

**Transportation Infrastructure Precast Innovation Center**

**(TRANS-IPIC)**

**University Transportation Center (UTC)**

Optimizing the Planning of Precast Concrete Bridge Construction Methods to Maximize Durability, Safety, and Sustainability

UI-23-RP-05

Quarterly Progress Report

For the performance period ending [9/30/2024]

**Submitted by:**

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**Collaborators / Partners:**

None

**Submitted to:**

TRANS-IPIC UTC

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Urbana, IL

**TRANS-IPIC Quarterly Progress Report:**

Project Description:

1. Research Plan - Statement of Problem

The poor conditions of aging bridges in the US prompted the federal government to enact a $1 trillion infrastructure bill in 2021 that includes $110 billion in additional funding for repairing and rebuilding US bridges and roadways (White House, 2022). State DOTs need to optimize the use of these investments to accomplish multiple objectives including maximizing durability, safety, sustainability, and mobility while minimizing life-cycle cost. This presents DOTs with a number of challenges including how to (1) select an optimal bridge construction method from a set of feasible alternatives including conventional cast-in-place, precast bridge elements or systems, precast lateral slide, and precast self-propelled modular transporter, for each planned project based on its specific conditions and requirements; (2) accurately predict the cost of these alternative bridge construction methods during the early project phase with limited design data; (3) optimize the planning of off-site PC manufacturing, transportation, and onsite installation; and (4) quantify and optimize the impact of important construction decisions on multiple objectives including safety and life-cycle cost.

1. Research Plan - Summary of Project Activities (Tasks)

Task 1: Develop novel predictive Machine Learning (ML) models that can be used by DOT planners during the early design phase to quantify the impact of conventional and PC accelerated bridge construction methods on construction cost during the early design phase.

Task 2: Create a novel multi-objective optimization model to assist DOTs in identifying optimal bridge construction planning decisions such as optimal size, number, transportation, and onsite installation of all bridge PC modules to maximize safety of travelling public and construction workers in and around work zone while minimizing bridge life-cycle cost.

Project Progress:

1. Progress for each research task

Task 1 progress [100% completed]. The research team successfully developed six machine learning (ML) models to support decision makers in estimating the cost of conventional and PC accelerated bridge construction projects during the early design phase. The ML models were developed in four main phases that focused on (1) collecting and analyzing a dataset of 413 bridge projects that were constructed in 29 US states; (2) preprocessing the dataset to classify, clean, and transform predictor and predicted variables as well as splitting the dataset into training and testing sets; (3) developing bridge cost estimating models using the six ML algorithms of Ordinary Least Squares, LASSO Regression, Ridge Regression, Random Forest Regressor, Gradient Boosting, and Extreme Gradient Boosting; and (4) evaluating and validating the performance of the developed ML models, as shown in Figure 1. The performance evaluation and validation results showed that the Extreme Gradient Boosting model outperformed the other models in three metrics as it achieved the lowest 𝑀𝐴𝑃𝐸 of 13.90%, 𝑀𝐴𝐸 of $64.28/sf, and 𝑀ed. 𝐴𝐸 of $29.94/sf. On the other hand, the GB model outperformed the other models in the fourth metric with the lowest RMSE of $113.01/sf.



Figure . Development Phases of Machine Learning Models.

Task 2 progress [60% completed]. Last quarter, the research team continued working on the second task that focuses on creating a novel multi-objective optimization model to identify optimal bridge construction planning decisions. The main objectives of the developed tool are (1) maximizing safety by minimizing work zone fatality and injury crashes using safety performance functions (SPF) that predict crash frequency based on site conditions (Schattler et al., 2020); and (2) minimizing life cycle costs that includes off-site prefabrication, PC transportation, on-site construction; road user, and maintenance costs, as shown in Figure 2. The model was developed in four main phases that focused on (i) identifying all decision variables that have a significant impact on planned bridge projects such as construction methods, size and number of bridge precast modules, and transportation methods; (ii) formulating optimization objectives and constraints; (iii) implementing the optimization model; and (iv) analyzing a real-life case study to illustrate the use of the developed optimization model, as shown in Figure 2.



Figure . Development Phases of the Multi-Objective Optimization Model

1. Percent of research project completed

75% of total project completed through the end of this quarter.

1. Expected progress for next quarter

In the next quarter, the final research task that focuses on developing a multi-objective optimization model for optimizing construction decisions of PC bridges will be completed. Additionally, a final report that includes a detailed description of each research task will be submitted.

1. Educational outreach and workforce development

The educational and workforce development (EWD) activities this quarter focused on: (1) continuing to enhance the analytical and research skills of a female PhD student, the lead research assistant, in collecting and analyzing bridge construction data from various databases and developing machine learning and multi-objective optimization models; (2) developing educational modules for two construction engineering courses (CEE 421 and CEE 526), which the PI teaches to over 120 students annually; and (3) presenting preliminary research findings during the TRANS-IPIC monthly webinar in August 2024 .

1. Technology Transfer

The research team developed (1) six different ML predictive models to estimate the construction cost of alternative bridge construction methods including conventional and precast concrete accelerated bridge construction methods; and (2) a multi-objective optimization model for optimizing construction decisions of PC bridges. The research team will develop a plan for sharing the ML and optimization models that will be developed in this research project.

Research Contribution:

1. Papers that include TRANS-IPIC UTC in the acknowledgments section:

The research team submitted two papers to leading construction engineering and management journals. One has already been accepted and is currently with the journal’s production editor, while the second paper is under its second review by the editor, as detailed below:

• Helaly, H., El-Rayes, K., Ignacio, E.J., and Joan, H. J. (Accepted on September 29, 2024) “Comparison of Machine Learning Algorithms for Estimating Cost of Conventional and Accelerated Bridge Construction Methods During Early Design Phase.” submitted to *Journal of Construction Engineering and Management*, ASCE.

• Helaly, H., El-Rayes, K., and Ignacio, E.J. (Under 2nd Review by Editor) “Predictive Models to Estimate Construction and Life Cycle Cost of Conventional and Precast Bridges During Early Design Phase.” submitted to *Canadian Journal of Civil Engineering*, CSCE, May 2024.

1. Presentations and Posters of TRANS-IPIC funded research:

The research team presented their research preliminary results during the TRANS-IPIC Monthly Webinar on August 22, 2024.

1. Please list any other events or activities that highlights the work of TRANS-IPIC occurring at your university (please include any pictures or figures you may have). Similarly, please list any references to TRANS-IPIC in the news or interviews from your research.

None

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