Prediction of Key Bridge Characteristics Using Machine Learning

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Acknowledgments

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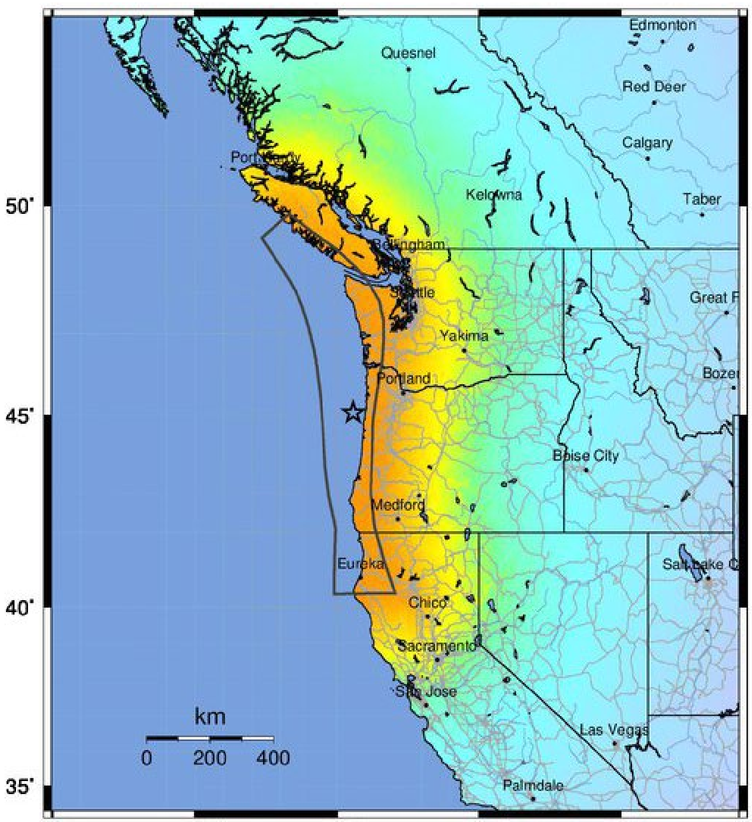
ACCELERATED BRIDGE CONSTRUCTION
UNIVERSITY TRANSPORTATION CENTER

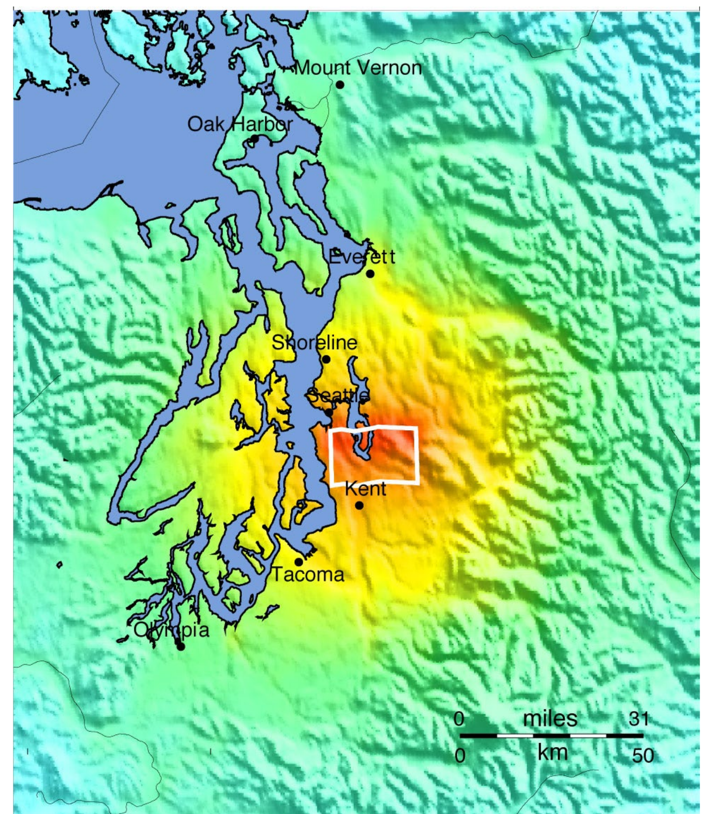
Washington State
Department of Transportation

Earthquake Scenarios

CSZ Full Rupture



Seattle Fault



https://earthquake.usgs.gov/scenarios/

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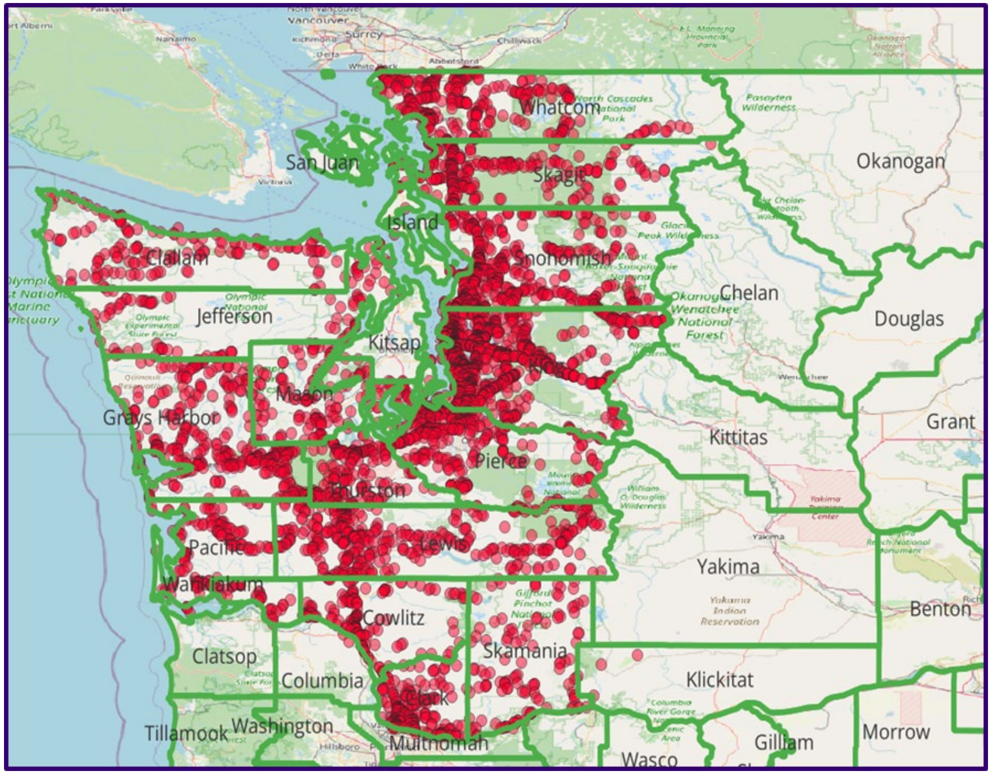
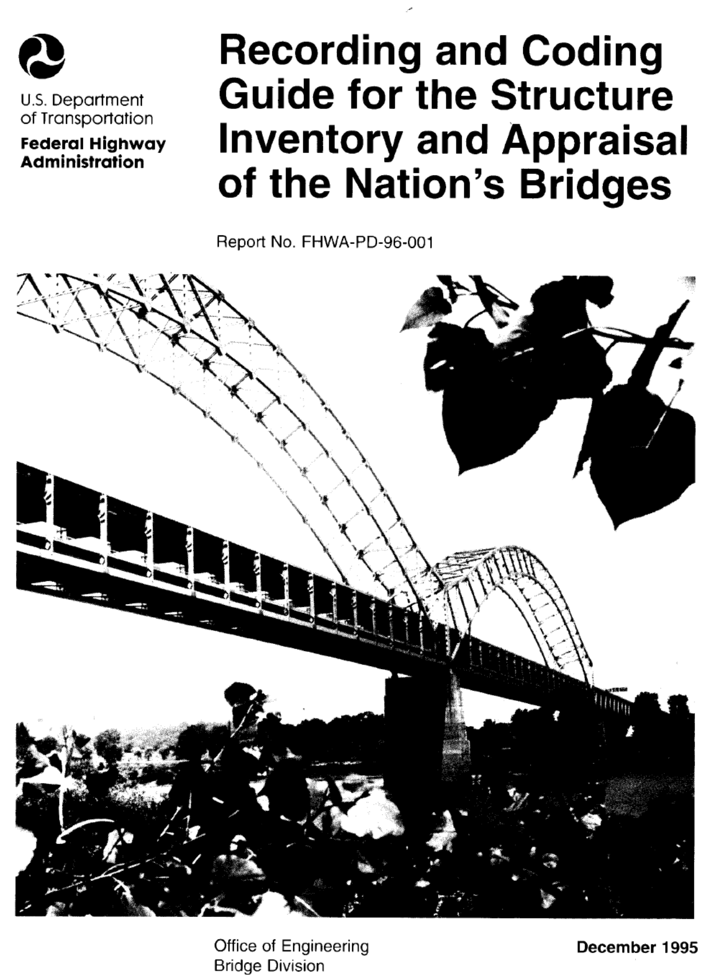
Numerous Bridges

Region	Number of Bridges
United States	620 k
California	26k
Washington State	8.5k



National Bridge Inventory (NBI)

- Identification & Location
- Clearance
- Traffic
- Inspection
- Funding/Owner
- Limited Structural Info.
  - Structure Type
  - Material
  - Maximum Span Length
  - Deck Width
  - Construction Year


U.S. Department of Transportation
Federal Highway Administration

Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges

Report No. FHWA-PD-96-001

Office of Engineering
Bridge Division

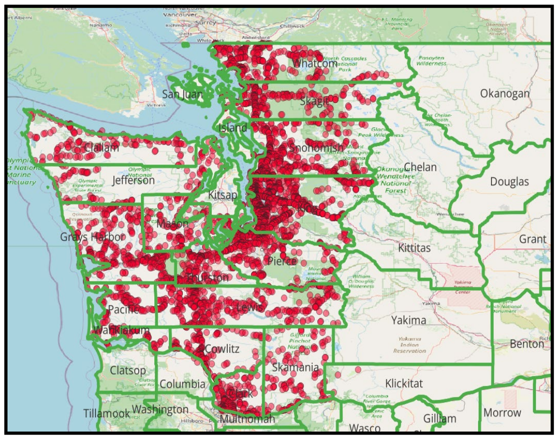
December 1995

Strategies

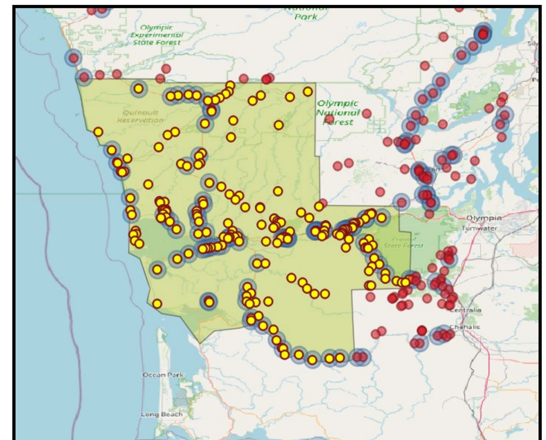
- Detailed Review of Bridge Drawings
  - Labor intensive / difficult to automate
  - Unclear or incomplete drawings
- General Curves Based on NBI (HAZUS)
  - Missing key properties
  - Large dispersion
- Rapid Visual Screening (Street View)
  - External geometry
- Extrapolate from NBI with Machine Learning
  - Start with key column properties

Overview of Strategy

National Bridge Inventory (~8000 Bridges)

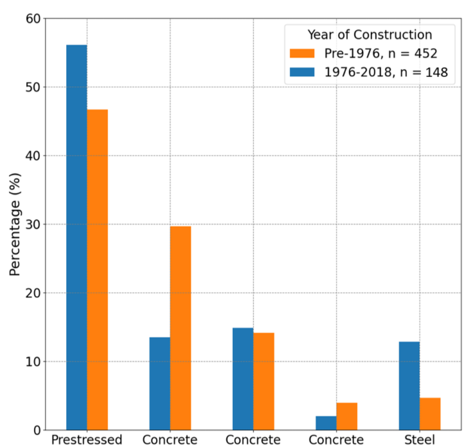


Detailed Bridge Database (~800 Bridges)



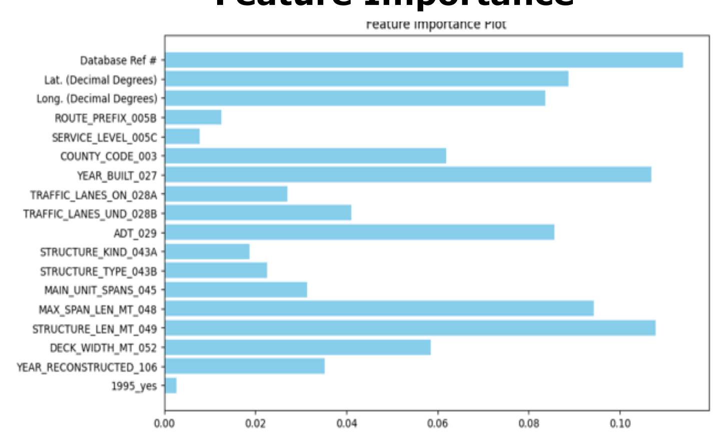
Train Algorithm

Target Properties



Implement Algorithm

Feature Importance



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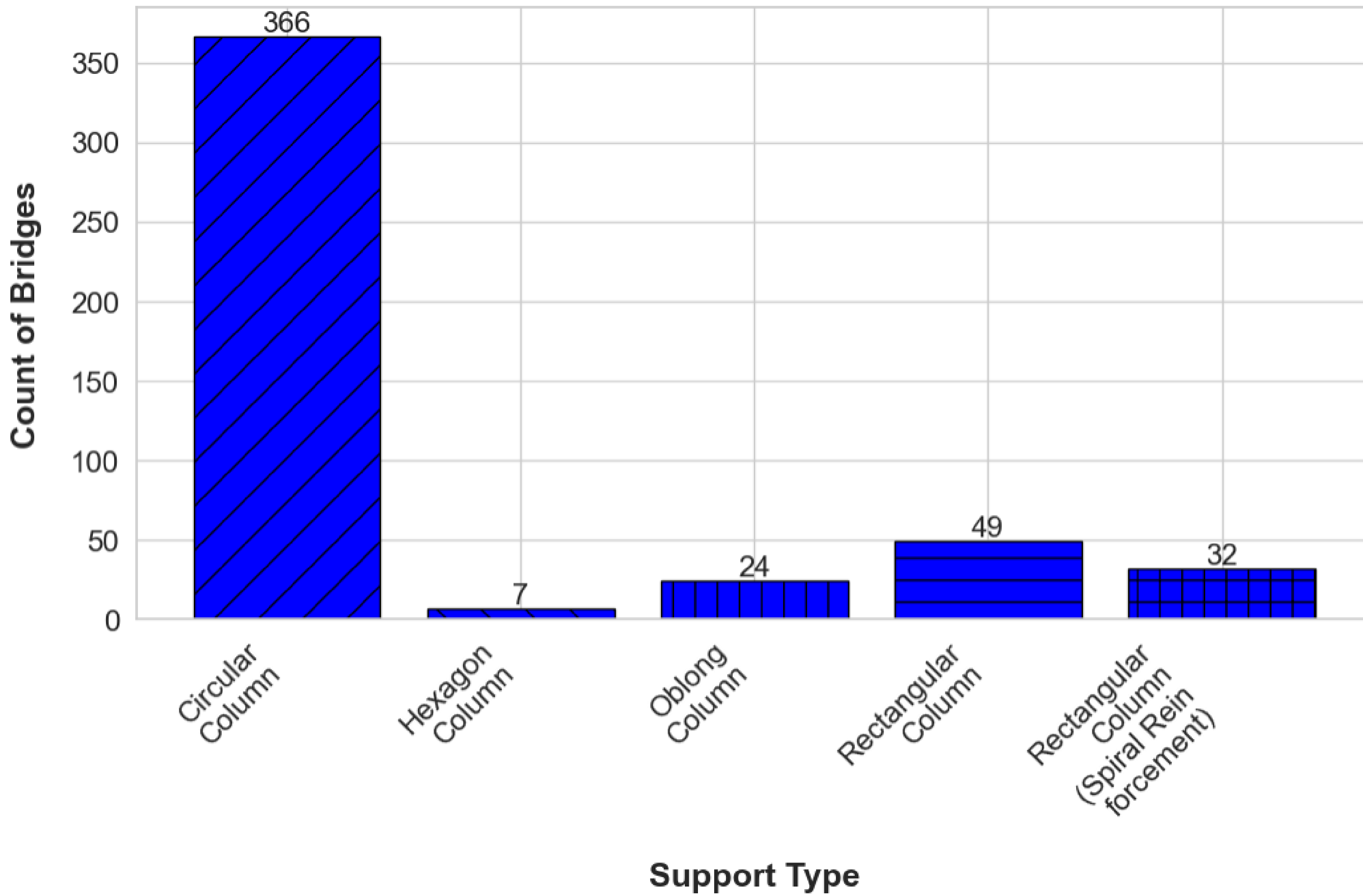
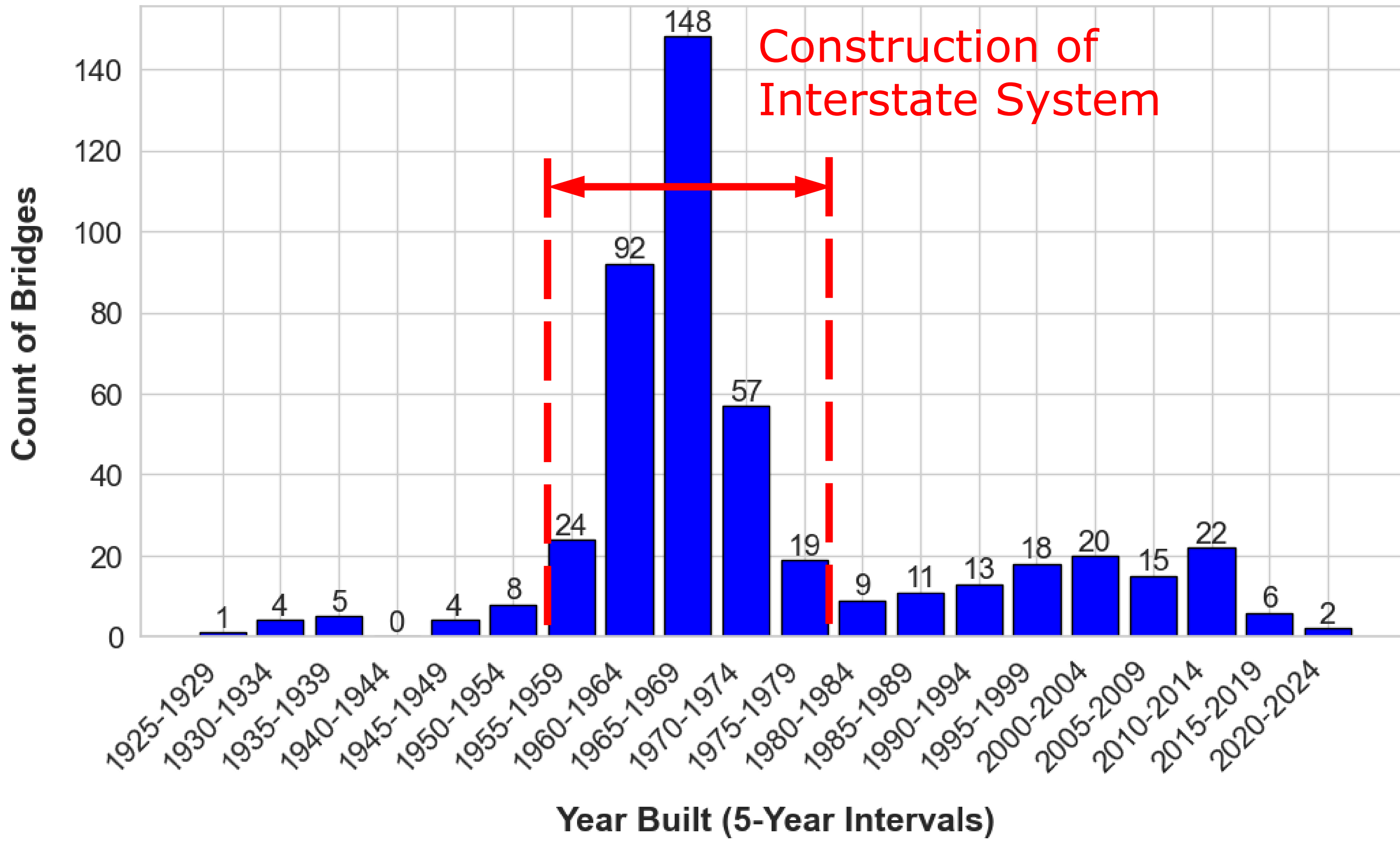
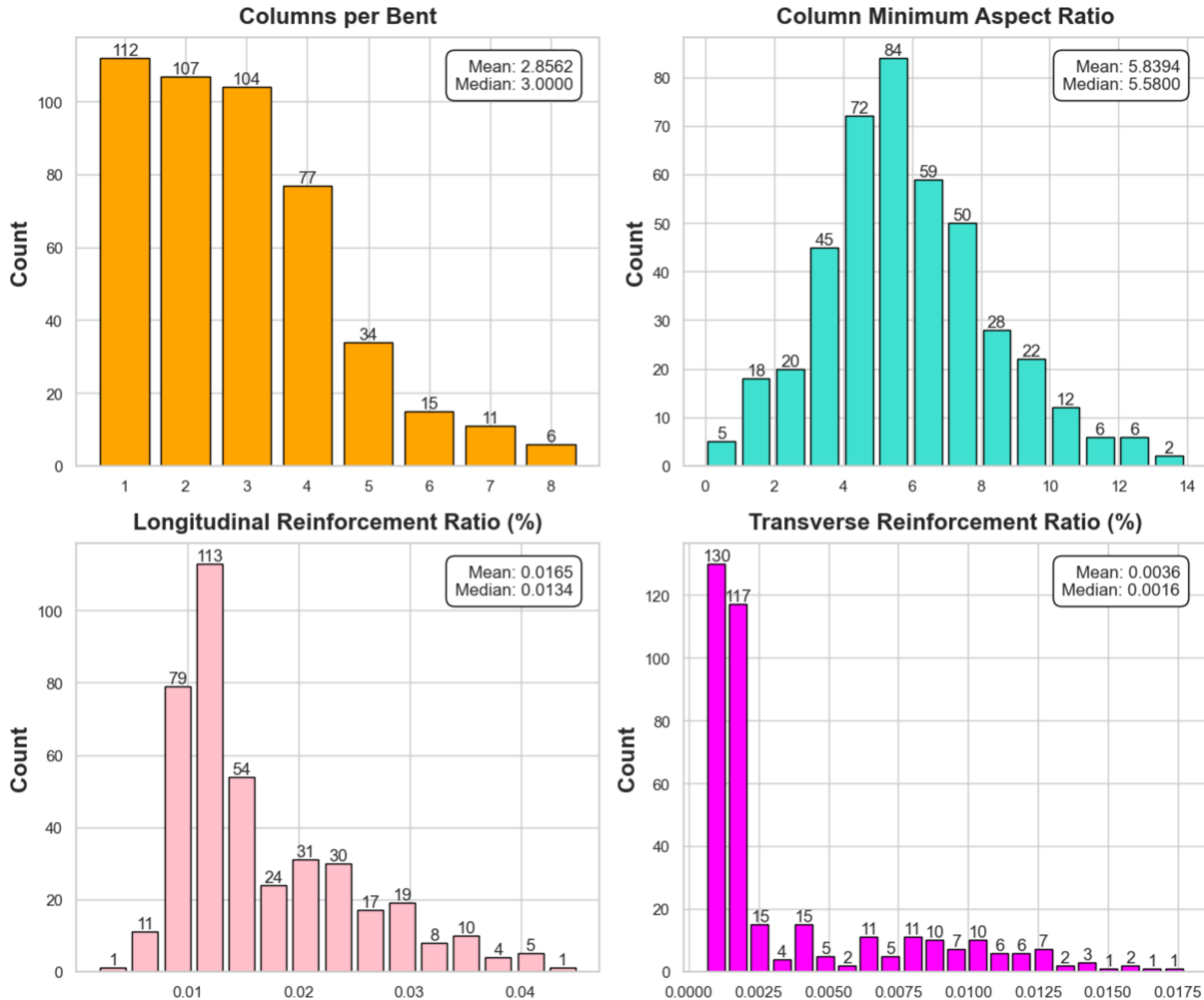
Column Type



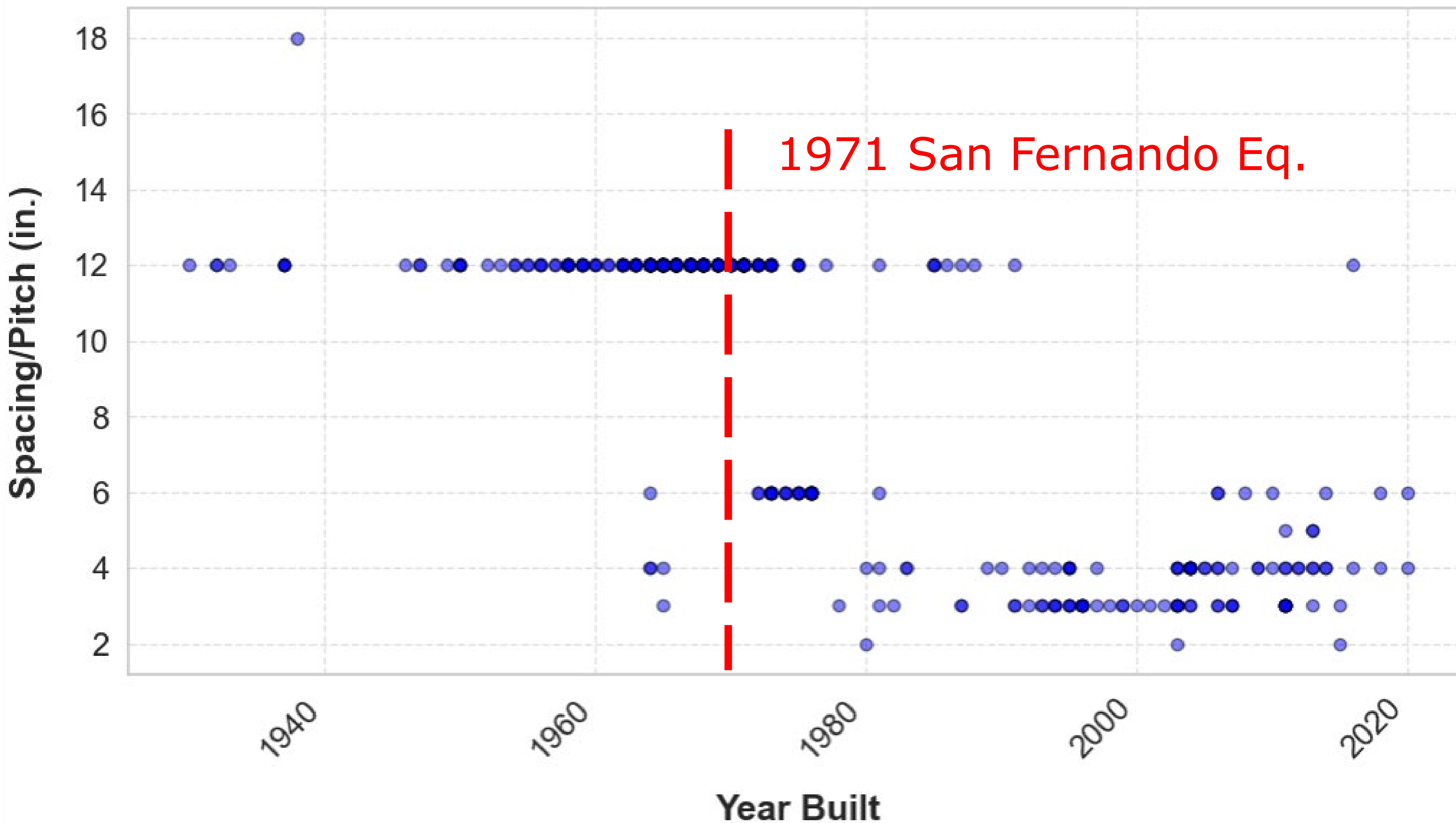
Count of Bridges
Support Type
366
7
24
49
32
0
50
100
150
200
250
300
350
Circular Column
Hexagon Column
Oblong Column
Rectangular Column
Rectangular Column (Spiral Reinforcement)

Year Constructed




Columns per Bent
Mean: 2.8562
Median: 3.0000
Count
112
107
104
77
34
15
11
6
1 2 3 4 5 6 7 8
0 20 40 60 80 100
Column Minimum Aspect Ratio
Mean: 5.8394
Median: 5.5800
Count
5
18
20
45
72
84
59
50
28
22
12
6
6
2
0 2 4 6 8 10 12 14
0 10 20 30 40 50 60 70 80
Longitudinal Reinforcement Ratio (%)
Mean: 0.0165
Median: 0.0134
Count
1
11
79
113
54
24
31
30
17
19
8
10
4
5
1
0.01 0.02 0.03 0.04
0 20 40 60 80 100
Transverse Reinforcement Ratio (%)
Mean: 0.0036
Median: 0.0016
Count
130
117
15
4
15
5
2
11
5
11
10
7
10
6
6
7
2
3
1
2
1
1
0.0000 0.0025 0.0050 0.0075 0.0100 0.0125 0.0150 0.0175
0 20 40 60 80 100 120

Spacing of Transverse Reinforcement



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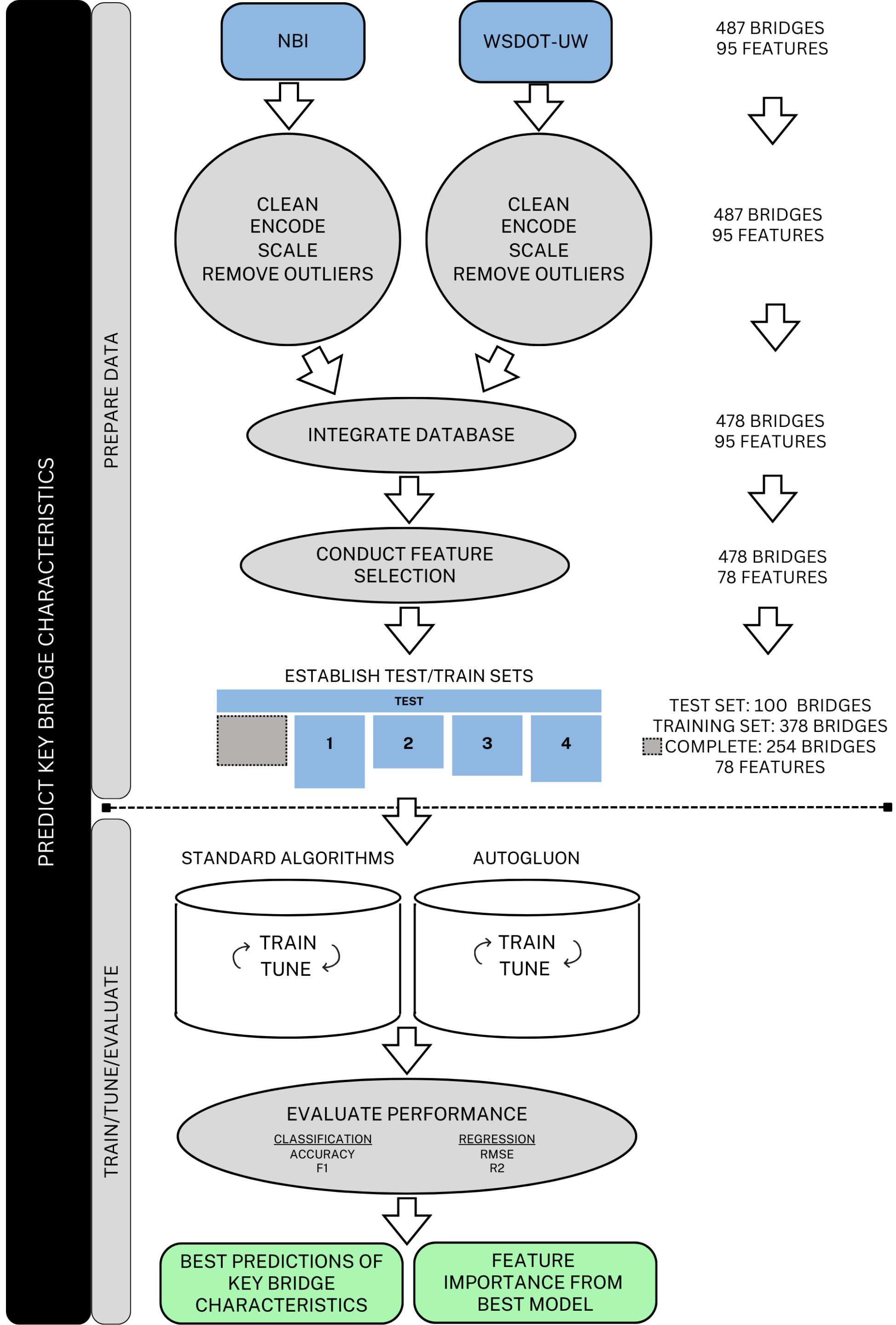
PREDICT KEY BRIDGE CHARACTERISTICS
PREPARE DATA
NBI
WSDOT-UW
487 BRIDGES
95 FEATURES
CLEAN
ENCODE
SCALE
REMOVE OUTLIERS
CLEAN
ENCODE
SCALE
REMOVE OUTLIERS
487 BRIDGES
95 FEATURES
INTEGRATE DATABASE
478 BRIDGES
95 FEATURES
CONDUCT FEATURE SELECTION
478 BRIDGES
78 FEATURES
ESTABLISH TEST/TRAIN SETS
TEST
1
2
3
4
TEST SET: 100 BRIDGES
TRAINING SET: 378 BRIDGES
COMPLETE: 254 BRIDGES
78 FEATURES
TRAIN/TUNE/EVALUATE
STANDARD ALGORITHMS
AUTOGLUON
TRAIN
TUNE
TRAIN
TUNE
EVALUATE PERFORMANCE
CLASSIFICATION
ACCURACY
F1
REGRESSION
RMSE
R2
BEST PREDICTIONS OF KEY BRIDGE CHARACTERISTICS
FEATURE IMPORTANCE FROM BEST MODEL

Performance

	Columns per bent		Minimum Aspect Ratio	
Model	**RMSE ± SE**	**R^2 ± SE**	**RMSE ± SE**	**R^2 ± SE**
Decision Trees	1.285 ± 0.054	0.238 ± 0.069	2.130 ± 0.052	0.194 ± 0.033
Random Forests	0.976 ± 0.033	0.570 ± 0.015	**1.818 ± 0.046**	0.415 ± 0.015
Support Vector Machines	1.100 ± 0.036	0.454 ± 0.019	2.073 ± 0.058	0.240 ± 0.021
Gradient Boosting	0.972 ± 0.019	0.573 ± 0.020	1.864 ± 0.021	0.385 ± 0.012
Neural Networks	1.345 ± 0.020	0.181 ± 0.029	2.131 ± 0.012	0.197 ± 0.014
AutoML	**0.945 ± 0.029**	0.598 ± 0.011	1.853 ± 0.047	0.393 ± 0.016

	Longitudinal Reinforcement Ratio		Transverse Reinforcement Ratio	
Model	**RMSE ± SE**	**R^2 ± SE**	**RMSE ± SE**	**R^2 ± SE**
Decision Trees	0.00789 ± 0.0003	0.000 ± 0.020	0.00248 ± 0.000	0.519 ± 0.044
Random Forests	0.00730 ± 0.0003	0.138 ± 0.034	**0.00173 ± 0.000**	0.767 ± 0.022
Support Vector Machines	0.00782 ± 0.0003	0.019 ± 0.014	0.00241 ± 0.000	0.544 ± 0.037
Gradient Boosting	0.00744 ± 0.014	0.108 ± 0.028	0.00174 ± 0.037	0.762 ± 0.020
Neural Networks	0.00786 ± 0.028	0.007 ± 0.018	0.00221 ± 0.020	0.623 ± 0.020
AutoML	**0.00724 ± 0.000**	0.154 ± 0.027	0.00175 ± 0.000	0.762 ± 0.019

AutoGluon Usually Best, Followed by Random Forests

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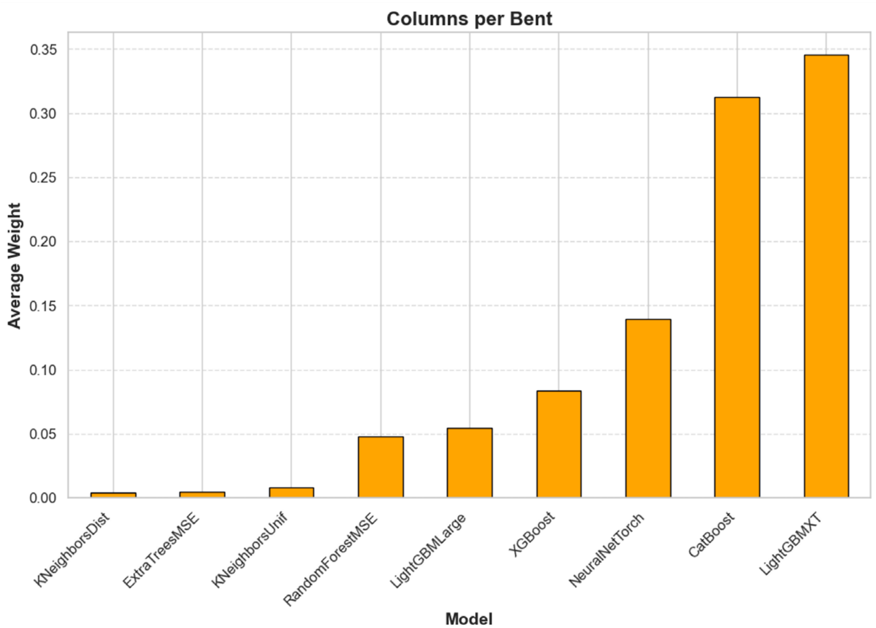
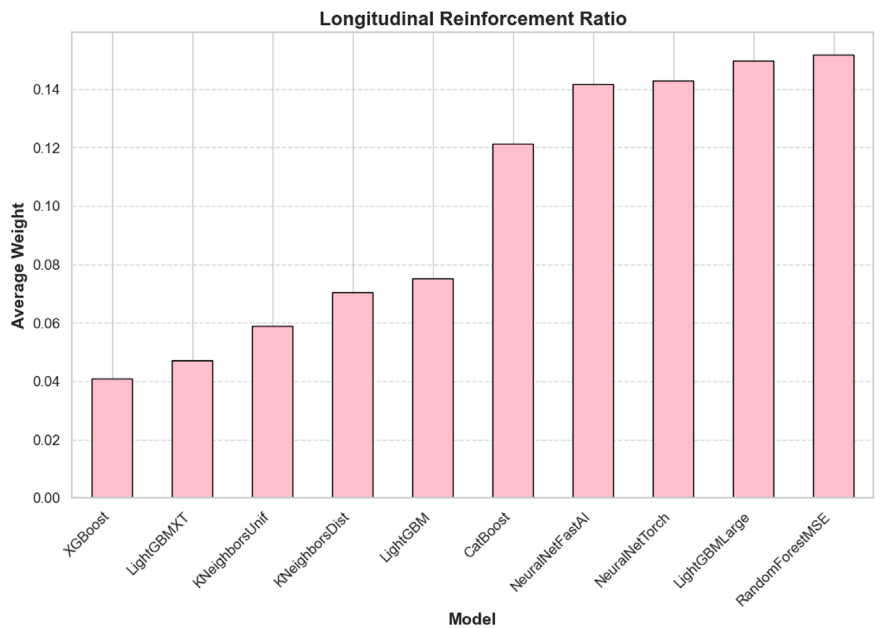
Auto ML Algorithm Weights





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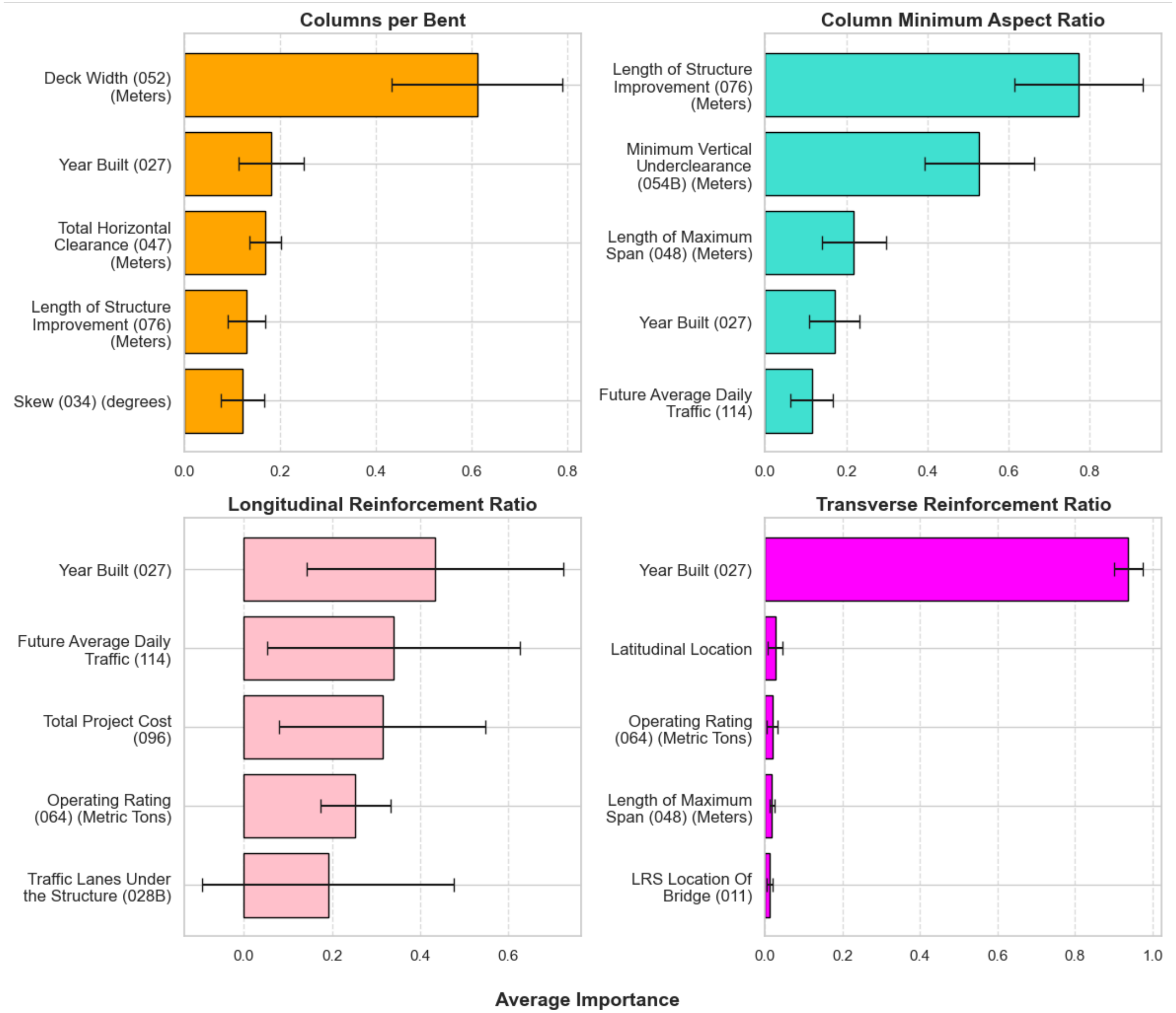
Feature Importance



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Application to Shear Failure Index

$$\text{Shear Failure Index} = \frac{\left[1.6\left(\frac{\sqrt{f'_c}}{f_y}\right) + 0.4 \cdot \mathrm{TRR}\left(\frac{f_{yt}}{f_y}\right)\right] \cdot \mathrm{L/H_{MIN}}}{\left[1.3Z\left(\frac{\pi}{4}\right)\eta \cdot \mathrm{LRR}\right]}$$

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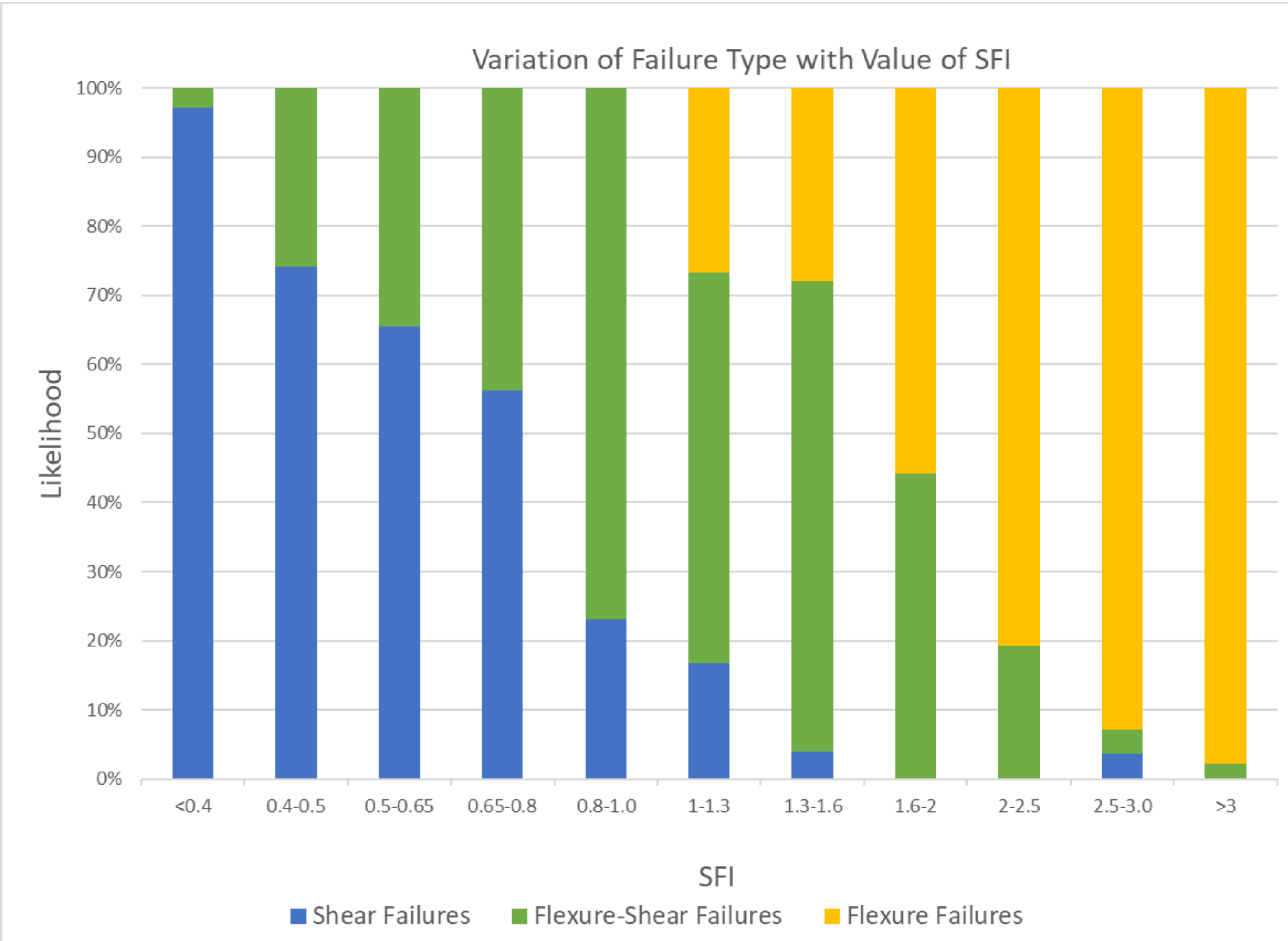
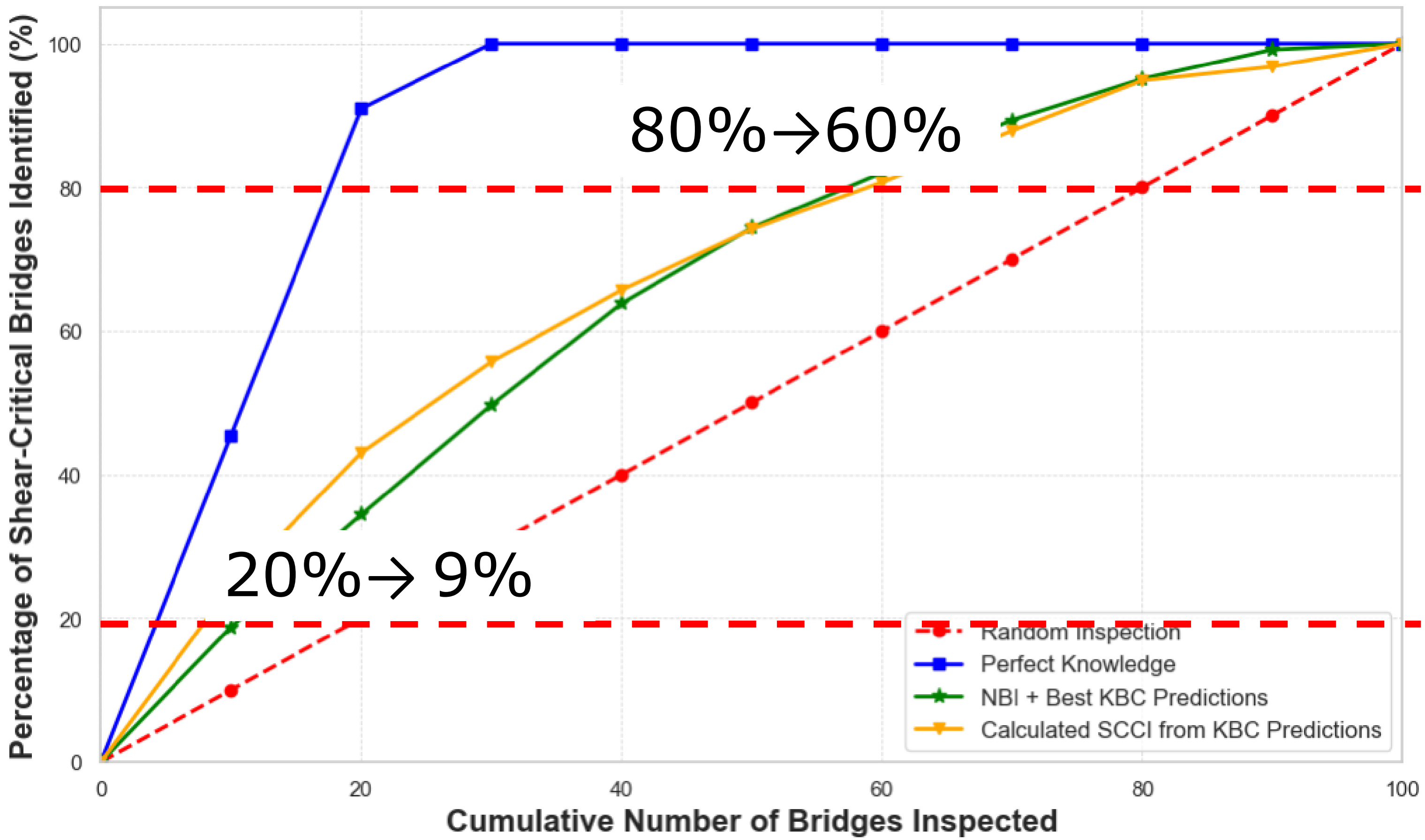
Performance of Shear-Failure Index



Finding Shear-Critical Columns



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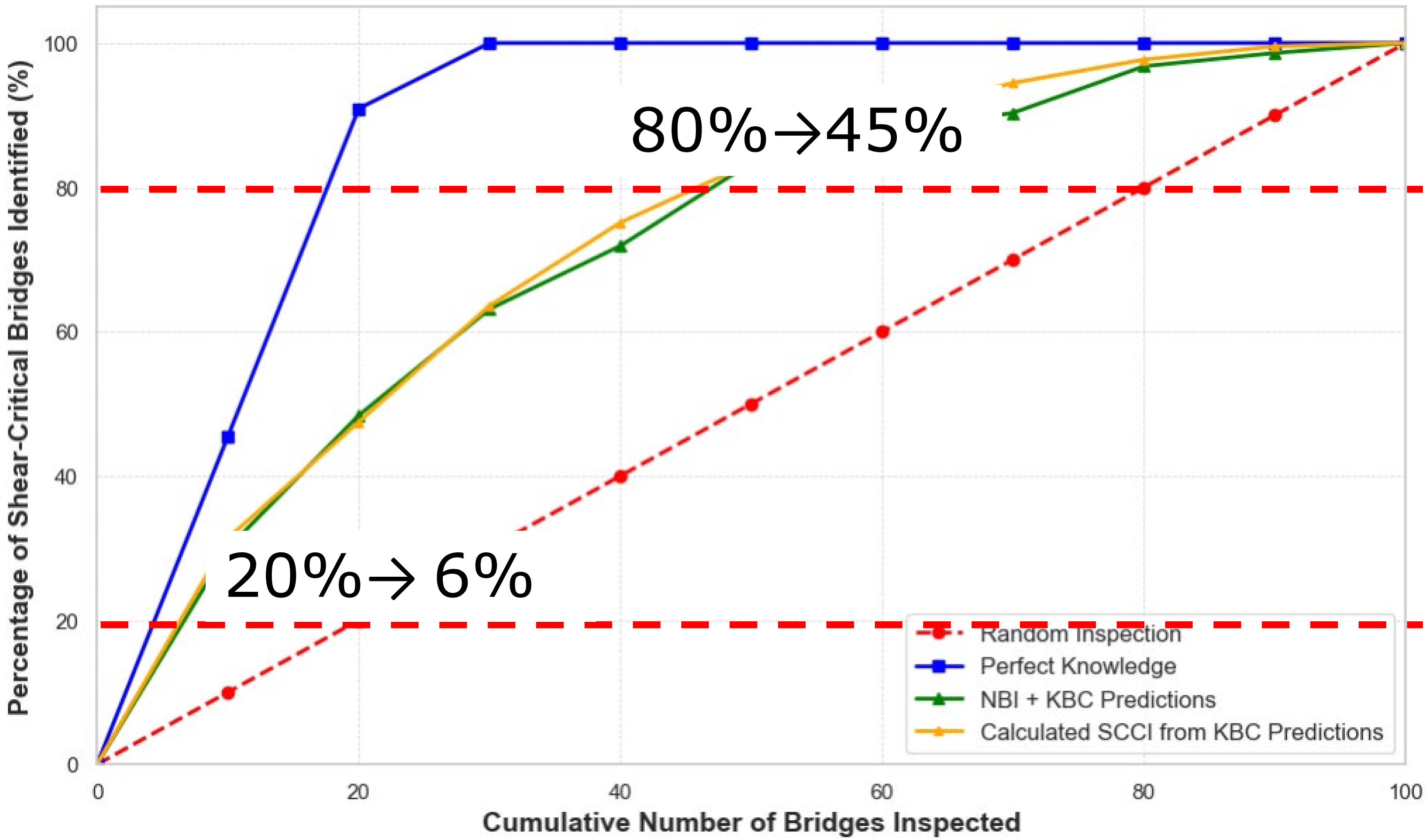
Include L/D as Feature (Street-View)



Conclusions

- AutoGluon Best Performance Overall
  - Repeated sampling (10)
  - Tool for identifying best algorithms
  - Tool for guiding pre-processing
- Performance Varied Greatly with Target
  - Insights into highest contributions
- Predictions of Shear Failure
  - Best at identifying subset of critical columns
  - Performance improved with added information
  - Combine with StreetView?

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Thank you