In [7]:
```
pip install pandas numpy matplotlib seaborn psutil
```

```
Defaulting to user installation because normal site-packages is not writeable
Requirement already satisfied: pandas in /shared/spack/opt/spack/linux-amzn2-
skylake_avx512/gcc-14.1.0/miniconda3-24.3.0-zxx5jostrj4myhf7bi3oap3ylkmegd3a/
envs/neuro140/lib/python3.11/site-packages (2.2.0)
Requirement already satisfied: numpy in /shared/spack/opt/spack/linux-amzn2-s
kylake_avx512/gcc-14.1.0/miniconda3-24.3.0-zxx5jostrj4myhf7bi3oap3ylkmegd3a/e
nvs/neuro140/lib/python3.11/site-packages (1.26.3)
Requirement already satisfied: matplotlib in /shared/spack/opt/spack/linux-am
zn2-skylake_avx512/gcc-14.1.0/miniconda3-24.3.0-zxx5jostrj4myhf7bi3oap3ylkmeg
d3a/envs/neuro140/lib/python3.11/site-packages (3.8.2)
Requirement already satisfied: seaborn in /shared/spack/opt/spack/linux-amzn2
-skylake_avx512/gcc-14.1.0/miniconda3-24.3.0-zxx5jostrj4myhf7bi3oap3ylkmegd3
a/envs/neuro140/lib/python3.11/site-packages (0.13.1)
Requirement already satisfied: psutil in /shared/spack/opt/spack/linux-amzn2-
skylake_avx512/gcc-14.1.0/miniconda3-24.3.0-zxx5jostrj4myhf7bi3oap3ylkmegd3a/
envs/neuro140/lib/python3.11/site-packages (6.1.1)
Requirement already satisfied: python-dateutil>=2.8.2 in /shared/spack/opt/sp
ack/linux-amzn2-skylake_avx512/gcc-14.1.0/miniconda3-24.3.0-zxx5jostrj4myhf7b
i3oap3ylkmegd3a/envs/neuro140/lib/python3.11/site-packages (from pandas) (2.
9.0.post0)
Requirement already satisfied: pytz>=2020.1 in /shared/spack/opt/spack/linux-
amzn2-skylake_avx512/gcc-14.1.0/miniconda3-24.3.0-zxx5jostrj4myhf7bi3oap3ylkm
egd3a/envs/neuro140/lib/python3.11/site-packages (from pandas) (2025.1)
Requirement already satisfied: tzdata>=2022.7 in /shared/spack/opt/spack/linu
x-amzn2-skylake_avx512/gcc-14.1.0/miniconda3-24.3.0-zxx5jostrj4myhf7bi3oap3yl
kmegd3a/envs/neuro140/lib/python3.11/site-packages (from pandas) (2025.1)
Requirement already satisfied: contourpy>=1.0.1 in /shared/spack/opt/spack/li
nux-amzn2-skylake_avx512/gcc-14.1.0/miniconda3-24.3.0-zxx5jostrj4myhf7bi3oap3
ylkmegd3a/envs/neuro140/lib/python3.11/site-packages (from matplotlib) (1.3.
1)
Requirement already satisfied: cycler>=0.10 in /shared/spack/opt/spack/linux-
amzn2-skylake_avx512/gcc-14.1.0/miniconda3-24.3.0-zxx5jostrj4myhf7bi3oap3ylkm
egd3a/envs/neuro140/lib/python3.11/site-packages (from matplotlib) (0.12.1)
Requirement already satisfied: fonttools>=4.22.0 in /shared/spack/opt/spack/l
inux-amzn2-skylake_avx512/gcc-14.1.0/miniconda3-24.3.0-zxx5jostrj4myhf7bi3oap
3ylkmegd3a/envs/neuro140/lib/python3.11/site-packages (from matplotlib) (4.5
5.8)
Requirement already satisfied: kiwisolver>=1.3.1 in /shared/spack/opt/spack/l
inux-amzn2-skylake_avx512/gcc-14.1.0/miniconda3-24.3.0-zxx5jostrj4myhf7bi3oap
3ylkmegd3a/envs/neuro140/lib/python3.11/site-packages (from matplotlib) (1.4.
7)
Requirement already satisfied: packaging>=20.0 in /shared/spack/opt/spack/lin
ux-amzn2-skylake_avx512/gcc-14.1.0/miniconda3-24.3.0-zxx5jostrj4myhf7bi3oap3y
lkmegd3a/envs/neuro140/lib/python3.11/site-packages (from matplotlib) (24.2)
Requirement already satisfied: pillow>=8 in /shared/spack/opt/spack/linux-amz
n2-skylake_avx512/gcc-14.1.0/miniconda3-24.3.0-zxx5jostrj4myhf7bi3oap3ylkmegd
3a/envs/neuro140/lib/python3.11/site-packages (from matplotlib) (10.2.0)
Requirement already satisfied: pyparsing>=2.3.1 in /shared/spack/opt/spack/li
nux-amzn2-skylake_avx512/gcc-14.1.0/miniconda3-24.3.0-zxx5jostrj4myhf7bi3oap3
ylkmegd3a/envs/neuro140/lib/python3.11/site-packages (from matplotlib) (3.2.
1)
Requirement already satisfied: six>=1.5 in /shared/spack/opt/spack/linux-amzn
2-skylake_avx512/gcc-14.1.0/miniconda3-24.3.0-zxx5jostrj4myhf7bi3oap3ylkmegd3
a/envs/neuro140/lib/python3.11/site-packages (from python-dateutil>=2.8.2->pa
ndas) (1.17.0)
Note: you may need to restart the kernel to use updated packages.
```

In [8]:
```
### IMPORTS

from resource_metrics_and_visualizations import (
    add_metrics_to_predictor,
    ResourceMetrics
)
from paper_visualizations import PaperVisualizations
from integration_example import run_tte_prediction_with_metrics
```

In [9]:
```
# Run the enhanced pipeline
predictor, model_comparison, figures = run_tte_prediction_with_metrics(
    './2241data/train_operational_readouts.csv',
    './2241data/train_tte.csv',
    config_path=None  # Or provide a path to your config file
)

# Generate paper summary
from integration_example import generate_paper_summary
summary_file = generate_paper_summary(predictor, "tte_prediction_paper_findir
```

```
Running on CPU (GPU disabled in config)

--- LOADING DATA ---
Loaded data with 39716 rows and 500 vehicles

--- CLEANING DATA ---
Data cleaned: 39716 rows remaining with 105 features

--- ENGINEERING FEATURES ---

Sample counts per variability level:
variability
high      13504
low       13106
medium    13106
Name: count, dtype: int64
Feature engineering complete. Total features: 124

--- CLEANING DATA ---
Data cleaned: 39716 rows remaining with 124 features

--- ENGINEERING FEATURES ---

Sample counts per variability level:
variability
high      13504
low       13106
medium    13106
Name: count, dtype: int64
Feature engineering complete. Total features: 124

--- ANALYZING SCENARIOS ---

Analyzing low variability scenario...
Processing 13106 samples for low variability
Created 8283 sequences for evaluation

Processing fold 1 of 2
Training with 2761 sequences, testing with 2761 sequences
Selected 20 features for Ridge Regression
LSTM input shape: (2761, 10, 124)
Epoch 1/15
2025-05-09 18:25:30.627441: E external/local_xla/xla/stream_executor/cuda/cud
a_driver.cc:274] failed call to cuInit: CUDA_ERROR_NO_DEVICE: no CUDA-capable
device is detected
2025-05-09 18:25:30.627477: I external/local_xla/xla/stream_executor/cuda/cud
a_diagnostics.cc:129] retrieving CUDA diagnostic information for host: gpu-pa
rallel-dy-gpu-parallel-cr-9
2025-05-09 18:25:30.627483: I external/local_xla/xla/stream_executor/cuda/cud
a_diagnostics.cc:136] hostname: gpu-parallel-dy-gpu-parallel-cr-9
2025-05-09 18:25:30.627604: I external/local_xla/xla/stream_executor/cuda/cud
a_diagnostics.cc:159] libcuda reported version is: 535.216.1
2025-05-09 18:25:30.627623: I external/local_xla/xla/stream_executor/cuda/cud
a_diagnostics.cc:163] kernel reported version is: 535.216.1
2025-05-09 18:25:30.627627: I external/local_xla/xla/stream_executor/cuda/cud
a_diagnostics.cc:241] kernel version seems to match DSO: 535.216.1
```

```
69/69 [==============================] - 2s 7ms/step - loss: 0.1313 - val_los
s: 0.0613
Epoch 2/15
69/69 [==============================] - 0s 4ms/step - loss: 0.0383 - val_los
s: 0.0473
Epoch 3/15
69/69 [==============================] - 0s 4ms/step - loss: 0.0267 - val_los
s: 0.0404
Epoch 4/15
69/69 [==============================] - 0s 4ms/step - loss: 0.0214 - val_los
s: 0.0392
Epoch 5/15
69/69 [==============================] - 0s 4ms/step - loss: 0.0181 - val_los
s: 0.0384
Epoch 6/15
69/69 [==============================] - 0s 3ms/step - loss: 0.0165 - val_los
s: 0.0385
Epoch 7/15
69/69 [==============================] - 0s 4ms/step - loss: 0.0155 - val_los
s: 0.0309
Epoch 8/15
69/69 [==============================] - 0s 3ms/step - loss: 0.0143 - val_los
s: 0.0314
Epoch 9/15
69/69 [==============================] - 0s 3ms/step - loss: 0.0141 - val_los
s: 0.0325
Epoch 10/15
69/69 [==============================] - 0s 3ms/step - loss: 0.0136 - val_los
s: 0.0350
87/87 [==============================] - 0s 1ms/step
LSTM model training and prediction successful
Best Ridge alpha: 10.0
Ridge Regression successful
Best ES smoothing level: 0.9
Exponential Smoothing successful
Ensemble model created successfully
Found 4 extreme prediction errors. Capping for metric calculation.
Found 4 extreme prediction errors. Capping for metric calculation.

Processing fold 2 of 2
Limiting training sequences from 5522 to 3000
Training with 3000 sequences, testing with 2761 sequences
Selected 20 features for Ridge Regression
LSTM input shape: (3000, 10, 124)
Epoch 1/15
75/75 [==============================] - 2s 7ms/step - loss: 0.1410 - val_los
s: 0.0715
Epoch 2/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0598 - val_los
s: 0.0506
Epoch 3/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0441 - val_los
s: 0.0353
Epoch 4/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0324 - val_los
s: 0.0243
Epoch 5/15
```

```
75/75 [==============================] - 0s 4ms/step - loss: 0.0242 - val_los
s: 0.0175
Epoch 6/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0202 - val_los
s: 0.0149
Epoch 7/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0185 - val_los
s: 0.0135
Epoch 8/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0166 - val_los
s: 0.0117
Epoch 9/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0156 - val_los
s: 0.0113
Epoch 10/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0153 - val_los
s: 0.0101
Epoch 11/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0137 - val_los
s: 0.0095
Epoch 12/15
75/75 [==============================] - 0s 3ms/step - loss: 0.0136 - val_los
s: 0.0098
Epoch 13/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0133 - val_los
s: 0.0087
Epoch 14/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0129 - val_los
s: 0.0086
Epoch 15/15
75/75 [==============================] - 0s 3ms/step - loss: 0.0129 - val_los
s: 0.0087
87/87 [==============================] - 0s 1ms/step
LSTM model training and prediction successful
Best Ridge alpha: 1.0
Ridge Regression successful
Best ES smoothing level: 0.3
Exponential Smoothing successful
Ensemble model created successfully

Analyzing medium variability scenario...
Processing 13106 samples for medium variability
Created 8942 sequences for evaluation

Processing fold 1 of 2
Training with 2982 sequences, testing with 2980 sequences
Selected 20 features for Ridge Regression
LSTM input shape: (2982, 10, 124)
Epoch 1/15
75/75 [==============================] - 2s 7ms/step - loss: 0.0674 - val_los
s: 0.0375
Epoch 2/15
75/75 [==============================] - 0s 5ms/step - loss: 0.0312 - val_los
s: 0.0213
Epoch 3/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0151 - val_los
s: 0.0200
```

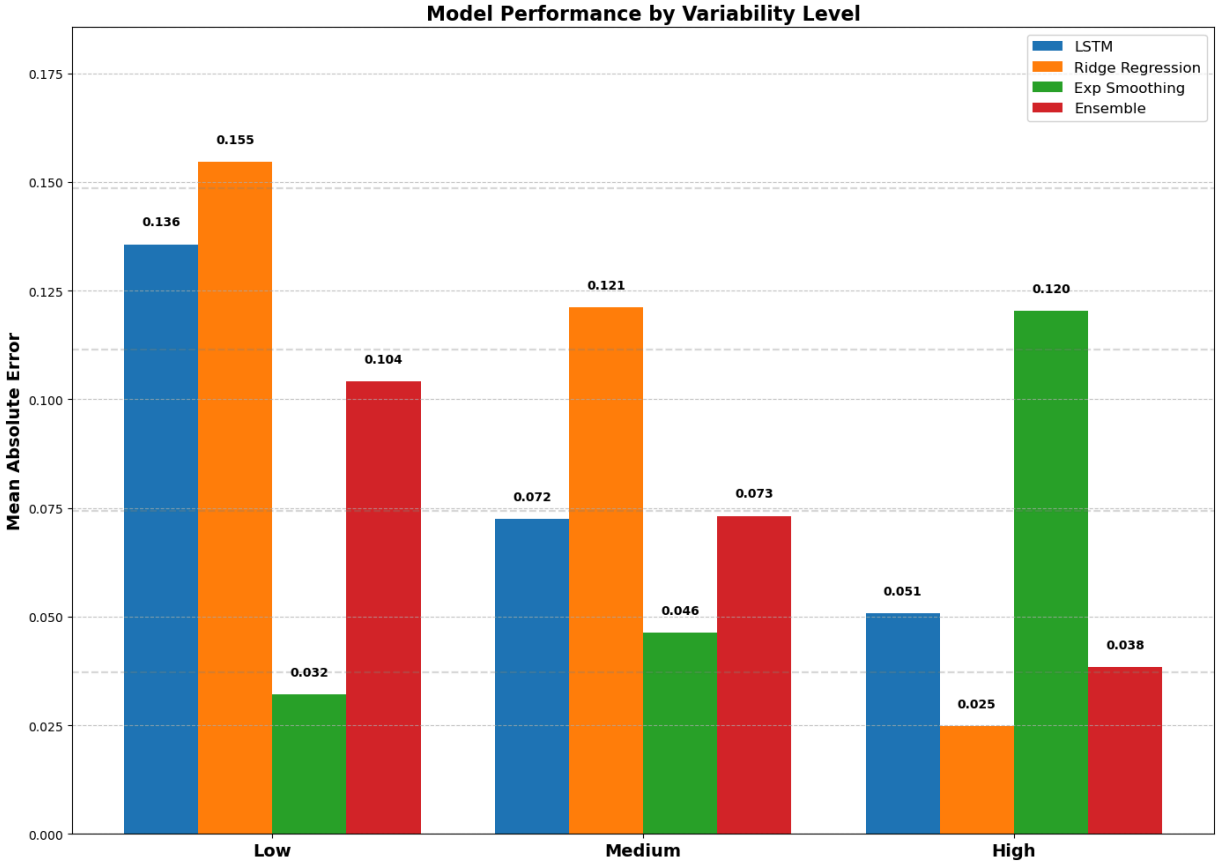
```
Epoch 4/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0109 - val_los
s: 0.0193
Epoch 5/15
75/75 [==============================] - 0s 5ms/step - loss: 0.0094 - val_los
s: 0.0148
Epoch 6/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0085 - val_los
s: 0.0142
Epoch 7/15
75/75 [==============================] - 0s 5ms/step - loss: 0.0079 - val_los
s: 0.0102
Epoch 8/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0072 - val_los
s: 0.0111
Epoch 9/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0075 - val_los
s: 0.0160
Epoch 10/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0066 - val_los
s: 0.0115
94/94 [==============================] - 0s 1ms/step
LSTM model training and prediction successful
Best Ridge alpha: 0.01
Ridge Regression successful
Best ES smoothing level: 0.9
Exponential Smoothing successful
Ensemble model created successfully

Processing fold 2 of 2
Limiting training sequences from 5962 to 3000
Training with 3000 sequences, testing with 2980 sequences
Selected 20 features for Ridge Regression
LSTM input shape: (3000, 10, 124)
Epoch 1/15
75/75 [==============================] - 2s 7ms/step - loss: 0.0558 - val_los
s: 0.0264
Epoch 2/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0218 - val_los
s: 0.0125
Epoch 3/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0137 - val_los
s: 0.0065
Epoch 4/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0101 - val_los
s: 0.0062
Epoch 5/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0093 - val_los
s: 0.0041
Epoch 6/15
75/75 [==============================] - 0s 3ms/step - loss: 0.0080 - val_los
s: 0.0044
Epoch 7/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0073 - val_los
s: 0.0035
Epoch 8/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0069 - val_los
```

```
s: 0.0032
Epoch 9/15
75/75 [==============================] - 0s 3ms/step - loss: 0.0064 - val_los
s: 0.0035
Epoch 10/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0063 - val_los
s: 0.0025
Epoch 11/15
75/75 [==============================] - 0s 3ms/step - loss: 0.0064 - val_los
s: 0.0027
Epoch 12/15
75/75 [==============================] - 0s 3ms/step - loss: 0.0064 - val_los
s: 0.0030
Epoch 13/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0057 - val_los
s: 0.0025
Epoch 14/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0060 - val_los
s: 0.0023
Epoch 15/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0055 - val_los
s: 0.0023
94/94 [==============================] - 0s 1ms/step
LSTM model training and prediction successful
Best Ridge alpha: 0.01
Ridge Regression successful
Best ES smoothing level: 0.3
Exponential Smoothing successful
Ensemble model created successfully

Analyzing high variability scenario...
Processing 13504 samples for high variability
Created 9848 sequences for evaluation

Processing fold 1 of 2
Limiting training sequences from 3284 to 3000
Limiting test sequences from 3282 to 3000
Training with 3000 sequences, testing with 3000 sequences
Selected 20 features for Ridge Regression
LSTM input shape: (3000, 10, 124)
Epoch 1/15
75/75 [==============================] - 2s 7ms/step - loss: 0.0565 - val_los
s: 0.0354
Epoch 2/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0286 - val_los
s: 0.0170
Epoch 3/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0154 - val_los
s: 0.0067
Epoch 4/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0107 - val_los
s: 0.0048
Epoch 5/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0091 - val_los
s: 0.0039
Epoch 6/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0086 - val_los
```

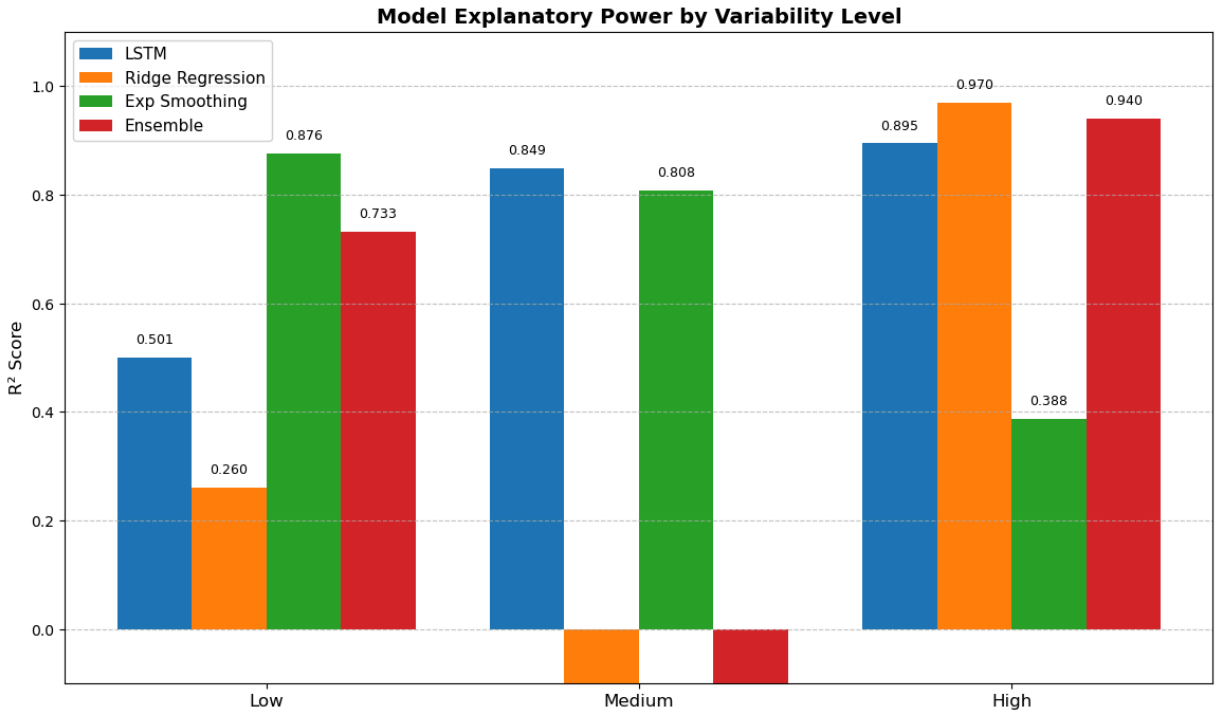
```
s: 0.0035
Epoch 7/15
75/75 [==============================] - 0s 3ms/step - loss: 0.0075 - val_los
s: 0.0045
Epoch 8/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0071 - val_los
s: 0.0029
Epoch 9/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0062 - val_los
s: 0.0027
Epoch 10/15
75/75 [==============================] - 0s 3ms/step - loss: 0.0063 - val_los
s: 0.0038
Epoch 11/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0057 - val_los
s: 0.0022
Epoch 12/15
75/75 [==============================] - 0s 3ms/step - loss: 0.0057 - val_los
s: 0.0026
Epoch 13/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0055 - val_los
s: 0.0022
Epoch 14/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0054 - val_los
s: 0.0021
Epoch 15/15
75/75 [==============================] - 0s 3ms/step - loss: 0.0055 - val_los
s: 0.0022
94/94 [==============================] - 0s 1ms/step
LSTM model training and prediction successful
Best Ridge alpha: 0.01
Ridge Regression successful
Best ES smoothing level: 0.1
Exponential Smoothing successful
Ensemble model created successfully

Processing fold 2 of 2
Limiting training sequences from 6566 to 3000
Limiting test sequences from 3282 to 3000
Training with 3000 sequences, testing with 3000 sequences
Selected 20 features for Ridge Regression
LSTM input shape: (3000, 10, 124)
Epoch 1/15
75/75 [==============================] - 2s 7ms/step - loss: 0.0709 - val_los
s: 0.0353
Epoch 2/15
75/75 [==============================] - 0s 5ms/step - loss: 0.0277 - val_los
s: 0.0178
Epoch 3/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0165 - val_los
s: 0.0080
Epoch 4/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0114 - val_los
s: 0.0049
Epoch 5/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0098 - val_los
s: 0.0038
```

```
Epoch 6/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0089 - val_los
s: 0.0034
Epoch 7/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0077 - val_los
s: 0.0030
Epoch 8/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0074 - val_los
s: 0.0026
Epoch 9/15
75/75 [==============================] - 0s 4ms/step - loss: 0.0067 - val_los
s: 0.0024
Epoch 10/15
75/75 [==============================] - 0s 3ms/step - loss: 0.0069 - val_los
s: 0.0025
Epoch 11/15
75/75 [==============================] - 0s 3ms/step - loss: 0.0062 - val_los
s: 0.0033
Epoch 12/15
75/75 [==============================] - 0s 3ms/step - loss: 0.0062 - val_los
s: 0.0026
94/94 [==============================] - 0s 1ms/step
LSTM model training and prediction successful
Best Ridge alpha: 0.01
Ridge Regression successful
Best ES smoothing level: 0.1
Exponential Smoothing successful
Ensemble model created successfully

--- DETAILED PERFORMANCE METRICS ---

LOW VARIABILITY SCENARIO:
  LSTM: MAE=0.1356, RMSE=0.1647, R²=0.5005, Median AE=0.1241, Explained Var=
0.5287
  Ridge Regression: MAE=0.1547, RMSE=0.2084, R²=0.2602, Median AE=0.1347, Exp
lained Var=0.2850
  Exponential Smoothing: MAE=0.0320, RMSE=0.0847, R²=0.8757, Median AE=0.007
5, Explained Var=0.8757
  Ensemble: MAE=0.1041, RMSE=0.1255, R²=0.7328, Median AE=0.0969, Explained V
ar=0.7353

  Top 5 Features (Ridge Regression):
    time_step_normalized: 0.3126
    171_0_roll_mean_5: 0.1488
    171_0: 0.1408
    171_0_roll_mean_10: 0.1200
    397_24: 0.0967

MEDIUM VARIABILITY SCENARIO:
  LSTM: MAE=0.0724, RMSE=0.1002, R²=0.8486, Median AE=0.0524, Explained Var=
0.8501
  Ridge Regression: MAE=0.1211, RMSE=0.5838, R²=-8.5355, Median AE=0.0513, Ex
plained Var=-8.3739
  Exponential Smoothing: MAE=0.0463, RMSE=0.1117, R²=0.8081, Median AE=0.020
1, Explained Var=0.8081
  Ensemble: MAE=0.0732, RMSE=0.2517, R²=-0.5450, Median AE=0.0363, Explained
Var=-0.5155
```

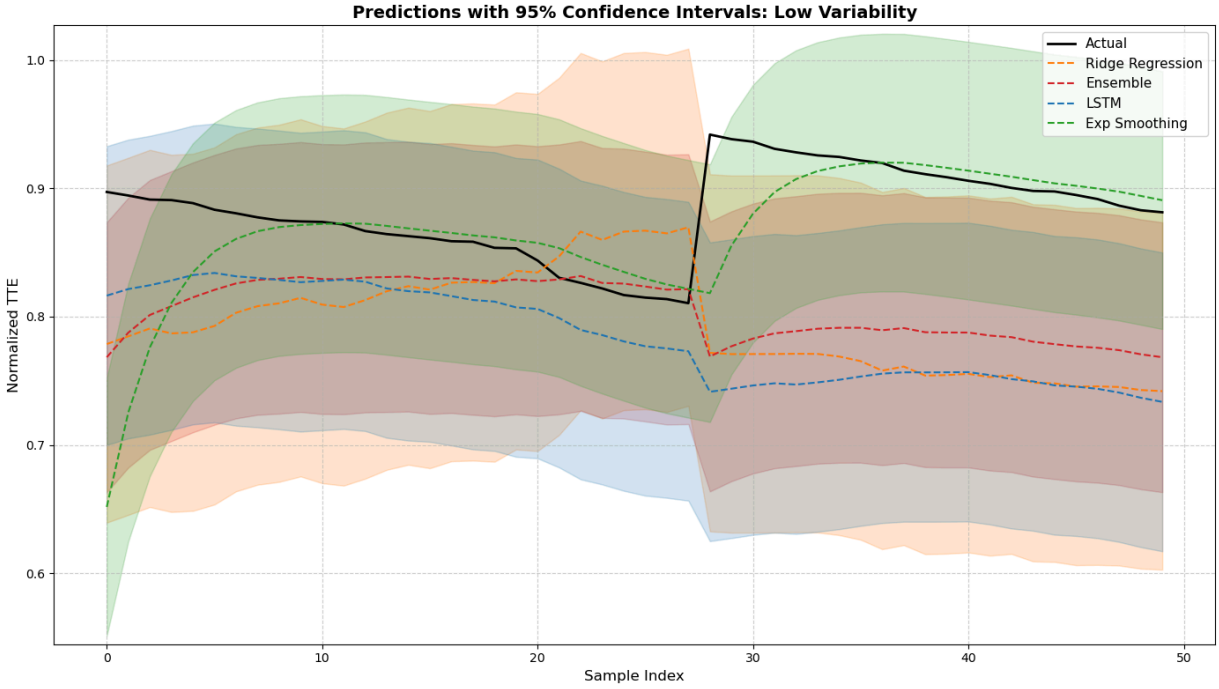
```
  Top 5 Features (Ridge Regression):
    427_0_roll_mean_20: 0.5150
    time_step_normalized: 0.4947
    171_0_roll_mean_10: 0.4256
    427_0: 0.3714
    427_0_roll_mean_10: 0.3183

HIGH VARIABILITY SCENARIO:
  LSTM: MAE=0.0508, RMSE=0.0667, R²=0.8946, Median AE=0.0409, Explained Var=
0.8978
  Ridge Regression: MAE=0.0248, RMSE=0.0355, R²=0.9698, Median AE=0.0181, Exp
lained Var=0.9715
  Exponential Smoothing: MAE=0.1203, RMSE=0.1607, R²=0.3877, Median AE=0.095
1, Explained Var=0.3877
  Ensemble: MAE=0.0384, RMSE=0.0502, R²=0.9402, Median AE=0.0314, Explained V
ar=0.9416

  Top 5 Features (Ridge Regression):
    171_0: 0.4264
    time_step_normalized: 0.4041
    427_0_roll_mean_10: 0.3836
    171_0_roll_mean_10: 0.3370
    427_0: 0.2840

--- CREATING VISUALIZATIONS ---
```



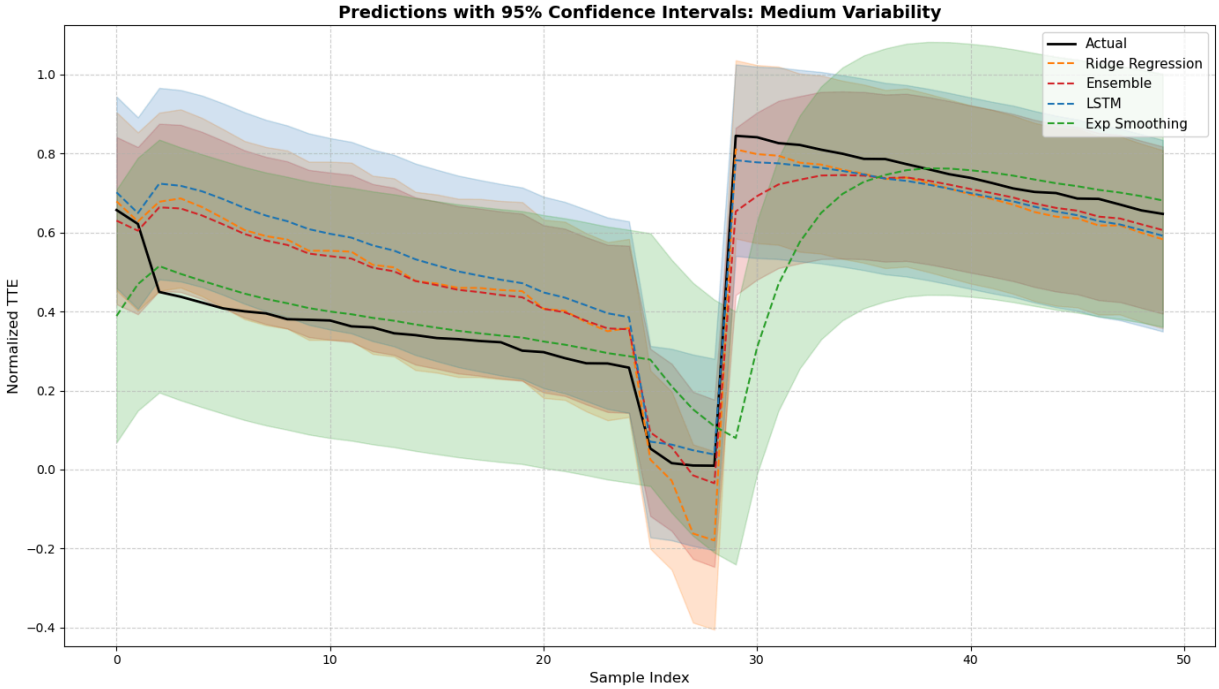

```
Zoomed MAE comparison plot saved to ./results/mae_comparison_zoomed_20250509_
182410.png
```


Model Explanatory Power by Variability Level
LSTM
Ridge Regression
Exp Smoothing
Ensemble
R² Score
1.0
0.8
0.6
0.4
0.2
0.0
0.501
0.260
0.876
0.733
0.849
-0.545
0.808
0.895
0.970
0.388
0.940
Low
Medium
High

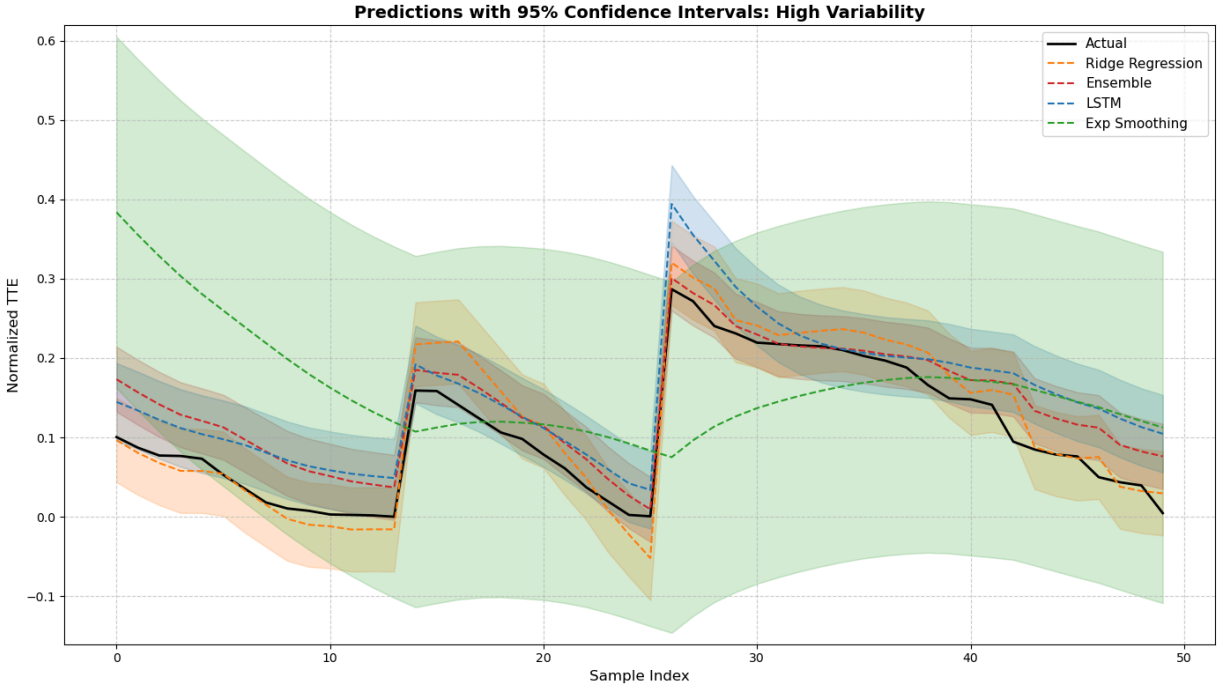
-8.536



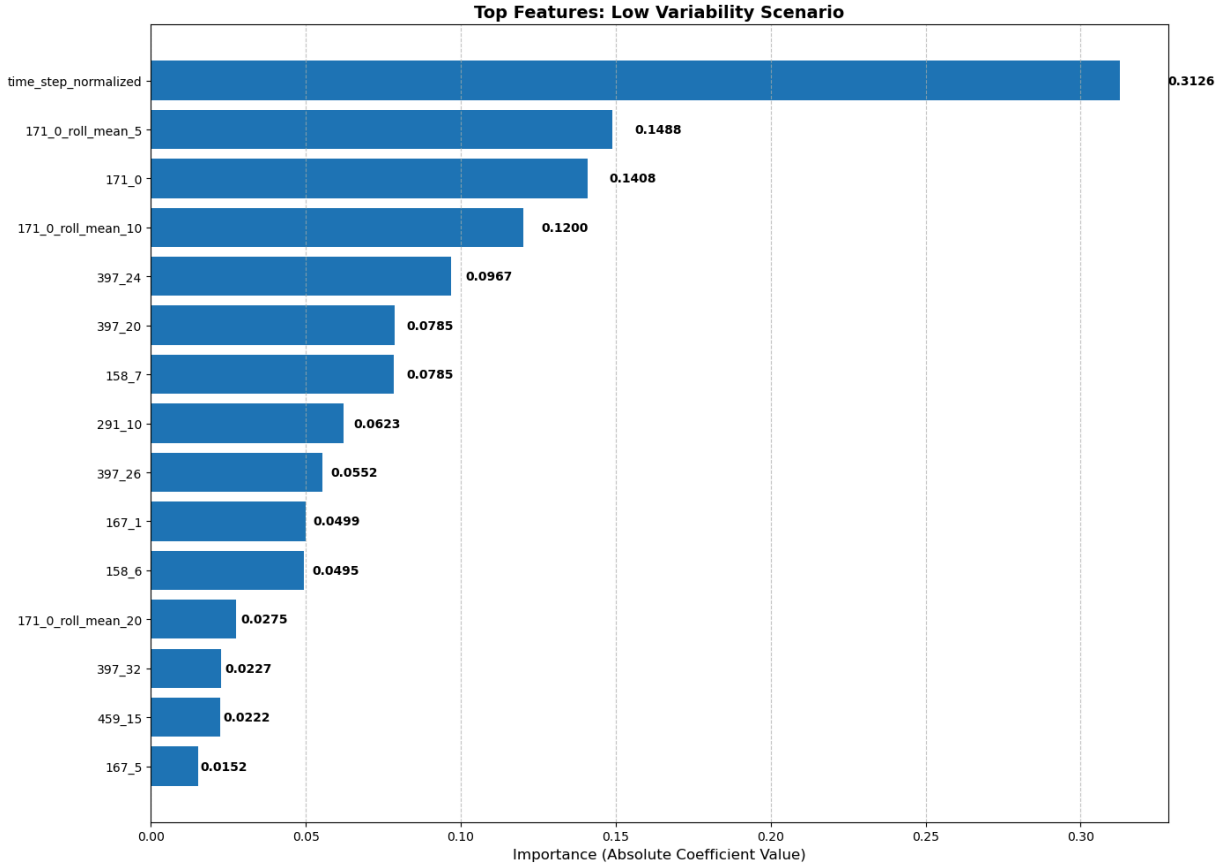
No prediction data available for error plot in low scenario
<Figure size 1400x800 with 0 Axes>

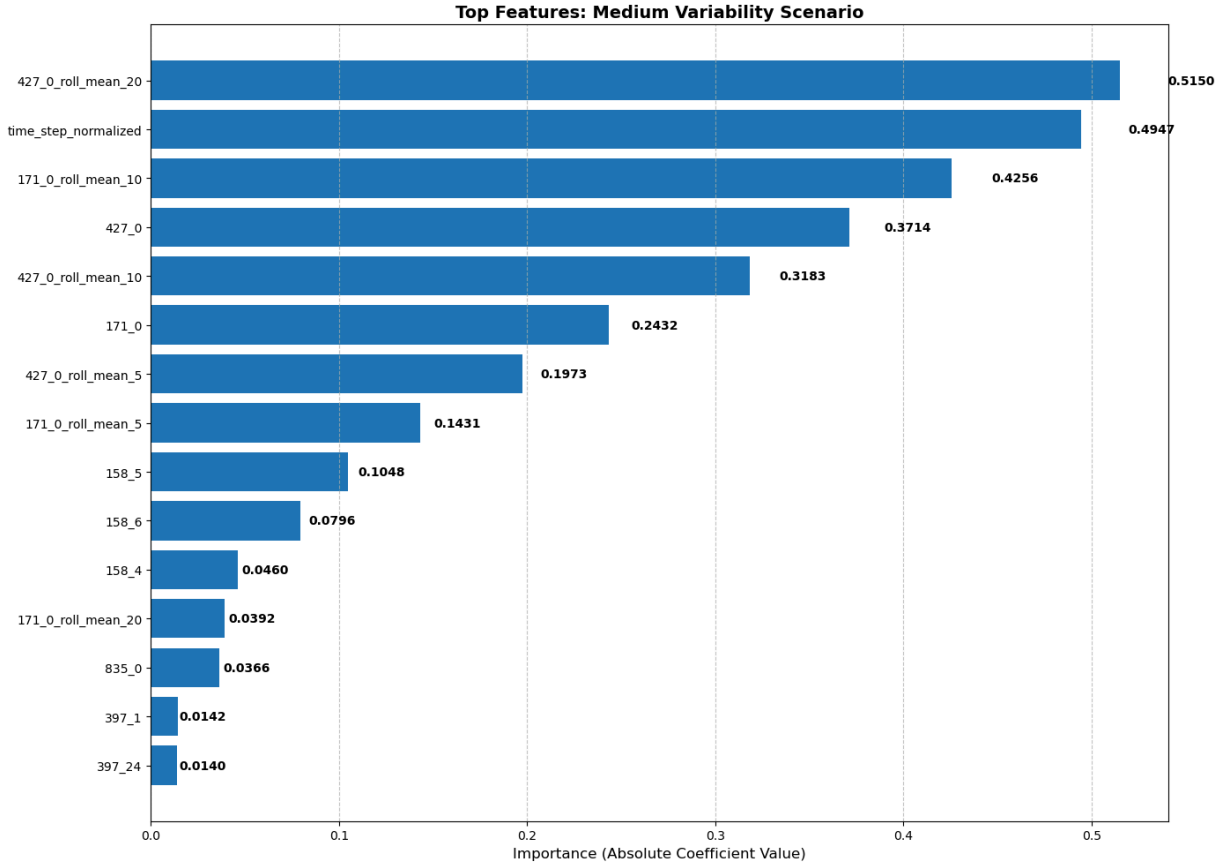


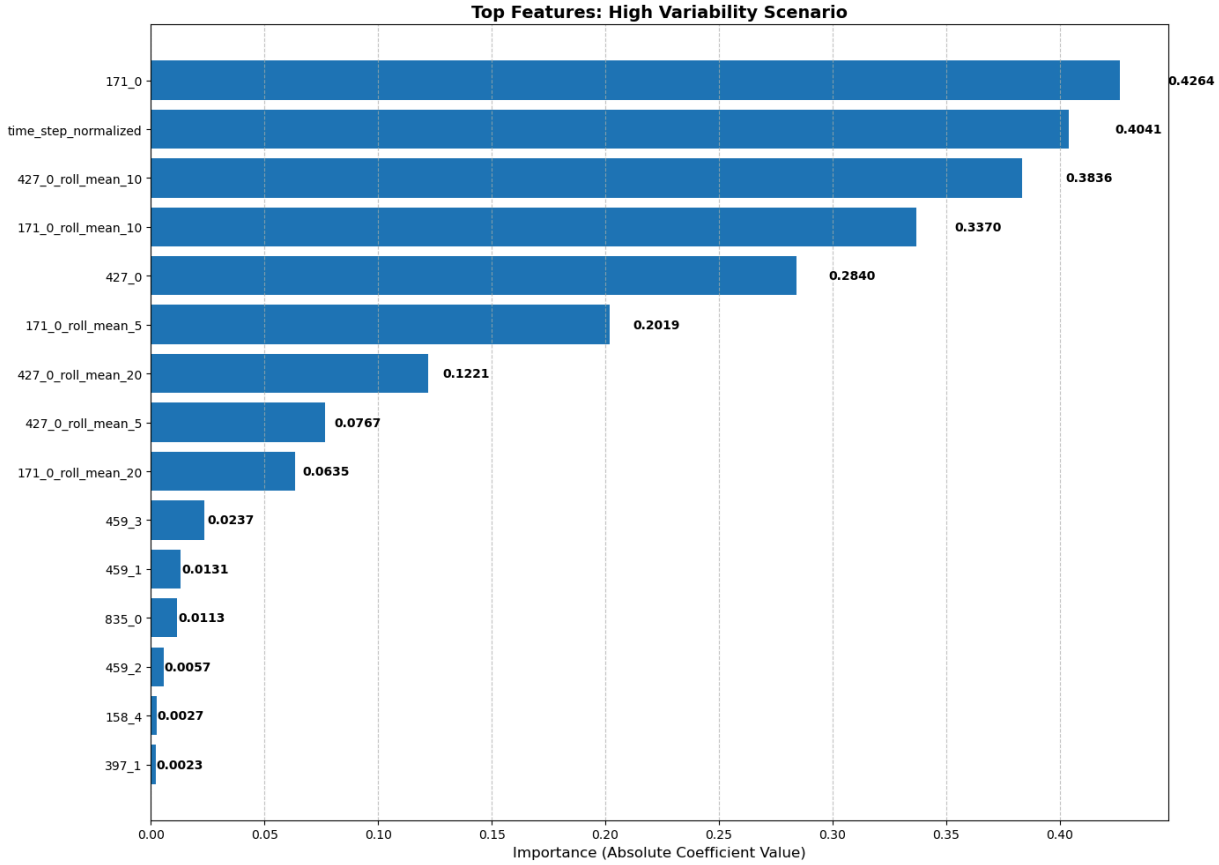
No prediction data available for error plot in medium scenario
<Figure size 1400x800 with 0 Axes>



No prediction data available for error plot in high scenario
<Figure size 1400x800 with 0 Axes>

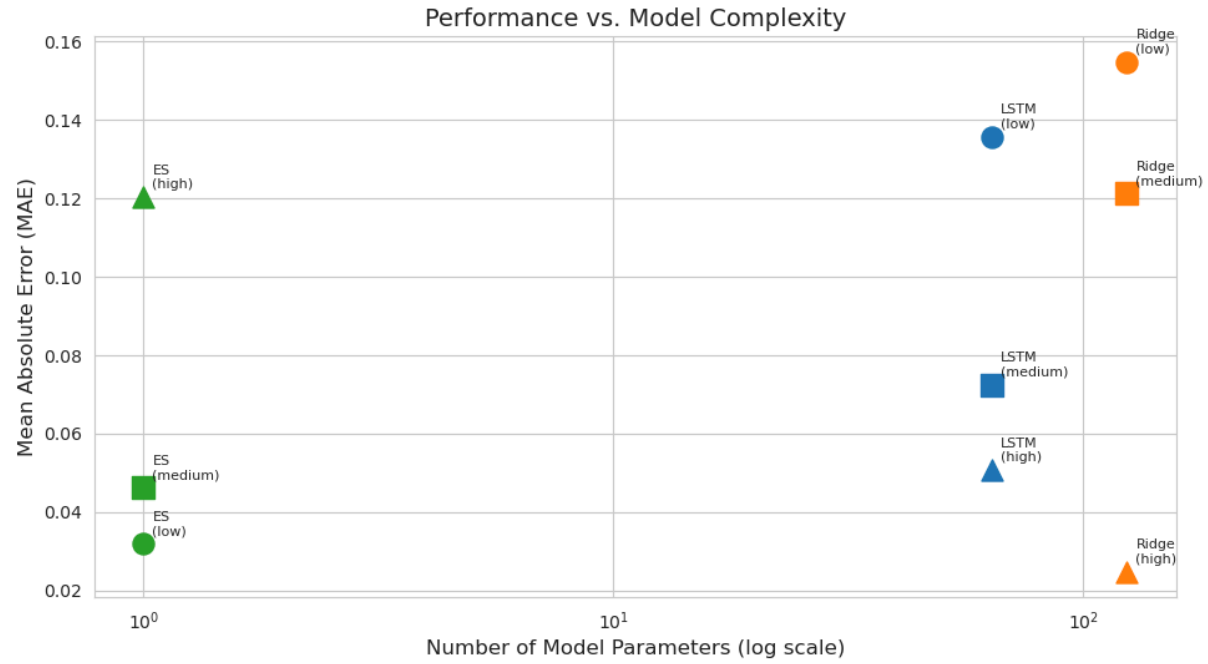


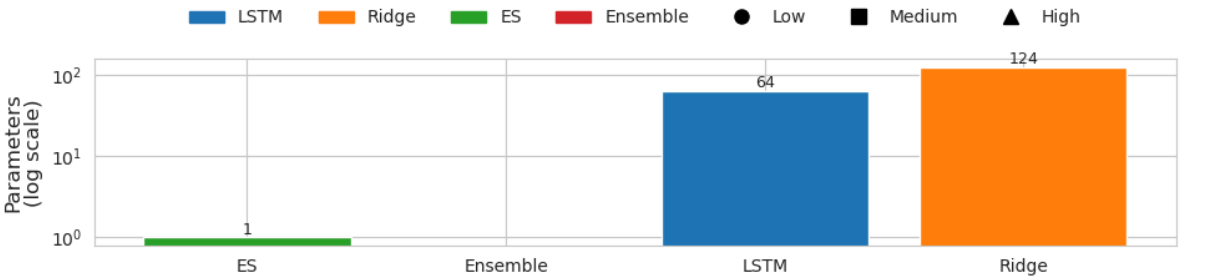

Top Features: Medium Variability Scenario
427_0_roll_mean_20
time_step_normalized
171_0_roll_mean_10
427_0
427_0_roll_mean_10
171_0
427_0_roll_mean_5
171_0_roll_mean_5
158_5
158_6
158_4
171_0_roll_mean_20
835_0
397_1
397_24
0.5150
0.4947
0.4256
0.3714
0.3183
0.2432
0.1973
0.1431
0.1048
0.0796
0.0460
0.0392
0.0366
0.0142
0.0140
0.0
0.1
0.2
0.3
0.4
0.5
Importance (Absolute Coefficient Value)

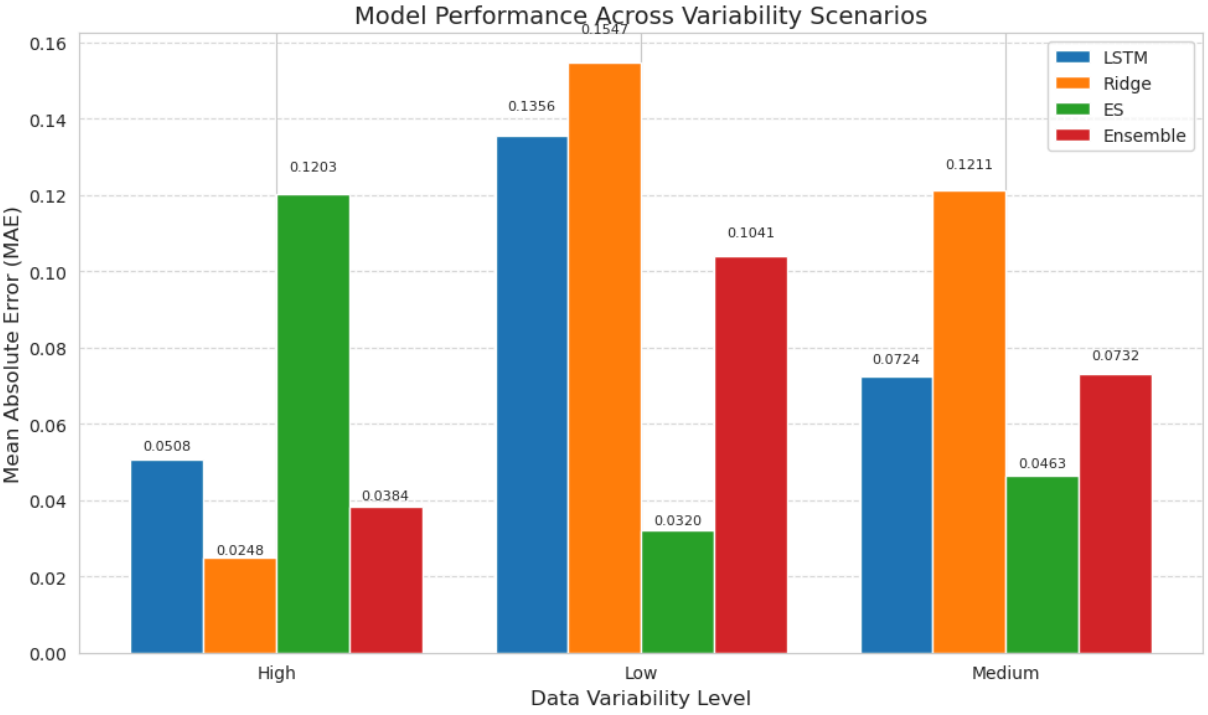

Top Features: High Variability Scenario
171_0
time_step_normalized
427_0_roll_mean_10
171_0_roll_mean_10
427_0
171_0_roll_mean_5
427_0_roll_mean_20
427_0_roll_mean_5
171_0_roll_mean_20
459_3
459_1
835_0
459_2
158_4
397_1
0.4264
0.4041
0.3836
0.3370
0.2840
0.2019
0.1221
0.0767
0.0635
0.0237
0.0131
0.0113
0.0057
0.0027
0.0023
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
Importance (Absolute Coefficient Value)

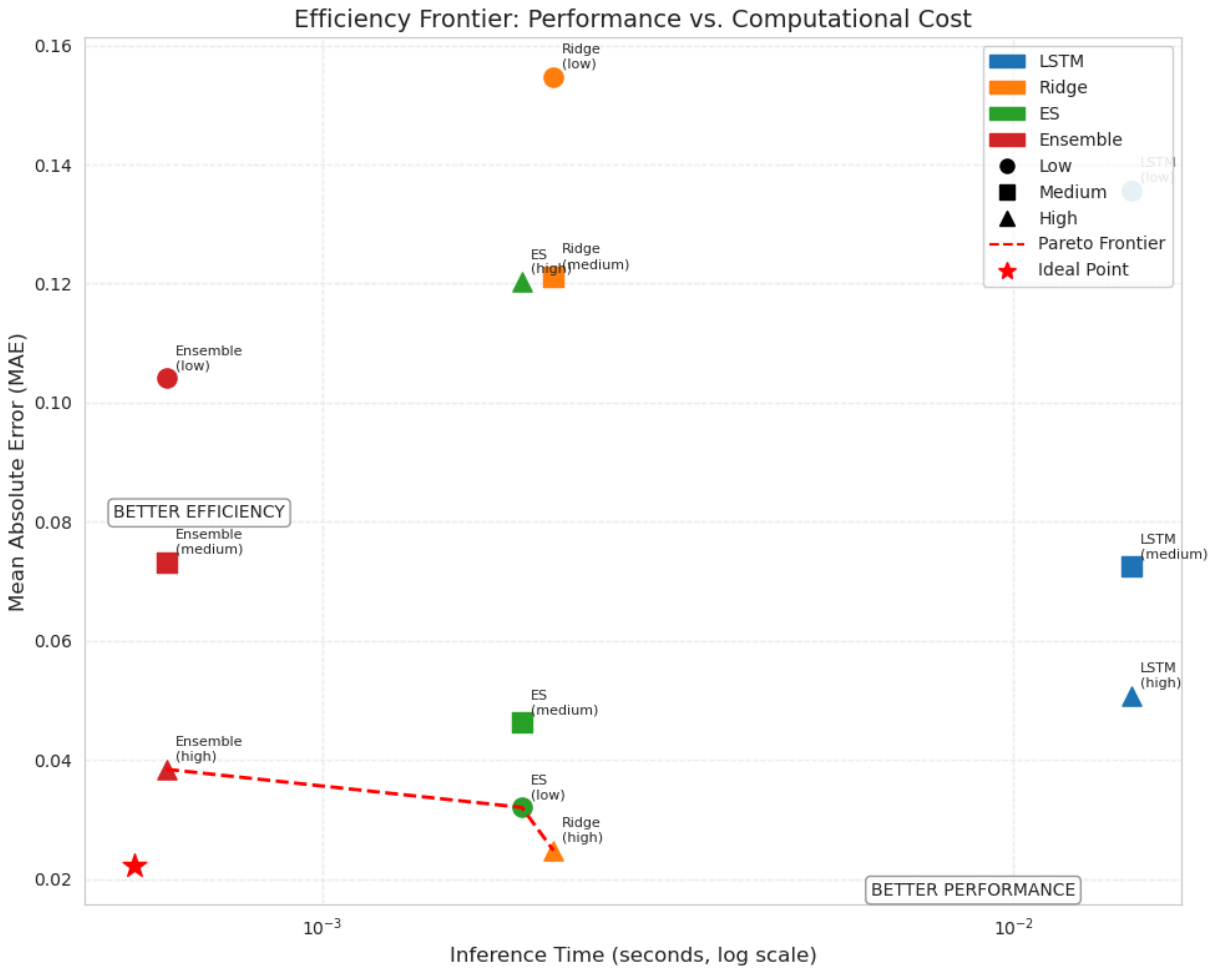
```
Performance Summary:
Scenario  LSTM MAE  LSTM R²  Ridge MAE  Ridge R²   ES MAE    ES R²  Ensemble
MAE  Ensemble R²
     Low  0.135634 0.500508   0.154691  0.260234 0.032016 0.875681      0.104
112     0.732812
  Medium  0.072427 0.848557   0.121147 -8.535544 0.046316 0.808058      0.073
188    -0.544965
    High  0.050757 0.894553   0.024803  0.969821 0.120273 0.387681      0.038
422     0.940210
Performance summary saved to ./results/performance_summary_20250509_182410.cs
v

--- MODEL SELECTION GUIDELINES ---

For Low Variability Scenario:
  Recommended Model: Exponential Smoothing
  MAE: 0.0320

For Medium Variability Scenario:
  Recommended Model: Exponential Smoothing
  MAE: 0.0463

For High Variability Scenario:
  Recommended Model: Ridge Regression
  MAE: 0.0248
  Top 3 Predictive Features:
    - 171_0: 0.4264
    - time_step_normalized: 0.4041
    - 427_0_roll_mean_10: 0.3836
Saved comparison table to ./metrics_20250509_182410/model_comparison_report/m
odel_comparison_table.csv
Saved mae performance plot to ./metrics_20250509_182410/model_comparison_repo
rt/performance_mae.png
Saved rmse performance plot to ./metrics_20250509_182410/model_comparison_rep
ort/performance_rmse.png
Saved r2 performance plot to ./metrics_20250509_182410/model_comparison_repor
t/performance_r2.png
Saved resource metrics plot to ./metrics_20250509_182410/model_comparison_rep
ort/resource_metrics.png
Saved inference metrics plot to ./metrics_20250509_182410/model_comparison_re
port/inference_metrics.png
Saved efficiency frontier plot to ./metrics_20250509_182410/model_comparison_
report/efficiency_frontier.png
Saved model complexity plot to ./metrics_20250509_182410/model_comparison_rep
ort/model_complexity.png
Saved radar chart to ./metrics_20250509_182410/model_comparison_report/radar_
chart.png

Comprehensive report generated in ./metrics_20250509_182410/model_comparison_
report
posx and posy should be finite values
posx and posy should be finite values
posx and posy should be finite values
posx and posy should be finite values
posx and posy should be finite values
posx and posy should be finite values
```

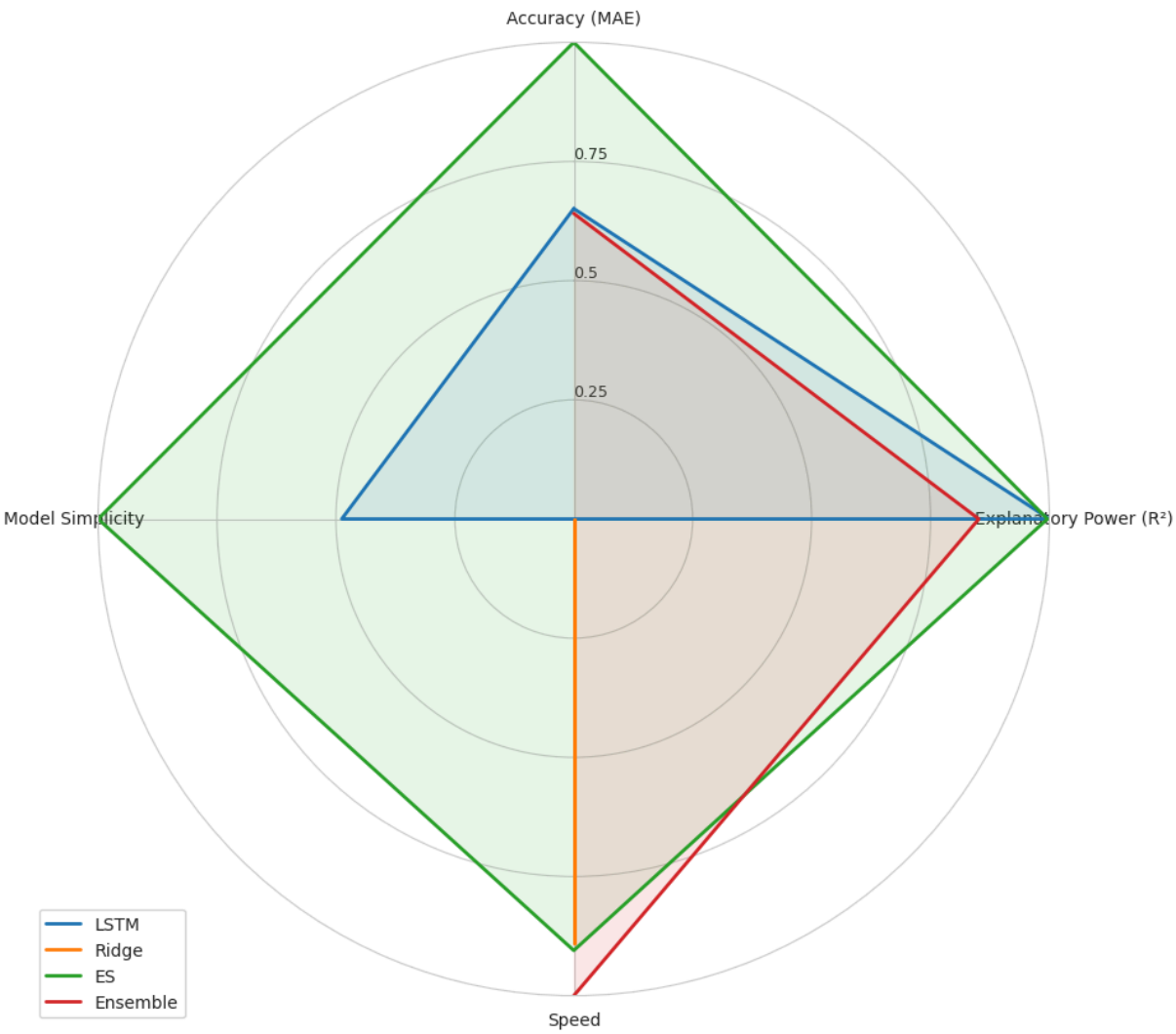
```
Missing required metrics: ['Memory_increase']
posx and posy should be finite values
===== RESOURCE USAGE SUMMARY =====

total_execution:
  Duration: 202.9792 seconds
  Memory increase: 761.68 MB
  Final memory: 1678.70 MB

data_loading_preprocessing:
  Duration: 2.3104 seconds
  Memory increase: 50.59 MB
  Final memory: 967.61 MB

cleaning_preprocessing:
  Duration: 31.4229 seconds
  Memory increase: 123.50 MB
  Final memory: 1091.11 MB

feature_engineering_preprocessing:
  Duration: 3.8700 seconds
  Memory increase: 0.12 MB
  Final memory: 1091.23 MB

Analysis complete.
Results saved to: ./results
Metrics saved to: ./metrics_20250509_182410
Paper figures saved to: ./paper_figures_20250509_182410
Paper summary generated: tte_prediction_paper_findings.md
posx and posy should be finite values
```

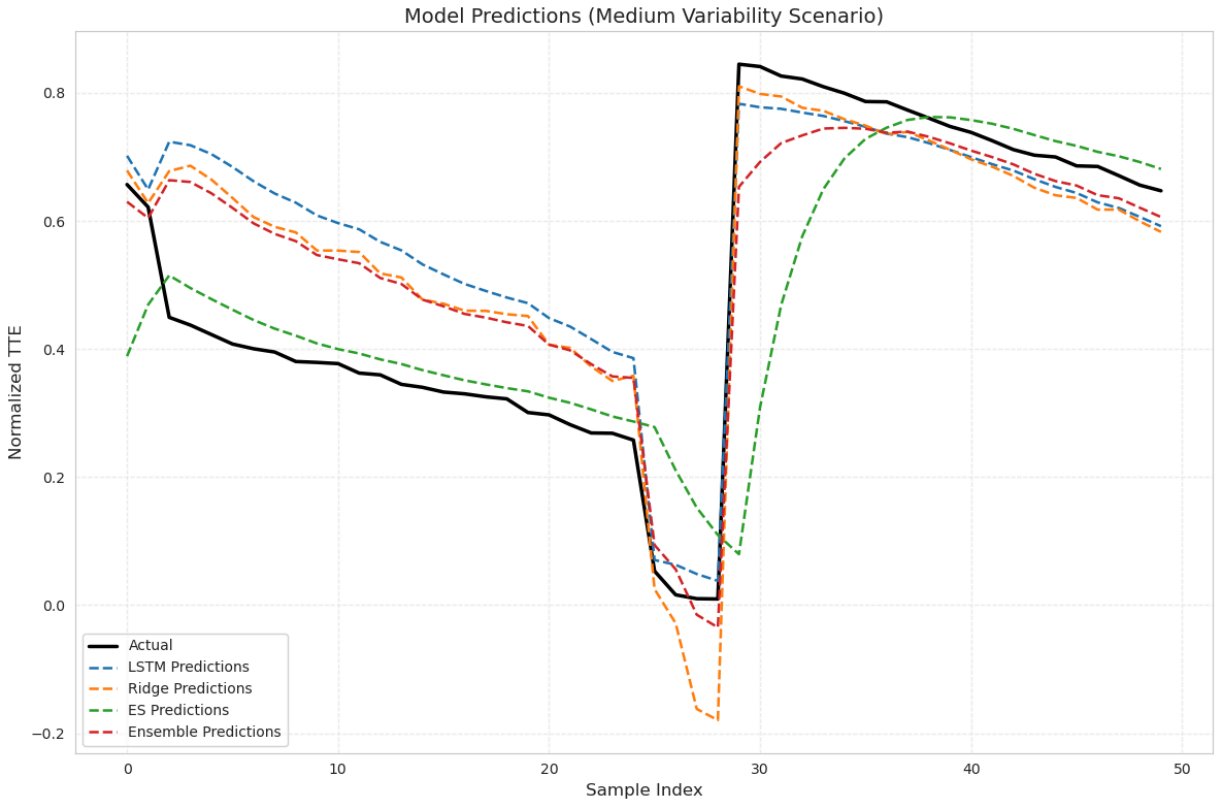

Performance vs. Model Complexity
Mean Absolute Error (MAE)
Number of Model Parameters (log scale)
Ridge (low)
LSTM (low)
ES (high)
Ridge (medium)
LSTM (medium)
LSTM (high)
ES (medium)
ES (low)
Ridge (high)

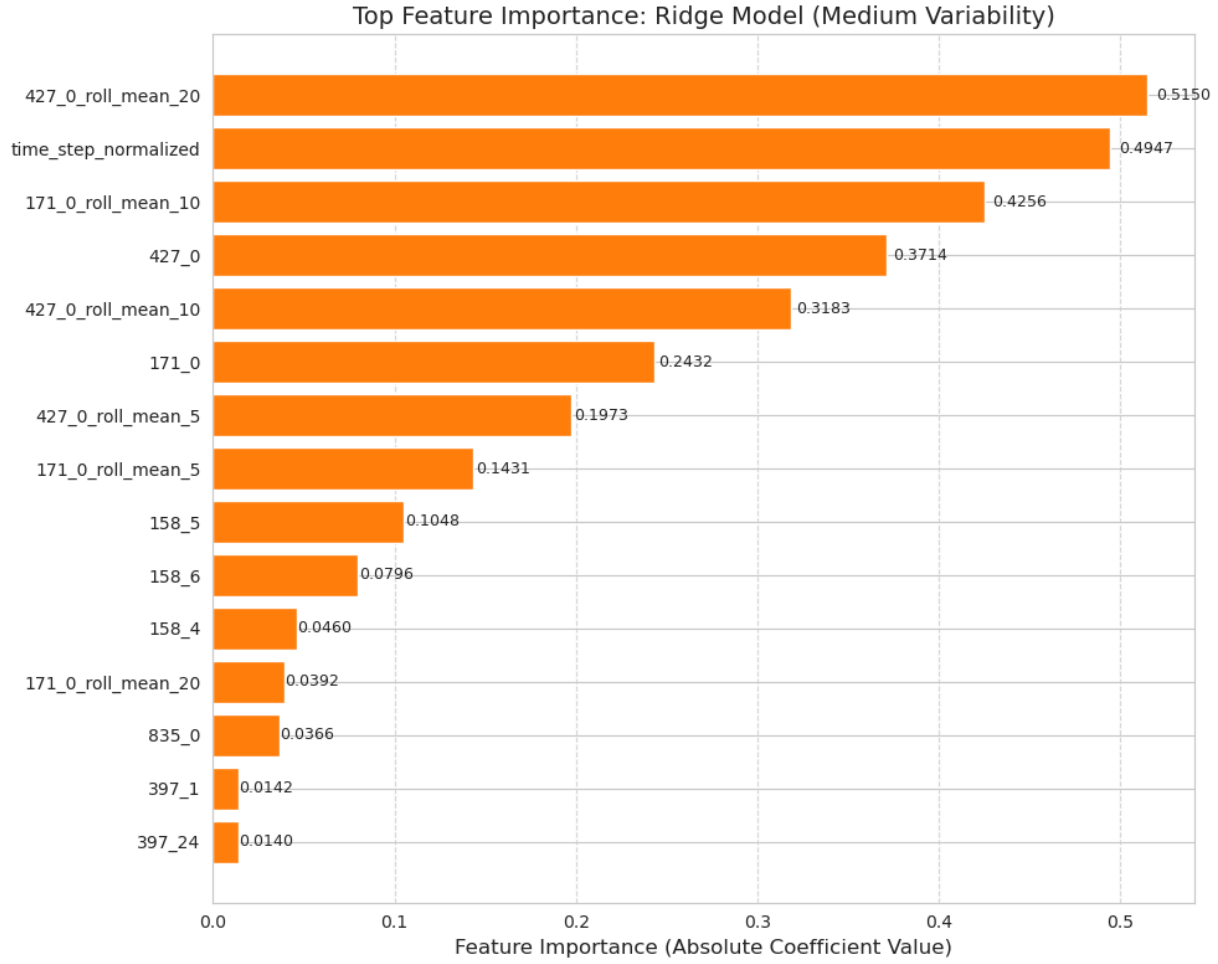

LSTM
Ridge
ES
Ensemble
Low
Medium
High
Parameters (log scale)
1
64
124
ES
Ensemble
LSTM
Ridge


Model Performance Across Variability Scenarios
LSTM
Ridge
ES
Ensemble
Mean Absolute Error (MAE)
0.0508
0.0248
0.1203
0.0384
0.1356
0.1547
0.0320
0.1041
0.0724
0.1211
0.0463
0.0732
High
Low
Medium
Data Variability Level


Efficiency Frontier: Performance vs. Computational Cost
Mean Absolute Error (MAE)
Inference Time (seconds, log scale)
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
10^{-3}
10^{-2}
LSTM
Ridge
ES
Ensemble
Low
Medium
High
Pareto Frontier
Ideal Point
Ridge (low)
ES (high)
Ridge (medium)
Ensemble (low)
BETTER EFFICIENCY
Ensemble (medium)
LSTM (medium)
LSTM (high)
ES (medium)
Ensemble (high)
ES (low)
Ridge (high)
BETTER PERFORMANCE


Multi-Metric Model Comparison (Medium Variability)
Accuracy (MAE)
0.75
0.5
0.25
Model Simplicity
Explanatory Power (R²)
Speed
LSTM
Ridge
ES
Ensemble


Model Predictions (Medium Variability Scenario)
Normalized TTE
Sample Index
Actual
LSTM Predictions
Ridge Predictions
ES Predictions
Ensemble Predictions


Top Feature Importance: Ridge Model (Medium Variability)
427_0_roll_mean_20
time_step_normalized
171_0_roll_mean_10
427_0
427_0_roll_mean_10
171_0
427_0_roll_mean_5
171_0_roll_mean_5
158_5
158_6
158_4
171_0_roll_mean_20
835_0
397_1
397_24
0.5150
0.4947
0.4256
0.3714
0.3183
0.2432
0.1973
0.1431
0.1048
0.0796
0.0460
0.0392
0.0366
0.0142
0.0140
Feature Importance (Absolute Coefficient Value)

In [ ]: