
# Drop Duplicates
# -----
df = df.drop_duplicates(subset=['MU_Name', 'Date'], keep='first')

df['Country'] = df['Country'].str.replace('Unknown', 'Greece')

df = df.sort_values(by=['Date', 'MU_Name']).reset_index(drop=True)

df['AssignedDep'] = df['AssignedDep'].astype(int).astype(str)

Country_dic = {'External':'Greece',
               'Czech Republic':'CZ',
               'Suriname':'ZA',
               'South Africa':'ZA',
               'United Kingdom':'GB'}
df['Country'] = df['Country'].replace(Country_dic)

# Generate the dictionary by passing each unique country name to holidays.country_holidays
country_to_code = {}

for country in df['Country'].unique():
    try:
        iso_code = holidays.country_holidays(country=country).country
        country_to_code[country] = iso_code
    except Exception as e:
        print(f"Error for country: {country} - {e}")

```

```

# Function to check if a date is a holiday
def is_holiday(row):
    country_code = country_to_code.get(row['Country'])
    if country_code:
        try:
            country_holidays = holidays.country_holidays(country=country_code, years=row['Date'].year)
            return 1 if row['Date'] in country_holidays else 0
        except Exception as e:
            print(f"Error checking holiday for {row['Country']} on {row['Date']}: {e}")
    return 0

# Apply the function to create the Is_Holiday column
df['Is_Holiday'] = df.apply(is_holiday, axis=1)

### Create extra Date columns

# Step 7: Convert 'Date' to datetime and set index
df['Date'] = pd.to_datetime(df['Date'])
df['Season'] = (df['Date'].dt.month % 12 + 3) // 3
df = df.set_index('Date')

# Step 8: Overwrite columns based on index
df['Year'] = df.index.year
df['Month'] = df.index.month
df['DayofMonth'] = df.index.day
df['DayofWeek'] = df.index.dayofweek # Monday=0, Sunday=6
df['WeekofYear'] = df.index.isocalendar().week

# Step 1: Encoding MU_Name with cat.codes and appending '_Cat'
df['MU_Name_Cat'] = df['MU_Name'].astype('category').cat.codes

df_mus = df[['MU_Name_Cat','MU_Name']].drop_duplicates(keep='first').reset_index(drop=True)
# Step 2: One-hot encoding with pd.get_dummies and renaming columns with '_Cat'
df_dummies = pd.get_dummies(df['MU_Name_Cat'], prefix='MU_Name')
# Step 3: Concatenating the encoded columns back to the original dataframe
df = pd.concat([df, df_dummies], axis=1)

df['Country_Cat'] = df['Country'].astype('category').cat.codes

df_Country = df[['Country_Cat','Country']].drop_duplicates(keep='first').reset_index(drop=True)
# Step 2: One-hot encoding with pd.get_dummies and renaming columns with '_Cat'
df_dummies = pd.get_dummies(df['Country_Cat'], prefix='Country')
# Step 3: Concatenating the encoded columns back to the original dataframe
df = pd.concat([df, df_dummies], axis=1)

# Step 4: Drop the original categorical column if needed
df.drop(columns=['MU_Name','Country','AssignedDep','Is_Actual'], inplace=True)

#####

##### ending_time = time.perf_counter()
total_in_sec = ending_time-starting_time
print("\n Data time in sec")
print(total_in_sec)
print("Data Cleaning Completed")

```

```
starting time: 16:49:36
```

```
Data time in sec
```

```
2.8216027000016766
```

```
Data Cleaning Completed
```

Why Use Sin-Cos Transformation for Cyclical Columns?

Cyclical features like Month, DayofWeek, and DayofMonth represent repeating patterns. Encoding them as integers (e.g., January = 1, December = 12) fails to capture their cyclic nature, where December and January are close.

Why It's Important

1. Preserves Cyclicity:

- Ensures the model understands repeating patterns (e.g., seasonality in months).

2. Avoids Misleading Distances:

- Prevents the model from treating December and January as far apart.

3. Improves Model Performance:

- Captures seasonal and periodic trends more effectively.

```
passthrough_cols = ['Year',
'Month',
'WeekofYear',
'DayofMonth',
'DayofWeek',
'Season',
'Is_Strike',
'Is_Holiday']

## Target Columns
target_col = ['Total_Lost']
### passthrough_cols
encoded_cols = df.columns[(df.columns.str.contains('MU_Name'))
| (df.columns.str.contains('Country'))].tolist()
passthrough_cols = passthrough_cols + encoded_cols

numeric_cols = df.columns.difference(target_col + passthrough_cols).tolist()
feature_cols = passthrough_cols+ numeric_cols
feature_cols_all = feature_cols+target_col

df = df[feature_cols_all]
df.dropna(axis=0, how='any', inplace=True)

# Display the result
print("Passthrough Columns:", len(passthrough_cols))
print("Numeric Columns:", len(numeric_cols))
print("Feature Columns:", len(feature_cols))
print("All Feature Columns (with target):", len(feature_cols_all))

# Find the max date where Is_Actual is 'Actual'
max_actual_date = df.index.max()
print(f'Sample Data Starting from {df.index.min()} until {max_actual_date}')
```

Passthrough Columns: 26

Numeric Columns: 164

Feature Columns: 190

All Feature Columns (with target): 191

Sample Data Starting from 2023-01-15 00:00:00 until 2025-02-06 00:00:00

Exploratory data analysis

Analysis of the Skewness Results

General Insights from the Skewness Values:

Highly Skewed Features ($|Skewness| > 1$):

Features with a skewness greater than 1 or less than -1 indicate a highly skewed distribution, meaning the data is not symmetric and could benefit from log transformation.

Positively skewed: Long right tail → candidates for log transformation.

Negatively skewed: Long left tail → might consider transformations like power or square root transformation instead.

Moderately Skewed Features ($0.5 < |Skewness| \leq 1$):

These features show moderate skewness and could benefit from a transformation in some cases, but it is not always necessary.

Symmetric Features ($|Skewness| \leq 0.5$):

These features are approximately symmetric and do not require any transformation.

```
def get_skewed_columns(data, numeric_columns, threshold=1.0):
    """
    Identify numeric columns with skewness above the specified threshold.

    Parameters:
    data (DataFrame): The DataFrame containing numeric columns.
    numeric_columns (list): List of numeric column names to check.
    threshold (float): Skewness threshold to determine highly skewed columns.

    Returns:
    list: Columns and their skewness values sorted by skewness strength.
    """
    skewed_cols = []

    for col in numeric_columns:
        skewness = skew(data[col].dropna()) # Drop missing values to avoid errors
        if abs(skewness) > threshold:
            skewed_cols.append((col, skewness)) # Append column and its skewness

    # Sort the skewed columns by absolute skewness strength in descending order
    skewed_cols = sorted(skewed_cols, key=lambda x: abs(x[1]), reverse=True)

    # Print the skewness values of the sorted columns
    for col, skewness in skewed_cols:
        print(f'Skewness of {col}: {skewness:.2f}')

    # Return only the column names
    return [col for col, _ in skewed_cols]

# Example usage with threshold of 1.0 (highly skewed data)
columns_to_log_transform = get_skewed_columns(df, numeric_cols, threshold=1.0)
```

```
Skewness of Strike_Participant%: 31.51
```

```
Skewness of lag14_AVG_Early%: 16.57
```

```
Skewness of lag7_AVG_Early%: 16.36
```

```
Skewness of lag14_Early%: 15.28
```

```
Skewness of lag14_AVG_Late_Hours: 15.17
```

```
Skewness of lag7_AVG_Late_Hours: 15.15
```

```
Skewness of lag14_AVG_Late%: 15.13
```

```
Skewness of lag7_AVG_Late%: 15.11
```

```
Skewness of lag7_Early%: 15.08
```

```
Skewness of lag14_Late%: 12.61
```

```
Skewness of lag7_Late%: 12.59
```

```
Skewness of lag14_AVG_Sick_Hours: 12.36
```

```
Skewness of lag7_AVG_Sick_Hours: 12.36
```

```
Skewness of lag14_AVG_Absence_Hours: 10.02
```

```
Skewness of lag14_AVG_Early_Hours: 10.02
```

```
print(  
    f"\nNumber of Columns selected for log transformation: {len(columns_to_log_transform)}"  
    f"\n{({len(columns_to_log_transform)} / len(numeric_cols)) * 100:.2f}%)")
```

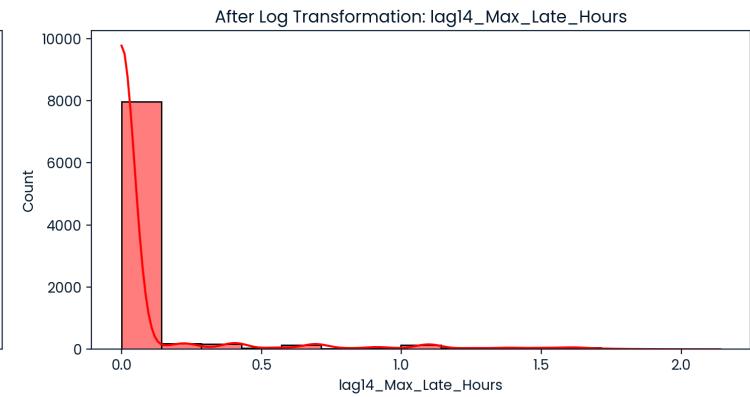
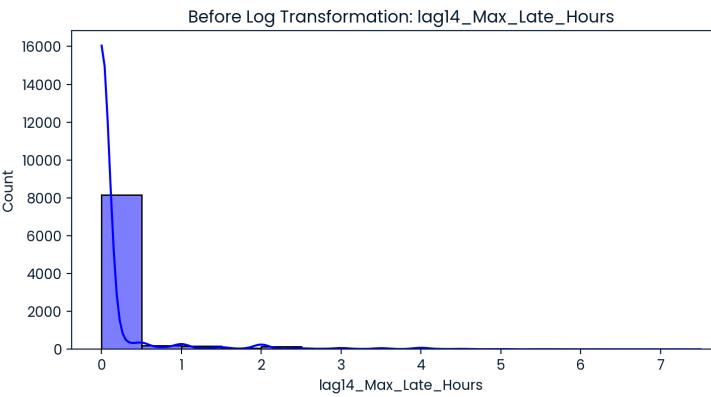
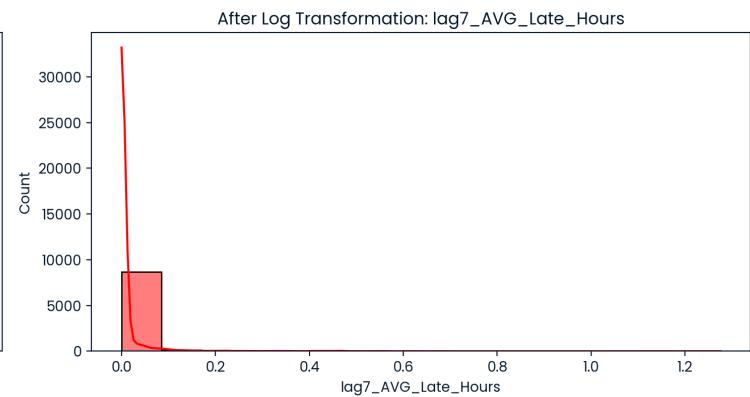
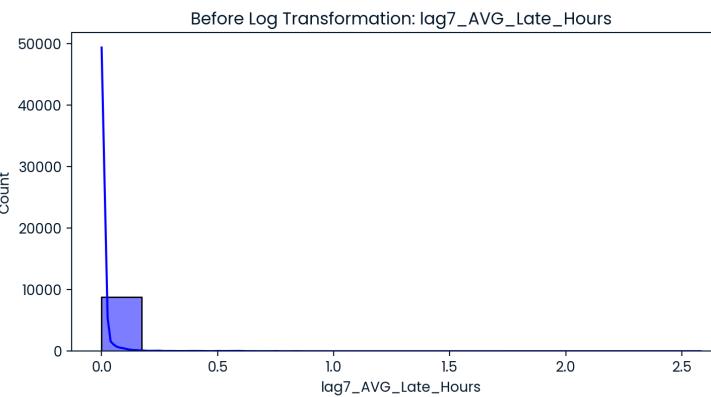
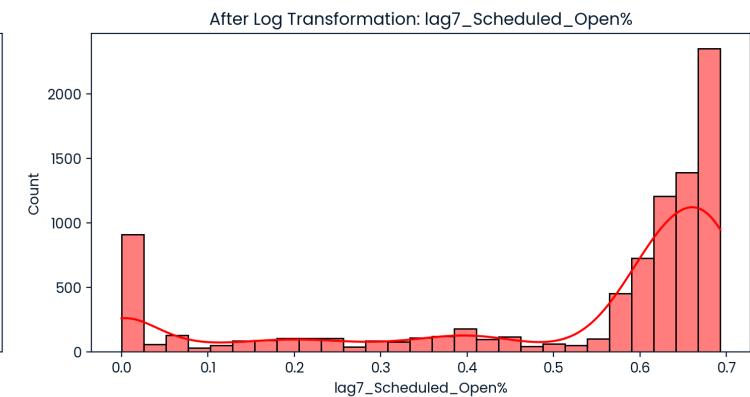
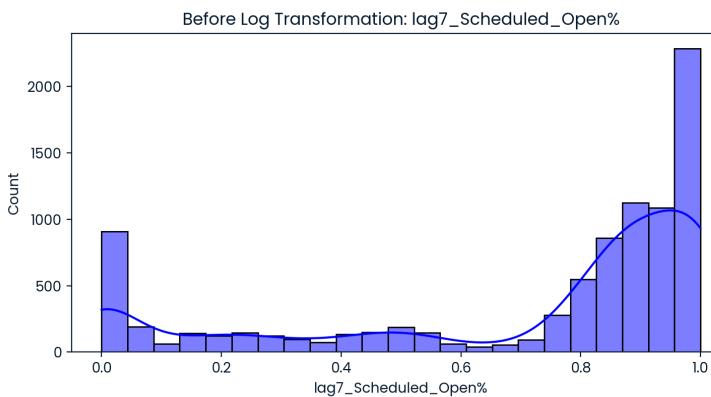
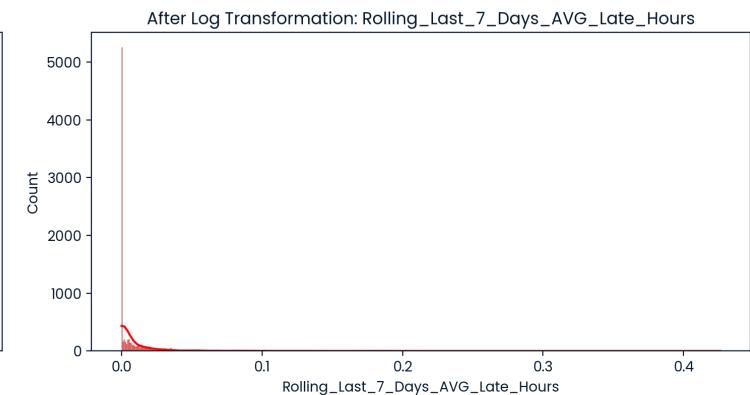
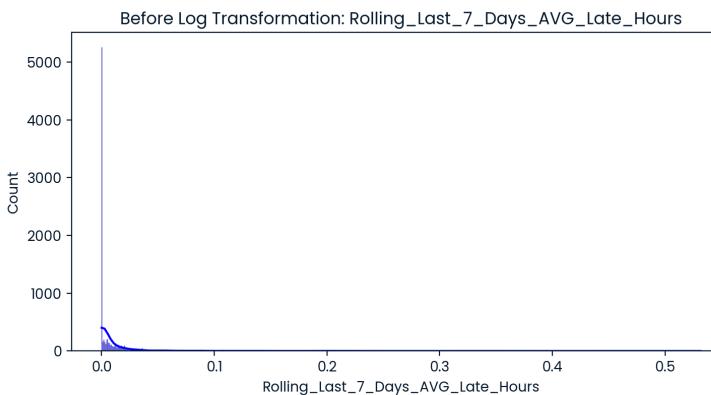
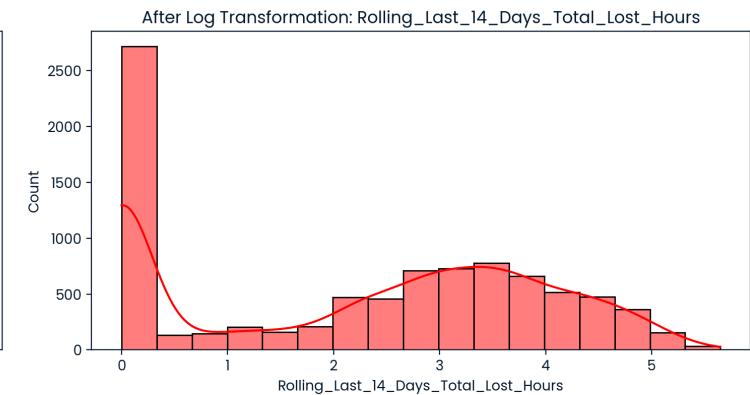
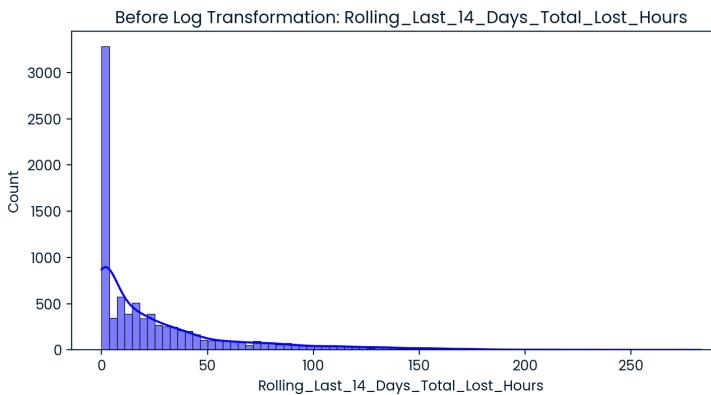
```
Number of Columns selected for log transformation: 125 (76.22%)
```

Columns Recommended for Log Transformation:

```
def log_transform(data, to_log):  
    X = data.copy()  
    for item in to_log:  
        # Ensure all values are positive to avoid log-related errors  
        X[item] = np.where(X[item] > 0, np.log1p(X[item]), 0)  
  
        # Replace potential infinities with NaNs and drop them  
        X[item].replace([np.inf, -np.inf], np.nan, inplace=True)  
        X[item].fillna(0, inplace=True) # Replace NaNs with 0 (or another strategy)  
  
    return X  
##  
# Apply the log transform safely  
df_log = log_transform(df, columns_to_log_transform)
```

```
# Randomly select 10 columns from columns_to_log_transform  
random_columns_to_log_transform = random.sample(columns_to_log_transform, min(5, len(columns_to_log_transform)))  
  
# Set figure size based on the number of randomly selected columns  
plt.figure(figsize=(15, len(random_columns_to_log_transform) * 4))  
  
# Loop through each randomly selected column to visualize before and after transformation  
for i, col in enumerate(random_columns_to_log_transform):  
    plt.subplot(len(random_columns_to_log_transform), 2, 2 * i + 1)  
    sns.histplot(df[col], kde=True, color='blue')  
    plt.title(f'Before Log Transformation: {col}')  
  
    plt.subplot(len(random_columns_to_log_transform), 2, 2 * i + 2)  
    sns.histplot(df_log[col], kde=True, color='red')  
    plt.title(f'After Log Transformation: {col}')  
  
plt.tight_layout()
```

```
plt.show()
```



Initial Train ,Valid ,Test Split with EDA

```
# Calculate the boundaries
df = df_log.sort_index() # ensure it's time-sorted if needed
dftrain = df.copy()

start_date = df.index.min()
end_date = df.index.max()

# Total duration in days
total_days = (end_date - start_date).days

# Calculate the boundaries
train_end_date = start_date + pd.Timedelta(days=int(0.7 * total_days))
valid_end_date = train_end_date + pd.Timedelta(days=int(0.15 * total_days))

# Split the dataset
train_df = df[df.index <= train_end_date]
valid_df = df[(df.index > train_end_date) & (df.index <= valid_end_date)]
test_df = df[df.index > valid_end_date]

#####

print(f'Number of Pass through Columns {len(passthrough_cols)}')
print(f'Number of numerical {len(numeric_cols)}')
print(f'Number of target_col {len(target_col)}')
print(f'Number of feature_cols_all {len(feature_cols_all)}')

# Split train and test
train = train_df.copy()
valid = valid_df.copy()
test = test_df.copy()

#####

print(f'\nNumber of rows in train {len(train)}')
print(f'Number of rows in test {len(test)}')
print(f'Number of rows in valid {len(valid)}')

# # Train-test split
# Step 3: Train-test split based on the index to avoid data leakage
X_train, X_valid, X_test = train[feature_cols], valid[feature_cols], test[feature_cols]
y_train, y_valid, y_test = train[target_col].values.ravel(), valid[target_col].values.ravel(), test[target_col].values.ravel()

print('Performance of Base Random Forest Model')
print(f'\nNumber of rows in X_train {len(X_train)}')
print(f'Number of rows in X_test {len(X_test)}')
print(f'Number of rows in X_valid {len(X_valid)}')
print(f'Number of rows in y_train {len(y_train)}')
print(f'Number of rows in y_valid {len(y_valid)}')
print(f'Number of rows in y_test {len(y_test)}')
```

```
Number of Pass through Columns 26
```

```
Number of numerical 164
```

```
Number of target_col 1
```

```
Number of feature_cols_all 191
```

```
Number of rows in train 6331
```

```
Number of rows in test 1342
```

```
Number of rows in valid 1242
```

```
Performance of Base Random Forest Model
```

```
Number of rows in X_train 6331
```

```
Number of rows in X_test 1342
```

```
Number of rows in X_valid 1242
```

```
Number of rows in y_train 6331
```

```
Number of rows in y_valid 1242
```

Create a Base model to Check Features

```
# Preprocessing pipeline
preprocessor = ColumnTransformer(
    transformers=[
        ('numeric_cols', StandardScaler(), numeric_cols), # Scale only numerical columns excluding dates
        ('passthrough', 'passthrough', passthrough_cols) # Pass through the date columns without transformation
    ]
)

# Define the model
rf = RandomForestRegressor(n_estimators=200
                           , max_depth=20
                           , min_samples_split=2
                           , min_samples_leaf=1
                           , random_state=42)

# Create a pipeline
pipeline = Pipeline(steps=[
    ('preprocessor', preprocessor),
    ('model', rf)
])

# Train the model
pipeline.fit(X_train, y_train)

# Evaluate on Validation Set
y_valid_pred = pipeline.predict(X_valid)
mse_valid = mean_squared_error(y_valid, y_valid_pred)
r2_valid = r2_score(y_valid, y_valid_pred)
mae_valid = mean_absolute_error(y_valid, y_valid_pred)
rmse_valid = np.sqrt(mse_valid)

print('Validation Performance of Base Random Forest Model:')
print(f'R-squared (R2): {r2_valid:.4f}')
print(f'MSE: {mse_valid:.4f}')
print(f'MAE: {mae_valid:.4f}')
print(f'RMSE: {rmse_valid:.4f}')
```

```

# Final evaluation on Test Set
y_test_pred = pipeline.predict(X_test)
mse_test = mean_squared_error(y_test, y_test_pred)
r2_test = r2_score(y_test, y_test_pred)
mae_test = mean_absolute_error(y_test, y_test_pred)
rmse_test = np.sqrt(mse_test)

# Print evaluation metrics
print('Test Performance of Base Random Forest Model')
print('Random Forest R-squared (R2) score: {:.4f}'.format(r2_test))
print('Random Forest Mean Squared Error (MSE): {:.4f}'.format(mse_test))
print('Random Forest Mean Absolute Error (MAE): {:.4f}'.format(mae_test))
print('Random Forest Root Mean Squared Error (RMSE): {:.4f}'.format(rmse_test))

# Extract feature importances from the Random Forest model
importances = pipeline.named_steps['model'].feature_importances_

# This ensures correct mapping of features
feature_names = numeric_cols + passthrough_cols

# Ensure the length matches
assert len(feature_names) == len(importances), "Mismatch between feature names and importances."

# Create a DataFrame for feature importances
feature_importances = pd.DataFrame({
    'Feature': feature_names,
    'Importance': importances
})

# Sort feature importances in descending order
feature_importances = feature_importances.sort_values(by='Importance', ascending=False)

# Display top 10 feature importances
print("\nTop 10 Feature Importances:")
print(feature_importances.head(10))

```

Validation Performance of Base Random Forest Model:

R-squared (R2): 0.4694

MSE: 14.3138

MAE: 2.1922

RMSE: 3.7834

Test Performance of Base Random Forest Model

Random Forest R-squared (R2) score: 0.5201

Random Forest Mean Squared Error (MSE): 14.0804

Random Forest Mean Absolute Error (MAE): 2.0001

Random Forest Root Mean Squared Error (RMSE): 3.7524

Top 10 Feature Importances:

	Feature	Importance
--	---------	------------

54	Rolling_Last_7_Days_Total_Lost_Hours	0.392537
62	Scheduled_HC%	0.044718

Comments on Model Performance: Basic vs. Modeled Dataset

Comparison of Results

● Basic Dataset (ML_Absenteeism)

- R2: 0.368 → Weak predictive power
- MSE: 242.98 | RMSE: 15.59 | MAE: 13.93 → High errors
- Avg Total_Lost (Actual vs. Predicted): 38.96 vs. 36.79 → Bias in predictions
- Issue: Lacks advanced features (rolling metrics, cyclical patterns)

● Modeled Dataset (ML_Absenteeism_MU_Grouped)

- R2: 0.5201 (Test) | 0.4694 (Validation) → Significant improvement
- MSE: 14.08 | RMSE: 3.75 | MAE: 2.00 (Test) → Much lower errors

🔥 Top 5 Feature Importances

1. Rolling_Last_7_Days_Total_Lost_Hours (39.26%)
2. Scheduled_HC% (4.51%)
3. AVG_Scheduled_Hours (3.37%)
4. Strike_Participant% (3.01%)
5. Rolling_Last_14_Days_Total_Lost_Hours (2.57%)

📌 Key Takeaways

- ✓ Feature Engineering Matters → Rolling metrics & lagged values drive performance
- ✓ Modeled Dataset Wins → Higher R2, lower errors, and better insights
- ✓ Iteration Works → Improving features directly impacts predictive power

Final Thought: Structured data leads to stronger models. ✎ 🔥

Class Distribution in Total_Lost for Zero Values vs Non Zero Values

⌚ Addressing Class Imbalance with a Classification Step

⚠ Why This Step?

Our dataset shows a severe class imbalance in the `Total_Lost` variable:

- Zero Total_Lost: 72%
- Non-zero Total_Lost: 28%

This imbalance can negatively impact regression models by:

- Biassing predictions towards zero
- Reducing sensitivity to non-zero absenteeism patterns

📌 What Are We Aiming For?

To tackle this, we've introduced a classification step that:

1. Identifies whether `Total_Lost` will be zero or non-zero (binary classification).
2. Improves regression accuracy by focusing on predicting non-zero values more effectively.

This approach helps the model:

- Reduce error rates on non-zero cases
- Enhance predictive power for critical absenteeism instances

Key Idea:

By treating the problem as a hurdle model, we first classify the likelihood of absenteeism and then predict the actual absenteeism amount for non-zero cases. This two-step method improves performance in imbalanced datasets like ours. 🚀

```
No_Total_Lost = (df['Total_Lost'] == 0).astype(int).sum()
Yes_Total_Lost = (df['Total_Lost'] > 0).astype(int).sum()
Total_Size = df.shape[0]
```

```

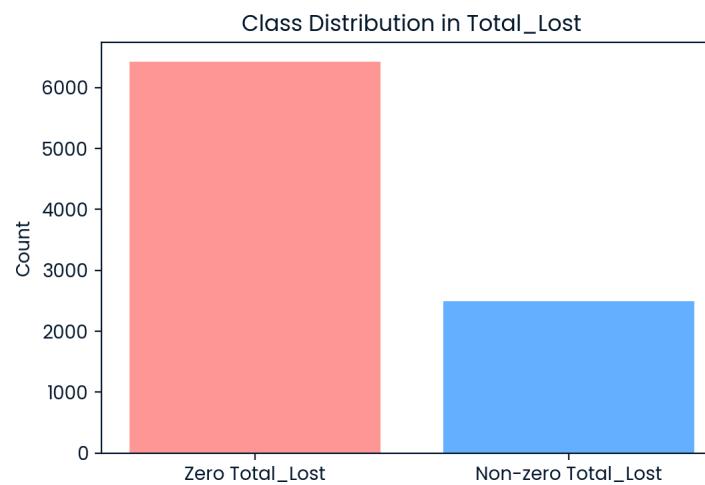
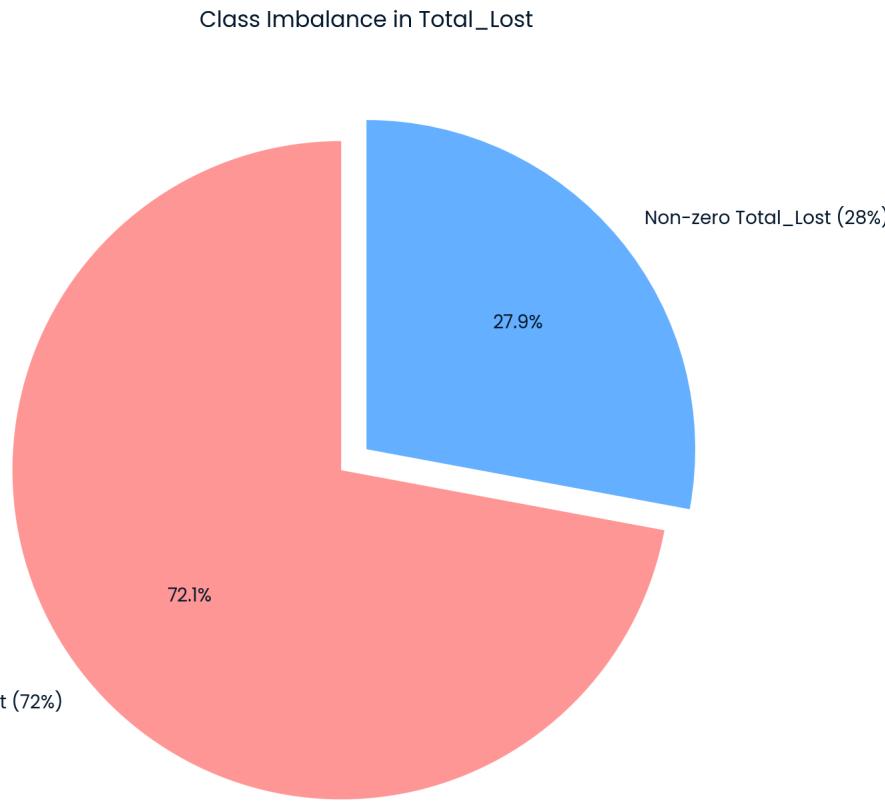
# Percentage Calculation
no_total_lost_percent = (No_Total_Lost / Total_Size) * 100
yes_total_lost_percent = (Yes_Total_Lost / Total_Size) * 100

# Pie Chart to Visualize Class Imbalance
labels = ['Zero Total_Lost (72%)', 'Non-zero Total_Lost (28%)']
sizes = [no_total_lost_percent, yes_total_lost_percent]
explode = (0.1, 0) # Explode the first slice (Zero Total_Lost)

plt.figure(figsize=(8, 8))
plt.pie(sizes, labels=labels, autopct='%1.1f%%', startangle=90, colors=['#ff9999', '#66b3ff'], explode=explode)
plt.title('Class Imbalance in Total_Lost')
plt.show()

# Bar Chart for Class Distribution
plt.figure(figsize=(6, 4))
plt.bar(['Zero Total_Lost', 'Non-zero Total_Lost'], [No_Total_Lost, Yes_Total_Lost], color=['#ff9999', '#66b3ff'])
plt.title('Class Distribution in Total_Lost')
plt.ylabel('Count')
plt.show()

```



Non Zero Total_Lost Prediction Flag Classifier

```
#####
# Define a transformer to ensure the input is a DataFrame
#####
class EnsureDataFrame(BaseEstimator, TransformerMixin):
    def __init__(self, columns):
        self.columns = columns
    def fit(self, X, y=None):
        return self
    def transform(self, X, y=None):
        # If X is not a DataFrame, create one using as many columns as available
        if not isinstance(X, pd.DataFrame):
            n_cols = X.shape[1]
            # Use the first n_cols of the expected columns
            cols = self.columns[:n_cols]
            X = pd.DataFrame(X, columns=cols)
        # Now, if any expected columns are missing, add them with NaN values.
        missing = [col for col in self.columns if col not in X.columns]
        for col in missing:
            X[col] = np.nan
        # Finally, reindex the DataFrame to ensure it has exactly self.columns in that order.
        return X[self.columns]

#####
# 3. Setup for Classification
#####
# For classification, we work with historical (labeled) data.
# Use only training data to create the classification target.
df_hurdle = train.copy()
df_hurdle['NonZeroFlag'] = (df_hurdle['Total_Lost'] > 0).astype(int)

# For evaluation purposes, ensure that valid and test sets also have the target.
if 'NonZeroFlag' not in valid.columns:
    valid['NonZeroFlag'] = (valid['Total_Lost'] > 0).astype(int)
if 'NonZeroFlag' not in test.columns:
    test['NonZeroFlag'] = (test['Total_Lost'] > 0).astype(int)

# Define the classification features: exclude the regression target and the flag.
class_feature_cols = [c for c in df_hurdle.columns if c not in ['Total_Lost', 'NonZeroFlag']]
X_train_class = df_hurdle[class_feature_cols]
y_train_class = df_hurdle['NonZeroFlag'].values

# Prepare the validation and test sets using the same features.
X_valid_class = valid[class_feature_cols]
X_test_class = test[class_feature_cols]

print("== Data Shapes ==")
print("Train Classification:", X_train_class.shape, y_train_class.shape)
print("Valid Classification:", X_valid_class.shape)
print("Test Classification:", X_test_class.shape)

#####
# 4. Define Classifiers + Random Search Distributions
#####
candidate_classifiers = {
    "RandomForest": (
        RandomForestClassifier(random_state=42),
        {
            "n_estimators": randint(50, 300),
            "max_depth": [None, 5, 10, 20],
            "min_samples_split": randint(2, 10),
            "min_samples_leaf": randint(1, 5)
        }
    ),
    "XGBoost": (
        XGBClassifier(random_state=42, use_label_encoder=False, eval_metric='logloss'),
        {
            "n_estimators": randint(50, 300),
            "max_depth": randint(2, 8),
            "learning_rate": uniform(0.01, 0.3),
            "subsample": uniform(0.5, 0.5),
            "colsample_bytree": uniform(0.5, 0.5)
        }
    ),
}
```

```

"LogisticRegression": (
    LogisticRegression(random_state=42, max_iter=2000),
    {
        "C": uniform(0.01, 10.0),
        "penalty": ["l2"]
    }
)

# Use the same preprocessing for classification as in regression.
# (Assumes that numeric_cols and passthrough_cols are defined elsewhere.)
preprocessor_class = ColumnTransformer([
    ('numeric_cols', StandardScaler(), numeric_cols),
    ('passthrough', 'passthrough', passthrough_cols)
])

#####
# 5. Randomized Search -> Best Hyperparams (Adjusted for validation)
#####

best_PIPELINES = {}
RESULTS_SUMMARY = {}

tscv = TimeSeriesSplit(n_splits=3)
print("\n== RANDOMIZED SEARCH ==")
for model_name, (model_obj, param_dist) in candidate_classifiers.items():
    print(f"\n== RandomizedSearchCV for {model_name} ==")

    pipe = Pipeline([
        ("preprocessor", preprocessor_class),
        ("classifier", model_obj)
    ])

    rand_search = RandomizedSearchCV(
        pipe,
        param_distributions={ "classifier__" + k: v for k, v in param_dist.items() },
        n_iter=10,
        scoring='accuracy',
        cv=tscv,
        random_state=42,
        n_jobs=-1,
        verbose=1
    )

    rand_search.fit(X_train_class, y_train_class)

    print("Best Params:", rand_search.best_params_)
    print(f"Best CV Score: {rand_search.best_score_:.4f}")

    # Evaluate on validation and test sets.
    best_model_pipeline = rand_search.best_estimator_
    y_valid_pred = best_model_pipeline.predict(X_valid_class)
    acc_valid = accuracy_score(valid['NonZeroFlag'], y_valid_pred)
    y_test_pred = best_model_pipeline.predict(X_test_class)
    acc_test = accuracy_score(test['NonZeroFlag'], y_test_pred)

    best_PIPELINES[model_name] = best_model_pipeline
    RESULTS_SUMMARY[model_name] = {
        "best_params": rand_search.best_params_,
        "cv_score": rand_search.best_score_,
        "valid_accuracy": acc_valid,
        "test_accuracy": acc_test
    }

    print(f"Validation Accuracy: {acc_valid:.4f}")
    print(f"Test Accuracy: {acc_test:.4f}")

#####
# 6. Integrated Pipeline with RFECV (Using the Best Classifier)
#####

# Select the best model based on validation accuracy.
best_MODEL_NAME = max(RESULTS_SUMMARY, key=lambda x: RESULTS_SUMMARY[x]['valid_accuracy'])
print(f"\n== Best Model after Randomized Search: {best_MODEL_NAME} ==")
best_PIPE = best_PIPELINES[best_MODEL_NAME]
print("Best Hyperparameters:", best_PIPE.named_steps['classifier'].get_params())

# Extract the best classifier.
best_classifier = best_PIPE.named_steps['classifier']

# Build an integrated pipeline where:

```

```

# 1. The preprocessor (ColumnTransformer) is applied first.
# 2. RFECV is applied to the transformed data using the best classifier.
pipe_rfecv = Pipeline([
    ('preprocessor', preprocessor_class),
    ('rfecv', RFECV(
        estimator=clone(best_classifier),
        step=1,
        cv=tscv,
        scoring='accuracy',
        n_jobs=-1,
        importance_getter=lambda est: (est.coef_ if hasattr(est, 'coef_') else est.feature_importances_)
    )))
])

# Fit the integrated pipeline on the training classification data.
pipe_rfecv.fit(X_train_class, y_train_class)

print("\n==== Integrated Pipeline with RFECV Results ===")
n_features_selected = pipe_rfecv.named_steps['rfecv'].n_features_
print("Optimal number of features selected by RFECV:", n_features_selected)
if hasattr(pipe_rfecv.named_steps['rfecv'], 'cv_results_'):
    best_cv_score = pipe_rfecv.named_steps['rfecv'].cv_results_['mean_test_score'].max()
    print("Best CV Score with selected features:", best_cv_score)
else:
    print("CV results not available.")

y_valid_pred_rfecv = pipe_rfecv.predict(X_valid_class)
val_acc_rfecv = accuracy_score(valid['NonZeroFlag'], y_valid_pred_rfecv)
y_test_pred_rfecv = pipe_rfecv.predict(X_test_class)
test_acc_rfecv = accuracy_score(test['NonZeroFlag'], y_test_pred_rfecv)
print("Validation Accuracy (RFECV):", val_acc_rfecv)
print("Test Accuracy (RFECV):", test_acc_rfecv)

#####
# 7. Threshold Tuning on Validation Set using the Integrated Pipeline
#####
# Generate out-of-fold (OOF) predictions using the RFECV pipeline.
oof_proba = np.zeros(len(X_train_class))
for train_idx, val_idx in tscv.split(X_train_class):
    X_train_fold, X_val_fold = X_train_class.iloc[train_idx], X_train_class.iloc[val_idx]
    y_train_fold = y_train_class[train_idx]

    # Clone the entire RFECV pipeline for each fold.
    fold_pipe = clone(pipe_rfecv)
    fold_pipe.fit(X_train_fold, y_train_fold)
    oof_proba[val_idx] = fold_pipe.predict_proba(X_val_fold)[:, 1]

# Threshold tuning on OOF predictions (not using the separate validation set).
thresholds = np.linspace(0.1, 0.9, 9)
best_thresh = 0.5
best_acc = 0
for th in thresholds:
    current_acc = accuracy_score(y_train_class, (oof_proba >= th).astype(int))
    if current_acc > best_acc:
        best_acc = current_acc
        best_thresh = th

print(f"\nOptimal Threshold: {best_thresh:.2f}, Training Accuracy: {best_acc:.4f}")

# Add OOF predictions to training data.
train['Pred_NonZeroProb'] = oof_proba
train['Pred_NonZeroFlag'] = (oof_proba >= best_thresh).astype(int)

#####
# 8. Final Predictions and Feature Engineering
#####
def add_predictions(data, pipe, threshold, feature_set):
    """Helper function to apply full pipeline and add prediction columns."""
    X = data[feature_set]
    proba = pipe.predict_proba(X)[:, 1]
    data['Pred_NonZeroProb'] = proba
    data['Pred_NonZeroFlag'] = (proba >= threshold).astype(int)
    return data

# Use the final RFECV pipeline for predictions.
valid = add_predictions(valid, pipe_rfecv, best_thresh, class_feature_cols)
test = add_predictions(test, pipe_rfecv, best_thresh, class_feature_cols)

```

```
#####
# 9. Update Feature Columns for Regression
#####
# For regression, include the new prediction features.
updated_passthrough_cols = passthrough_cols + ['Pred_NonZeroProb', 'Pred_NonZeroFlag']
reg_feature_cols = updated_passthrough_cols + numeric_cols
reg_feature_cols_all = reg_feature_cols + target_col

# Final data splits for regression.
X_train = train[reg_feature_cols]
y_train = train[target_col].values.ravel()

X_valid = valid[reg_feature_cols]
y_valid = valid[target_col].values.ravel()

X_test = test[reg_feature_cols]
y_test = test[target_col].values.ravel()

print("\n== Final Data Shapes for Regression ==")
print("Train:", X_train.shape)
print("Valid:", X_valid.shape)
print("Test:", X_test.shape)
```

==== Data Shapes ===

Train Classification: (6331, 190) (6331,)

Valid Classification: (1242, 190)

Test Classification: (1342, 190)

==== RANDOMIZED SEARCH ===

==== RandomizedSearchCV for RandomForest ===

Fitting 3 folds for each of 10 candidates, totalling 30 fits

Best Params: {'classifier__max_depth': 20, 'classifier__min_samples_leaf': 4, 'classifier__min_samples_split': 6, 'classifier__n_estimators': 210}

Best CV Score: 0.8089

Validation Accuracy: 0.8245

Test Accuracy: 0.8629

```
#####
updated_passthrough_cols
reg_feature_cols
reg_feature_cols_all
#####
print(f'Number of Pass through Columns {len(updated_passthrough_cols)}')
print(f'Number of numerical {len(numeric_cols)}')
print(f'Number of target_col {len(target_col)}')
print(f'Number of feature_cols_all {len(reg_feature_cols_all)}')
```

Base Model with Classifiers

```
# Preprocessing pipeline
preprocessor = ColumnTransformer(
    transformers=[
        ('numeric_cols', StandardScaler(), numeric_cols), # Scale only numerical columns excluding dates
        ('passthrough', 'passthrough', updated_passthrough_cols) # Pass through the date columns without transformation
    ]
)
```

```

# Define the model
rf = RandomForestRegressor(n_estimators=200
                           , max_depth=20
                           , min_samples_split=2
                           , min_samples_leaf=1
                           , random_state=42)

# Create a pipeline
pipeline = Pipeline(steps=[
    ('preprocessor', preprocessor),
    ('model', rf)
])

# Train the model
pipeline.fit(X_train, y_train)

# Evaluate on Validation Set
y_valid_pred = pipeline.predict(X_valid)
mse_valid = mean_squared_error(y_valid, y_valid_pred)
r2_valid = r2_score(y_valid, y_valid_pred)
mae_valid = mean_absolute_error(y_valid, y_valid_pred)
rmse_valid = np.sqrt(mse_valid)

print('Validation Performance of Base Random Forest Model with Classifiers :')
print(f'R-squared (R2): {r2_valid:.4f}')
print(f'MSE: {mse_valid:.4f}')
print(f'MAE: {mae_valid:.4f}')
print(f'RMSE: {rmse_valid:.4f}')

# Final evaluation on Test Set
y_test_pred = pipeline.predict(X_test)
mse_test = mean_squared_error(y_test, y_test_pred)
r2_test = r2_score(y_test, y_test_pred)
mae_test = mean_absolute_error(y_test, y_test_pred)
rmse_test = np.sqrt(mse_test)

# Print evaluation metrics
print('Test Performance of Base Random Forest Model with Classifiers :')
print('Random Forest R-squared (R2) score: {:.4f}'.format(r2_test))
print('Random Forest Mean Squared Error (MSE): {:.4f}'.format(mse_test))
print('Random Forest Mean Absolute Error (MAE): {:.4f}'.format(mae_test))
print('Random Forest Root Mean Squared Error (RMSE): {:.4f}'.format(rmse_test))

# Extract feature importances from the Random Forest model
importances = pipeline.named_steps['model'].feature_importances_

# This ensures correct mapping of features
feature_names = numeric_cols + updated_passthrough_cols

# Ensure the length matches
assert len(feature_names) == len(importances), "Mismatch between feature names and importances."

# Create a DataFrame for feature importances
feature_importances = pd.DataFrame({
    'Feature': feature_names,
    'Importance': importances
})

# Sort feature importances in descending order
feature_importances = feature_importances.sort_values(by='Importance', ascending=False)

# Display top 10 feature importances
print("\nTop 10 Feature Importances:")
print(feature_importances.head(10))

```

Validation Performance of Base Random Forest Model with Classifiers :

R-squared (R2): 0.4728

MSE: 14.2214

MAE: 2.1838

RMSE: 3.7711

Test Performance of Base Random Forest Model with Classifiers :

Random Forest R-squared (R2) score: 0.5156

Random Forest Mean Squared Error (MSE): 14.2135

Random Forest Mean Absolute Error (MAE): 1.9999

Random Forest Root Mean Squared Error (RMSE): 3.7701

Top 10 Feature Importances:

	Feature	Importance
54	Rolling_Last_7_Days_Total_Lost_Hours	0.389008
62	Scheduled_HC%	0.045265

Base Random Forest Model with Selected Features and Classifier

```
# Calculate cumulative sum of importances
feature_importances['Cumulative_Importance'] = np.cumsum(feature_importances['Importance']) * 100

# Determine the number of features required to reach 90% and 95% cumulative importance
cumulative_feature_importances_90 = len(feature_importances[feature_importances.Cumulative_Importance <= 90])
cumulative_feature_importances_95 = len(feature_importances[feature_importances.Cumulative_Importance <= 95])

print(f'{cumulative_feature_importances_90} features required to fulfill approximately 90% of the highest features in the dataset')
print(f'{cumulative_feature_importances_95} features required to fulfill approximately 95% of the highest features in the dataset')

# Select the top N features covering 95% importance
N = cumulative_feature_importances_95
top_features = feature_importances.head(N)[['Feature']].tolist()

# Filter the original dataset to only include the selected features

selected_features = top_features
selected_features_rf = selected_features
X_train_selected = X_train[selected_features]
X_valid_selected = X_valid[selected_features]
X_test_selected = X_test[selected_features]

# Re-train the pipeline with the selected features
# Rebuild the preprocessing pipeline with selected features
selected_numeric_cols = [col for col in selected_features if col in numeric_cols]
selected_passthrough_cols = [col for col in selected_features if col in updated_passthrough_cols]
# Updated ColumnTransformer to match the selected features
preprocessor = ColumnTransformer(
    transformers=[
        ('numeric_cols', StandardScaler(), selected_numeric_cols),
        ('passthrough', 'passthrough', selected_passthrough_cols)
    ]
)

# Rebuild the pipeline
pipeline = Pipeline(steps=[
    ('preprocessor', preprocessor),
    ('model', rf)
])
```

```

pipeline.fit(X_train_selected, y_train)

# Evaluate on Validation Set
y_valid_pred = pipeline.predict(X_valid_selected)
mse_valid = mean_squared_error(y_valid, y_valid_pred)
r2_valid = r2_score(y_valid, y_valid_pred)
mae_valid = mean_absolute_error(y_valid, y_valid_pred)
rmse_valid = np.sqrt(mse_valid)

print('Validation Performance of Base Random Forest Model with Selected Features')
print(f'R-squared (R2): {r2_valid:.4f}')
print(f'MSE: {mse_valid:.4f}')
print(f'MAE: {mae_valid:.4f}')
print(f'RMSE: {rmse_valid:.4f}')

# Final evaluation on Test Set
y_test_pred = pipeline.predict(X_test_selected)
mse_test = mean_squared_error(y_test, y_test_pred)
r2_test = r2_score(y_test, y_test_pred)
mae_test = mean_absolute_error(y_test, y_test_pred)
rmse_test = np.sqrt(mse_test)

# Print evaluation metrics
print('Test Performance of Base Random Forest Model with Selected Features')
print('Random Forest R-squared (R2) score: {:.4f}'.format(r2_test))
print('Random Forest Mean Squared Error (MSE): {:.4f}'.format(mse_test))
print('Random Forest Mean Absolute Error (MAE): {:.4f}'.format(mae_test))
print('Random Forest Root Mean Squared Error (RMSE): {:.4f}'.format(rmse_test))

# Display top 10 feature importances
print("\nTop 10 Feature Importances:")
print(feature_importances.head(10))

# Adjusted plot for top feature importances
plt.figure(figsize=(14, max(8, len(feature_importances.head(N)) * 0.5))) # Dynamic height based on the number of features
sns.barplot(
    x=feature_importances.head(N)[ 'Importance'],
    y=feature_importances.head(N)[ 'Feature'],
    palette='viridis'
)

# Customize plot aesthetics
plt.xlabel('Feature Importance', fontsize=14)
plt.ylabel('Feature', fontsize=14)
plt.title(f'Top {N} Feature Importances from Random Forest', fontsize=16, pad=20)
plt.xticks(fontsize=12)
plt.yticks(fontsize=12)

# Adjust layout for better spacing
plt.tight_layout()
plt.show()

```

88 features required to fulfill approximately 90% of the highest features in the dataset

118 features required to fulfill approximately 95% of the highest features in the dataset

Validation Performance of Base Random Forest Model with Selected Features

R-squared (R2): 0.4686

MSE: 14.3355

MAE: 2.2024

RMSE: 3.7862

Test Performance of Base Random Forest Model with Selected Features

Random Forest R-squared (R2) score: 0.5107

Random Forest Mean Squared Error (MSE): 14.3556

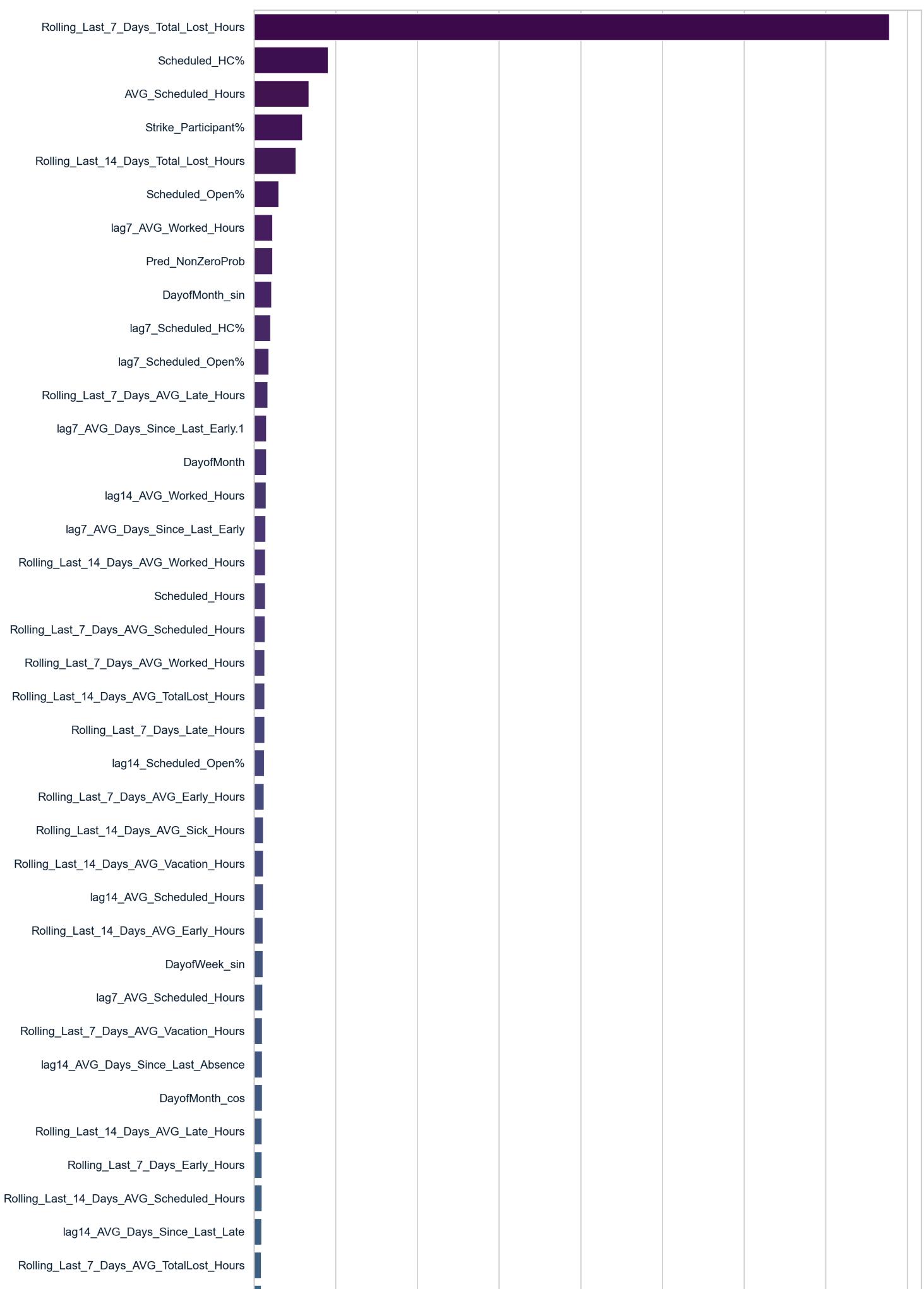
Random Forest Mean Absolute Error (MAE): 2.0105

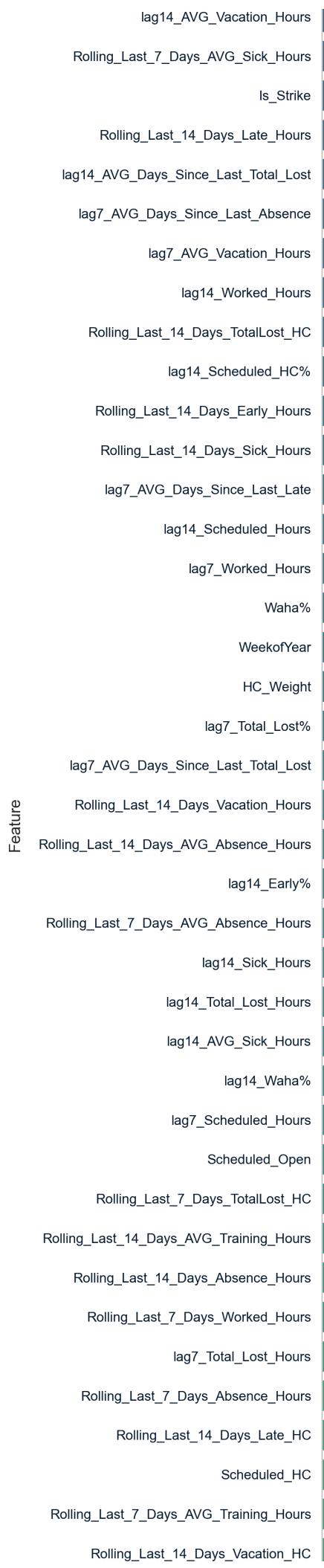
Random Forest Root Mean Squared Error (RMSE): 3.7889

Top 10 Feature Importances:

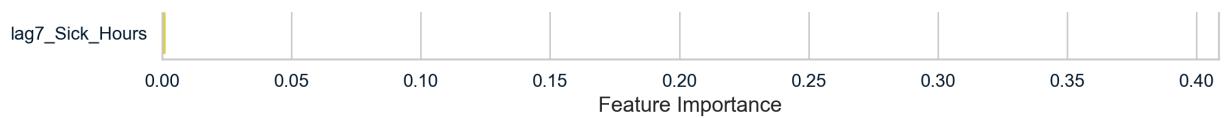
Feature	Importance	Cumulative_Importance
---------	------------	-----------------------

Top 118 Feature Importances from Random Forest





lag7_AVG_Sick_Hours
DayofWeek
lag14_Worked_HC
Rolling_Last_7_Days_Training_Hours
Rolling_Last_7_Days_Late_HC
Rolling_Last_7_Days_Vacation_Hours
lag14_Total_Lost%
Rolling_Last_7_Days_Sick_Hours
lag7_AVG_Training_Hours
lag14_Max_Early_Hours
Rolling_Last_14_Days_Worked_Hours
Rolling_Last_14_Days_Early_HC
Rolling_Last_7_Days_Vacation_HC
DayofWeek_cos
Rolling_Last_14_Days_Scheduled_Hours
lag14_AVG_Absence%
Rolling_Last_7_Days_Scheduled_HC
Rolling_Last_7_Days_Early_HC
Rolling_Last_7_Days_Scheduled_Hours
lag7_AVG_Early%
lag14_AVG_Training_Hours
Rolling_Last_14_Days_Training_HC
Rolling_Last_14_Days_Training_Hours
lag14_Absence%
lag14_Early_Hours
lag7_AVG_Total_Lost%
lag14_Scheduled_Open
lag7_Scheduled_Open
lag7_AVG_TotalLost_Hours
Rolling_Last_14_Days_Worked_HC
lag7_Late%
lag7_Early%
lag7_AVG_Absence%
Rolling_Last_14_Days_Absence_HC
lag7_Waha%
Month_cos
Rolling_Last_7_Days_Worked_HC
lag14_AVG_Early%
Rolling_Last_7_Days_Training_HC



Model Performance Comparison

1 Base Random Forest Model (Without Classification)

Validation Performance:

- R-squared (R2): 0.4694
- MSE: 14.3138
- MAE: 2.1922
- RMSE: 3.7834

Test Performance:

- R-squared (R2): 0.5201
- MSE: 14.0804
- MAE: 2.0001
- RMSE: 3.7524

2 With Classification Step (Before Feature Selection)

Validation Performance:

- R-squared (R2): 0.4728 (\uparrow Slight Improvement)
- MSE: 14.2214 (\downarrow Slight Decrease)
- MAE: 2.1838 (\downarrow Slight Decrease)
- RMSE: 3.7711 (\downarrow Slight Decrease)

Test Performance:

- R-squared (R2): 0.5156 (\downarrow Decreased)
- MSE: 14.2135 (\uparrow Increased)
- MAE: 1.9999 (\approx Same as Base Model)
- RMSE: 3.7701 (\uparrow Increased)

3 With Classification + Selected Features (After RFECV)

Validation Performance:

- R-squared (R2): 0.4686 (\downarrow Decreased)
- MSE: 14.3355 (\uparrow Increased)
- MAE: 2.2024 (\uparrow Increased)
- RMSE: 3.7862 (\uparrow Increased)

Test Performance:

- R-squared (R2): 0.5107 (\downarrow Decreased)
- MSE: 14.3556 (\uparrow Increased)
- MAE: 2.0105 (\uparrow Increased)
- RMSE: 3.7889 (\uparrow Increased)

⚠️ Key Observations

✗ 1. The Classification Step Does NOT Improve Performance

- Test R2 decreased from 0.5201 \rightarrow 0.5156 after adding the classification step, showing **reduced generalization capability**.
- MSE & RMSE increased on the test set, meaning the model's predictions became **less accurate**.

- **Conclusion:**
Despite a minor validation improvement, the classification step fails to improve real-world performance and may even introduce unnecessary complexity without added benefit.

🚫 2. RFECV Feature Selection Further Reduces Performance

- R2 dropped on both validation and test sets after feature selection (0.5156 → 0.5107 on the test set).
- Error metrics worsened, indicating that critical features were removed, leading to underfitting.
- Conclusion:
RFECV seems to have negatively impacted the model by over-selecting features, further degrading performance.

🚀 Final Conclusion

- **The Classification Step Adds No Value:**
It reduces model performance on the test set, indicating it's ineffective in handling class imbalance in this context.
- **Feature Selection (RFECV) Worsens the Issue:**
Removing features leads to poorer performance due to the loss of important predictive signals.

⚡ Recommendation:

- Remove the classification step and focus on optimizing the base model.
- Re-evaluate feature selection strategies—consider using model-based feature importance instead of RFECV.
- Focus on regularization or advanced ensemble techniques to handle class imbalance more effectively.

Bottom Line:

The classification step, instead of enhancing performance, introduces complexity and slightly degrades results. The base model remains the most reliable approach for this problem. 🚫

```
#####
X_train = train[feature_cols]
y_train = train[target_col].values.ravel()

X_valid = valid[feature_cols]
y_valid = valid[target_col].values.ravel()

X_test = test[feature_cols]
y_test = test[target_col].values.ravel()

#####
print(f'Number of Pass through Columns {len(passthrough_cols)}')
print(f'Number of numerical {len(numeric_cols)}')
print(f'Number of target_col {len(target_col)}')
print(f'Number of feature_cols_all {len(feature_cols_all)}')
```

Before Standard Scaler

```
X_train[numeric_cols].describe()
```

...	↑↓	AVG_Scheduled_...	...	↑↓	DayofM...	...	↑↓	DayofMont...	...	↑↓	Dayof...	...	↑↓	Dayof...	...	↑↓	HC	...	↑↓	HC_...	...	↑↓	Month_c...
count		6331			6331			6331			6331			6331			6331			6331			
mean		5.3698992547			-0.0299637811			-0.0128672971			0.0039743828			0.001554993			19.9881535302			0.0832935134			-0.
std		2.6723442478			0.699715699			0.7137873318			0.707592902			0.7067192132			14.8331324596			0.0614898356			0.6
min		0			-0.9948693234			-0.9987165072			-0.9009688679			-0.9749279122			1			0.0035842294			
25%		3.6428461538			-0.7587581227			-0.7247927872			-0.9009688679			-0.7818314825			8			0.0350877193			-0.8
50%		6.4597297297			-0.0506491688			-2.449293598e-16			-0.222520934			0			15			0.0598290598			6.1232
75%		7.3333333333			0.6889669191			0.7247927872			0.6234898019			0.7818314825			34			0.1441244738			
max		8.0909090909			1			0.9987165072			1			0.9749279122			58			0.2256809339			

Rows: 8 ↓

```
# Select numerical columns for scaling
X_train_numeric = X_train[numeric_cols]
X_test_numeric = X_test[numeric_cols]
X_valid_numeric = X_valid[numeric_cols]
```

```

# Initialize a standard scaler and fit it
scaler = StandardScaler()
scaler.fit(X_train_numeric)

# Scale and center the numerical data
X_train_scaled_numeric = scaler.transform(X_train_numeric)
X_test_scaled_numeric = scaler.transform(X_test_numeric)
X_valid_scaled_numeric = scaler.transform(X_valid_numeric)

# Replace the scaled numerical columns in the original DataFrame
X_train_e_l_n = X_train.copy()
X_test_e_l_n = X_test.copy()
X_valid_e_l_n = X_valid.copy()

X_train_e_l_n[numeric_cols] = X_train_scaled_numeric
X_test_e_l_n[numeric_cols] = X_test_scaled_numeric
X_valid_e_l_n[numeric_cols] = X_valid_scaled_numeric

```

After Standar Scaler

```
X_train_e_l_n[numeric_cols].describe()
```

	...	↑↓	AVG_Scheduled_...	...	↑↓	DayofMon...	...	↑↓	DayofMon...	...	↑↓	DayofWee...	...	↑↓	DayofWeek...	...	↑↓	HC	...	↑↓	HC_Weight	...
count			6331			6331			6331			6331			6331			6331			6331	
mean			2.648682446e-16			-1.12232307e-18			2.020181526e-17			7.800145338e-17			-2.020181526e-17			1.057789494e-16			1.952842142e-16	
std			1.0000789858			1.0000789858			1.0000789858			1.0000789858			1.0000789858			1.0000789858			1.0000789858	
min			-2.0095926657			-1.3791054819			-1.3812616648			-1.2790048145			-1.3818218258			-1.2802186845			-1.29640255	
25%			-0.6463199922			-1.0416400649			-0.9974703815			-1.2790048145			-1.1085708968			-0.8082649068			-0.7840255	
50%			0.4078503573			-0.0295648956			0.0180282177			-0.3201179747			-0.002200472			-0.336311129			-0.3816290	
75%			0.7347815177			1.0275423098			1.033526817			0.8755943569			1.1041699527			0.9447062679			0.9893629	
max			1.0182912473			1.4720909294			1.4173181002			1.4077364064			1.3774208818			2.562833506			2.3158082	

Rows: 8 ↓

Please note that:

Tree-based models: Algorithms such as Decision Trees, Random Forest, and Gradient Boosting (e.g., XGBoost, LightGBM) do not require scaling because they split on feature values rather than relying on distances or gradients.

However:

Scaling after log transformations: Even for tree-based models, scaling after applying log transformations to skewed columns ensures that the transformed features are properly centered and normalized, which can improve preprocessing consistency and interpretability.

Additionally:

Standard Scaler: Applying the Standard Scaler ensures a smooth testing period by standardizing numerical features, especially when transitioning between training, validation, and testing datasets.

```

print(range(X_train_e_l_n.shape[1]))

# Set attributes for PCA analysis
n=X_train_e_l_n[feature_cols].shape[1]

columns = ['PCA_' + str(i+1) for i in range(X_train_e_l_n[feature_cols].shape[1])]

# Create the PCA instance and fit and transform the data with pca
pca = PCA(n_components=n)
pc = pca.fit_transform(X_train_e_l_n[feature_cols])
df_pc = pd.DataFrame(pc, columns=columns, index=X_train_e_l_n[feature_cols].index)

df_pc.head()

range(0, 190)

```

Date	... ↑↓	PCA_1	... ↑↓	PCA_2	... ↑↓	PCA_3	... ↑↓	PCA_4	... ↑↓	PCA_5	... ↑↓	PCA...	... ↑↓	PCA_7	... ↑↓
2023-01-15T00:00:00.000		-21.6389870493		-0.5640688872		-9.9419604765		-3.0371757429		-3.4034862982		5.4474558785		-5.8321024374	
2023-01-15T00:00:00.000		-21.4759719494		-0.5248892002		-7.4900809516		-1.7793598872		-1.6026456274		2.2727083757		-3.6827611379	
2023-01-15T00:00:00.000		-21.7023102767		-0.5689364304		-7.8710169695		-0.8534355658		-2.3116002185		2.1717185331		-6.0871332534	
2023-01-15T00:00:00.000		-21.7711206311		-0.5331706786		-5.9043307911		-0.8628049855		-5.6881139668		3.0980235837		-7.6612481589	
2023-01-15T00:00:00.000		-21.7827206899		-0.5390480499		-5.2652263336		-0.5177754247		-4.3521043815		1.6595820179		-7.4583887693	

Rows: 5 ↓

X_train_e_l_n.shape

(6331, 190)

```
cumulative_var_explained = np.cumsum(pca.explained_variance_ratio_)*100
cumulative_var_explained_high = len(cumulative_var_explained[cumulative_var_explained<=95])
cumulative_var_explained = len(cumulative_var_explained[cumulative_var_explained<=90])
print(f'{cumulative_var_explained} feautres required to explain approximately 90% of the variance in the dataset'))
print(f'{cumulative_var_explained_high} feautres required to explain approximately 95% of the variance in the dataset'))
```

14 feautres required to explain approximately 90% of the variance in the dataset

24 feautres required to explain approximately 95% of the variance in the dataset

```
#Convert y_train to a Pandas Series
y_train_series = pd.Series(y_train, index=X_train_e_l_n[feature_cols].index, name='Target')

# Concatenate PCA components with target variable
df_PCA = pd.concat([df_pc, y_train_series], axis=1)

# Display the first few rows
df_PCA.head()
```

Date	... ↑↓	PCA_1	... ↑↓	PCA_2	... ↑↓	PCA_3	... ↑↓	PCA_4	... ↑↓	PCA_5	... ↑↓	PCA...	... ↑↓	PCA_7	... ↑↓
2023-01-15T00:00:00.000		-21.6389870493		-0.5640688872		-9.9419604765		-3.0371757429		-3.4034862982		5.4474558785		-5.8321024374	
2023-01-15T00:00:00.000		-21.4759719494		-0.5248892002		-7.4900809516		-1.7793598872		-1.6026456274		2.2727083757		-3.6827611379	
2023-01-15T00:00:00.000		-21.7023102767		-0.5689364304		-7.8710169695		-0.8534355658		-2.3116002185		2.1717185331		-6.0871332534	
2023-01-15T00:00:00.000		-21.7711206311		-0.5331706786		-5.9043307911		-0.8628049855		-5.6881139668		3.0980235837		-7.6612481589	
2023-01-15T00:00:00.000		-21.7827206899		-0.5390480499		-5.2652263336		-0.5177754247		-4.3521043815		1.6595820179		-7.4583887693	

Rows: 5 ↓

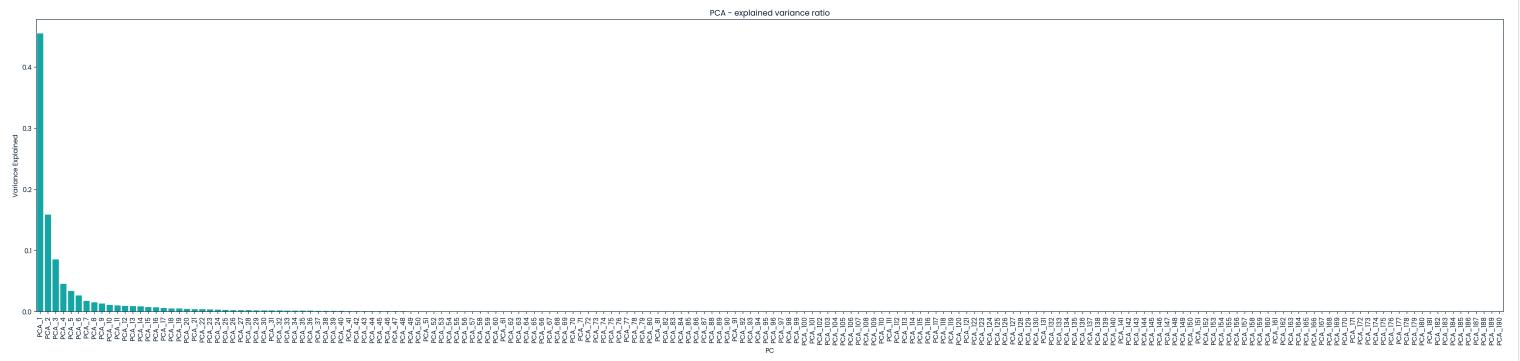
```
# Instantiate
pca = PCA(n_components=n)

# Fit and transform
principalComponents = pca.fit_transform(X_train_e_l_n[feature_cols])

# List principal components names
principal_components =columns

# Create a DataFrame
pca_df = pd.DataFrame({'Variance Explained': pca.explained_variance_ratio_,
                       'PC':principal_components})

plt.figure(figsize=(40, 8))
plt.title('PCA - explained variance ratio')
# Plot DataFrame
sns.barplot(x='PC',y='Variance Explained',
            data=pca_df, color="c")
plt.xticks(rotation=90)
plt.show()
```



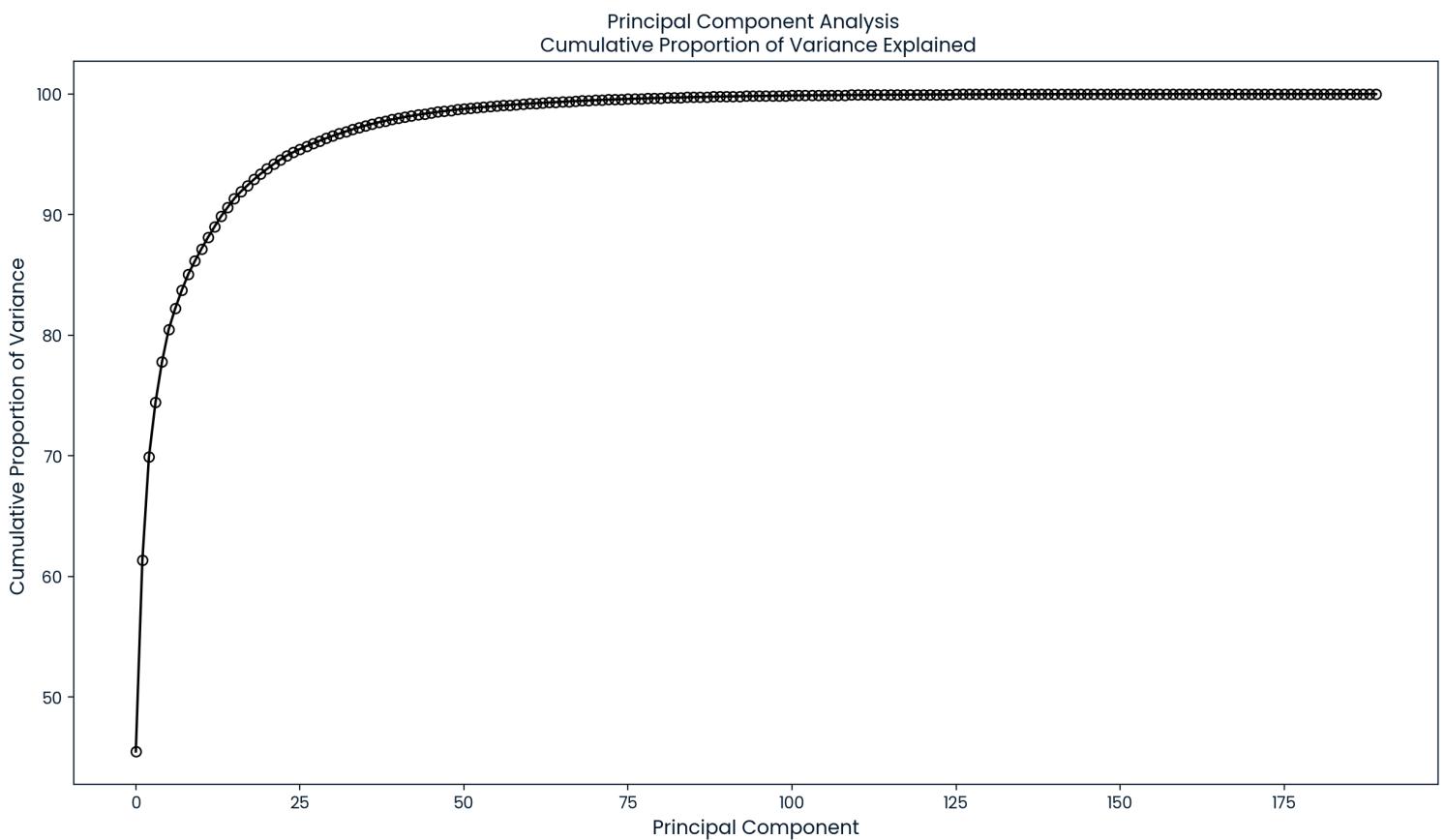
```

plt.figure(figsize=(15, 8))
# Instantiate, fit and transform

# Assign variance explained
var = pca.explained_variance_ratio_

# Plot cumulative variance
cumulative_var = np.cumsum(var)*100
plt.plot(cumulative_var, 'k-o', markerfacecolor='None', markeredgecolor='k')
plt.title('Principal Component Analysis \n Cumulative Proportion of Variance Explained', fontsize=12)
plt.xlabel("Principal Component", fontsize=12)
plt.ylabel("Cumulative Proportion of Variance ", fontsize=12)
plt.show()

```



From the plots above, we see that 14 features are needed to explain approximately 90% of the variance in the dataset. From the plots above, we see that 24 features are needed to explain approximately 95% of the variance in the dataset. This gives us a good intuition of the number of features required in our model.

Next, We will next use RFE to which are the important features for modelling.

```

# Define the model
rf = RandomForestRegressor(n_estimators=200, max_depth=20, min_samples_split=2, min_samples_leaf=1, random_state=42)

# Preprocessing pipeline
preprocessor = ColumnTransformer(

```

```

transformers=[  

    ('passthrough', 'passthrough', feature_cols) # Pass through the columns without transformation  

]  

)  
  

# Create a pipeline  

pipeline = Pipeline(steps=[  

    ('preprocessor', preprocessor),  

    ('model', rf)
])  
  

# Train the model  

pipeline.fit(X_train_e_l_n, y_train)  
  

# Extract feature importances  

importances = pipeline.named_steps['model'].feature_importances_  
  

feature_names = feature_cols  
  

# Create a DataFrame for feature importances  

feature_importances = pd.DataFrame({'Feature': feature_names, 'Importance': importances})  

feature_importances = feature_importances.sort_values(by='Importance', ascending=False)  
  

# Calculate cumulative sum of importances  

feature_importances['Cumulative Importance'] = feature_importances['Importance'].cumsum()  
  

# Select the top cumulative_var_explained_high features  
  

N = cumulative_var_explained_high # Number of top feature required from PCA analysis  

top_features = feature_importances.head(N)[['Feature']].tolist()  

top_features_rf = feature_importances.head(N)[['Feature']].tolist()  
  

# Re-train the model with the selected top N features  
  

# Filter the original dataset to only include the selected features  
  

selected_features = top_features  

selected_features_rf = selected_features  

X_train_selected = X_train_e_l_n[selected_features]  

X_valid_selected = X_valid_e_l_n[selected_features]  

X_test_selected = X_test_e_l_n[selected_features]  
  

# Re-train the pipeline with the selected features  

# Rebuild the preprocessing pipeline with selected features  

selected_numeric_cols = [col for col in selected_features if col in numeric_cols]  

selected_passthrough_cols = [col for col in selected_features if col in passthrough_cols]  

# Updated ColumnTransformer to match the selected features  

preprocessor = ColumnTransformer(  

    transformers=[  

        ('passthrough', 'passthrough', selected_features)
    ]
)  
  

# Rebuild the pipeline  

pipeline = Pipeline(steps=[  

    ('preprocessor', preprocessor),  

    ('model', rf)
])  
  

pipeline.fit(X_train_selected, y_train)  
  

# Evaluate the model  
  

# Evaluate on Validation Set  

y_valid_pred = pipeline.predict(X_valid_selected)  

mse_valid = mean_squared_error(y_valid, y_valid_pred)  

r2_valid = r2_score(y_valid, y_valid_pred)  

mae_valid = mean_absolute_error(y_valid, y_valid_pred)  

rmse_valid = np.sqrt(mse_valid)  
  

print('Validation Performance of Base Random Forest Model After Log transformation/Standart Scaling and cumulative_var_explained_high')  

print(f'R-squared (R2): {r2_valid:.4f}')  

print(f'MSE: {mse_valid:.4f}')  

print(f'MAE: {mae_valid:.4f}')  

print(f'RMSE: {rmse_valid:.4f}')

```

```

# Final evaluation on Test Set
y_test_pred = pipeline.predict(X_test_selected)
mse_test = mean_squared_error(y_test, y_test_pred)
r2_test = r2_score(y_test, y_test_pred)
mae_test = mean_absolute_error(y_test, y_test_pred)
rmse_test = np.sqrt(mse_test)

# Print evaluation metrics
print('Test Performance of Base Random Forest Model After Log transformation/Standart Scaling and cumulative_var_explained_high')
print('Random Forest R-squared (R2) score: {:.4f}'.format(r2_test))
print('Random Forest Mean Squared Error (MSE): {:.4f}'.format(mse_test))
print('Random Forest Mean Absolute Error (MAE): {:.4f}'.format(mae_test))
print('Random Forest Root Mean Squared Error (RMSE): {:.4f}'.format(rmse_test))

# Adjusted plot for top feature importances
plt.figure(figsize=(14, max(8, len(feature_importances.head(N)) * 0.5))) # Dynamic height based on the number of features
sns.barplot(
    x=feature_importances.head(N)[ 'Importance'],
    y=feature_importances.head(N)[ 'Feature'],
    palette='viridis'
)

# Customize plot aesthetics
plt.xlabel('Feature Importance', fontsize=14)
plt.ylabel('Feature', fontsize=14)
plt.title(f'Top {N} Feature Importances from Random Forest', fontsize=16, pad=20)
plt.xticks(fontsize=12)
plt.yticks(fontsize=12)

# Adjust layout for better spacing
plt.tight_layout()
plt.show()

```

Validation Performance of Base Random Forest Model After Log transformation/Standart Scaling and cumulative_var_explained_high

R-squared (R2): 0.4414

MSE: 15.0692

MAE: 2.2283

RMSE: 3.8819

Test Performance of Base Random Forest Model After Log transformation/Standart Scaling and cumulative_var_explained_high

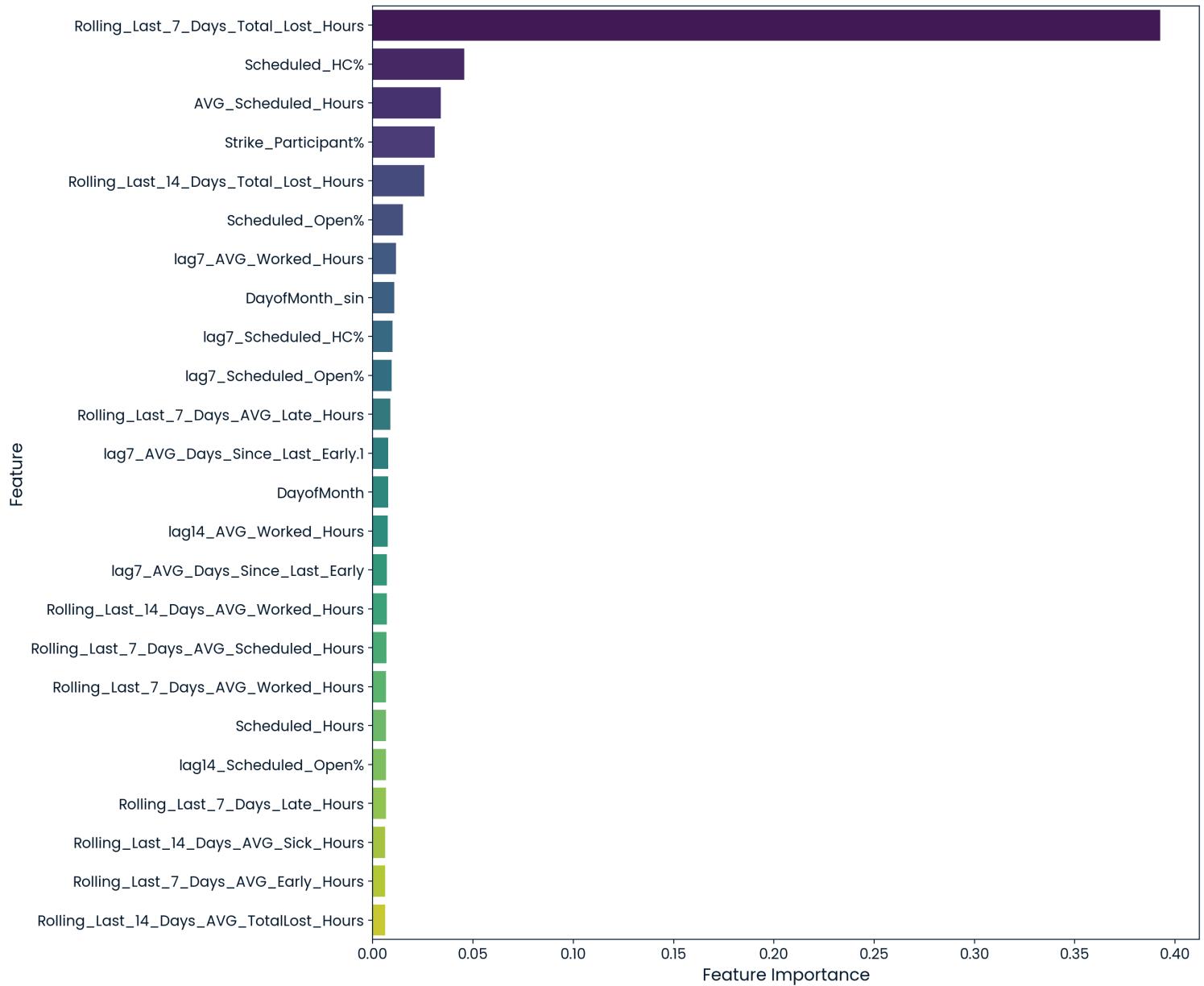
Random Forest R-squared (R2) score: 0.5037

Random Forest Mean Squared Error (MSE): 14.5601

Random Forest Mean Absolute Error (MAE): 2.0154

Random Forest Root Mean Squared Error (RMSE): 3.8158

Top 24 Feature Importances from Random Forest



Model Performance Comparison with Log Transformation, Standard Scaling, and PCA

Validation Performance:

- R-squared (R²): 0.4414
- MSE: 15.0692
- MAE: 2.2283
- RMSE: 3.8819

Test Performance:

- R-squared (R²): 0.5037
- MSE: 14.5601
- MAE: 2.0154
- RMSE: 3.8158

Observations & Key Insights

1 Performance Decline:

- R2 dropped to 0.5037 (Test) from higher previous scores (0.5201 without transformations), showing a reduced ability to explain variance.
- MSE, MAE, and RMSE increased, indicating less accurate predictions:
 - RMSE rose from 3.7524 (Base Model) to 3.8158 after transformations.

2 Impact of Preprocessing:

- Log Transformation and Standard Scaling had a negative effect because Random Forests are scale-invariant—they don't require feature scaling, unlike models like linear regression or SVMs.
- PCA likely removed important features during dimensionality reduction, causing loss of key information.

3 Tree-Based Models & PCA Conflict:

- Random Forests rely on original feature splits for decision-making.
- PCA distorts feature relationships, reducing the model's ability to capture critical patterns.

🚀 Conclusion

- The preprocessing steps (Log Transformation, Standard Scaling, PCA) didn't improve performance.
- They reduced R2 and increased error metrics, confirming that such transformations are not beneficial for tree-based models like Random Forests.
- Next Steps:
 - Avoid unnecessary transformations for Random Forest models.
 - Focus on feature selection (e.g., RFECV) and model-based importance rather than aggressive dimensionality reduction techniques like PCA.

Key Takeaway:

Random Forests perform better on raw or minimally processed data. Over-processing, like scaling or PCA, can reduce model effectiveness. For optimal performance, it's best to rely on feature importance techniques inherent to tree-based models. 🌱

```
X_train_e_l_n_m = X_train[feature_cols].copy()
X_valid_e_l_n_m = X_valid[feature_cols].copy()
X_test_e_l_n_m = X_test[feature_cols].copy()
```

```
# List of models with basic parameters
models = {
    "Linear Regression": LinearRegression(),
    "Ridge Regression": Ridge(alpha=1.0),
    "Random Forest": RandomForestRegressor(n_estimators=100, random_state=42),
    "XGBoost": XGBRegressor(n_estimators=100, learning_rate=0.1, random_state=42, verbosity=0),
    "LightGBM": LGBMRegressor(n_estimators=100, learning_rate=0.1, random_state=42, verbosity=-1)
}

# Function to evaluate models
def evaluate_model(model, X_train, X_valid, y_train, y_valid, scale=False):
    if scale:
        preprocessor = ColumnTransformer(
            transformers=[
                ('numeric_cols', StandardScaler(), numeric_cols),
                ('passthrough', 'passthrough', passthrough_cols)
            ]
        )
        pipeline = Pipeline(steps=[
            ('preprocessor', preprocessor),
            ('model', model)
        ])
    else:
        pipeline = Pipeline(steps=[
            ('model', model)
        ])

    pipeline.fit(X_train, y_train)
    y_valid_pred = pipeline.predict(X_valid)
    mse_valid = mean_squared_error(y_valid, y_valid_pred)
    r2_valid = r2_score(y_valid, y_valid_pred)
    mae_valid = mean_absolute_error(y_valid, y_valid_pred)
    rmse_valid = np.sqrt(mse_valid)

    print(f'Validation Performance of {model.__class__.__name__}:')
    print(f'R-squared (R2): {r2_valid:.4f}')
    print(f'MSE: {mse_valid:.4f}')
    print(f'MAE: {mae_valid:.4f}')
    print(f'RMSE: {rmse_valid:.4f}\n')

    return pipeline
```

```

# Iterate through models and evaluate
pipelines = {}
for name, model in models.items():
    scale = True if name in ["Linear Regression", "Ridge Regression"] else False
    pipeline = evaluate_model(model, X_train_e_l_n_m, X_valid_e_l_n_m, y_train, y_valid, scale)
    pipelines[name] = pipeline

# Final evaluation on Test Set
for name, pipeline in pipelines.items():
    y_test_pred = pipeline.predict(X_test)
    mse_test = mean_squared_error(y_test, y_test_pred)
    r2_test = r2_score(y_test, y_test_pred)
    mae_test = mean_absolute_error(y_test, y_test_pred)
    rmse_test = np.sqrt(mse_test)

    print(f'Test Performance of {name}:')
    print(f'R-squared (R2): {r2_test:.4f}')
    print(f'MSE: {mse_test:.4f}')
    print(f'MAE: {mae_test:.4f}')
    print(f'RMSE: {rmse_test:.4f}\n')

# SHAP Analysis
print('SHAP Analysis for {name}:')
if name in ["Random Forest", "XGBoost", "LightGBM"]:
    explainer = shap.TreeExplainer(pipeline.named_steps['model'])
elif name in ["Linear Regression", "Ridge Regression"]:
    explainer = shap.LinearExplainer(pipeline.named_steps['model'], X_valid_e_l_n_m)
else:
    explainer = shap.Explainer(pipeline.named_steps['model'])

shap_values = explainer.shap_values(X_valid_e_l_n_m)

# SHAP Summary Plot
shap.summary_plot(shap_values, X_valid_e_l_n_m, plot_type="bar")

```

Validation Performance of LinearRegression:

R-squared (R2): 0.4294

MSE: 15.3923

MAE: 2.4407

RMSE: 3.9233

Validation Performance of Ridge:

R-squared (R2): 0.4326

MSE: 15.3068

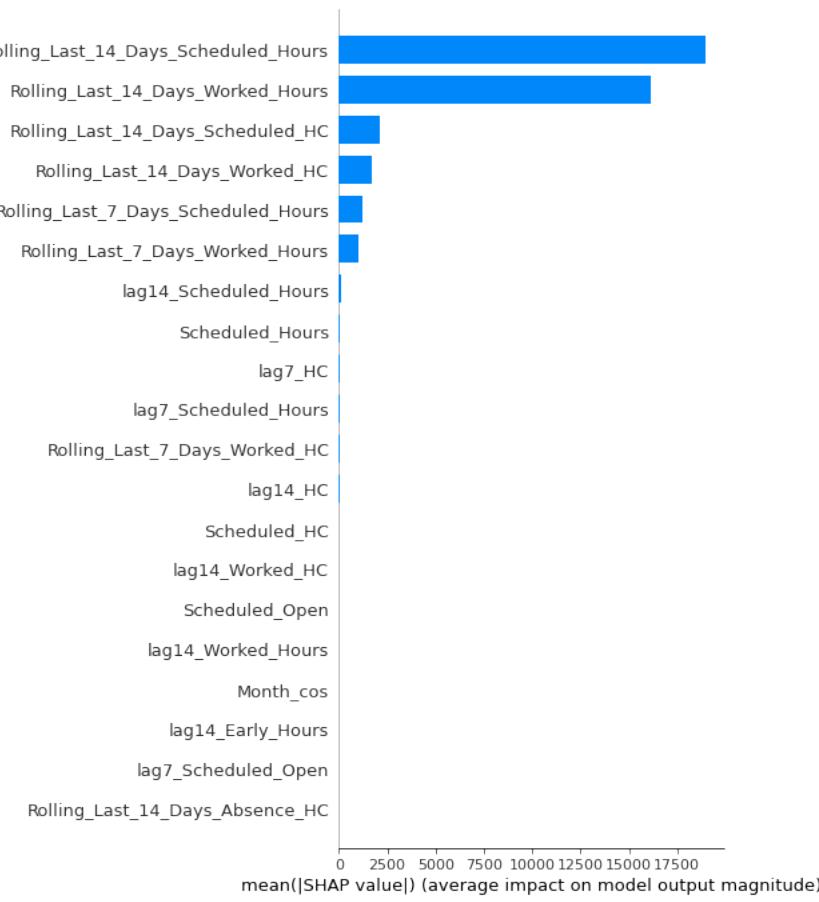
MAE: 2.4297

RMSE: 3.9124

Validation Performance of RandomForestRegressor:

R-squared (R2): 0.4613

MSE: 14.5327



Test Performance of Ridge Regression:

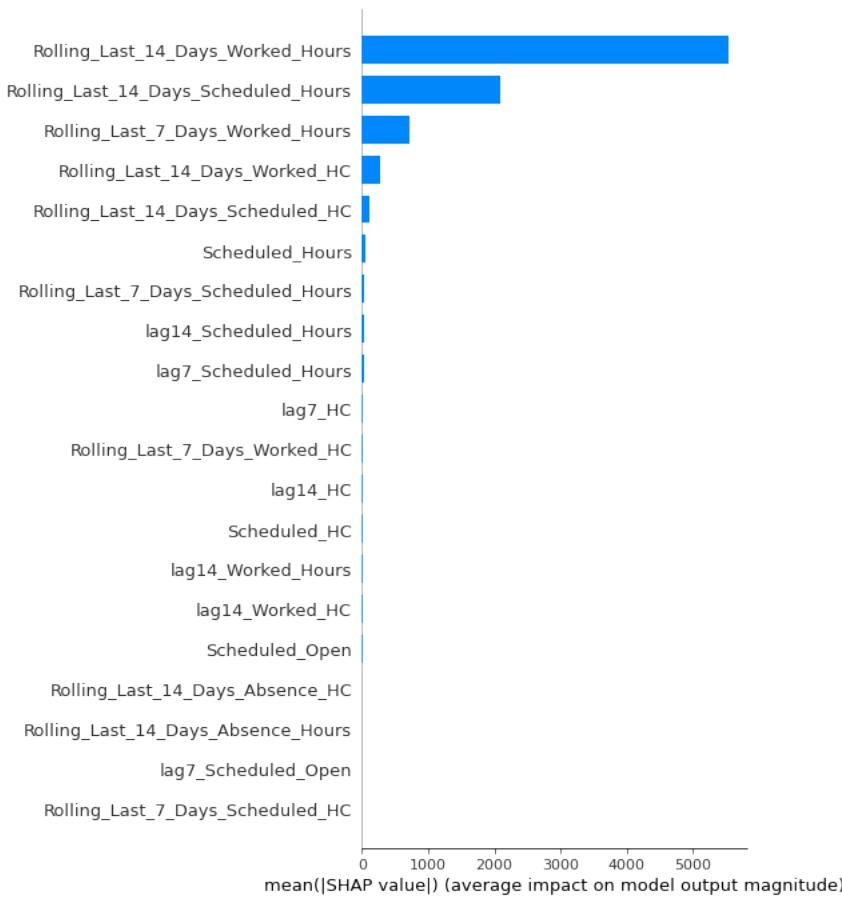
R-squared (R2): 0.2977

MSE: 20.6055

MAE: 2.5875

RMSE: 4.5393

SHAP Analysis for Ridge Regression:



Test Performance of Random Forest:

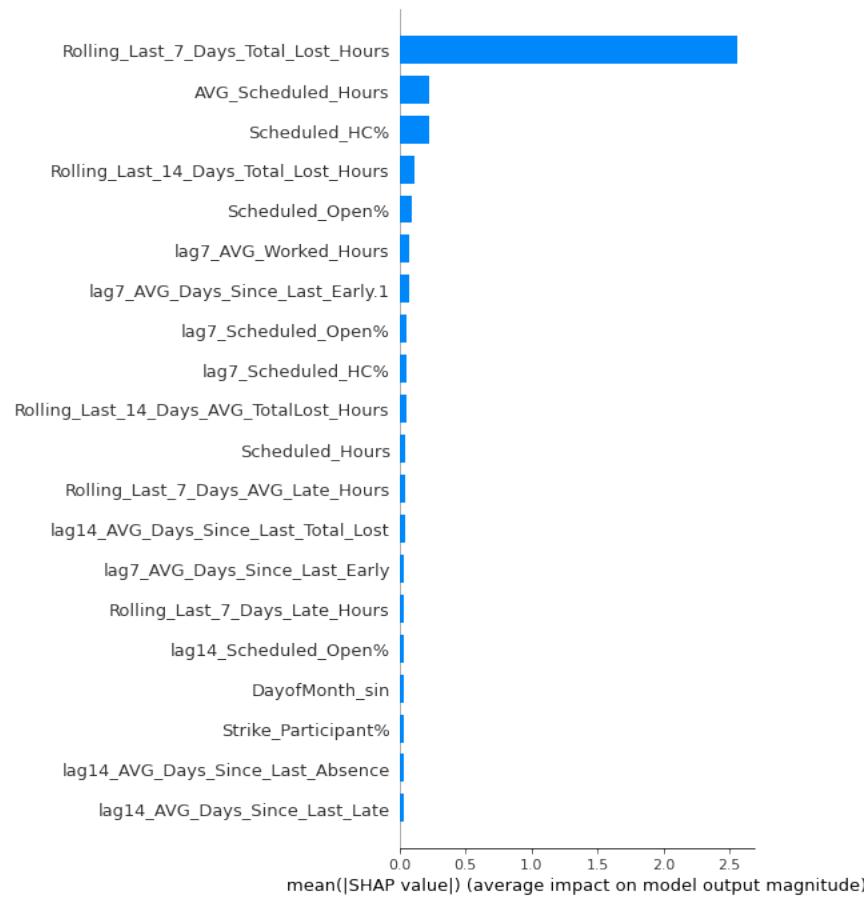
R-squared (R2): 0.5068

MSE: 14.4704

MAE: 2.0393

RMSE: 3.8040

SHAP Analysis for Random Forest:



Test Performance of XGBoost:

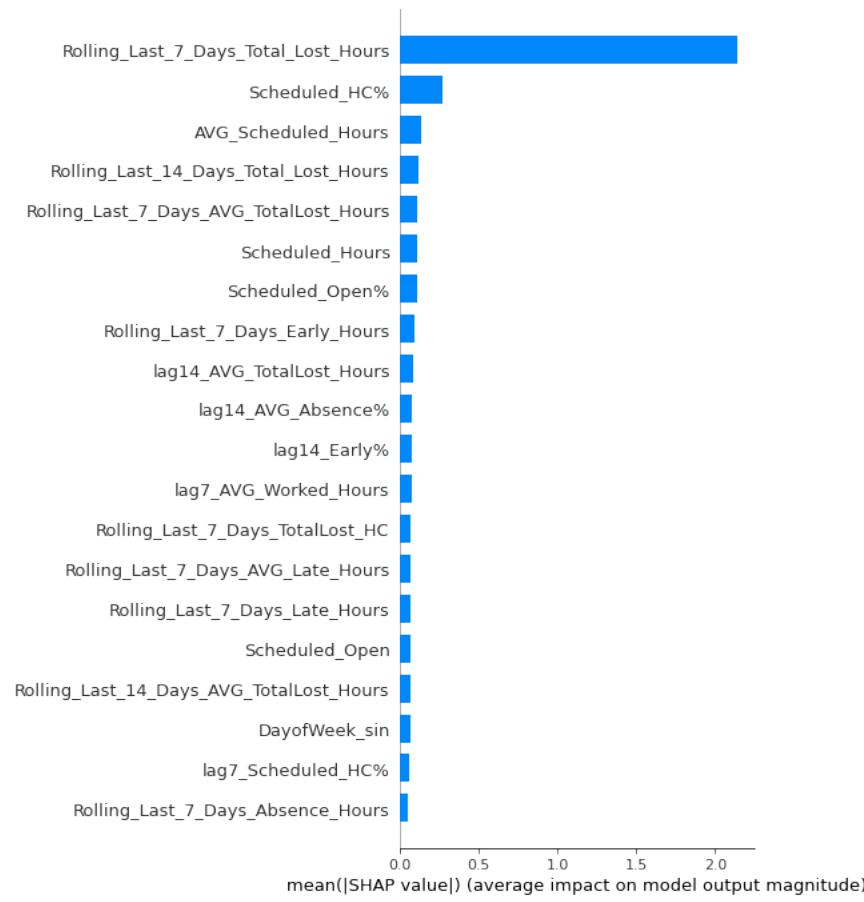
R-squared (R2): 0.5081

MSE: 14.4334

MAE: 1.9749

RMSE: 3.7991

SHAP Analysis for XGBoost:



Test Performance of LightGBM:

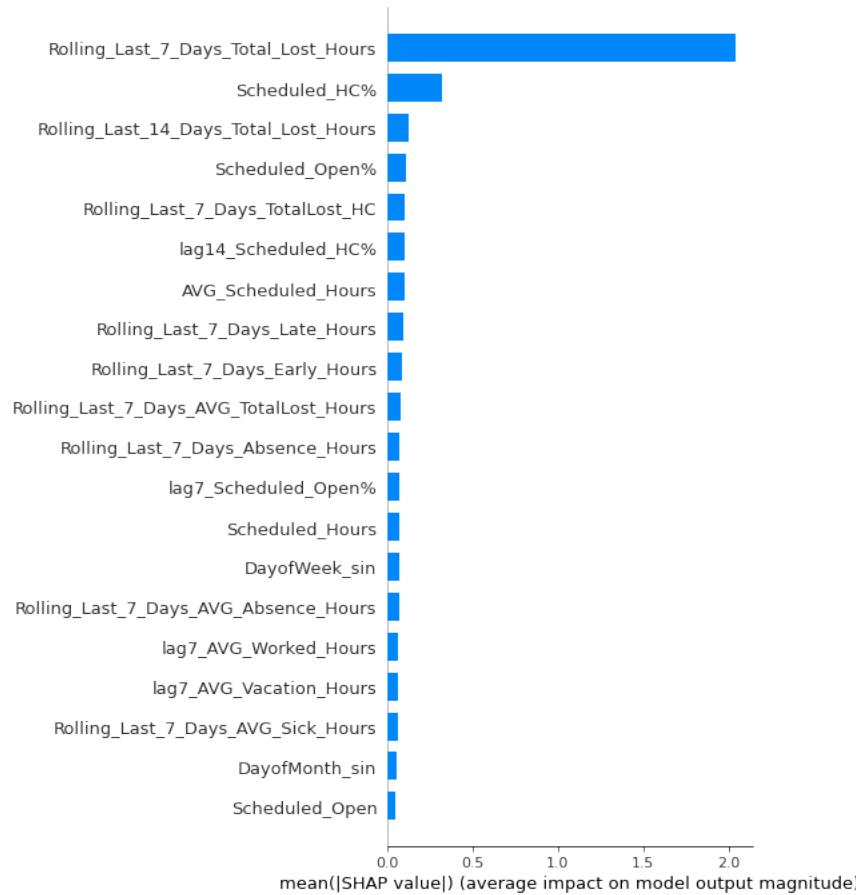
R-squared (R2): 0.4964

MSE: 14.7746

MAE: 1.9884

RMSE: 3.8438

SHAP Analysis for LightGBM:



```

# -----
# Function for Ridge and Linear Regression
# -----
tscv = TimeSeriesSplit(n_splits=3)

def train_linear_models(X_train, y_train, X_test, y_test, numerical_cols, passthrough_cols):
    param_dist_ridge = {
        'preprocessor__num__poly__degree': randint(1, 3), # Correct path
        'ridge__alpha': uniform(1e-3, 1e3),
        'ridge__fit_intercept': [True, False],
        'ridge__solver': ['auto', 'svd'],
        'ridge__tol': uniform(1e-3, 1e-2)
    }

    param_dist_linear = {
        'preprocessor__num__poly__degree': randint(1, 3), # Correct path
        'Linear__fit_intercept': [True, False],
        'Linear__copy_X': [True, False],
        'Linear__positive': [True, False]
    }

    best_params = {}
    best_features = {}

    # Preprocessing pipeline for numerical and passthrough columns
    preprocessor = ColumnTransformer(transformers=[
        ('num', Pipeline([
            ('scaler', StandardScaler()),
            ('poly', PolynomialFeatures(interaction_only=True, include_bias=False))
        ]), numerical_cols),
        ('passthrough', 'passthrough', passthrough_cols)
    ])

    # Ridge Regression Pipeline
    ridge_pipe = Pipeline([
        ('preprocessor', preprocessor),
        ('ridge', Ridge())
    ])
    print("\nTuning Ridge...")
    random_search_ridge = RandomizedSearchCV(
        ridge_pipe,
        param_distributions=param_dist_ridge,
        n_iter=10,
        cv=tscv,
        scoring='neg_mean_squared_error',
        verbose=1
    )
    random_search_ridge.fit(X_train, y_train)
    best_params['Ridge'] = random_search_ridge.best_params_
    best_features['Ridge'] = preprocessor.get_feature_names_out()

```

```

n_iter=10,
cv=tscv,
scoring='neg_mean_squared_error',
n_jobs=2,
error_score='raise',
random_state=42
)
random_search_ridge.fit(X_train, y_train)
best_params['Ridge'] = random_search_ridge.best_params_

# Linear Regression Pipeline
print("\nTuning Linear...")
linear_pipe = Pipeline([
    ('preprocessor', preprocessor),
    ('Linear', LinearRegression())
])
random_search_linear = RandomizedSearchCV(
    linear_pipe,
    param_distributions=param_dist_linear,
    n_iter=10,
    cv=tscv,
    scoring='neg_mean_squared_error',
    n_jobs=2,
    random_state=42
)
random_search_linear.fit(X_train, y_train)
best_params['Linear'] = random_search_linear.best_params_

# -----
# Feature Selection with RFECV
# -----
models_for_rfecv = {
    'Ridge': Ridge(**{key.split('__')[1]: value for key, value in best_params['Ridge'].items() if key.startswith('ridge__')}),
    'Linear': LinearRegression(**{key.split('__')[1]: value for key, value in best_params['Linear'].items() if key.startswith('Linear__')})
}

for name, model in models_for_rfecv.items():
    print(f"\nPerforming RFECV for {name}...")
    rfecv = RFECV(estimator=model, step=1, cv=tscv,
                   scoring='neg_mean_squared_error', n_jobs=2)
    rfecv.fit(X_train, y_train)
    best_features[name] = X_train.columns[rfecv.support_].tolist()
    print(f"Optimal features for {name}: {rfecv.n_features_}")

# -----
# Create Meta Features (Union)
# -----
all_features = set()
for features in best_features.values():
    all_features.update(features)
meta_features = list(all_features)

# -----
# Final Model Training and Evaluation
# -----
results_lin = []
final_models = {
    'Ridge': Ridge(**{key.split('__')[1]: value for key, value in best_params['Ridge'].items() if key.startswith('ridge__')}),
    'Linear': LinearRegression(**{key.split('__')[1]: value for key, value in best_params['Linear'].items() if key.startswith('Linear__')})
}

for model_name, model in final_models.items():
    features = best_features[model_name]
    model.fit(X_train[features], y_train)
    preds = model.predict(X_test[features])

    results_lin.append({
        'Model': model_name,
        'R2': r2_score(y_test, preds),
        'MSE': mean_squared_error(y_test, preds),
        'MAE': mean_absolute_error(y_test, preds),
        'RMSE': np.sqrt(mean_squared_error(y_test, preds))
    })

results_df_lin = pd.DataFrame(results_lin)
print("\nFinal Evaluation Results:")
print(results_df_lin)

```

```
# ✅ Matching the return structure with the tree models
return {
    'best_params': best_params,
    'best_features': best_features,
    'meta_features': meta_features,
    'results': results_df_lin
}
```

```
# Start timer
start_time = time.perf_counter()
print('')
print('Starting time: ', datetime.datetime.now().strftime("%H:%M:%S"))
print('')

# Train the models and get the results
results_lin = train_linear_models(X_train_e_l_n_m, y_train, X_test_e_l_n_m, y_test, numeric_cols, passthrough_cols)

# End timing
end_time = time.perf_counter()
duration = end_time - start_time
print(f"\nTotal execution time: {duration:.2f} seconds")
```

Starting time: 17:56:07

Tuning Ridge...

Tuning Linear...

Performing RFECV for Ridge...

Optimal features for Ridge: 45

Performing RFECV for Linear...

Optimal features for Linear: 13

Final Evaluation Results:

1 hidden cell

```
# Extract outputs
best_features_models_lin = results_lin['best_features']
meta_features_all_models_lin = results_lin['meta_features']
final_hyperparameters_all_models_lin = results_lin['best_params']
evaluation_results_all_models_lin = results_lin['results']

# Print final results
print("\nEvaluation Results:")
print(evaluation_results_all_models_lin)

#####
```

Evaluation Results:

	Model	R2	MSE	MAE	RMSE
0	Ridge	0.451044	16.106328	2.333565	4.013269
1	Linear	0.444200	16.307117	2.355120	4.038207

```
# Define the time series split for cross-validation
tscv = TimeSeriesSplit(n_splits=3)

def train_models(X_train, y_train, X_valid, y_valid, X_test, y_test):
    # Parameter distributions for random search
    param_dist_rf = {
        'n_estimators': randint(50, 400),
        'max_depth': [5, 10, 20, None],
        'min_samples_split': randint(2, 10),
        'min_samples_leaf': randint(1, 4),
        'max_features': ['sqrt', 'log2'],
        'bootstrap': [True, False]
    }

    param_dist_xgb = {
        'n_estimators': randint(100, 300),
        'learning_rate': uniform(0.01, 0.1),
        'max_depth': randint(3, 7),
        'subsample': uniform(0.8, 0.2),
        'colsample_bytree': uniform(0.8, 0.2),
        'gamma': uniform(0, 0.3),
        'reg_alpha': uniform(0, 0.1),
        'reg_lambda': uniform(1, 1.5)
    }

    param_dist_lgbm = {
        'n_estimators': randint(100, 300),
        'learning_rate': uniform(0.01, 0.1),
        'max_depth': randint(3, 7),
        'num_leaves': randint(31, 100),
        'subsample': uniform(0.8, 0.2),
        'colsample_bytree': uniform(0.8, 0.2),
        'reg_alpha': uniform(0, 0.1),
        'reg_lambda': uniform(1, 1.5)
    }

    best_params = {}
    best_features = {}

    # -----
    # Hyperparameter Tuning
    # -----
    print("\nTuning RandomForest...")
    rf_model = RandomForestRegressor(random_state=42)
    random_search_rf = RandomizedSearchCV(
        rf_model,
        param_distributions=param_dist_rf,
        n_iter=20,                                     # Number of random combinations
        cv=tscv,
        scoring='neg_mean_squared_error',
        n_jobs=-1,
        random_state=42
    )
    random_search_rf.fit(X_train, y_train)
    best_params['RandomForest'] = random_search_rf.best_params_

    print("\nTuning XGBoost...")
    xgb_model = XGBRegressor(objective='reg:squarederror', random_state=42)
    random_search_xgb = RandomizedSearchCV(
        xgb_model,
        param_distributions=param_dist_xgb,
        n_iter=20,
        cv=tscv,
        scoring='neg_mean_squared_error',
        n_jobs=-1
    )
```

```

random_search_xgb.fit(X_train, y_train, eval_set=[(X_valid, y_valid)],
                      early_stopping_rounds=50, verbose=0)
best_params['XGBoost'] = random_search_xgb.best_params_

print("\nTuning LGBM...")
lgbm_model = LGBMRegressor(random_state=42, verbosity=-1)
random_search_lgbm = RandomizedSearchCV(
    lgbm_model,
    param_distributions=param_dist_lgbm,
    n_iter=20,
    cv=tscv,
    scoring='neg_mean_squared_error',
    n_jobs=-1
)
random_search_lgbm.fit(X_train, y_train, eval_set=[(X_valid, y_valid)],
                       callbacks=[early_stopping(50, verbose=0)])
best_params['LGBM'] = random_search_lgbm.best_params_

# -----
# Feature Selection with RFECV
# -----
models_for_rfecv = {
    'RandomForest': RandomForestRegressor(**best_params['RandomForest'], random_state=42),
    'XGBoost': XGBRegressor(**best_params['XGBoost'], random_state=42),
    'LGBM': LGBMRegressor(**best_params['LGBM'], random_state=42)
}

for name, model in models_for_rfecv.items():
    print(f"\nPerforming RFECV for {name}...")
    rfecv = RFECV(estimator=model, step=1, cv=tscv,
                  scoring='neg_mean_squared_error', n_jobs=-1)
    rfecv.fit(X_train, y_train)
    best_features[name] = X_train.columns[rfecv.support_].tolist()
    print(f"Optimal features for {name}: {rfecv.n_features_}")

# -----
# Final Model Training and Evaluation
# -----
final_models = {
    'RandomForest': RandomForestRegressor(**best_params['RandomForest'], random_state=42),
    'XGBoost': XGBRegressor(**best_params['XGBoost'], random_state=42),
    'LGBM': LGBMRegressor(**best_params['LGBM'], random_state=42)
}

# Create meta features
all_features = set()
for features in best_features.values():
    all_features.update(features)
meta_features = list(all_features)

results = []
for model_name, model in final_models.items():
    features = best_features[model_name]
    model.fit(X_train[features], y_train)
    preds = model.predict(X_test[features])

    results.append({
        'Model': model_name,
        'R2': r2_score(y_test, preds),
        'MSE': mean_squared_error(y_test, preds),
        'MAE': mean_absolute_error(y_test, preds),
        'RMSE': np.sqrt(mean_squared_error(y_test, preds))
    })

results_df = pd.DataFrame(results)
print("\nFinal Evaluation Results:")
print(results_df)

return {
    'best_params': best_params,
    'best_features': best_features,
    'meta_features': meta_features,
    'results': results_df
}

```

```

# Start timer
start_time = time.perf_counter()

```

```

print('')
print('Starting time: ', datetime.datetime.now().strftime("%H:%M:%S"))
print('')

# Train the models and get the results
results = train_models(X_train_e_l_n_m, y_train, X_valid_e_l_n_m, y_valid, X_test_e_l_n_m, y_test)

# End timing
end_time = time.perf_counter()
duration = end_time - start_time
print(f"\nTotal execution time: {duration:.2f} seconds")

```

Hidden output

1 hidden cell

```

# Extract outputs
best_features_models = results['best_features']
meta_features_all_models = results['meta_features']
final_hyperparameters_all_models = results['best_params']
evaluation_results_all_models = results['results']

# Print final results
print("\nEvaluation Results:")
print(evaluation_results_all_models)

#####

```

Evaluation Results:

	Model	R2	MSE	MAE	RMSE
0	RandomForest	0.539967	13.497322	1.871065	3.673870
1	XGBoost	0.537604	13.566646	1.865540	3.683293
2	LGBM	0.388664	17.936555	2.092890	4.235157

```

# Start timer
start_time = time.perf_counter()
print('\nStarting time:', datetime.datetime.now().strftime("%H:%M:%S"), '\n')

#####
# Combine Train & Validation Sets
X_final_train = pd.concat([X_train_e_l_n_m, X_valid_e_l_n_m], axis=0)

y_final_train = pd.concat([pd.Series(y_train), pd.Series(y_valid)], axis=0)

# Initialize dictionary to store final trial results
final_trial_results = {}

# ----- Trial 1: RandomForest -----
print("\n--- Training Final RandomForest Model ---")
start_time_rf = time.time()
rf_final = RandomForestRegressor(**final_hyperparameters_all_models['RandomForest'], random_state=42)
X_rf_selected = X_final_train[best_features_models['RandomForest']]

# Train the model
rf_final.fit(X_rf_selected, y_final_train)

# Predict and evaluate
preds_rf_final = rf_final.predict(X_test_e_l_n_m[best_features_models['RandomForest']])
r2_rf = r2_score(y_test, preds_rf_final)
mse_rf = mean_squared_error(y_test, preds_rf_final)
mae_rf = mean_absolute_error(y_test, preds_rf_final)
rmse_rf = np.sqrt(mse_rf)

final_trial_results['RandomForest'] = {'R2': r2_rf, 'MSE': mse_rf, 'MAE': mae_rf, 'RMSE': rmse_rf}

print(f"✅ RandomForest - R²: {r2_rf:.4f}, MSE: {mse_rf:.4f}, MAE: {mae_rf:.4f}, RMSE: {rmse_rf:.4f}")
print(f"⌚ RandomForest training completed in {time.time() - start_time_rf:.2f} seconds")

# ----- Trial 2: XGBoost -----

```

```

print("\n--- Training Final XGBoost Model ---")
start_time_xgb = time.time()
xgb_final = XGBRegressor(**final_hyperparameters_all_models['XGBoost'], random_state=42)
X_xgb_selected = X_final_train[best_features_models['XGBoost']]

# Train the model
xgb_final.fit(X_xgb_selected, y_final_train, verbose=0)

# Predict and evaluate
preds_xgb_final = xgb_final.predict(X_test_e_l_n_m[best_features_models['XGBoost']])
r2_xgb = r2_score(y_test, preds_xgb_final)
mse_xgb = mean_squared_error(y_test, preds_xgb_final)
mae_xgb = mean_absolute_error(y_test, preds_xgb_final)
rmse_xgb = np.sqrt(mse_xgb)

final_trial_results['XGBoost'] = {'R2': r2_xgb, 'MSE': mse_xgb, 'MAE': mae_xgb, 'RMSE': rmse_xgb}

print(f"✓ XGBoost - R2: {r2_xgb:.4f}, MSE: {mse_xgb:.4f}, MAE: {mae_xgb:.4f}, RMSE: {rmse_xgb:.4f}")
print(f"⌚ XGBoost training completed in {time.time() - start_time_xgb:.2f} seconds")

# ----- Trial 3: LightGBM -----
print("\n--- Training Final LGBM Model ---")
start_time_lgbm = time.time()
lgbm_final = LGBMRegressor(**final_hyperparameters_all_models['LGBM'], random_state=42, verbosity=-1)
X_lgbm_selected = X_final_train[best_features_models['LGBM']]

# Train the model
lgbm_final.fit(X_lgbm_selected, y_final_train)

# Predict and evaluate
preds_lgbm_final = lgbm_final.predict(X_test_e_l_n_m[best_features_models['LGBM']])
r2_lgbm = r2_score(y_test, preds_lgbm_final)
mse_lgbm = mean_squared_error(y_test, preds_lgbm_final)
mae_lgbm = mean_absolute_error(y_test, preds_lgbm_final)
rmse_lgbm = np.sqrt(mse_lgbm)

final_trial_results['LGBM'] = {'R2': r2_lgbm, 'MSE': mse_lgbm, 'MAE': mae_lgbm, 'RMSE': rmse_lgbm}

print(f"✓ LGBM - R2: {r2_lgbm:.4f}, MSE: {mse_lgbm:.4f}, MAE: {mae_lgbm:.4f}, RMSE: {rmse_lgbm:.4f}")
print(f"⌚ LGBM training completed in {time.time() - start_time_lgbm:.2f} seconds")

# ----- Trial 4: Ridge Regression -----
print("\n--- Training Final Ridge Model ---")
start_time_ridge = time.time()
ridge_final = Ridge(**{key.split('__')[1]: value for key, value in final_hyperparameters_all_models_lin['Ridge'].items() if key.startswith('ridge_')})
X_ridge_selected = X_final_train[best_features_models_lin['Ridge']]

# Train the model
ridge_final.fit(X_ridge_selected, y_final_train)

# Predict and evaluate
preds_ridge_final = ridge_final.predict(X_test_e_l_n_m[best_features_models_lin['Ridge']])
r2_ridge = r2_score(y_test, preds_ridge_final)
mse_ridge = mean_squared_error(y_test, preds_ridge_final)
mae_ridge = mean_absolute_error(y_test, preds_ridge_final)
rmse_ridge = np.sqrt(mse_ridge)

final_trial_results['Ridge'] = {'R2': r2_ridge, 'MSE': mse_ridge, 'MAE': mae_ridge, 'RMSE': rmse_ridge}

print(f"✓ Ridge - R2: {r2_ridge:.4f}, MSE: {mse_ridge:.4f}, MAE: {mae_ridge:.4f}, RMSE: {rmse_ridge:.4f}")
print(f"⌚ Ridge training completed in {time.time() - start_time_ridge:.2f} seconds")

# ----- Trial 5: Linear Regression -----
print("\n--- Training Final Linear Model ---")
start_time_linear = time.time()
linear_final = LinearRegression(**{key.split('__')[1]: value for key, value in final_hyperparameters_all_models_lin['Linear'].items() if key.startswith('Linear_')})
X_linear_selected = X_final_train[best_features_models_lin['Linear']]

# Train the model
linear_final.fit(X_linear_selected, y_final_train)

# Predict and evaluate
preds_linear_final = linear_final.predict(X_test_e_l_n_m[best_features_models_lin['Linear']])
r2_linear = r2_score(y_test, preds_linear_final)

```

```

mse_linear = mean_squared_error(y_test, preds_linear_final)
mae_linear = mean_absolute_error(y_test, preds_linear_final)
rmse_linear = np.sqrt(mse_linear)

final_trial_results['Linear'] = {'R2': r2_linear, 'MSE': mse_linear, 'MAE': mae_linear, 'RMSE': rmse_linear}

print(f"✓ Linear - R2: {r2_linear:.4f}, MSE: {mse_linear:.4f}, MAE: {mae_linear:.4f}, RMSE: {rmse_linear:.4f}")
print(f"⌚ Linear training completed in {time.time() - start_time_linear:.2f} seconds")

# ----- Display Final Results -----
final_trial_df = pd.DataFrame(final_trial_results).T

print("\n📊 Final Model Performance Comparison:")
display(final_trial_df)

#####
# End timing
end_time = time.perf_counter()
duration = end_time - start_time
print(f"\n⌚ Total execution time: {duration:.2f} seconds")

```

Starting time: 16:51:27

--- Training Final RandomForest Model ---

✓ RandomForest - R²: 0.5624, MSE: 12.8404, MAE: 1.8248, RMSE: 3.5833
⌚ RandomForest training completed in 0.50 seconds

--- Training Final XGBoost Model ---

✓ XGBoost - R²: 0.5597, MSE: 12.9173, MAE: 1.8215, RMSE: 3.5941
⌚ XGBoost training completed in 0.13 seconds

--- Training Final LGBM Model ---

✓ LGBM - R²: 0.4252, MSE: 16.8644, MAE: 2.0270, RMSE: 4.1066
⌚ LGBM training completed in 0.03 seconds

	R2	MSE	MAE	RMSE
RandomForest	0.562359	12.840352	1.824781	3.583344
XGBoost	0.559736	12.917313	1.821479	3.594066
LGBM	0.425207	16.864369	2.026983	4.106625
Ridge	0.462823	15.760725	2.322369	3.969978
Linear	0.445896	16.257351	2.361754	4.032041

⌚ Total execution time: 0.70 seconds

```

# Plot settings
sns.set(style="whitegrid", context="notebook")

# ----- Comparison: Real vs Predicted for RandomForest -----
plt.figure(figsize=(10, 6))
plt.scatter(y_test, preds_rf_final, alpha=0.6, label="Predicted", color="blue")
plt.plot([y_test.min(), y_test.max()], [y_test.min(), y_test.max()], 'r--', lw=2, label="Perfect Fit")
plt.title("RandomForest: Real vs Predicted")
plt.xlabel("Real Values")
plt.ylabel("Predicted Values")
plt.legend()
plt.show()

# ----- Comparison: Real vs Predicted for XGBoost -----
plt.figure(figsize=(10, 6))
plt.scatter(y_test, preds_xgb_final, alpha=0.6, label="Predicted", color="green")
plt.plot([y_test.min(), y_test.max()], [y_test.min(), y_test.max()], 'r--', lw=2, label="Perfect Fit")
plt.title("XGBoost: Real vs Predicted")
plt.xlabel("Real Values")
plt.ylabel("Predicted Values")
plt.legend()
plt.show()

# ----- Comparison: Real vs Predicted for LightGBM -----
plt.figure(figsize=(10, 6))
plt.scatter(y_test, preds_lgbm_final, alpha=0.6, label="Predicted", color="purple")
plt.plot([y_test.min(), y_test.max()], [y_test.min(), y_test.max()], 'r--', lw=2, label="Perfect Fit")
plt.title("LightGBM: Real vs Predicted")
plt.xlabel("Real Values")
plt.ylabel("Predicted Values")
plt.legend()
plt.show()

# ----- Comparison: Real vs Predicted for Ridge -----
plt.figure(figsize=(10, 6))
plt.scatter(y_test, preds_ridge_final, alpha=0.6, label="Predicted", color="orange")
plt.plot([y_test.min(), y_test.max()], [y_test.min(), y_test.max()], 'r--', lw=2, label="Perfect Fit")
plt.title("Ridge Regression: Real vs Predicted")
plt.xlabel("Real Values")
plt.ylabel("Predicted Values")
plt.legend()
plt.show()

# ----- Comparison: Real vs Predicted for Linear Regression -----
plt.figure(figsize=(10, 6))
plt.scatter(y_test, preds_linear_final, alpha=0.6, label="Predicted", color="red")
plt.plot([y_test.min(), y_test.max()], [y_test.min(), y_test.max()], 'r--', lw=2, label="Perfect Fit")
plt.title("Linear Regression: Real vs Predicted")
plt.xlabel("Real Values")
plt.ylabel("Predicted Values")
plt.legend()
plt.show()

# ----- Combined Real vs Predicted for All Models -----
plt.figure(figsize=(12, 8))
plt.scatter(y_test, preds_rf_final, alpha=0.6, label="RandomForest", color="blue")
plt.scatter(y_test, preds_xgb_final, alpha=0.6, label="XGBoost", color="green")
plt.scatter(y_test, preds_lgbm_final, alpha=0.6, label="LightGBM", color="purple")
plt.scatter(y_test, preds_ridge_final, alpha=0.6, label="Ridge", color="orange")
plt.scatter(y_test, preds_linear_final, alpha=0.6, label="Linear", color="red")
plt.plot([y_test.min(), y_test.max()], [y_test.min(), y_test.max()], 'r--', lw=2, label="Perfect Fit")
plt.title("Real vs Predicted: All Models")
plt.xlabel("Real Values")
plt.ylabel("Predicted Values")
plt.legend()
plt.show()

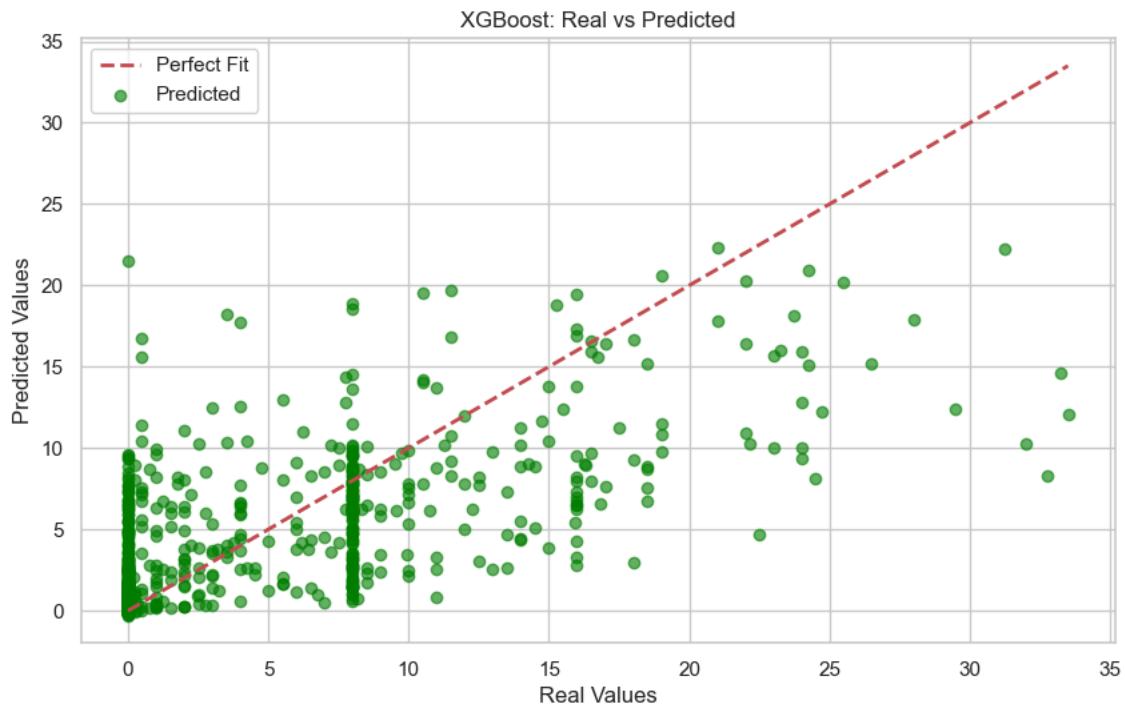
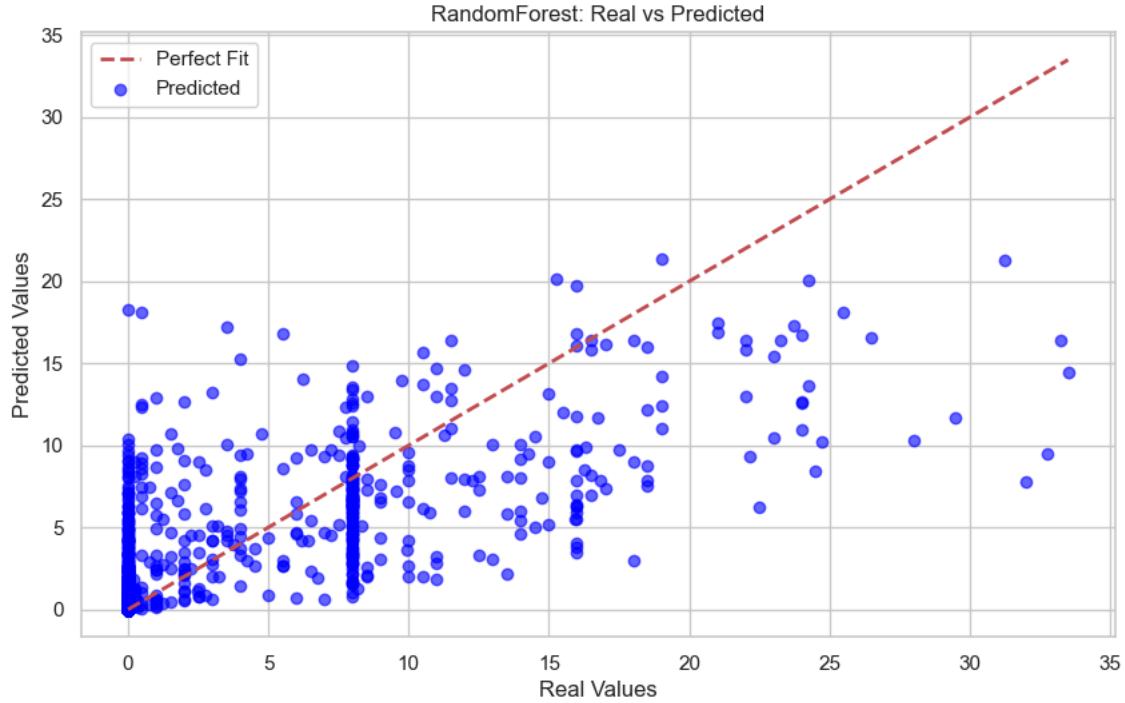
# ----- Line Plot for Real vs Predicted (Subset for Visualization) -----
# Use a subset of data for better line visualization
subset_index = slice(0, 100) # Adjust this range as needed

```

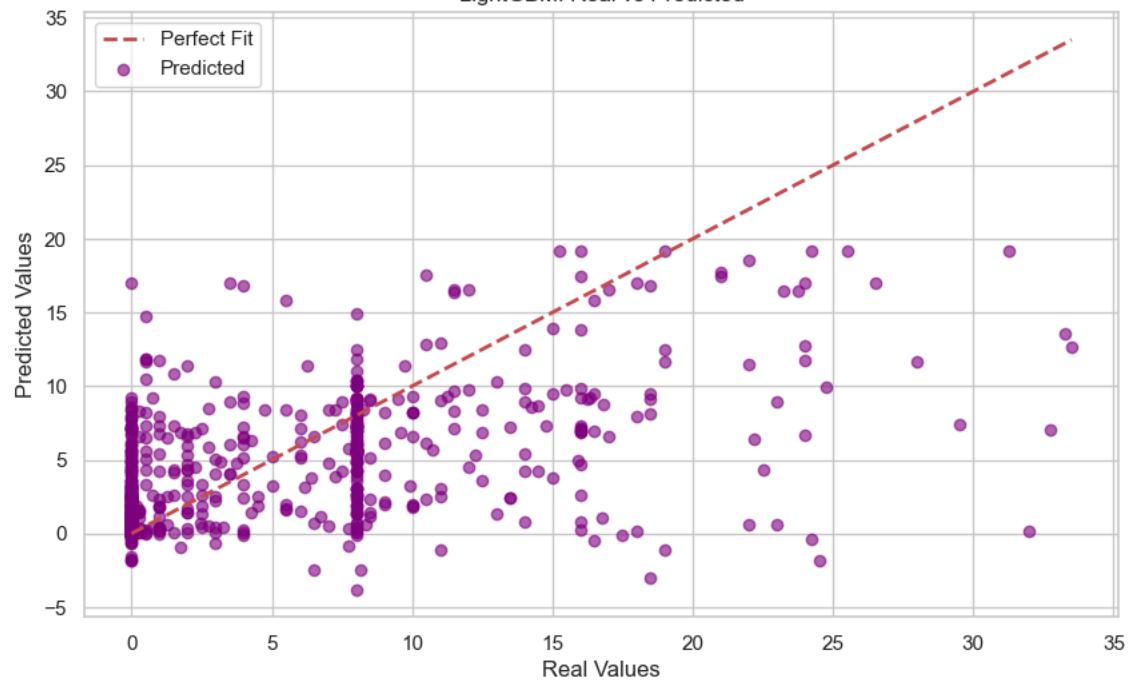
```

plt.figure(figsize=(12, 6))
plt.plot(range(len(y_test[subset_index])), y_test[subset_index], label="Real", color="black", linewidth=2)
plt.plot(range(len(y_test[subset_index])), preds_rf_final[subset_index], label="RandomForest", color="blue", linestyle="--")
plt.plot(range(len(y_test[subset_index])), preds_xgb_final[subset_index], label="XGBoost", color="green", linestyle="--")
plt.plot(range(len(y_test[subset_index])), preds_lgbm_final[subset_index], label="LightGBM", color="purple", linestyle="--")
plt.plot(range(len(y_test[subset_index])), preds_ridge_final[subset_index], label="Ridge", color="orange", linestyle="--")
plt.plot(range(len(y_test[subset_index])), preds_linear_final[subset_index], label="Linear", color="red", linestyle="--")
plt.title("Real vs Predicted (Subset): Line Plot Comparison")
plt.xlabel("Index")
plt.ylabel("Values")
plt.legend()
plt.show()

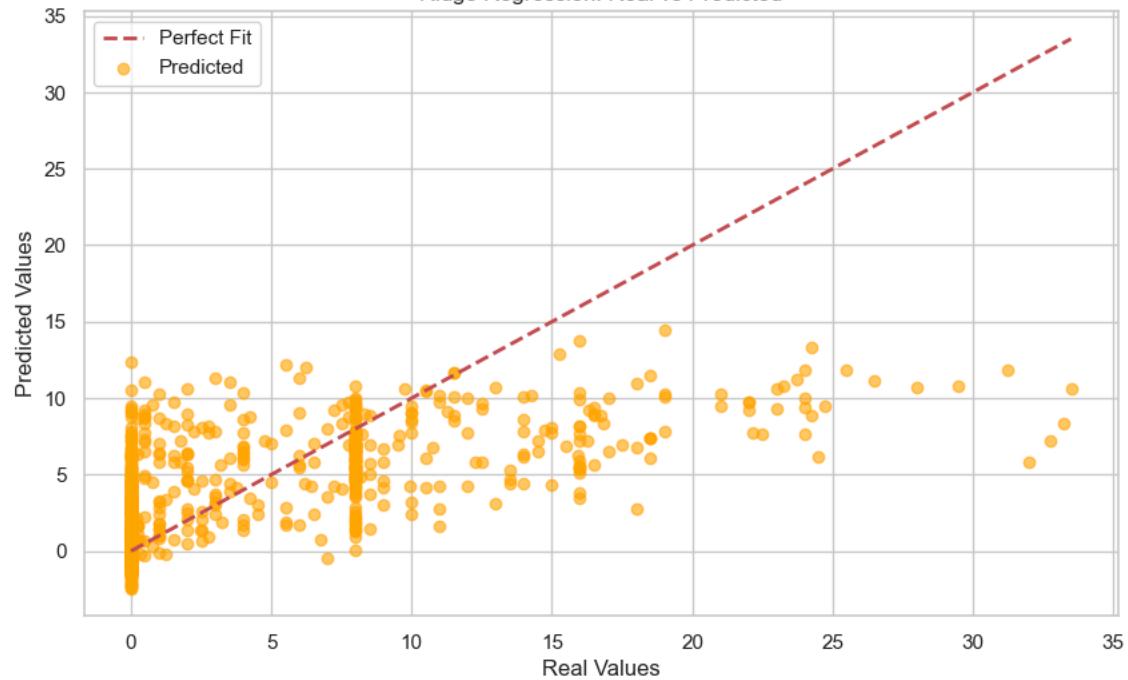
```



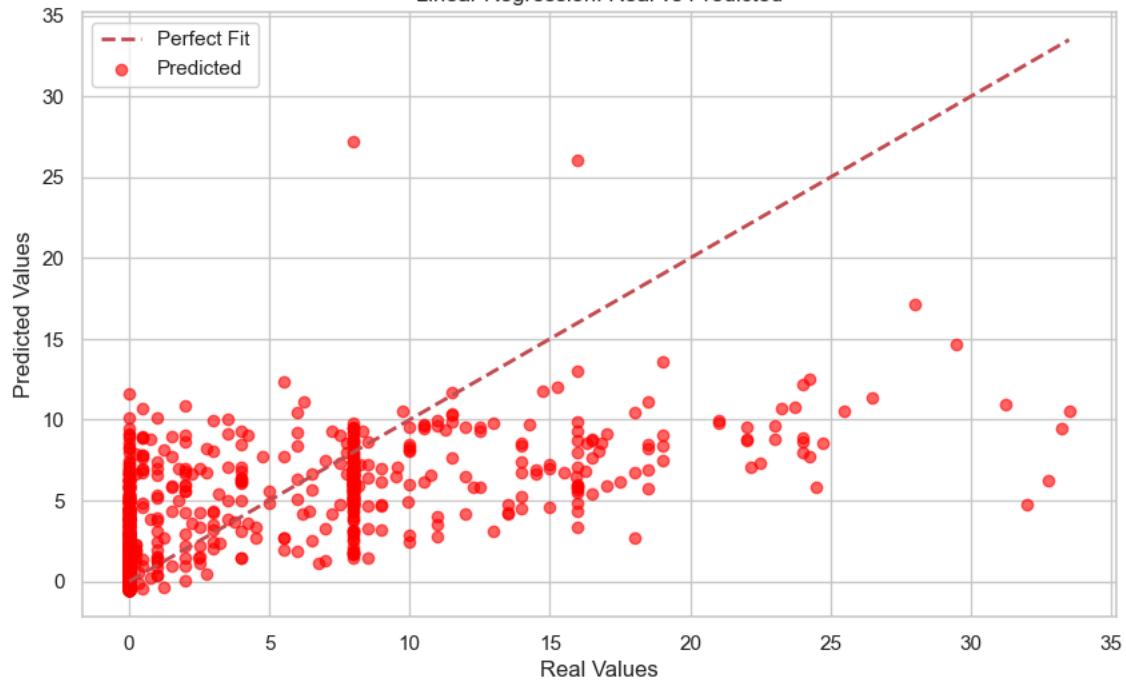
LightGBM: Real vs Predicted



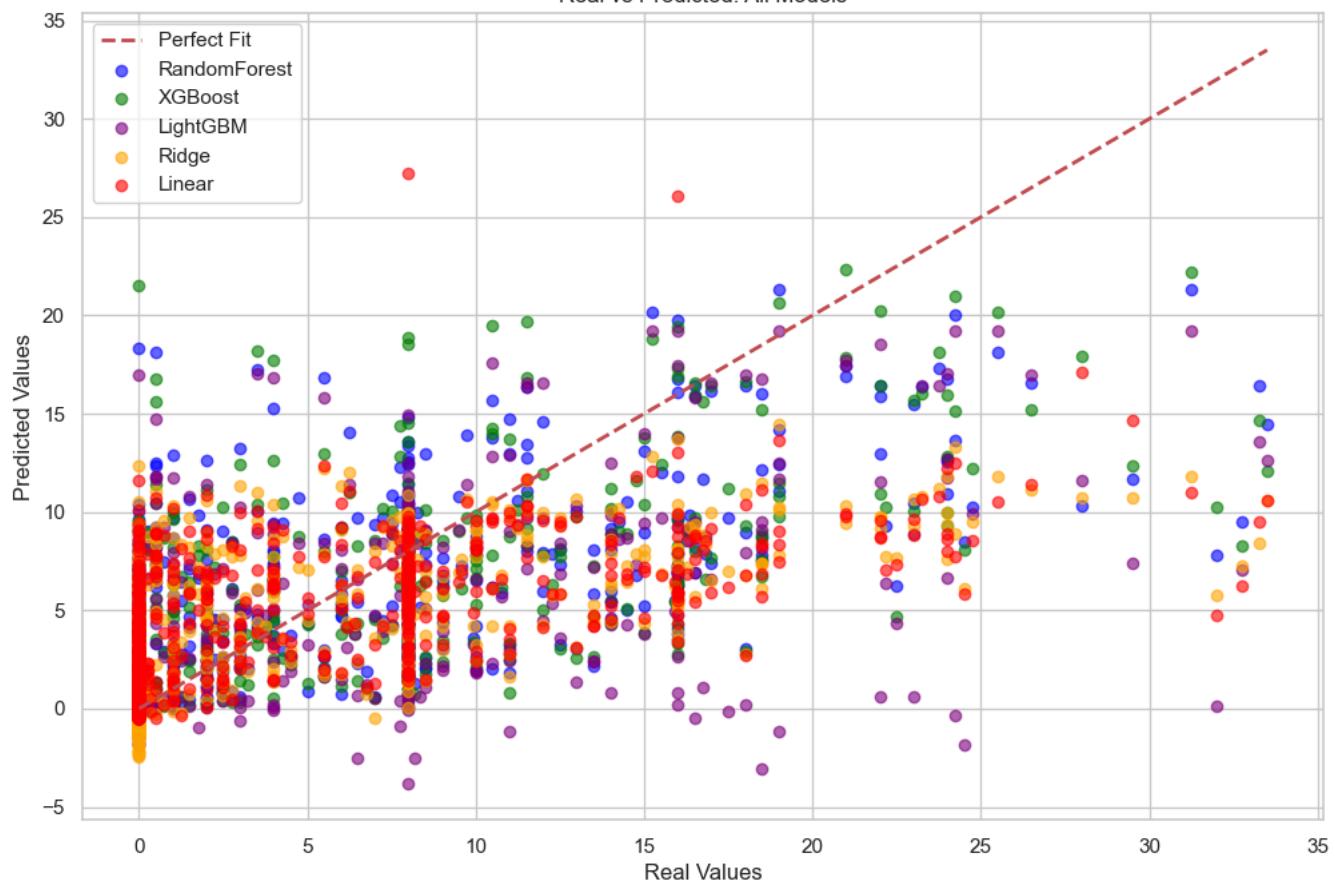
Ridge Regression: Real vs Predicted



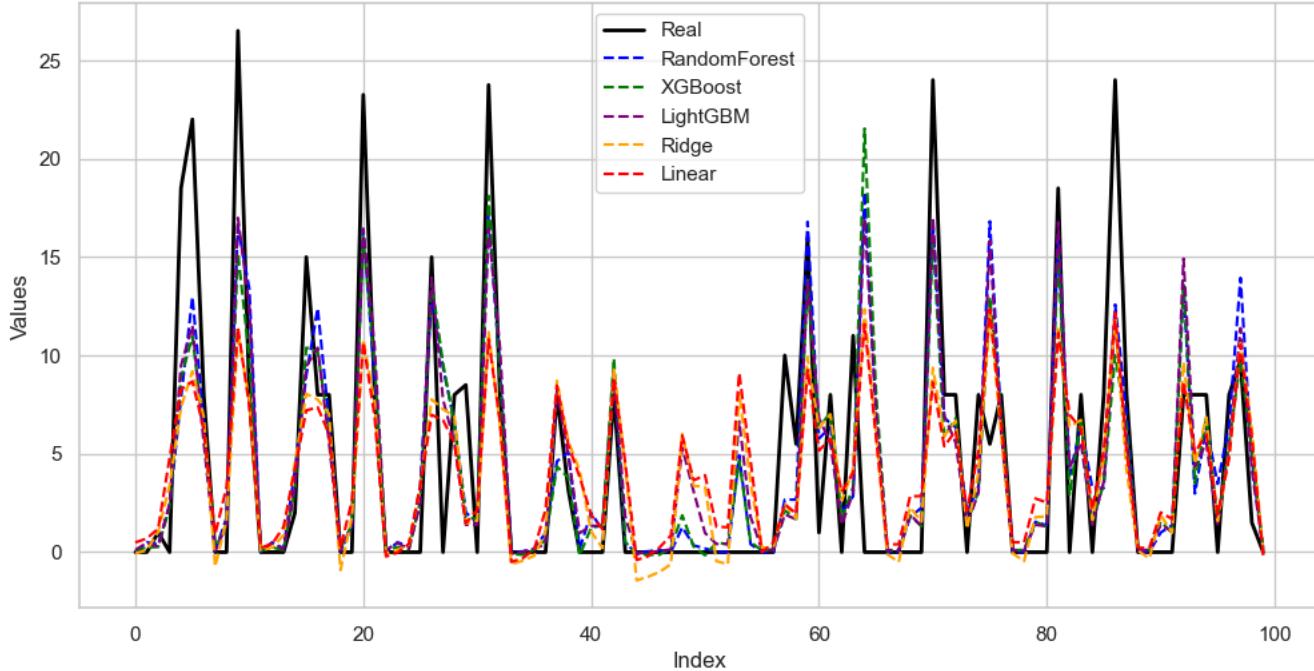
Linear Regression: Real vs Predicted



Real vs Predicted: All Models



Real vs Predicted (Subset): Line Plot Comparison



```

# Plot settings
sns.set(style="whitegrid", context="notebook", font_scale=1.1)
plt.rcParams["figure.dpi"] = 100 # High resolution

# ----- Shared Parameters -----
AXIS_LABEL_FONTSIZE = 12
TITLE_FONTSIZE = 14
PERFECT_FIT_COLOR = "#FF4C4C"
SCATTER_ALPHA = 0.7
SCATTER_EDGECOLOR = "w" # White edges for better visibility

# ----- Individual Model Plots -----
def plot_model_comparison(y_true, y_pred, model_name, color):
    plt.figure(figsize=(10, 6))
    plt.scatter(y_true, y_pred, alpha=SCATTER_ALPHA, label=f"{model_name} Predicted",
                color=color, edgecolor=SCATTER_EDGECOLOR, s=80)
    plt.plot([y_true.min(), y_true.max()], [y_true.min(), y_true.max()],
             linestyle='--', lw=2, color=PERFECT_FIT_COLOR, label="Perfect Fit")

    # Axis limits with buffer
    axis_min = min(y_true.min(), y_pred.min()) - 0.5
    axis_max = max(y_true.max(), y_pred.max()) + 0.5
    plt.xlim(axis_min, axis_max)
    plt.ylim(axis_min, axis_max)

    plt.title(f"{model_name}: Actual vs Predicted Total_Lost", fontsize=TITLE_FONTSIZE, pad=15)
    plt.xlabel("Actual Total_Lost", fontsize=AXIS_LABEL_FONTSIZE)
    plt.ylabel("Predicted Total_Lost", fontsize=AXIS_LABEL_FONTSIZE)
    plt.legend(loc='upper left', frameon=True, facecolor='white')
    plt.tight_layout()
    plt.show()

# Generate individual plots
plot_model_comparison(y_test, preds_rf_final, "RandomForest", "#1F77B4") # Blue
plot_model_comparison(y_test, preds_xgb_final, "XGBoost", "#2CA02C") # Green
plot_model_comparison(y_test, preds_lgbm_final, "LightGBM", "#9467BD") # Purple
plot_model_comparison(y_test, preds_ridge_final, "Ridge", "#FF7F0E") # Orange
plot_model_comparison(y_test, preds_linear_final, "Linear", "#D62728") # Red

# ----- Combined Model Comparison -----
plt.figure(figsize=(12, 8))
# RandomForest
plt.scatter(y_test, preds_rf_final, alpha=SCATTER_ALPHA, label="RandomForest",
            color="#1F77B4", edgecolor=SCATTER_EDGECOLOR, s=80)
# XGBoost
plt.scatter(y_test, preds_xgb_final, alpha=SCATTER_ALPHA, label="XGBoost",
            color="#2CA02C", marker="s", edgecolor=SCATTER_EDGECOLOR, s=80)
# LightGBM
plt.scatter(y_test, preds_lgbm_final, alpha=SCATTER_ALPHA, label="LightGBM",
            color="#9467BD", edgecolor=SCATTER_EDGECOLOR, s=80)

```

```

        color="#9467BD", marker="^", edgecolor=SCATTER_EDGECOLOR, s=80)
# Ridge
plt.scatter(y_test, preds_ridge_final, alpha=SCATTER_ALPHA, label="Ridge",
            color="#FF7F0E", marker="d", edgecolor=SCATTER_EDGECOLOR, s=80)
# Linear
plt.scatter(y_test, preds_linear_final, alpha=SCATTER_ALPHA, label="Linear",
            color="#D62728", marker="x", edgecolor=SCATTER_EDGECOLOR, s=80)

plt.plot([y_test.min(), y_test.max()], [y_test.min(), y_test.max()],
         linestyle='--', lw=2, color=PERFECT_FIT_COLOR, label="Perfect Fit")

plt.title("Model Comparison: Actual vs Predicted Total_Lost", fontsize=TITLE_FONTSIZE, pad=15)
plt.xlabel("Actual Total_Lost", fontsize=AXIS_LABEL_FONTSIZE)
plt.ylabel("Predicted Total_Lost", fontsize=AXIS_LABEL_FONTSIZE)
plt.xlim(y_test.min() - 0.5, y_test.max() + 0.5)
plt.ylim(y_test.min() - 0.5, y_test.max() + 0.5)
plt.legend(loc='upper left', frameon=True, facecolor='white', borderpad=1)
plt.tight_layout()
plt.show()

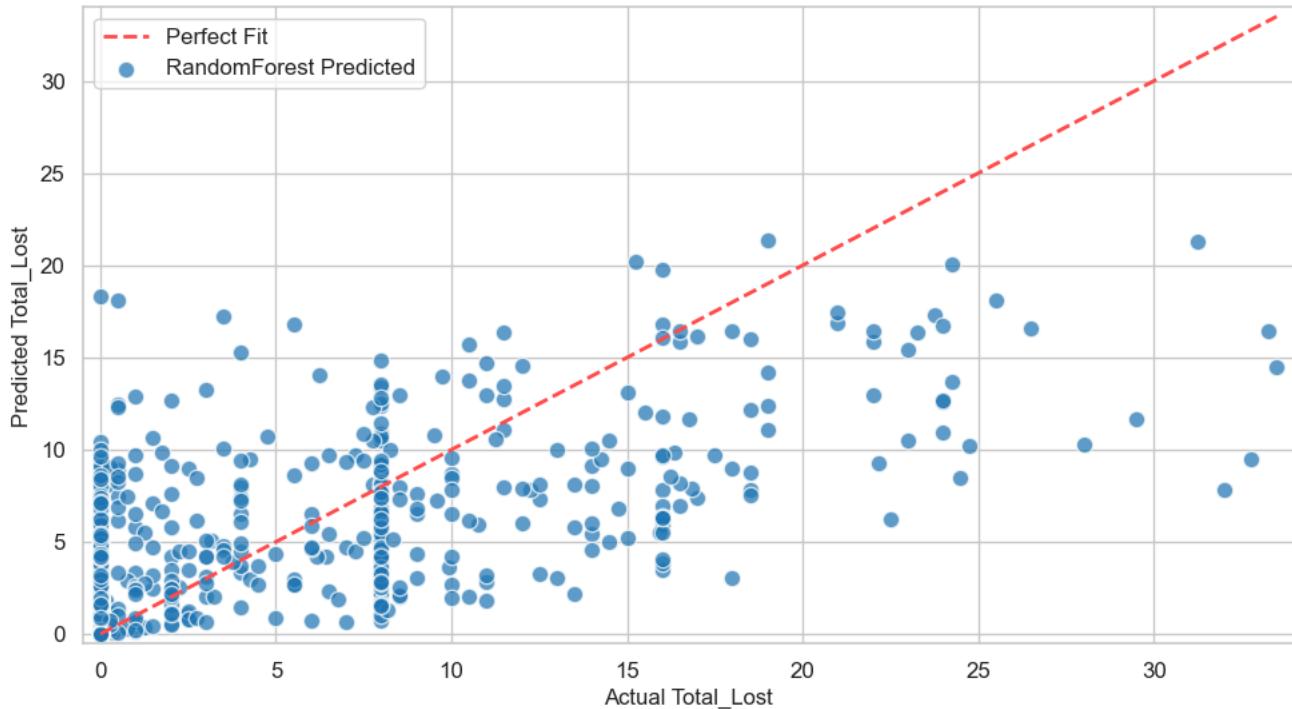
# ----- Time Series Subset Comparison -----
subset_index = slice(-100, None) # First 100 samples

plt.figure(figsize=(12, 6))
# Actual Values
plt.plot(y_test[subset_index], label="Actual", color="black", lw=2, zorder=3)
# Model Predictions
plt.plot(preds_rf_final[subset_index], label="RandomForest", color="#1F77B4", linestyle="--")
plt.plot(preds_xgb_final[subset_index], label="XGBoost", color="#2CA02C", linestyle="--")
plt.plot(preds_lgbm_final[subset_index], label="LightGBM", color="#9467BD", linestyle="--")
plt.plot(preds_ridge_final[subset_index], label="Ridge", color="#FF7F0E", linestyle="--")
plt.plot(preds_linear_final[subset_index], label="Linear", color="#D62728", linestyle="--")

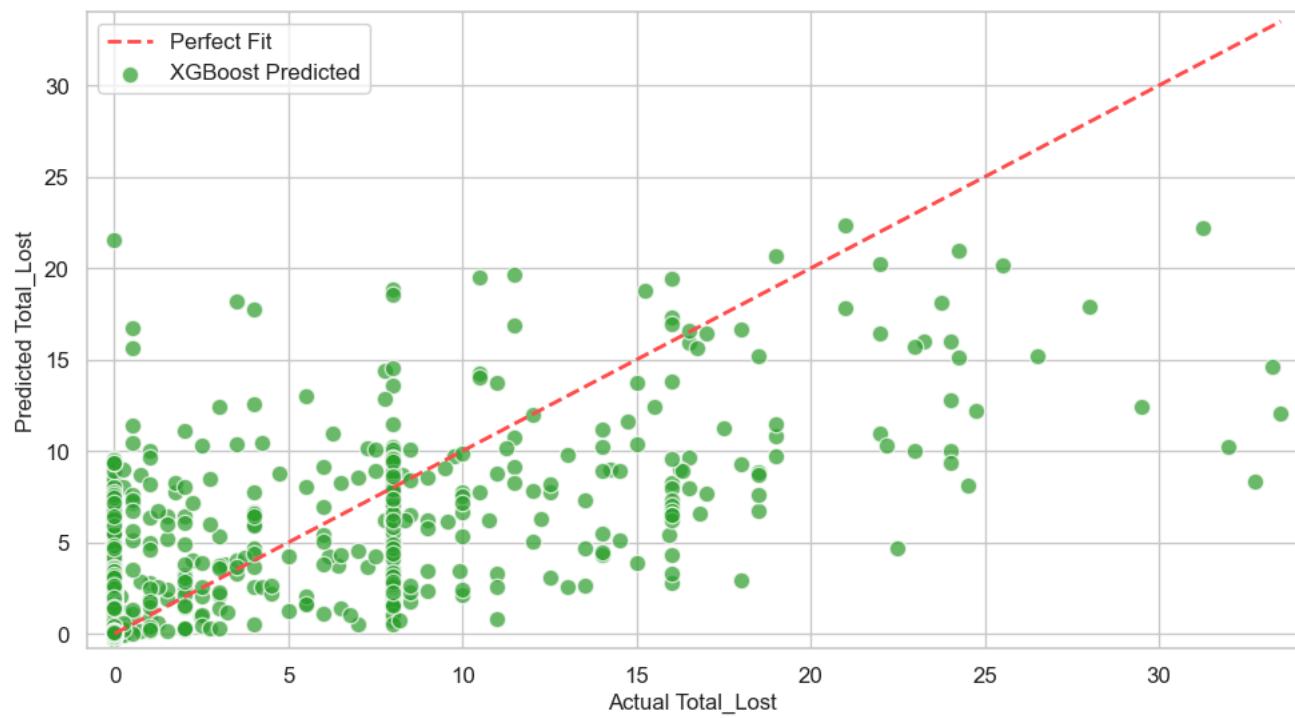
plt.title("Time Series Subset: Actual vs Predicted Total_Lost", fontsize=TITLE_FONTSIZE, pad=15)
plt.xlabel("Time Step", fontsize=AXIS_LABEL_FONTSIZE)
plt.ylabel("Total_Lost", fontsize=AXIS_LABEL_FONTSIZE)
plt.legend(loc='upper right', frameon=True, facecolor='white')
plt.grid(True, linestyle='--', alpha=0.7)
plt.tight_layout()
plt.show()

```

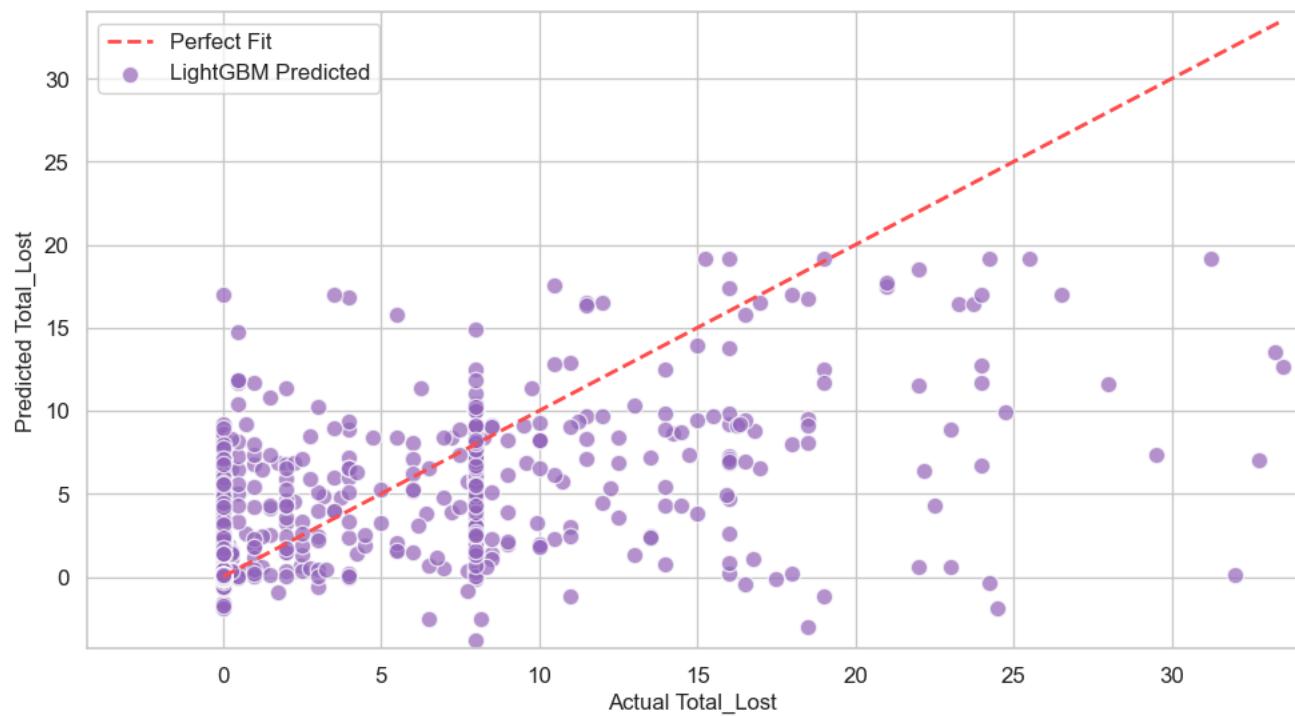
RandomForest: Actual vs Predicted Total_Lost



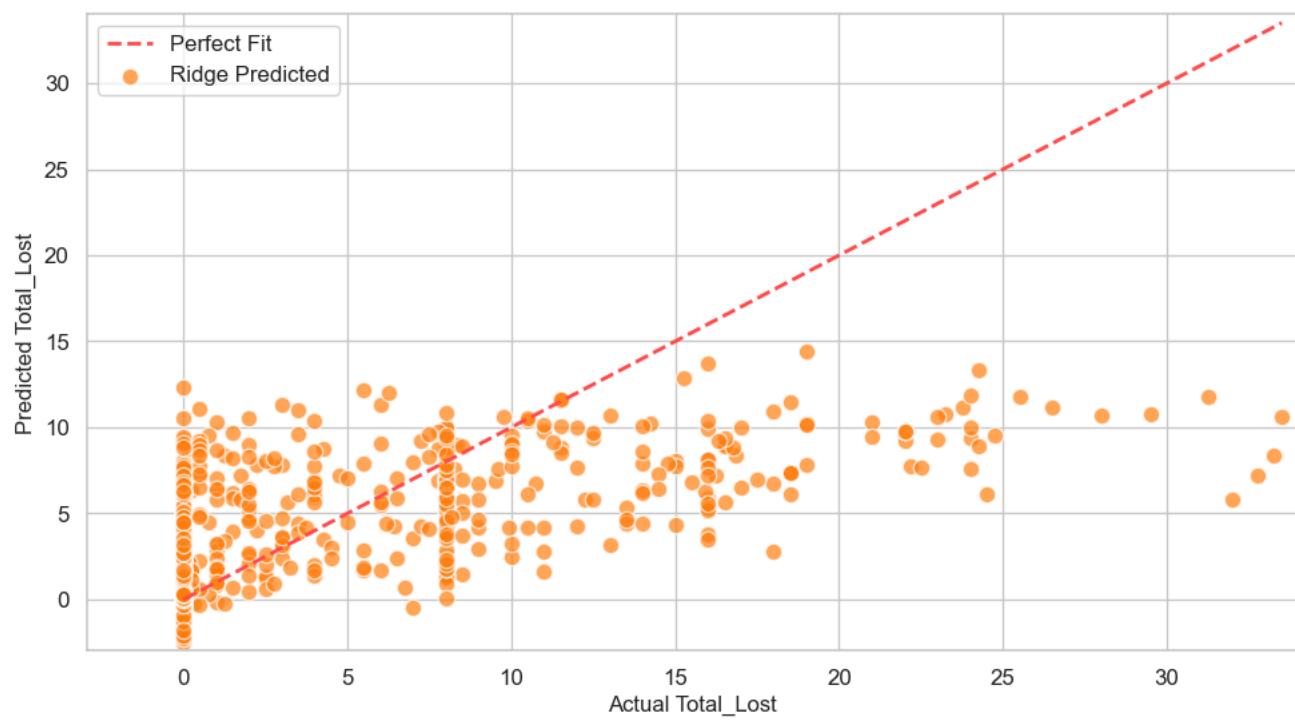
XGBoost: Actual vs Predicted Total_Lost



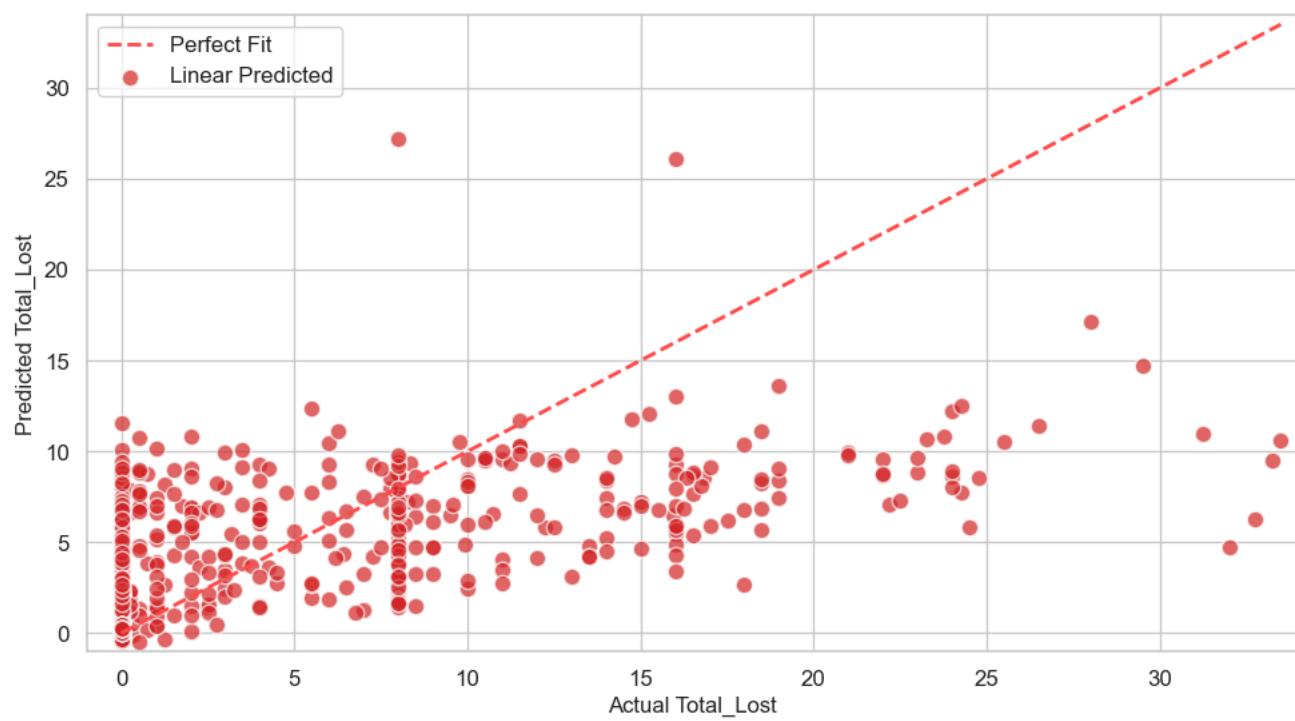
LightGBM: Actual vs Predicted Total_Lost



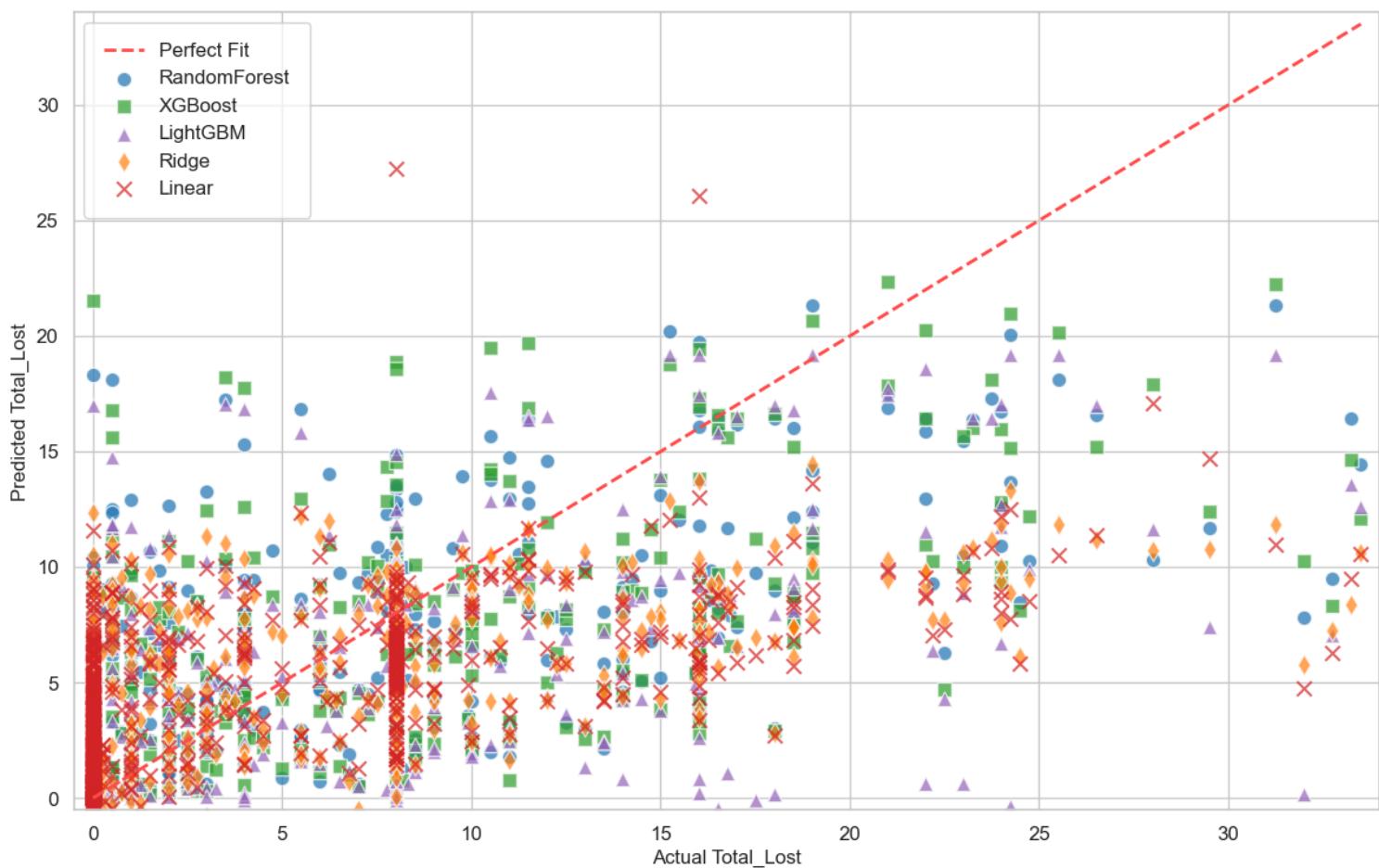
Ridge: Actual vs Predicted Total_Lost



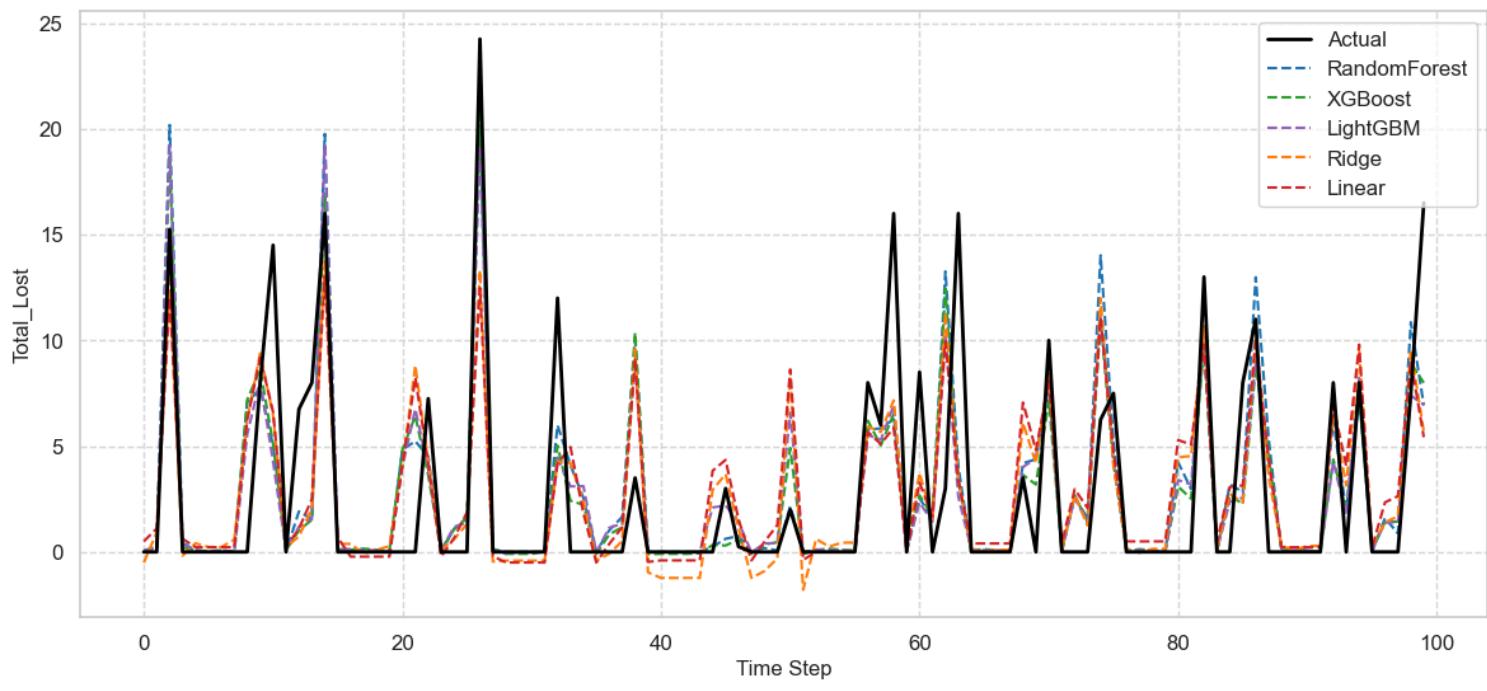
Linear: Actual vs Predicted Total_Lost



Model Comparison: Actual vs Predicted Total_Lost



Time Series Subset: Actual vs Predicted Total_Lost



Predicting Absenteeism from Total_Lost

The core objective of this section is to evaluate the model's performance not just in predicting Total_Lost, but also in its ability to predict Absenteeism, which is the true business metric of interest.

Absenteeism Formula

$$\text{Absenteeism} = (\text{Total_Lost}) \div (\text{Scheduled Hours})$$

Where:

- **Total_Lost** = The total hours lost due to absenteeism.
- **Scheduled Hours** = The total hours an employee was scheduled to work.

Key Objectives:

- Assess both **actual** and **predicted absenteeism rates**.
- Compare model performance using key metrics:
 - **R2 (R-squared)**: Measures the proportion of variance explained by the model.
 - **MSE (Mean Squared Error)**: Quantifies the average squared difference between actual and predicted absenteeism.
 - **MAE (Mean Absolute Error)**: Shows the average magnitude of errors in predictions.
 - **RMSE (Root Mean Squared Error)**: Provides error magnitude in the same unit as absenteeism for better interpretability.

Why This Matters:

While **Total_Lost** predictions are essential for operational analysis, the **true business impact** lies in predicting absenteeism rates, which directly affect productivity and workforce management decisions.

This dual evaluation ensures the model is not only technically sound but also **business-relevant**.

```
# ----- Function to Calculate Absenteeism -----
def calculate_absenteeism(total_lost, scheduled):
    with np.errstate(divide='ignore', invalid='ignore'):
        absenteeism = np.where(scheduled != 0, total_lost / scheduled, 0)
    return absenteeism

# ----- Function to Evaluate Absenteeism Predictions -----
def evaluate_absenteeism(y_true, y_pred, scheduled):
    actual_absenteeism = calculate_absenteeism(y_true, scheduled)
    predicted_absenteeism = calculate_absenteeism(y_pred, scheduled)

    r2 = r2_score(actual_absenteeism, predicted_absenteeism)
    mse = mean_squared_error(actual_absenteeism, predicted_absenteeism)
    mae = mean_absolute_error(actual_absenteeism, predicted_absenteeism)
    rmse = np.sqrt(mse)

    return actual_absenteeism, predicted_absenteeism, {'R2': r2, 'MSE': mse, 'MAE': mae, 'RMSE': rmse}

# ----- Absenteeism Evaluation -----
# DataFrame to store absenteeism metrics
absenteeism_metrics_df = pd.DataFrame()

# X_test_e_l_n_m has a 'Scheduled_Hours' column
scheduled = X_test_e_l_n_m['Scheduled_Hours'].values

# Evaluate Absenteeism for Each Model
for model_name, preds_final in {
    "RandomForest": preds_rf_final,
    "XGBoost": preds_xgb_final,
    "LightGBM": preds_lgbm_final,
    "Ridge": preds_ridge_final,
    "Linear": preds_linear_final
}.items():
    actual_abs, predicted_abs, metrics = evaluate_absenteeism(y_test, preds_final, scheduled)

    print(f"{model_name} Absenteeism Metrics: {metrics}")
    # Save metrics to DataFrame
    metrics['Model'] = model_name
    absenteeism_metrics_df = pd.concat([absenteeism_metrics_df, pd.DataFrame([metrics])], ignore_index=True)

# Display absenteeism metrics
print("\nAbsenteeism Metrics for All Models:")
print(absenteeism_metrics_df)
absenteeism_metrics_df
```

RandomForest Absenteeism Metrics: {'R2': 0.5383500006197872, 'MSE': 0.005325633518027475, 'MAE': 0.02414126760309447, 'RMSE': 0.07297693826153215}

XGBoost Absenteeism Metrics: {'R2': 0.377612474310423, 'MSE': 0.007179915244155999, 'MAE': 0.026119951158263512, 'RMSE': 0.0847343805320839}

LightGBM Absenteeism Metrics: {'R2': 0.6096314682077553, 'MSE': 0.004503324466775814, 'MAE': 0.025063218523795616, 'RMSE': 0.06710681386249695}

Ridge Absenteeism Metrics: {'R2': 0.48818255540629807, 'MSE': 0.005904369417738202, 'MAE': 0.03127852634554316, 'RMSE': 0.07683989470150386}

Linear Absenteeism Metrics: {'R2': 0.4875668855026011, 'MSE': 0.0059114718379257285, 'MAE': 0.03335280565083788, 'RMSE': 0.07688609651897883}

Absenteeism Metrics for All Models:

	R2	MSE	MAE	RMSE	Model
0	0.538350	0.005326	0.024141	0.072977	RandomForest
1	0.377612	0.007180	0.026120	0.084734	XGBoost
2	0.609631	0.004503	0.025063	0.067107	LightGBM
3	0.488183	0.005904	0.031279	0.076840	Ridge
4	0.487567	0.005911	0.033353	0.076886	Linear