Deep-learning based seismic risk assessment and retrofitting of road networks

Jack Baker and Rodrigo Silva-Lopez

Why use machine learning in earthquake engineering?

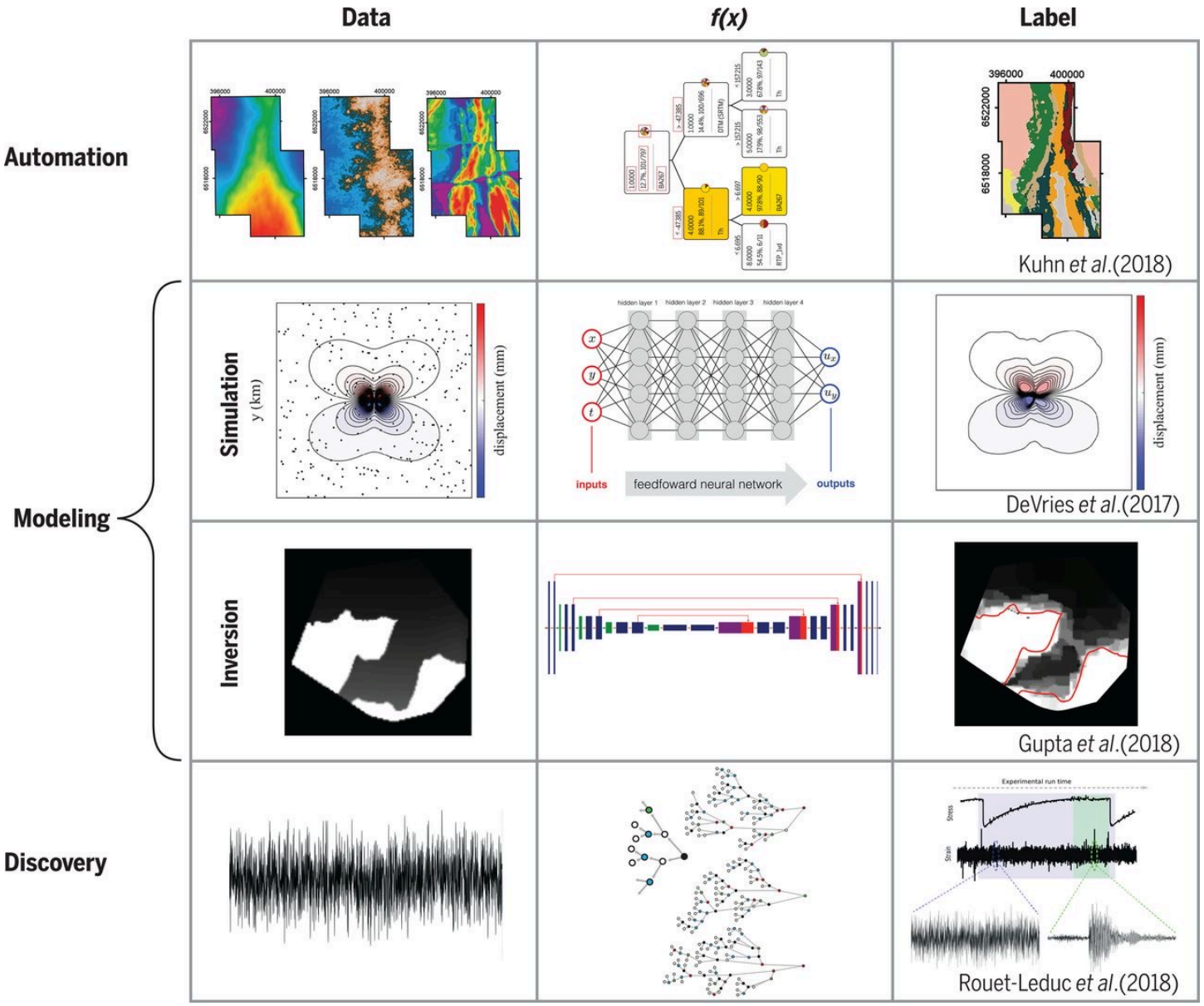
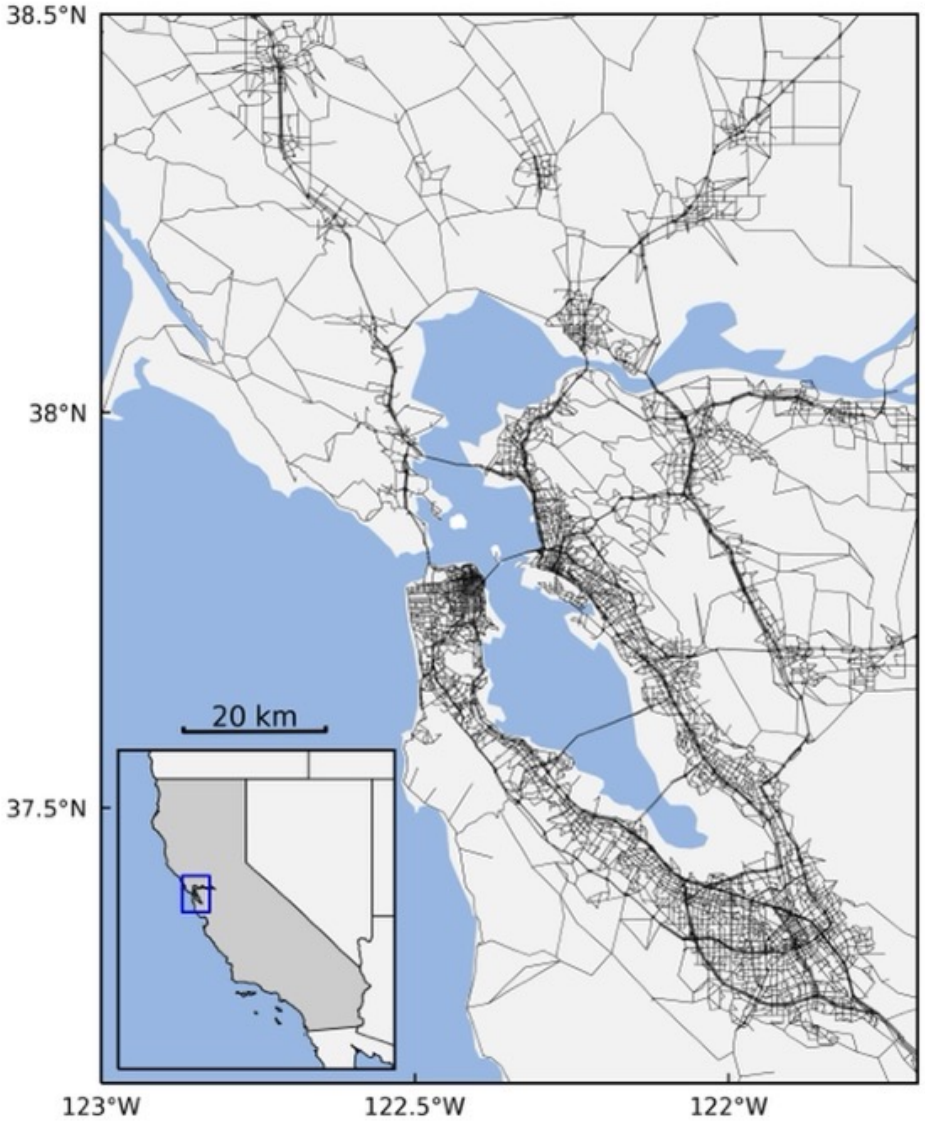


Image from Beroza et al., (2019) *Science*

Project objective: Select bridges to retrofit to minimize impacts of seismic road network disruption

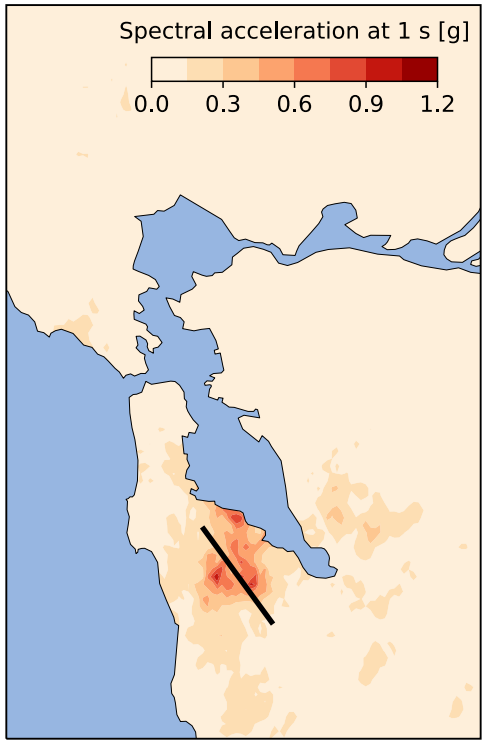


Bay Area model

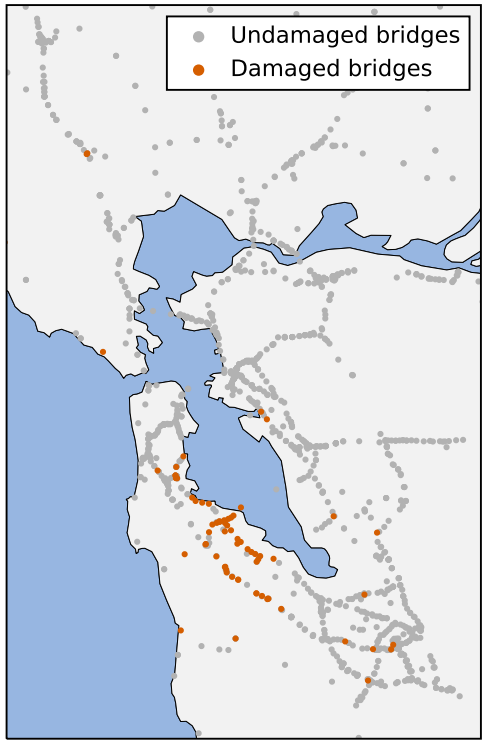
- 32,858 road segments
- 20 million trips per day
- 1743 state-owned bridges

1992 earthquake scenarios (fault, magnitude, extent) and resulting ground motion simulations

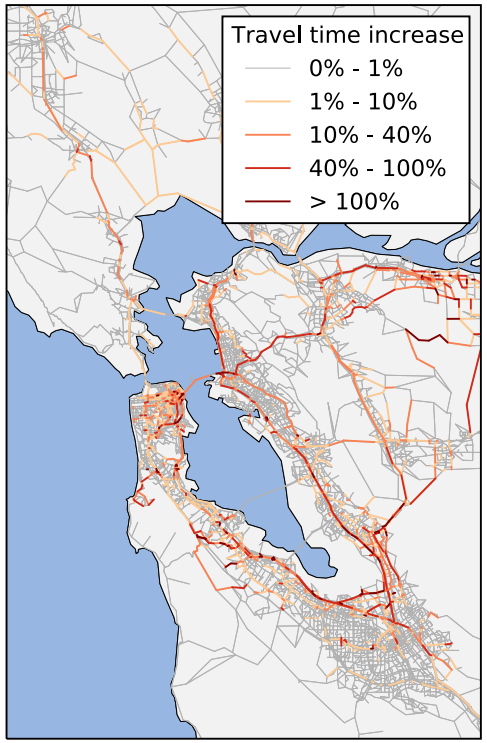
Seismic risk assessment workflow



Seismic Scenario



Bridge Damage



Traffic Assignment

$$\Delta tp = 10.4\%$$

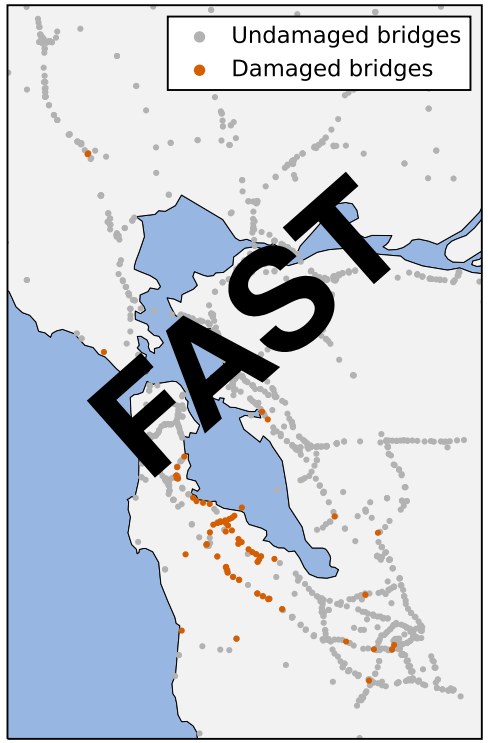
(percent travel time increase)

Traffic performance metric

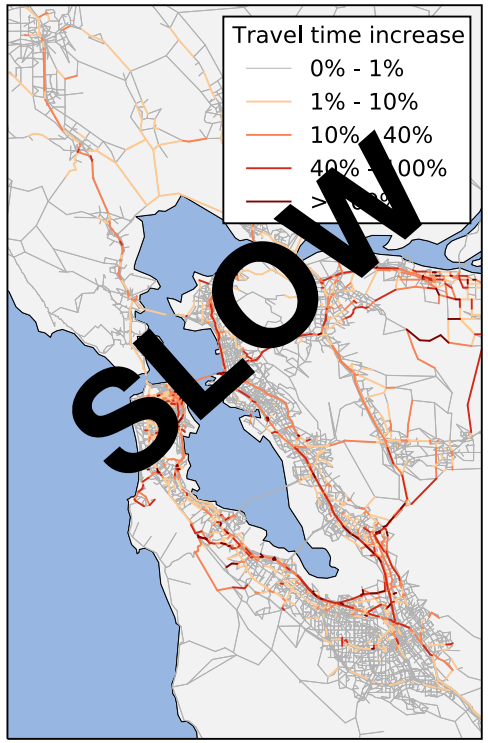
Seismic risk assessment workflow

Computational costs

Seismic Scenario



Bridge Damage

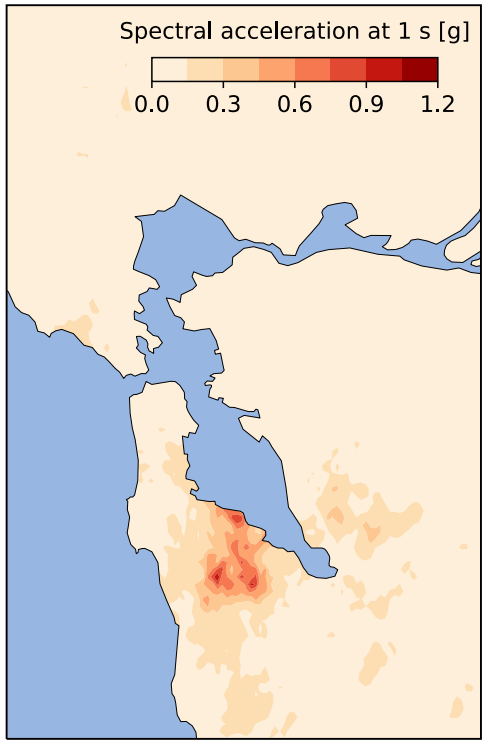


Traffic Assignment

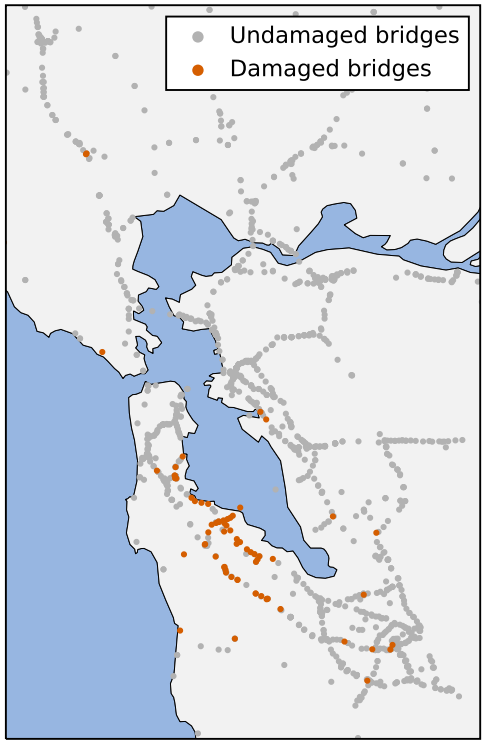
$$\Delta tp = 10.4\%$$

Traffic performance metric

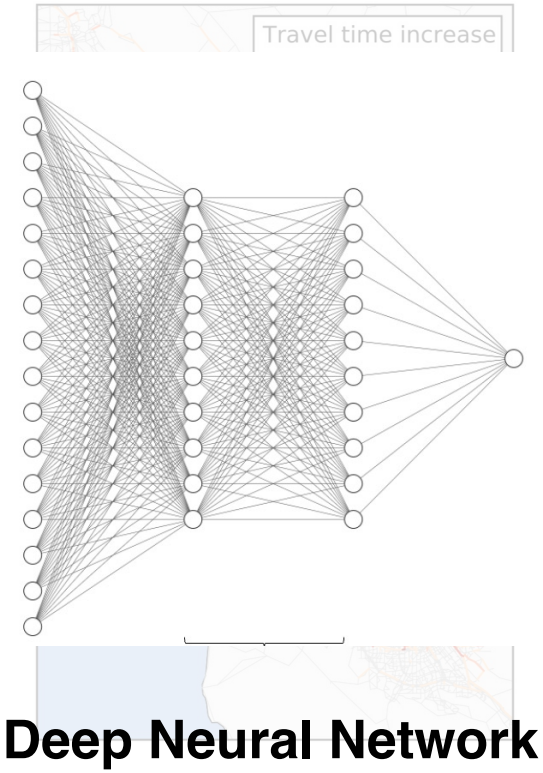
Deep neural networks fast-track risk assessment



Seismic Scenario



Bridge Damage



Deep Neural Network

Traffic Assignment

$$\Delta tp = 10.4\%$$

Traffic performance metric

Challenges to train the deep neural network

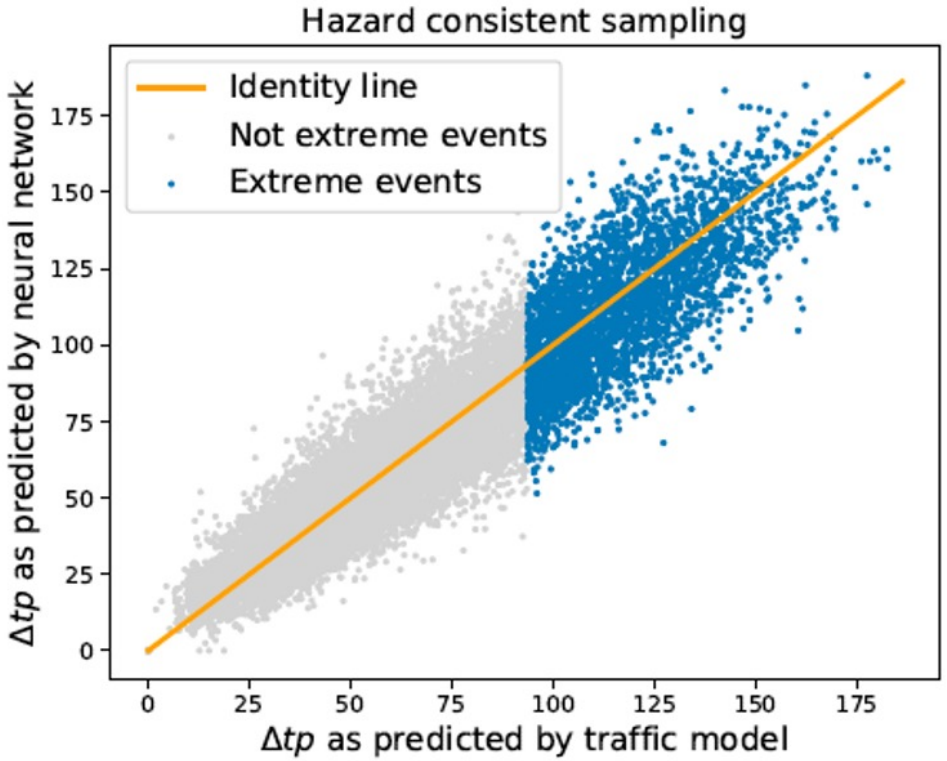
1. *Sampling protocols*: How to account for extreme events?

2. *Definition of hyperparameters* of the neural network
   - Number of layers.
   - Learning rate.
   - Neurons per layer.
   - Activation function.

3. *Parameters for evaluation*: prediction statistics and loss curves

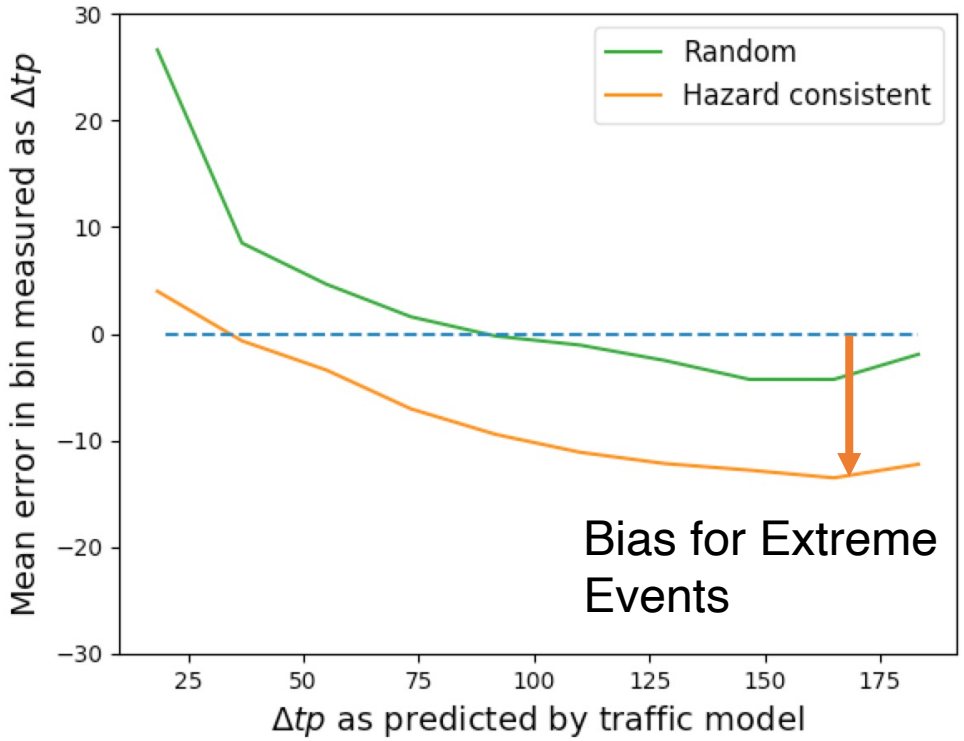
Data sampling protocols

Goodness of fit



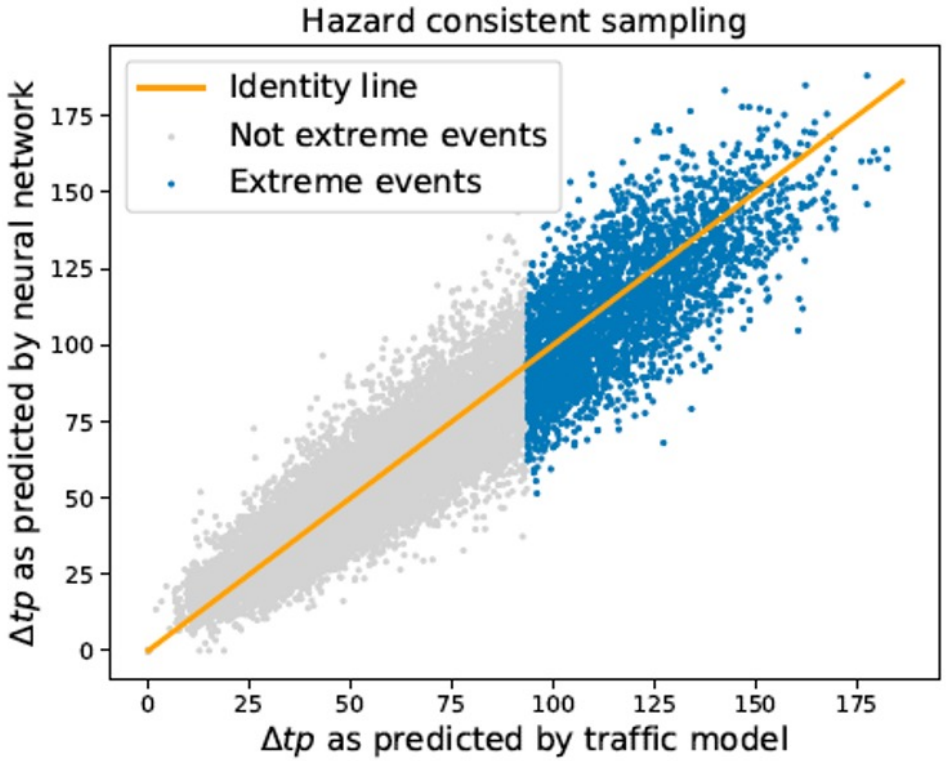
R^2= 0.94

Bias Analysis



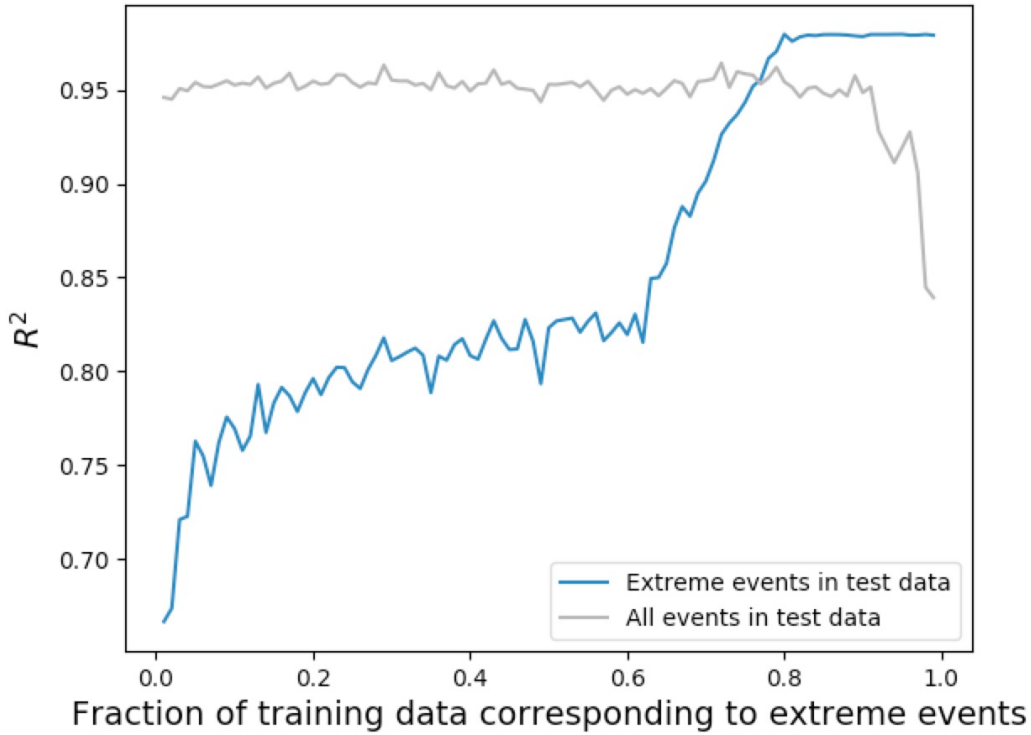
Data sampling protocols

Goodness of fit



R^2= 0.94

Effect of extreme event sampling



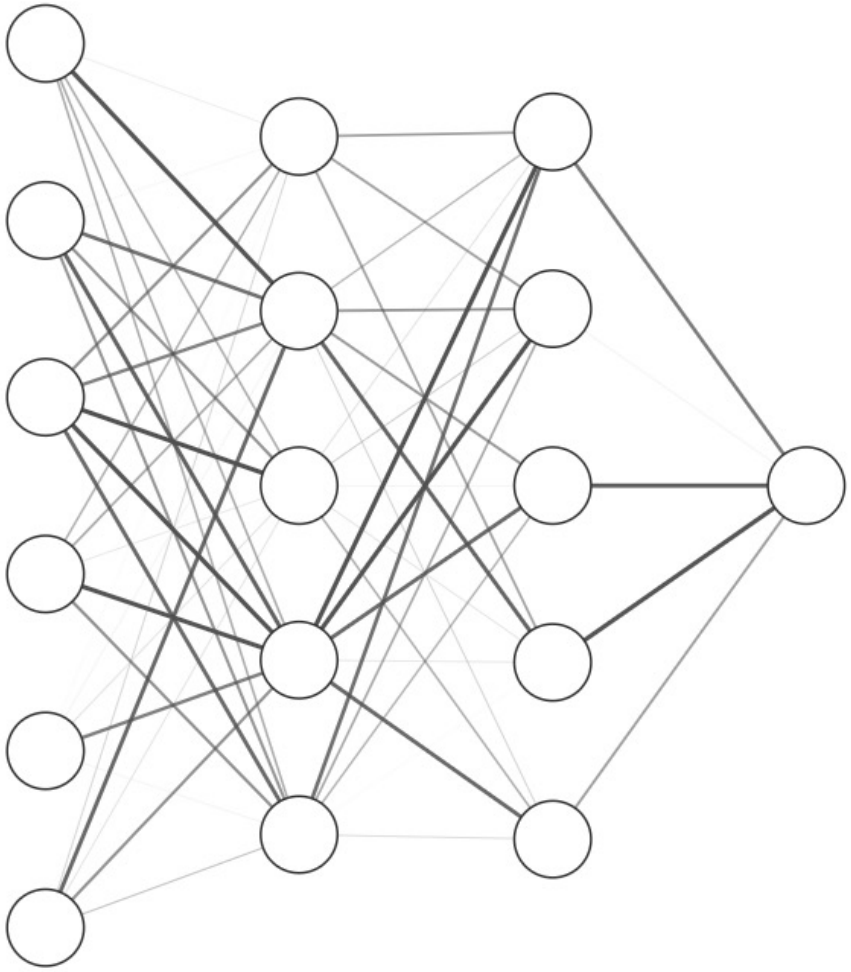
Traffic loss curves using the 1992 seismic scenarios

With traffic model = 8 hours

With neural network = 0.3 seconds

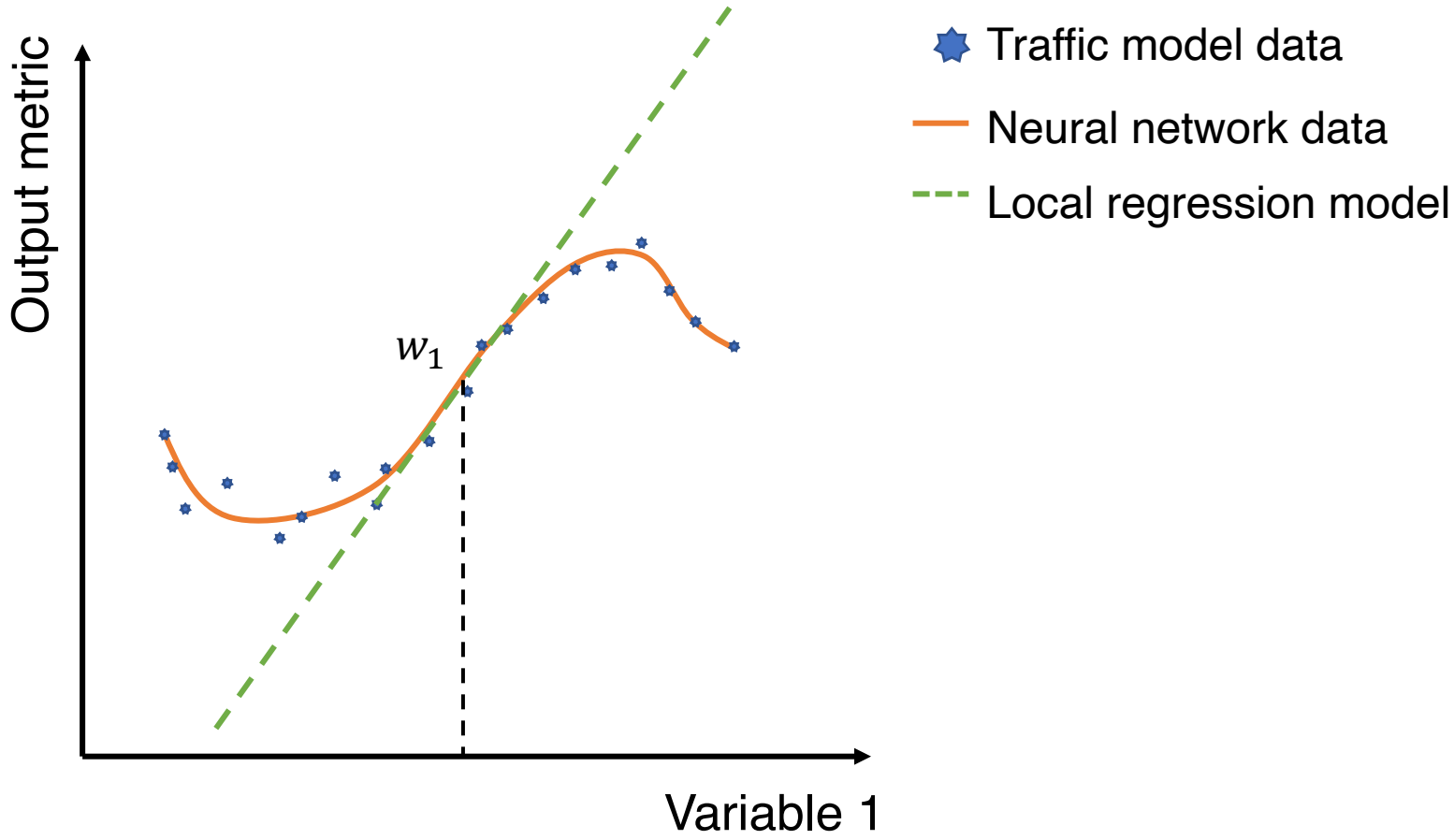
Understanding the neural network using the LIME (*local interpretable model-agnostic*) algorithm

Bridge Damage States

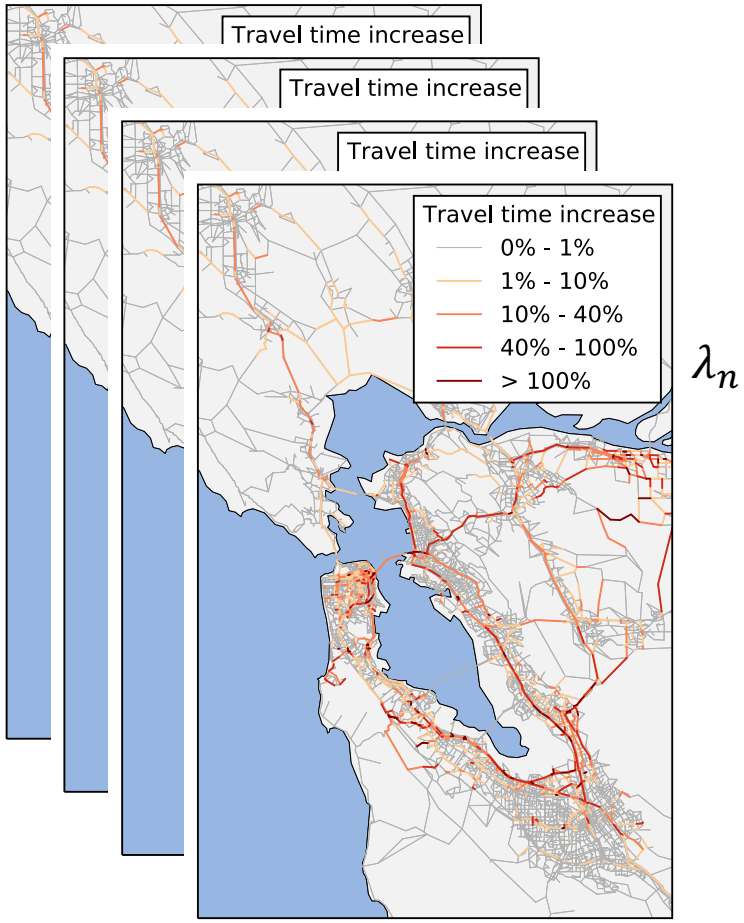


Traffic Performance

LIME uses local regression models



LIME-TI: Aggregate over earthquake scenarios



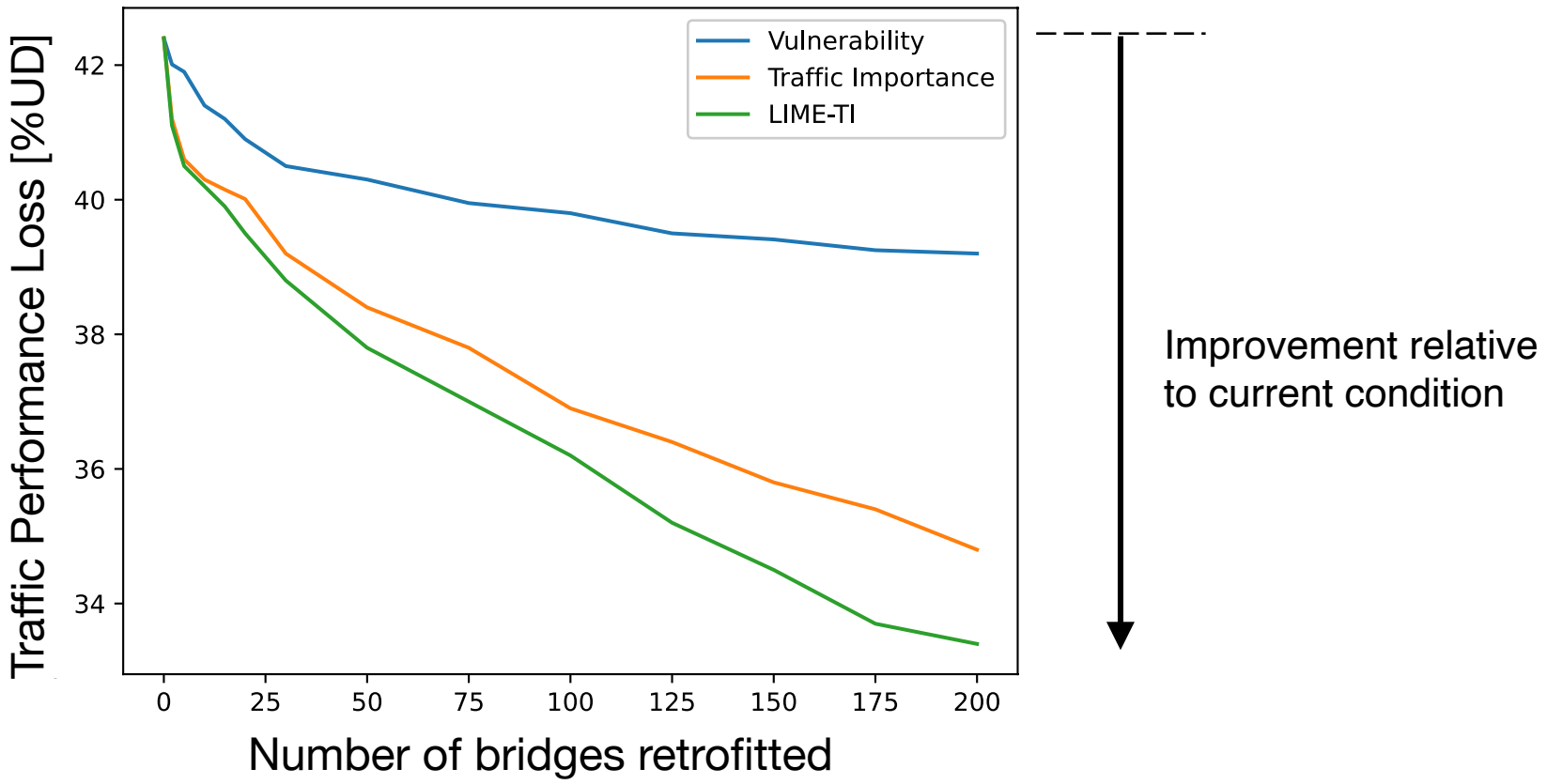
Bridge Importance

$$I_b = \sum_i \lambda_i C_{b,i}$$

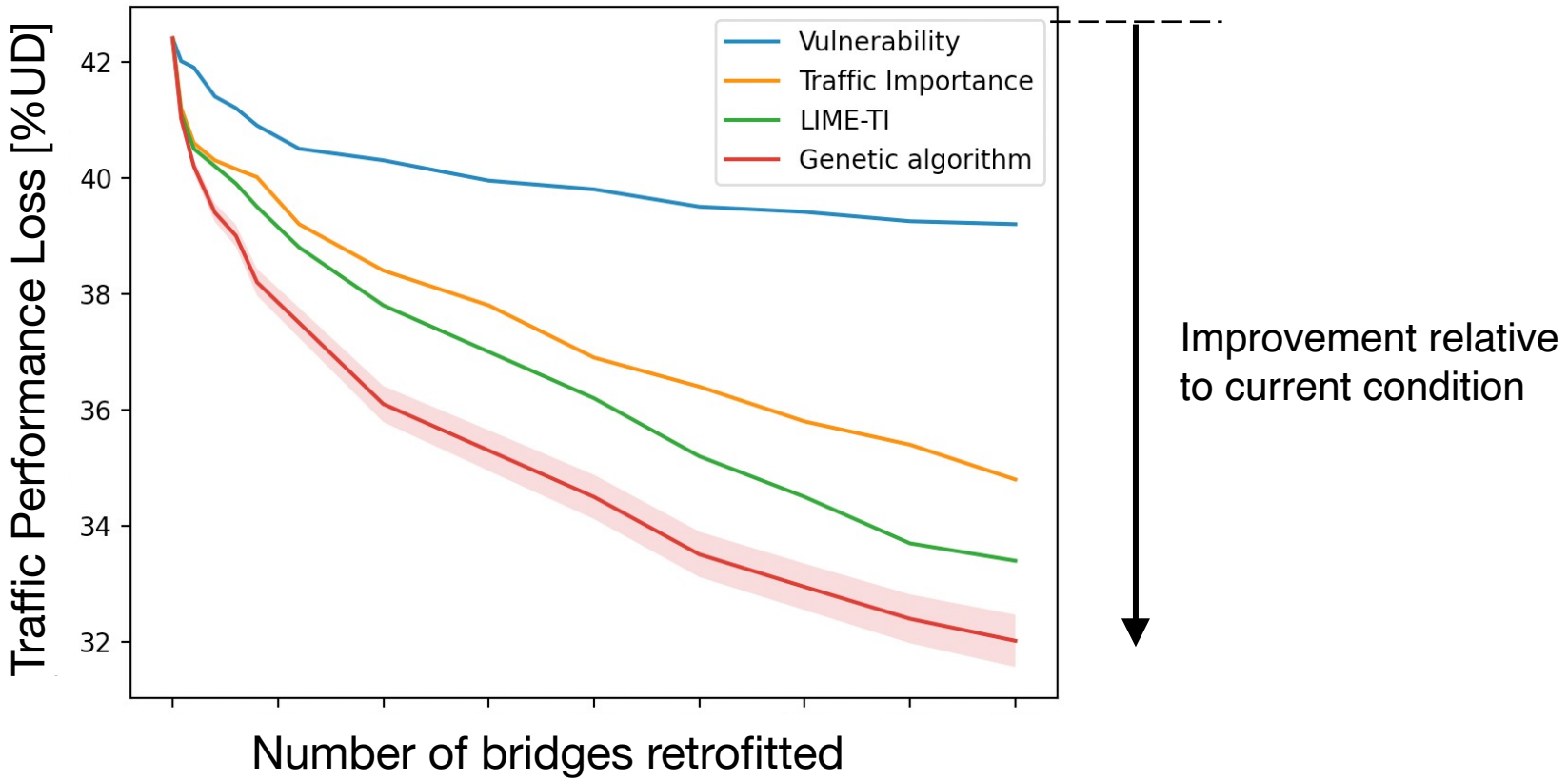
Scenario's rate of occurrence

LIME-TI Coefficient

Retrofitting bridges using LIME

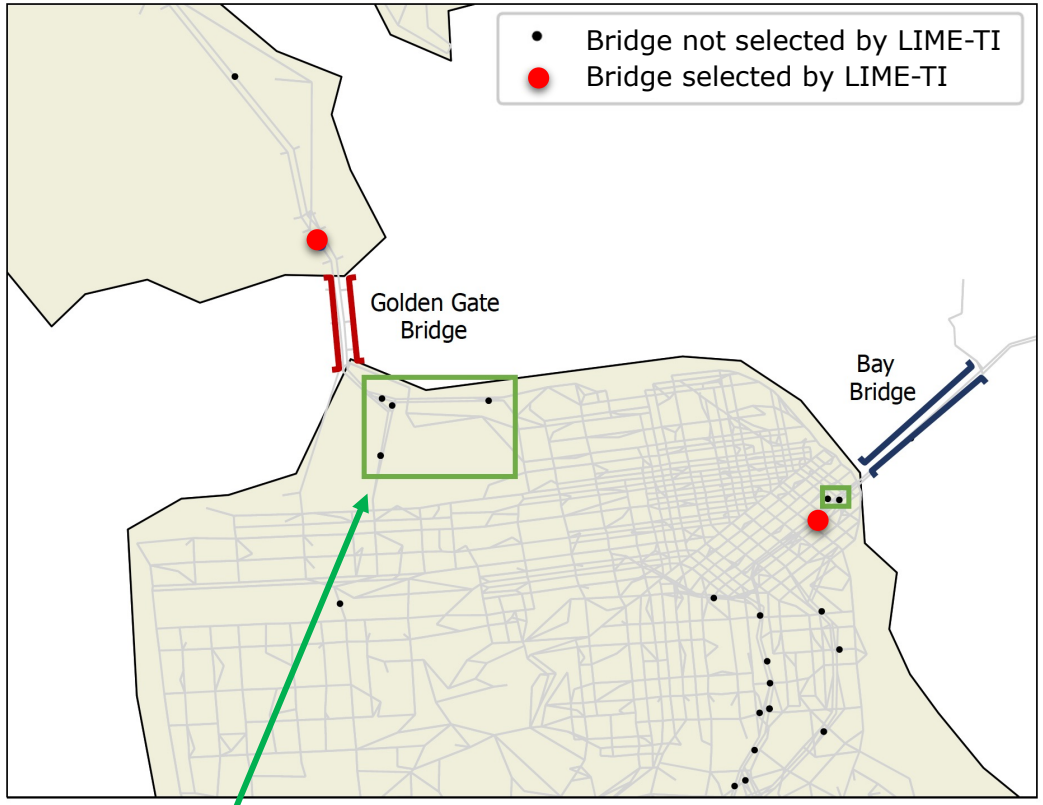


We can do even better with optimization (enabled by the neural network)



Interpretation of LIME-identified bridges

LIME-TI Selects bridges that are vulnerable, secondary, but leading to primary bridges.



Conclusions

- Neural networks can accurately and rapidly predict traffic disruption in a large transportation model
- Over-sampling extreme events in the training data is valuable
- Explainable AI can be used to understand the model and identify risk-reducing actions
- Surrogate model are also valuable for explicit optimization

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Silva Lopez, Baker, Poulos (2022). "Deep learning-based retrofitting and seismic risk assessment of road networks." ASCE Journal of Computing in Civil Engineering.