Performance Forecasts of Bridge Networks—Machine Learning Model

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1. Background

The Machine Learning Model is a forecast model of bridge network performances. A bridge network is a group of user-selected bridges. The Machine Learning Model complements the Federal Highway Administration (FHWA) Long Term Bridge Performance (LTBP) InfoBridge™ (FHWA, 2020a) data visualization tools in depicting future performance trends of highway bridge networks.

Historical bridge condition rating data from the FHWA National Bridge Inventory (NBI) (FHWA, 1995; FHWA 2020b) are used in conjunction with climate data to develop the Machine Learning Model. The research methodology employed is a deep learning-aided bridge deterioration modeling approach (Liu et al., 2021; Liu and Zhang, 2020).

Deep learning is a machine-learning technique that allows computational models comprising multiple processing layers to learn *data representations* of a high-dimensional and complex dataset. In the context of condition forecast, *data representations* are equivalent to the statistical interrelationships or data patterns that describe how various factors influence the bridge-component deterioration process. The current modeling effort considers 24 factors, such as traffic volumes, construction materials, and climate factors. The specific deep-learning algorithm employed for data analysis is the convolutional neural network (CNN); Liu and Zhang (2020) introduce an application of CNN in condition rating data modeling. *Deep Learning* in *Nature* (LeCun et al., 2015) and *Deep Learning* by Goodfellow et al. (2016) provide additional information about deep learning.

The content in this documentation provides a general introduction to the model. For additional modeling details, a full-length technical paper is in process to be published in a peer-reviewed journal. A reference to the paper will be provided after publication.

2. Network Performance Definition

The performance measures (PMs) established by FHWA (2017) evaluate the condition of bridges carrying the National Highway System (NHS). A network may include both NHS and non-NHS bridges. The Machine Learning Model adopts FHWA's measures for evaluating bridge networks' performances.

The PMs calculate the percentages of bridges classified as in good/fair/poor condition weighted with deck area (FHWA, 2018), as expressed in Equation (1),

$$\text{Percentage by Bridge Deck Area (Good/Fair/Poor)} = \frac{\sum_{i=1}^{N^*} A_i}{\sum_{s=1}^{N} A_s} \qquad \text{Equation (1)}$$

where N^* is the total number of applicable bridges as in good/fair/poor condition; i is an applicable bridge as in good/fair/poor condition; s is an applicable bridge; N is the total number of applicable bridges; A is the deck area of an applicable bridge.

The classification of the good/fair/poor condition is based on the lowest condition rating of four NBI items: 58 (deck), 59 (superstructure), 60 (substructure), and 62 (culvert). The good condition classification requires the lowest condition rating to be 7, 8, or 9. The poor condition classification requires the lowest condition rating to be equal to or less than 4. The fair condition classification requires the lowest condition rating to be 5 or 6.

In addition to the PMs by percentages of bridge deck area, the Machine Learning Model also provides PMs by bridge count and by percentages of bridge count. Equation (2) expresses the PMs by bridge count,

$$\text{Bridge Count (Good/Fair/Poor)} = N^* \qquad \text{Equation (2)}$$

and Equation (3) expresses the PMs by percentages of bridge count.

$$\text{Percentage by Bridge Count (Good/Fair/Poor)} = N^*/N \qquad \text{Equation (3)}$$

3. Network Performance Forecast

The performances of a bridge network depend on conditions of individual bridges, as indicated in equations (1) - (3). The ML Model incorporates condition forecasts from each deck, superstructure, substructure, and culvert in the network. In other words, the ML Model involves developing separate forecast models for condition ratings of decks, superstructures, substructures, and culverts. The performance forecasts are probabilistic. InfoBridge displays the expected value (or mean) based on computed probability distribution.

4. Levels of Forecasts

The Machine Learning Model currently implements two levels of forecasts: level-1 and level-2.

The level-1 forecast refers to the model assumption of not considering condition improvement effects in deterioration modeling of bridge decks, superstructures, substructures, and culverts. Specifically, the model development only utilizes data from bridges with no condition rating increase in their history. The bridge selection infers the effects of maintenance, preservation, or rehabilitation activities were limited. The forecasts will reflect an increasing trend in PMs of bridges in the poor condition.

The level-2 forecast refers to the model assumption of considering condition improvement effects in deterioration modeling of bridge decks, superstructures, substructures, and culverts. The modeled condition improvement effects describe a smoothed influence on the network PMs. The smoothed influence reflects an aggregated effect that annually intervenes in the deterioration of bridge conditions. The modeling calibrates the forecast models at level-1 to match historical performances of bridge networks, including bridges with condition rating increases in their history. The calibration infers the effects of maintenance, preservation, or rehabilitation activities are incorporated. The forecasts will reflect a stable or decreasing trend in PMs of bridges in the poor condition.

5. References

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