PREDICTION OF BRIDGE INVENTORY CHARACTERISTICS USING MACHINE LEARNING

Quarterly Progress Report
For the period ending March, 2024

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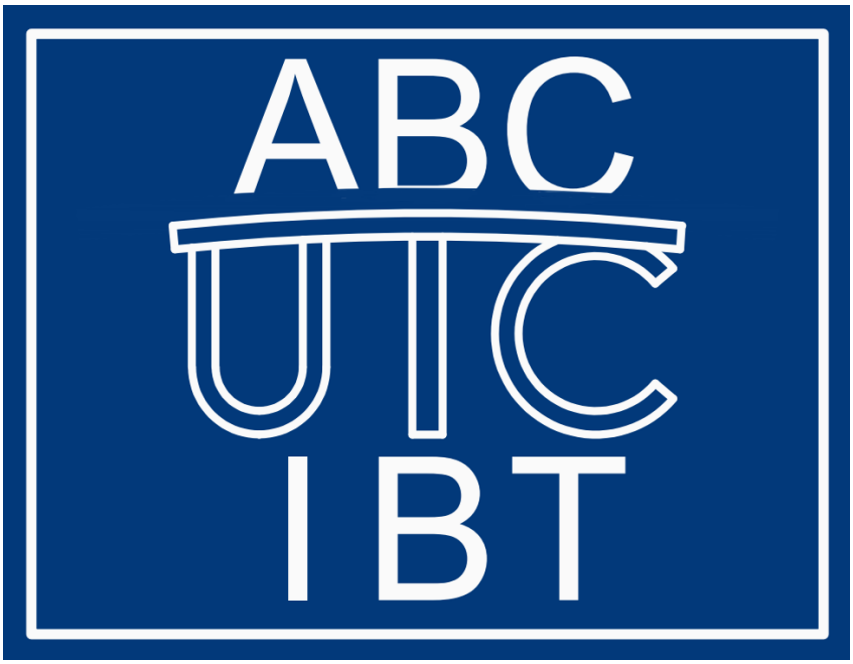

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1. Background and Introduction

This project will develop a methodology and machine learning tool for predicting key characteristics of bridges in a bridge inventory. The machine learning tool will use individual bridge information available from the National Bridge Inventory (NBI) to predict other bridge characteristics that are better aligned with predictions of current bridge condition ratings and bridge performance in natural hazards. The methodology will help DOTs better quantify the current state of their bridge infrastructure, identify prioritization for modernization and retrofit, and will enable more realistic emergency planning for natural hazards and disasters.

2. Problem Statement

Prediction of bridge condition based on bridge characteristics has been a topic of great interest to FHWA, state DoT's, and researchers. Several methods for predicting bridge condition from the inventory information in the NBI are in the literature (e.g., Martinez et al. 2020, Cattan and Mohammadi, 1997, Rafiq et al., 2015, and Jiang, 2010, among other). While different approaches have been used to predict bridge condition, in general, all of them predict bridge condition more accurately with additional information on the individual bridges. Often collecting this additional information requires on-site bridge inspection, detailed review of bridge plans, and maintenance of large databases of this bridge information. Some Departments of Transportation (DOTs) are able to collect and maintain this more detailed information on individual bridges. However, for many DOTs staffing levels are inadequate to support database maintenance at a high level.

With machine learning, it is possible to predict the detailed characteristics of bridge inventories at the individual bridge level using smaller training samples of bridges. The predicted inventory characteristics would use the NBI information on each bridge as input into a machine learning derived model that then predicts the more detailed characteristics of each bridge. These predicted inventory characteristics can then be used in existing models that predict, for example, long-term bridge condition, bridge seismic performance, and bridge performance in flooding and storm surge. Of course, such information is of great importance for DOT planning tasks, such as budget planning for maintenance and replacement, retrofit for functionality, and emergency operations planning in the event of natural hazards. While not as accurate as characteristics derived from detailed site inspections and plan review, the machine learning generated characteristics should provide a great improvement in the understanding of bridge inventory characteristics relative to NBI data alone.

3. Objectives and Research Approach

The proposed project will break new ground in asset management for DOTs, will impact planning for bridge repair and replacement, and will provide critical inventory information for emergency planning in the face of extreme events such as natural hazards. The project will build upon an extensive database of bridge properties collected for more than 700 bridges in Washington State, leveraging substantial efforts from previous research projects that were supported by WSDOT, PacTrans, and the National Science Foundation. The detailed information on these 700 bridges is substantially more comprehensive than that in the NBI and can be used to select and apply models for prediction of long-term condition, seismic fragility, and storm surge and flooding fragility. Of

particular importance, the data collected includes information on the substructure, including the piers, abutments, bearings, shear keys, and foundations, which are often critically important when predicting long-term bridge condition and bridge performance in natural hazards. Coupled with the NBI information and geographic information that provides the setting for the bridge (e..g., size of the river crossing), this is a unique data set that is available to the research team. The following tasks outline a year-long research project to utilize the collected data to train and assess the accuracy of a machine learning-based model to predict the characteristics of the remaining 4,000 plus bridges in Washington State, publish the model and prepare it for use in other states.

4. Description of Research Project Tasks

The following is a description of tasks carried out to date.

Task 1 –Train a Machine Learning Model.

Proposed Task Description: Prof. Choe is a data scientist who specializes in machine learning with heterogenous data of infrastructures and natural hazards and will lead the development of a machine learning model for predicting key bridge characteristics using the data available in NBI and limited geographic setting information. The NBI information for the bridges in the detailed database has also already been curated. Prof. Choe and his student will develop the machine learning model in Python such that it is open source and can be shared and advanced in future projects. The modeling process will be multi-pronged, including highly interpretable models (e.g., regression and rule-based models) and latest deep learning architectures with few-shot tuning to obviate the need for a large training sample (Molnar et al., 2020; Liu et al., 2023).

Description of Work Performed Up To This Period: Prof. Choe identified the Ph.D. student, Julia Carier Lensing, who will work on this project. Julia has extensive experience in machine learning. She has begun work on understanding both the detailed bridge database and the National Bridge Inventory. This includes understanding the data types and their relationships.

Task 2 – Collect Detailed Information on Additional Bridges.

Proposed Task Description: Extending the database of detailed WSDOT bridge characteristics will be completed by Prof's. Berman, Eberhard and their student. The research team has access to drawings of the vast majority of bridges in WSDOT's inventory and will use the drawings to collect the additional detailed information on at least 300 more bridges. The bridges will be systematically selected from the WSDOT inventory to maximize the database's representation of the inventory in terms of NBI-based characteristics using a combination of representation learning and outlier ranking implemented by Prof. Choe (Pang et al., 2018).

Description of Work Performed Up To This Period: Prof. Berman and Eberhard worked with undergraduate students Grace Zhang and Maryam Tasnim Ali to identify additional Washington State bridges in the study area of the collaborative project supported by the National Science Foundation to contribute (Cascadia CoPesHUB). Structural drawings for the additional bridges have been interrogated to complete the entries in the detailed database. Additional work will continue through the coming quarters.

Task 3- Test the Bridge Inventory Characteristics Model.

Proposed Task Description: The machine learning derived predictive model will be used to predict the characteristics of the bridges in a representative hold-out dataset including some bridges databased in Task 2 using only their NBI information and geographic setting information. The model's predictive performance will be analyzed to inform the necessary revisions (e.g., which bridges and their characteristics make the prediction difficult and why).

Description of Work Performed Up To This Period: Nothing completed in this reporting period.

Task 4- Model Revision if Necessary.

Proposed Task Description: If the results in Task 3 indicate opportunities to improve the model, Tasks 1-3 will be iterated until the revised model attains a satisfactory performance (i.e., reliably deployable in practice) on a representative test data set (never used in training).

Description of Work Performed Up To This Period: Nothing completed in this reporting period.

Task 5 - Dissemination.

Proposed Task Description: The research team will disseminate the inventory prediction model through journal papers and presentation at national conferences. The team will prepare a report on the model development and accuracy as is standard for IBT/ABC UTC projects.

Description of Work Performed Up To This Period: Nothing completed in this reporting period.

5. Expected Results and Specific Deliverables

Bridge inventory management is at the heart of the mission of all DOTs. The decision to replace a bridge and, in particular, to adopt ABC methods often stems from the understanding of a bridge's critical value to the functioning of a regional transportation system and the impacts of bridge replacement times on the functioning of a highway system. Those planning decisions are may be made with the help of regional simulation of highway systems, which require estimates of bridge functionality. Similarly, DOTs may use regional simulations to identify bridges that are critical in the response to natural hazards. Better estimates of bridge characteristics at the regional scale can improve regional level simulations and help DOTs more robustly identify those bridges that should be prioritized for replacement and for which ABC methods should be employed to minimize network disruption.

The proposed output of the project will be a set of machine learning derived models that predict the key features of individual bridges in a bridge inventory that are necessary for improved simulation of transportation network reliability under normal and extreme conditions. The models will be developed using data already collected for bridges in Washington State and will be tested on inventories in other selected states. The models will then be made available to DoT's for use in emergency response planning and bridge retrofit and replacement prioritization.

After one quarter of work the research team sees no need to modify the expected results and specific deliverables.

6. Schedule

Progress of tasks in this project is shown in the table below.

Task	% Completed
1. Train a Machine Learning Model.	25%
2. Collect Detailed Information on Additional Bridges	25%
3. Test the Bridge Inventory Characteristics Model.	0%
4. Model Revision if Necessary.	0%
5. Dissemination.	0%

	2024												2025					
Task	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J
1: *Train a Machine Learning Model*																		
2: *Collect Detailed Information on Additional Bridges*																		
3: *Test the Bridge Inventory Characteristics Model*																		
4: *Model Revision if Necessary*																		
5: *Dissemination*																		
Work Performed																		
Work to be Performed																		

7. References

Bu, G. P., Lee, J. H., Guan, H., Loo, Y. C., & Blumenstein, M. (2015). Prediction of long-term bridge performance: Integrated deterioration approach with case studies. Journal of Performance of Constructed Facilities, 29(3), 04014089.

Cattan, J., & Mohammadi, J. (1997). Analysis of bridge condition rating data using neural networks. Computer-Aided Civil and Infrastructure Engineering, 12(6), 419-429.

Liu, X., McDuff, D., Kovacs, G., Galatzer-Levy, I., Sunshine, J., Zhan, J., ... & Patel, S. (2023). Large language models are few-shot health learners. arXiv preprint arXiv:2305.15525.

Martinez, P., Mohamed, E., Mohsen, O., & Mohamed, Y. (2020). Comparative study of data mining models for prediction of bridge future conditions. Journal of Performance of Constructed Facilities, 34(1), 04019108.

Molnar, C., Casalicchio, G., & Bischl, B. (2020). Interpretable machine learning–a brief history, state-of-the-art and challenges. In Joint European Conference on Machine Learning and Knowledge Discovery in Databases (pp. 417-431). Cham: Springer International Publishing.

Pang, G., Cao, L., Chen, L., & Liu, H. (2018). Learning representations of ultrahigh-dimensional data for random distance-based outlier detection. In Proceedings of the 24th ACM SIGKDD International Conference on Knowledge Discovery & Data Mining (pp. 2041-2050).

Rafiq, M. I., Chryssanthopoulos, M. K., & Sathananthan, S. (2015). Bridge condition modelling and prediction using dynamic Bayesian belief networks. Structure and Infrastructure Engineering, 11(1), 38-50.

Jiang, Y. (2010, June). Application and comparison of regression and Markov chain methods in bridge condition prediction and system benefit optimization. In Journal of the Transportation Research Forum (Vol. 49, No. 2, pp. 91-110).