```
from google.colab import files
uploaded = files.upload()
```

Choose Files waam_dataset.xlsx

waam_dataset.xlsx(application/vnd.openxmlformats-officedocument.spreadsheetml.sheet) - 64190 bytes, last modified: 12/1/2025 - 100% done

```
Saving waam_dataset.xlsx to waam_dataset.xlsx
```

```
import pandas as pd
import numpy as np
from sklearn.model_selection import train_test_split
from sklearn.preprocessing import StandardScaler
import matplotlib.pyplot as plt
import seaborn as sns

# 1. LOAD DATASET
# Replace with your actual file path
df = pd.read_excel("waam_dataset.xlsx")

print("Dataset Loaded Successfully!")
df.head()
```

```
Dataset Loaded Successfully!
```

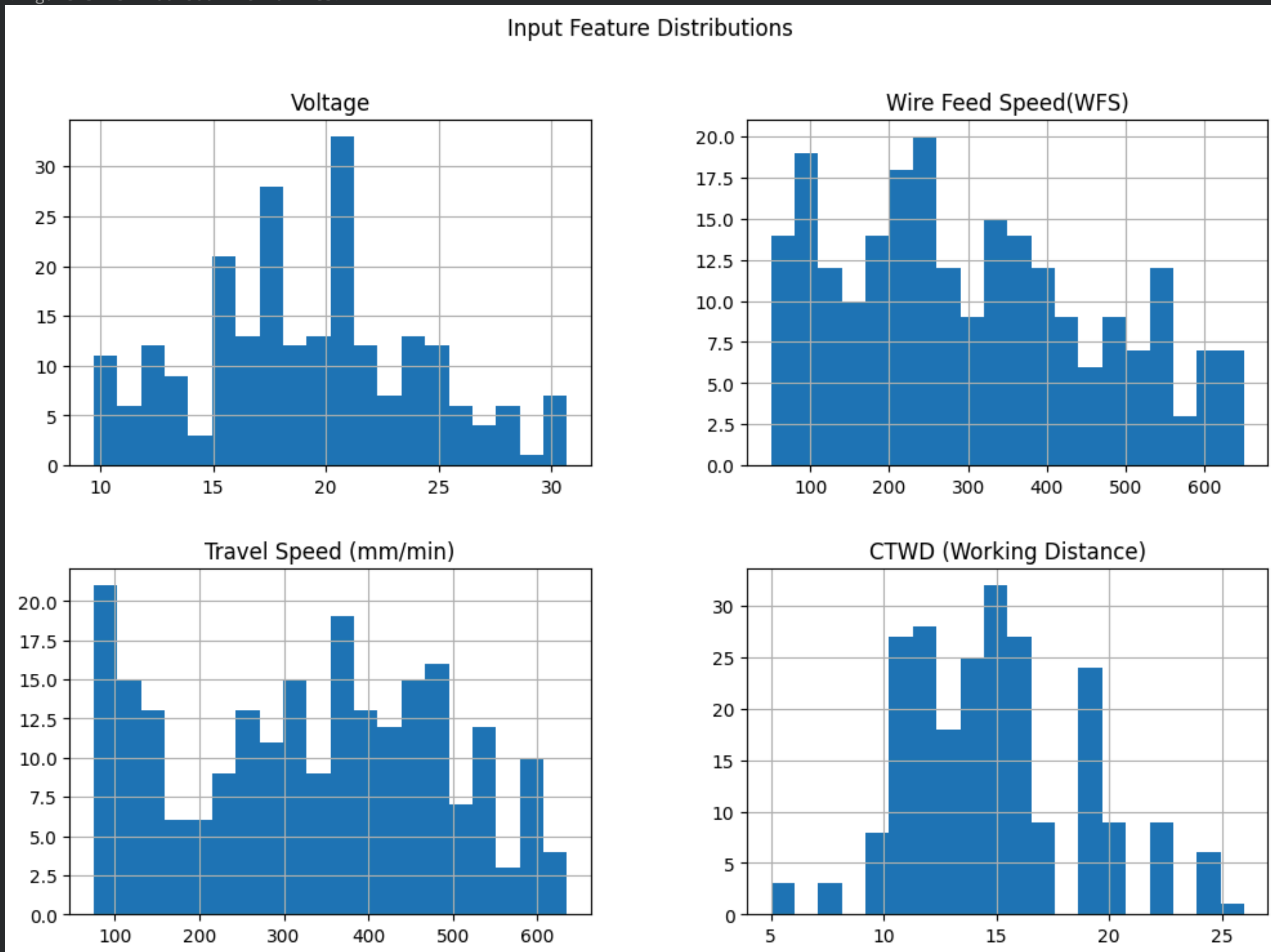
	EXPERIMENTS	Voltage	Wire Feed Speed(WFS)	Travel Speed (mm/min)	CTWD (Working Distance)	Sz1	Sz2	Sz3	Sz4	Sz5	Sz6	Sz7	Sz8	Sz9	Sz10	Sz11	Sz12	Sz13
0	1	12.0	75	100	10.5	5.00	4.35	3.46	4.22	4.21	3.33	3.44	3.08	3.91	2.75	4.01	3.60	3.46
1	2	12.0	75	100	10.5	3.78	3.84	3.85	3.67	3.75	3.82	4.99	3.36	3.67	3.63	3.58	3.41	3.73
2	3	12.0	75	100	10.5	3.68	3.45	3.53	3.63	3.86	3.70	3.84	3.81	3.79	3.93	3.75	3.78	3.74
3	4	14.0	100	125	11.0	3.16	3.11	3.12	3.15	3.03	3.07	2.98	3.22	3.14	3.31	3.13	3.57	3.68
4	5	14.0	100	125	11.0	3.18	3.12	3.12	3.45	3.15	3.09	3.38	3.23	3.18	3.40	3.64	4.01	3.87

Next steps: Generate code with df New interactive sheet

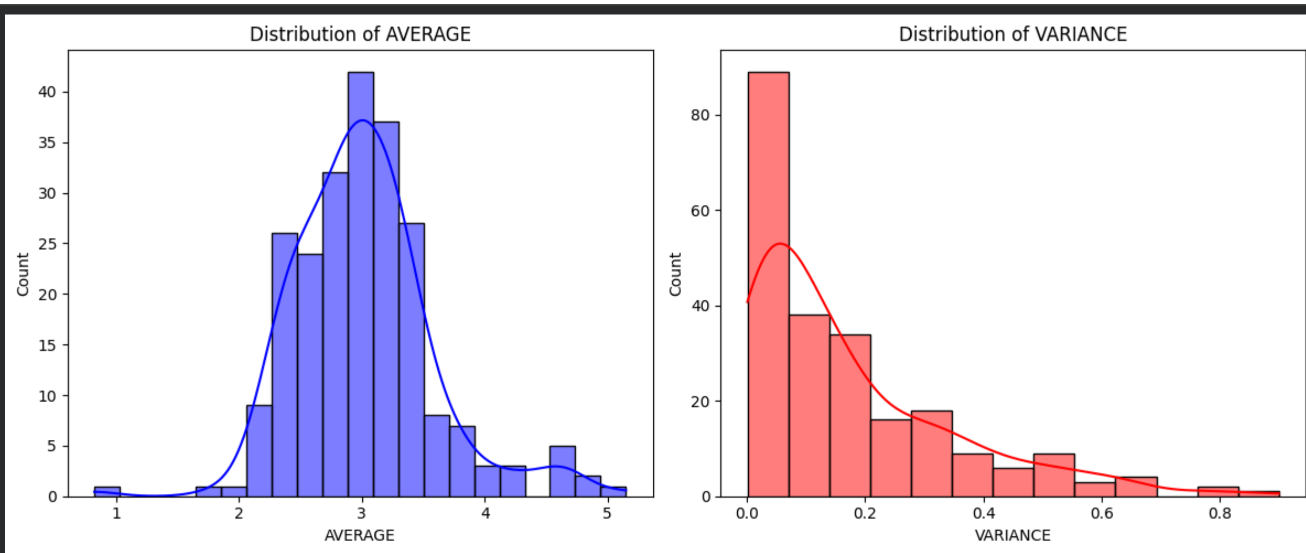
```
df.columns = df.columns.str.strip()        # remove spaces
df.columns = df.columns.str.replace('\n','')
df.columns = df.columns.str.replace('\r','')
df.columns = df.columns.str.replace('  ', ' ')
df.columns = df.columns.str.replace(u'\xa0', '')  # remove non-breaking spaces
```

```
import matplotlib.pyplot as plt
import seaborn as sns

plt.figure(figsize=(12,8))
df[['Voltage','Wire Feed Speed(WFS)','Travel Speed (mm/min)','CTWD (Working Distance)']].hist(
    bins=20, figsize=(12,8)
)
plt.suptitle("Input Feature Distributions")
plt.show()
```

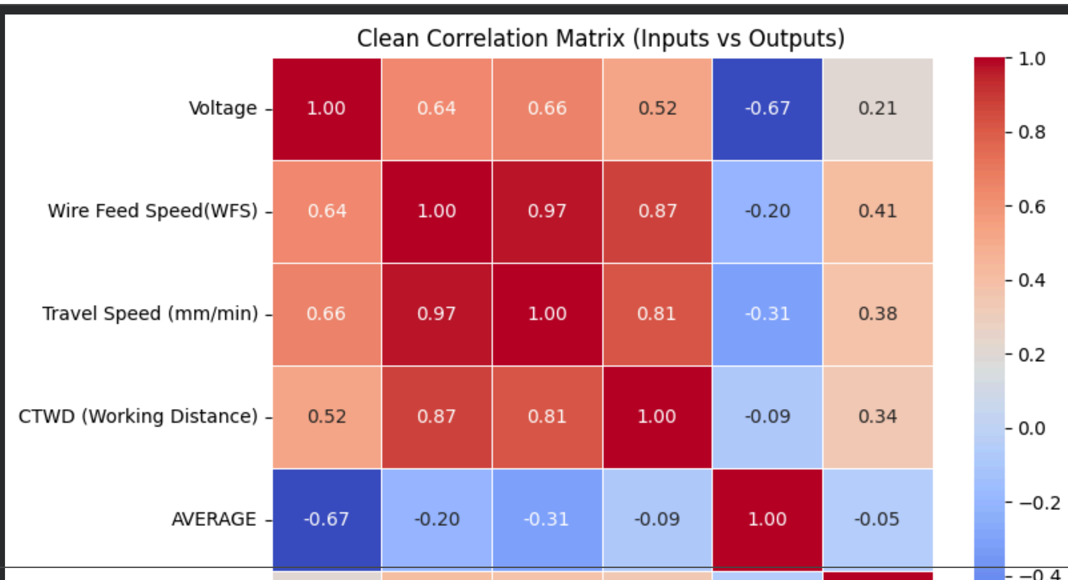
```
<Figure size 1200x800 with 0 Axes>
```



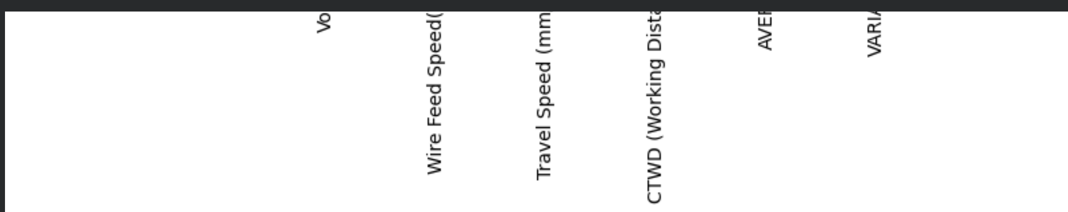

```
plt.figure(figsize=(12,5))

plt.subplot(1,2,1)
sns.histplot(df['AVERAGE'], kde=True, color='blue')
plt.title("Distribution of AVERAGE")

plt.subplot(1,2,2)
sns.histplot(df['VARIANCE'], kde=True, color='red')
plt.title("Distribution of VARIANCE")

plt.tight_layout()
plt.show()
```

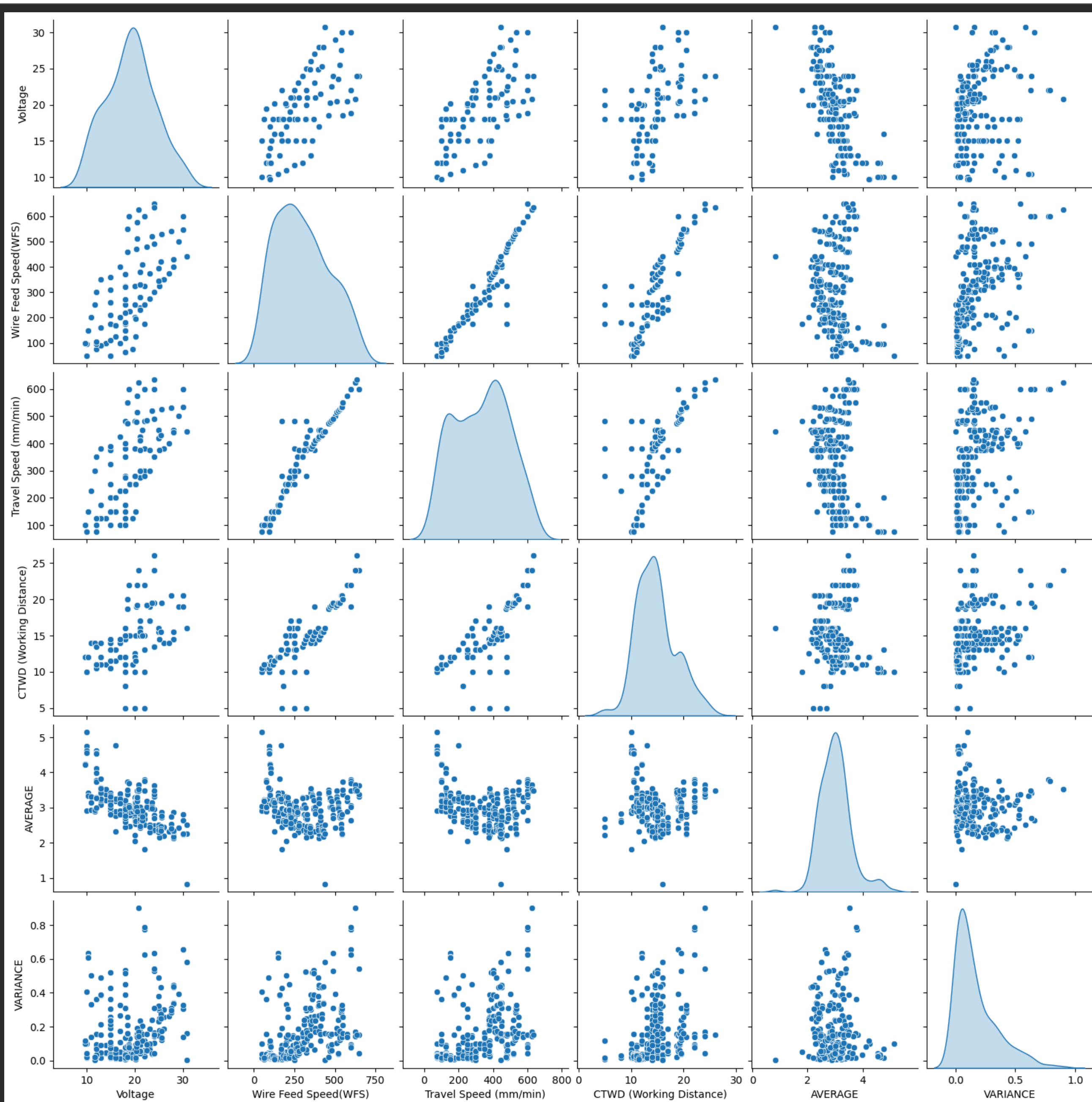



```
import pandas as pd
import seaborn as sns
import matplotlib.pyplot as plt

# Columns we want to keep
selected_columns = [
    'Voltage',
    'Wire Feed Speed(WFS)',
    'Travel Speed (mm/min)',
    'CTWD (Working Distance)',
    'AVERAGE',
    'VARIANCE'
]

# Filter dataframe
df_clean = df[selected_columns]

# Compute correlation
corr_clean = df_clean.corr()

# Display correlation table
corr_clean

plt.figure(figsize=(8,6))
sns.heatmap(
    corr_clean,
    annot=True,
    cmap="coolwarm",
    fmt=".2f",
    linewidths=0.5
)
plt.title("Correlation Matrix (Inputs vs Outputs)")
plt.show()
```

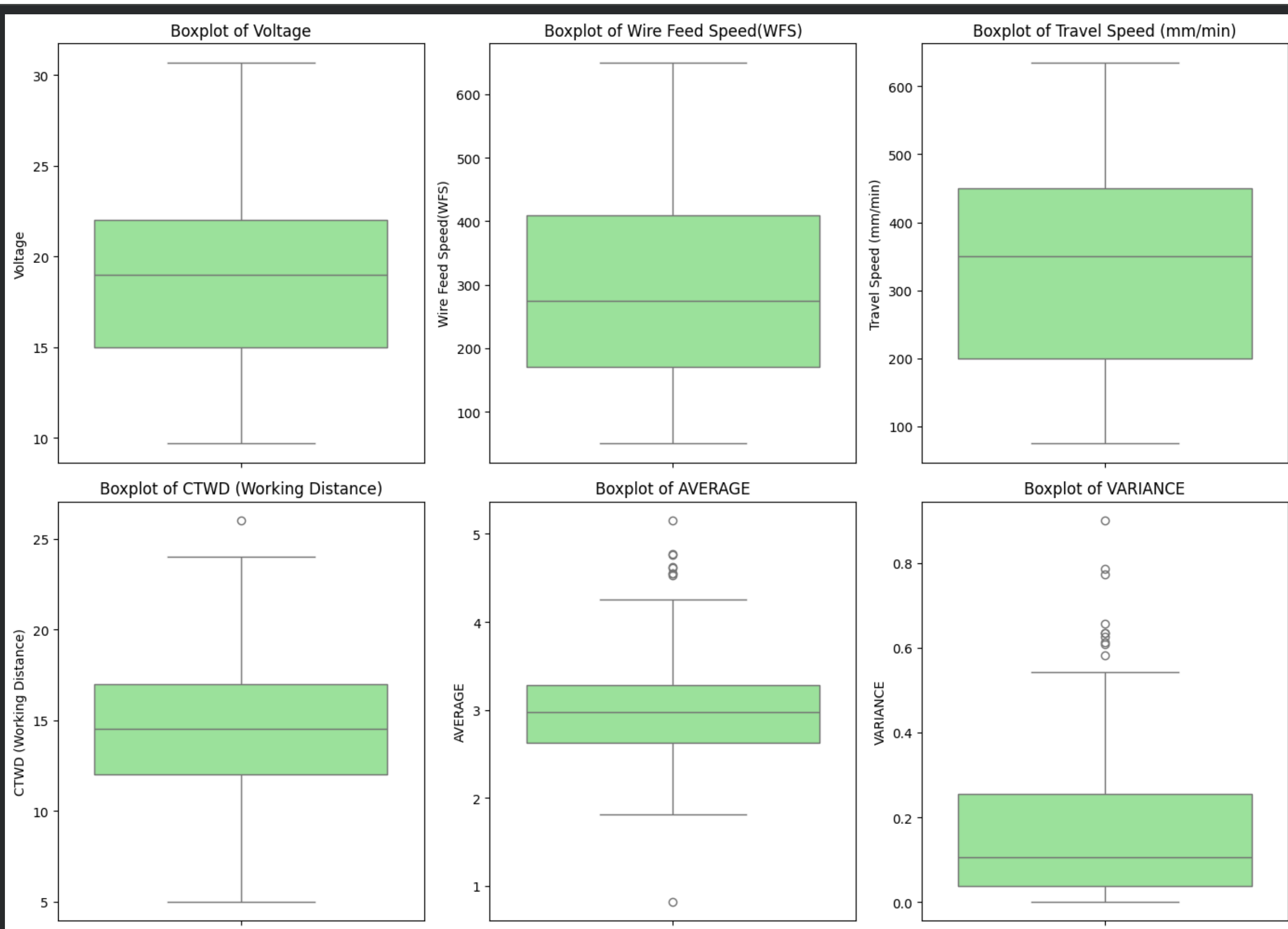



```
sns.pairplot(df[['Voltage','Wire Feed Speed(WFS)','Travel Speed (mm/min)',
                 'CTWD (Working Distance)','AVERAGE','VARIANCE']],
             diag_kind='kde')
plt.show()
```



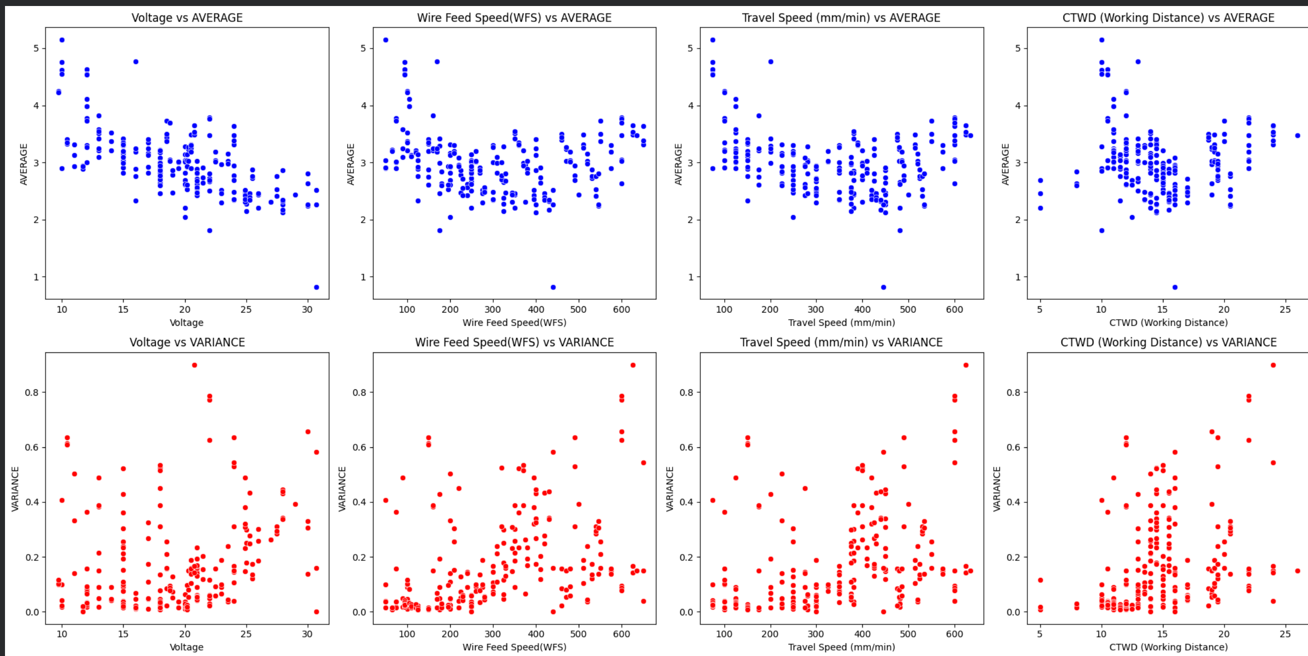



```
plt.figure(figsize=(14,10))
cols = ['Voltage','Wire Feed Speed(WFS)','Travel Speed (mm/min)',
        'CTWD (Working Distance)','AVERAGE','VARIANCE']

for i, col in enumerate(cols):
    plt.subplot(2,3,i+1)
    sns.boxplot(y=df[col], color='lightgreen')
    plt.title(f"Boxplot of {col}")

plt.tight_layout()
plt.show()
```




```
import matplotlib.pyplot as plt
import seaborn as sns

# Define inputs and targets
inputs = ['Voltage', 'Wire Feed Speed(WFS)', 'Travel Speed (mm/min)', 'CTWD (Working Distance)']
targets = ['AVERAGE', 'VARIANCE']

# Create combined grid: 2 rows (AVERAGE, VARIANCE) × 4 columns (the 4 inputs)
fig, axes = plt.subplots(2, 4, figsize=(20, 10))

# Plot: Inputs vs AVERAGE (top row)
for i, feature in enumerate(inputs):
    sns.scatterplot(
        x=df[feature],
        y=df['AVERAGE'],
        ax=axes[0, i],
        color='blue'
    )
    axes[0, i].set_title(f"{feature} vs AVERAGE")
    axes[0, i].set_xlabel(feature)
    axes[0, i].set_ylabel("AVERAGE")

# Plot: Inputs vs VARIANCE (bottom row)
for i, feature in enumerate(inputs):
    sns.scatterplot(
        x=df[feature],
        y=df['VARIANCE'],
        ax=axes[1, i],
        color='red'
    )
    axes[1, i].set_title(f"{feature} vs VARIANCE")
    axes[1, i].set_xlabel(feature)
    axes[1, i].set_ylabel("VARIANCE")
```

```
plt.tight_layout()

plt.show()
```



Random Forest Regression.

```
# Select Features and Targets
# Inputs = First 4 features
X = df[['Voltage', 'Wire Feed Speed(WFS)', 'Travel Speed (mm/min)', 'CTWD (Working Distance)']]

# Outputs = Average & Variance
y = df[['AVERAGE', 'VARIANCE']]

print("Input shape:", X.shape)
print("Output shape:", y.shape)
```

```
Input shape: (229, 4)
Output shape: (229, 2)
```

```
from sklearn.model_selection import train_test_split
# Train/Test Split
X_train, X_test, y_train, y_test = train_test_split(
    X, y, test_size=0.2, random_state=42
)
```

```
from sklearn.preprocessing import StandardScaler
# Scale Inputs
scaler = StandardScaler()
X_train_scaled = scaler.fit_transform(X_train)
X_test_scaled = scaler.transform(X_test)
```

```
from sklearn.ensemble import RandomForestRegressor
# Training Random Forest Regressor
rf_avg = RandomForestRegressor(n_estimators=300, random_state=42)
rf_var = RandomForestRegressor(n_estimators=300, random_state=42)

# Train models
rf_avg.fit(X_train_scaled, y_train['AVERAGE'])
```

```
rf_var.fit(X_train_scaled, y_train['VARIANCE'])
```

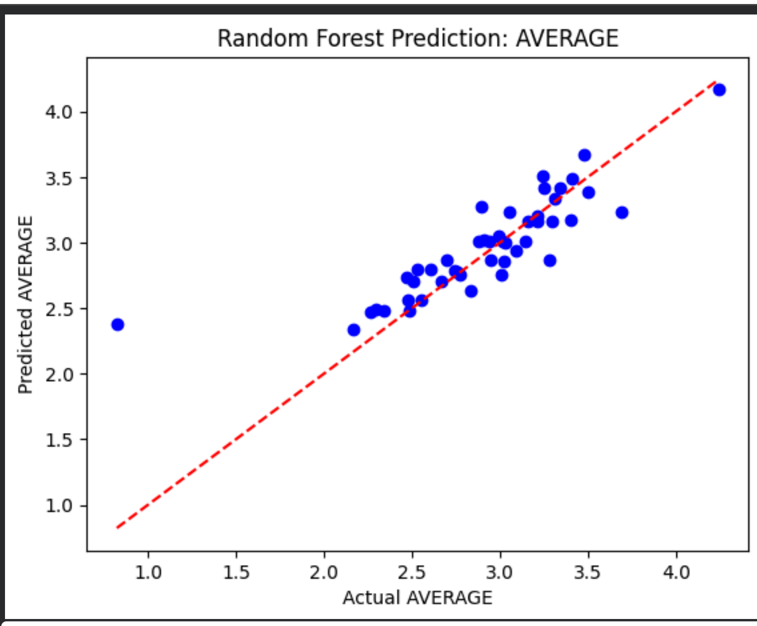
```
RandomForestRegressor
RandomForestRegressor(n_estimators=300, random_state=42)
```

```
#prediction
y_pred_avg = rf_avg.predict(X_test_scaled)
y_pred_var = rf_var.predict(X_test_scaled)
```

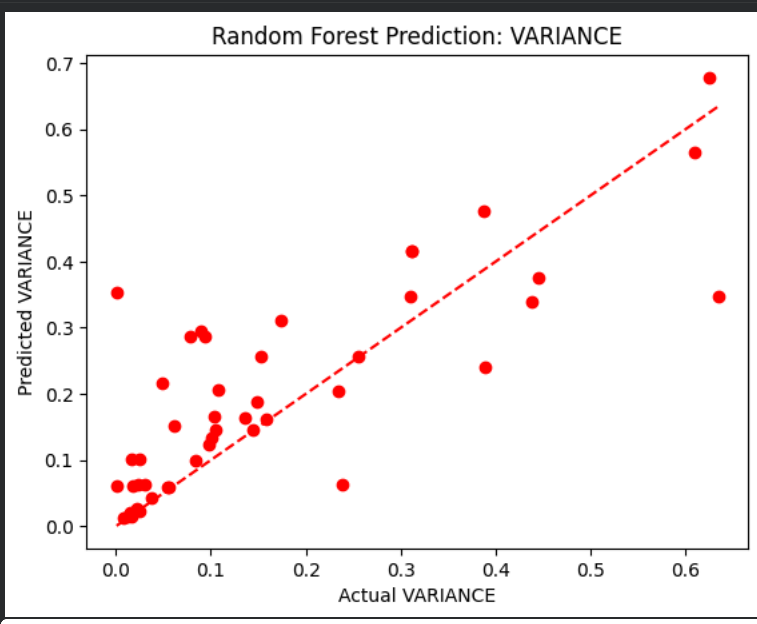
```
from sklearn.metrics import mean_squared_error, mean_absolute_error, r2_score
import numpy as np
# Evaluation Metrics
# AVERAGE
rmse_avg = np.sqrt(mean_squared_error(y_test['AVERAGE'], y_pred_avg))
mae_avg = mean_absolute_error(y_test['AVERAGE'], y_pred_avg)
r2_avg = r2_score(y_test['AVERAGE'], y_pred_avg)

# VARIANCE
rmse_var = np.sqrt(mean_squared_error(y_test['VARIANCE'], y_pred_var))
mae_var = mean_absolute_error(y_test['VARIANCE'], y_pred_var)
r2_var = r2_score(y_test['VARIANCE'], y_pred_var)

print("===== AVERAGE (Bead Height) =====")
print("RMSE:", rmse_avg)
print("MAE:", mae_avg)
print("R² Score:", r2_avg)

print("\n===== VARIANCE (Bead Stability) =====")
print("RMSE:", rmse_var)
print("MAE:", mae_var)
print("R² Score:", r2_var)
```

```
===== AVERAGE (Bead Height) =====
RMSE: 0.2880085567811965
MAE: 0.16956072036961944
R² Score: 0.6851073115314978

===== VARIANCE (Bead Stability) =====
RMSE: 0.10832201589862321
MAE: 0.07432176669992319
R² Score: 0.6034158196013664
```

```
# Plot Actual vs Predicted
plt.scatter(y_test['AVERAGE'], y_pred_avg, color='blue')
plt.xlabel("Actual AVERAGE")
plt.ylabel("Predicted AVERAGE")
plt.title("Random Forest Prediction: AVERAGE")
plt.plot([y_test['AVERAGE'].min(), y_test['AVERAGE'].max()],
         [y_test['AVERAGE'].min(), y_test['AVERAGE'].max()],
         'r--')
plt.show()
```




```
# VARIANCE
plt.scatter(y_test['VARIANCE'], y_pred_var, color='red')
plt.xlabel("Actual VARIANCE")
plt.ylabel("Predicted VARIANCE")
plt.title("Random Forest Prediction: VARIANCE")
plt.plot([y_test['VARIANCE'].min(), y_test['VARIANCE'].max()],
         [y_test['VARIANCE'].min(), y_test['VARIANCE'].max()],
         'r--')
plt.show()
```



Deep Learning Model Using Keras (TensorFlow)

```
import tensorflow as tf
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense
from tensorflow.keras.callbacks import EarlyStopping
```

```
# Building the Neural Network Model
model = Sequential([
    Dense(64, activation='relu', input_shape=(X_train_scaled.shape[1],)),
```

```
    Dense(32, activation='relu'),
    Dense(16, activation='relu'),
    Dense(2)   # output layer: [AVERAGE, VARIANCE]
])

model.compile(optimizer='adam', loss='mse')
model.summary()
```

```
/usr/local/lib/python3.12/dist-packages/keras/src/layers/core/dense.py:93: UserWarning: Do not pass an `input_shape`/`input_dim`
  super().__init__(activity_regularizer=activity_regularizer, **kwargs)
Model: "sequential"
```

Layer (type)	Output Shape	Param #
dense (Dense)	(None, 64)	320
dense_1 (Dense)	(None, 32)	2,080
dense_2 (Dense)	(None, 16)	528
dense_3 (Dense)	(None, 2)	34

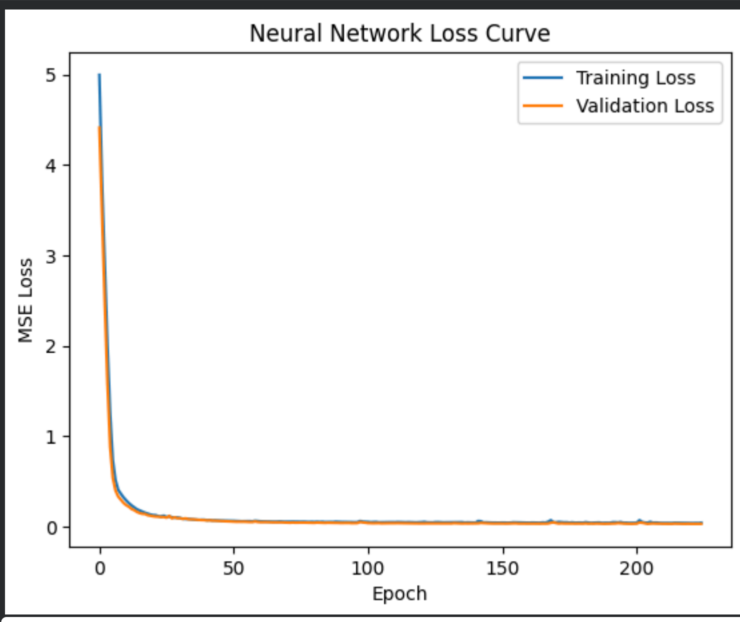
```
Total params: 2,962 (11.57 KB)
Trainable params: 2,962 (11.57 KB)
Non-trainable params: 0 (0.00 B)
```

```
# Training the Model
early_stop = EarlyStopping(monitor='val_loss', patience=20, restore_best_weights=True)

history = model.fit(
    X_train_scaled, y_train,
    validation_split=0.2,
    epochs=300,
    batch_size=16,
    callbacks=[early_stop],
    verbose=1
)
```

```
10/10 ━━━━━━━━━━━━━━━━━━━━ 0s 17ms/step - loss: 0.0488 - val_loss: 0.0349
```

```
Epoch 207/300
10/10 ━━━━━━━━━━━━━━━━━━━━ 0s 30ms/step - loss: 0.0450 - val_loss: 0.0376
Epoch 208/300
10/10 ━━━━━━━━━━━━━━━━━━━━ 0s 23ms/step - loss: 0.0610 - val_loss: 0.0356
Epoch 209/300
10/10 ━━━━━━━━━━━━━━━━━━━━ 0s 33ms/step - loss: 0.0401 - val_loss: 0.0357
Epoch 210/300
10/10 ━━━━━━━━━━━━━━━━━━━━ 1s 29ms/step - loss: 0.0305 - val_loss: 0.0342
Epoch 211/300
10/10 ━━━━━━━━━━━━━━━━━━━━ 1s 27ms/step - loss: 0.0420 - val_loss: 0.0341
Epoch 212/300
10/10 ━━━━━━━━━━━━━━━━━━━━ 0s 18ms/step - loss: 0.0419 - val_loss: 0.0336
Epoch 213/300
10/10 ━━━━━━━━━━━━━━━━━━━━ 0s 19ms/step - loss: 0.0469 - val_loss: 0.0340
Epoch 214/300
10/10 ━━━━━━━━━━━━━━━━━━━━ 0s 26ms/step - loss: 0.0314 - val_loss: 0.0333
```

```
# Plot Training & Validation Loss
plt.plot(history.history['loss'], label='Training Loss')
plt.plot(history.history['val_loss'], label='Validation Loss')
plt.title("Neural Network Loss Curve")
plt.xlabel("Epoch")
plt.ylabel("MSE Loss")
plt.legend()
plt.show()
```




```
# Predictions
y_pred_dl = model.predict(X_test_scaled)

y_pred_avg_dl = y_pred_dl[:, 0]
y_pred_var_dl = y_pred_dl[:, 1]
```

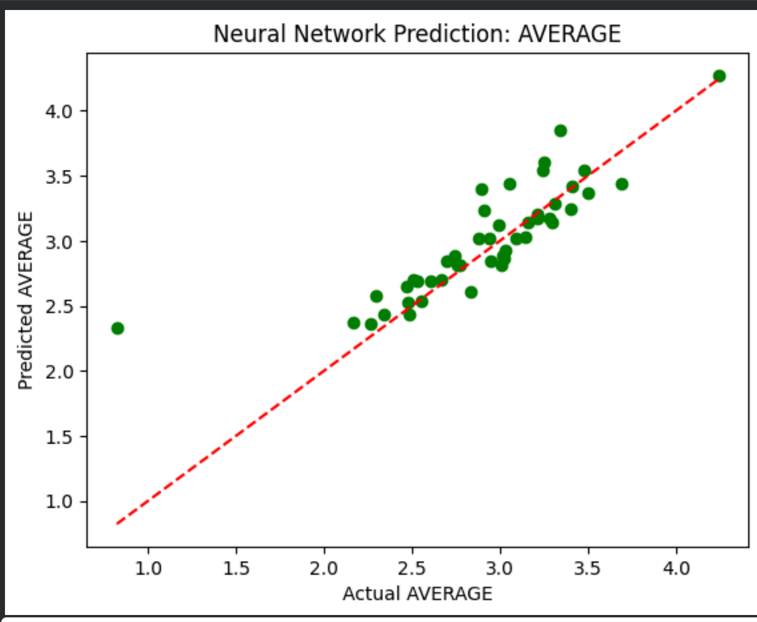
```
2/2 ━━━━━━━━━━━━━━━━━━━━ 0s 54ms/step
```

```
# Evaluation Metrics
# AVERAGE
rmse_avg_dl = np.sqrt(mean_squared_error(y_test['AVERAGE'], y_pred_avg_dl))
mae_avg_dl = mean_absolute_error(y_test['AVERAGE'], y_pred_avg_dl)
r2_avg_dl = r2_score(y_test['AVERAGE'], y_pred_avg_dl)

# VARIANCE
rmse_var_dl = np.sqrt(mean_squared_error(y_test['VARIANCE'], y_pred_var_dl))
mae_var_dl = mean_absolute_error(y_test['VARIANCE'], y_pred_var_dl)
r2_var_dl = r2_score(y_test['VARIANCE'], y_pred_var_dl)

print("===== DEEP LEARNING: AVERAGE =====")
print("RMSE:", rmse_avg_dl)
print("MAE:", mae_avg_dl)
print("R²:", r2_avg_dl)
```

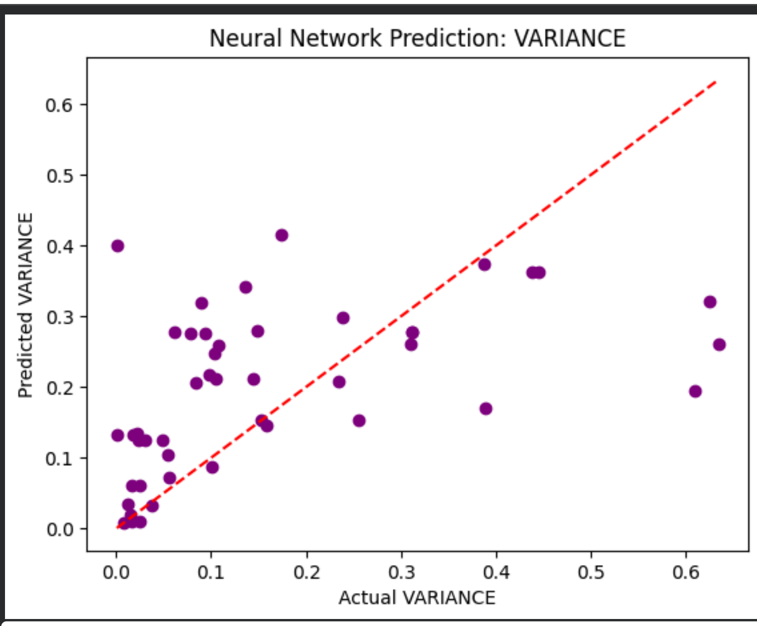
```
print("\n===== DEEP LEARNING: VARIANCE =====")
print("RMSE:", rmse_var_dl)
print("MAE:", mae_var_dl)
print("R²:", r2_var_dl)
```

```
===== DEEP LEARNING: AVERAGE =====
RMSE: 0.2916460455501037
MAE: 0.1780771492070414
R²: 0.6771030228308927

===== DEEP LEARNING: VARIANCE =====
RMSE: 0.1541764745199306
MAE: 0.11198555854382042
R²: 0.1965883219358292
```

```
#scatter plot
plt.scatter(y_test['AVERAGE'], y_pred_avg_dl, color='green')
plt.plot([y_test['AVERAGE'].min(), y_test['AVERAGE'].max()],
         [y_test['AVERAGE'].min(), y_test['AVERAGE'].max()],
         'r--')
plt.xlabel("Actual AVERAGE")
plt.ylabel("Predicted AVERAGE")
plt.title("Neural Network Prediction: AVERAGE")
plt.show()
```




```
# Variance
plt.scatter(y_test['VARIANCE'], y_pred_var_dl, color='purple')
plt.plot([y_test['VARIANCE'].min(), y_test['VARIANCE'].max()],
         [y_test['VARIANCE'].min(), y_test['VARIANCE'].max()],
         'r--')
plt.xlabel("Actual VARIANCE")
plt.ylabel("Predicted VARIANCE")
plt.title("Neural Network Prediction: VARIANCE")
plt.show()
```



Comparism

```
# Comparison Table
comparison = pd.DataFrame({
    "Model": ["Random Forest (AVG)", "Neural Network (AVG)",
              "Random Forest (VAR)", "Neural Network (VAR)"],
    "RMSE": [rmse_avg, rmse_avg_dl, rmse_var, rmse_var_dl],
    "MAE": [mae_avg, mae_avg_dl, mae_var, mae_var_dl],
    "R² Score": [r2_avg, r2_avg_dl, r2_var, r2_var_dl]
})

comparison
```

	Model	RMSE	MAE	R^2 Score
0	Random Forest (AVG)	0.288009	0.169561	0.685107
1	Neural Network (AVG)	0.291646	0.178077	0.677103
2	Random Forest (VAR)	0.108322	0.074322	0.603416
3	Neural Network (VAR)	0.154176	0.111986	0.196588

Next steps: Generate code with comparison New interactive sheet

```
# Feature Importance for Random Forest
importances_avg = rf_avg.feature_importances_
importances_var = rf_var.feature_importances_

features = ['Voltage', 'Wire Feed Speed', 'Travel Speed', 'CTWD']

for name, importance in zip(features, importances_avg):
    print(f"AVG - {name}: {importance:.4f}")

for name, importance in zip(features, importances_var):
    print(f"VAR - {name}: {importance:.4f}")
```

```
AVG - Voltage: 0.5339
AVG - Wire Feed Speed: 0.1778
AVG - Travel Speed: 0.2135
AVG - CTWD: 0.0748
VAR - Voltage: 0.3469
VAR - Wire Feed Speed: 0.4151
VAR - Travel Speed: 0.1439
VAR - CTWD: 0.0941
```

```
# Bar plot
plt.bar(features, importances_avg)
plt.title("Feature Importance for AVERAGE")
plt.show()

plt.bar(features, importances_var)
plt.title("Feature Importance for VARIANCE")
plt.show()
```