Transportation Infrastructure Precast Innovation Center (TRANS-IPIC)

University Transportation Center (UTC)

DEVELOPING A COST-EFFECTIVE, RELIABLE, AND SUSTAINABLE PRECAST SUPPLY SYSTEM UNDER PRICE VOLATILITY AND UNCERTAINTY OF MATERIAL SUPPLY
[LS-23-RP-04]
LSU Proposal ID: AWD-005947, GR-00014941/GR-00014942

Quarterly Progress Report-3
Performance period: *July 1- September 30, 2024*

Submitted by:

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Collaborators / Partners:

Dr. Tyson Rupnow, Associate Director
Louisiana Transportation Research Center (LTRC) [advising on project].
Team is in contact with Rinker*, Gainey's, Premier Concrete Products, and WASKEY* for collaboration and validation of research works.

Submitted to:

TRANS-IPIC UTC
University of Illinois Urbana-Champaign
Urbana, IL

TRANS-IPIC Quarterly Progress Report

A. PROJECT DESCRIPTION

1. Research Plan - Statement of Problem

The supply channel of the precast process begins with the procurement of raw materials that are processed through the PC (precast concrete) manufacturing operations and subsequently transporting the final products to the point of delivery for assembly or installation on site. This entire process involves different steps that may happen one after another or at the same time, and these processes affect the cost, time, and reliability of the final product or assignment.

Research Goal*:* Thus, this research aims at developing a cost-effective, sustainable, and reliable supply system considering the presence of price volatility and uncertainty of materials. By understanding these price changes, the study seeks to find the best way to plan the PC supply system to save money and still be reliable and sustainable to deliver the precast products to the transportation construction sites.

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

The costs, sustainability, and reliability of the PC systems and components related to the transportation are the three main ingredients that need to be addressed in this research. The one-year (2024) research undertaken includes:

A. **Task 1:** A *Structural Self-Interaction matrix* to be developed to extract different controlling variables and system parameters or factors that affect the stated performance outcome of the PC supply system, the reliability and manufacturing cost of precast concretes.

   - A *diagrammatic* representation with variables and corresponding factors will provide the precedence and parallel relationships of general understandings of the system.
   - The interrelationships and dependencies of variables, factors, and their related variants will be constructed for information of DOT and the construction community.

B. **Task 2:** *CRS Problem:* A cost-reliability-sustainability (CRS) model will be formulated to minimize the expected PC supply system's cost and simultaneously improve the system's reliability and sustainability of the system.

   - To accomplish this activity, dependent and independent jobs will be programmed in series and/or parallel configurations, respectively, such that various products can be completed in the shortest time and/or with maximum reliability.
   - The CRS problem will provide a cost-effective optimal process/activity sequence to enhance higher reliability and sustainability; it will provide multiple alternative solutions to the management to choose the most suitable one for implementation purposes.

C. **Task 3:** UPV (*Uncertainty and Price Volatility*): Process variability and expected cost with individual material's prices and supply uncertainty will be considered for refurbishing the warehouse in time.

- Supplying the PC components to the site(s) and sustaining the supply of the material ingredients are another part of the problem wherein repair/replacement is to be incorporated.
- The UPV problem will evaluate the cost, reliability, and sustainability when the prices are fluctuating, and uncertainty exists in the procurement of materials as they are directly dependent on the cost significantly.

B. PROJECT PROGRESS

3. Progress for each research task

3.1 Task 1 (QPR-1): Development of Interrelationships of hierarchical factors, (~ 90% completed)

A hierarchical framework has been developed to represent the interdependencies among the factors of production process and supply systems of Precast Concrete (PC), which have their significant impact on durability of Transportation Infrastructure. This graphical representation has also classified the factors based on their Interrelationships. In the following table, the factors are described that are related to these three main ingredients (cost, reliability, and sustainability) have been addressed in this research.

3.2 Task 2 (QPR-2): Minimizing Operational (curing) Cost of Precast Concrete production (~ 75% completed)

During this quarter, the team focused on addressing key challenges faced by precast concrete (PC) manufacturers in meeting tight deadlines, particularly in large-scale transportation infrastructure projects. The team's efforts were directed towards optimizing the curing process and improving pallet space utilization, both of which are critical for reducing production costs and avoiding delays.

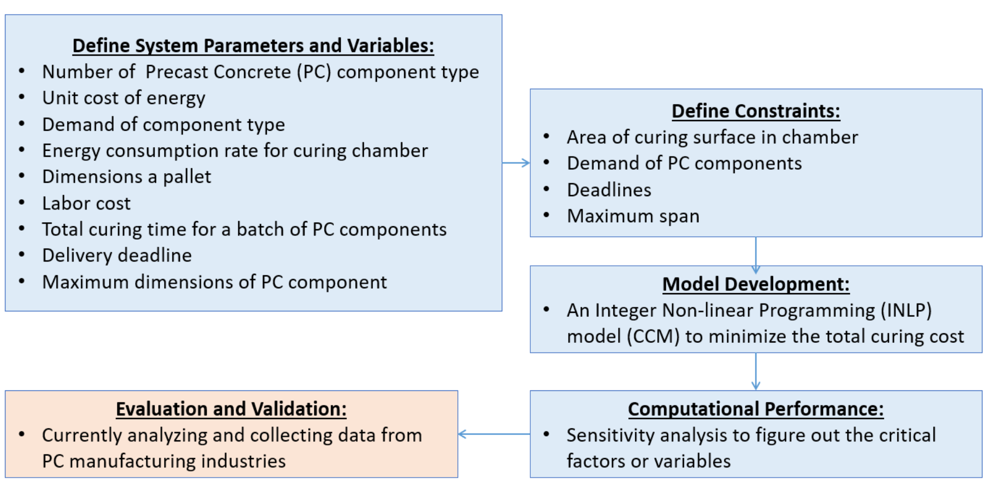

Figure 1. Development of Curing Cost Minimization Model

A Curing Cost Minimization (CCM) model was developed (Figure 1) to maximize pallet capacity while minimizing energy and labor expenses. This model incorporates various technical constraints, such as component dimensions and delivery deadlines, to determine the optimal number of pallets and configurations required for efficient and cost-effective operations. These findings suggest that the model not only enhances production efficiency but also promotes sustainability, ensuring that PC components meet the required quality standards while supporting the development of durable and economical transportation infrastructure projects. To evaluate the CCM model several random values were assigned to some variables such as dimensions of PC components, demand for those PC products and dimensions of the surface of curing chamber. From the research perspective, the computational performance results were analyzed and found out the following points:

- When the demand per PC component increases, the curing cost as well as the computational time also increases.
- When the length and width of PC component increases, the curing cost and CPU time also increase but at comparatively lower rate.
- If more components are assigned on a pallet of curing chamber, fewer pallets are needed and so are the batch sizes leading to lesser cost.

We are currently collaborating with WASKEY and Gainey's to gather data and critical information to adapt and refine our model for real-world applications.

3.3 Task 3 (QPR-3): Uncertain Demand and Price Volatility (~ 50% completed)

The primary objective of this quarter was to address demand uncertainty in the field of precast concrete for construction projects involving various transportation infrastructures. A mathematical model has been developed to find optimal order policy for raw materials and other resources for precast concrete industries. Since, there can be uncertainty of demands which can affect the amount of ordering quantity of raw materials for the PC industries. A key aspect of this model is the consideration of material ordering quantities as a function of demand for PC products and purchase costs, where demand itself can be influenced by the selling price. Therefore, the demand for PC components can be a function of time, price, and other transportation and environmental factors. For instance, the frequency of advertisements and the record of past construction projects completed by a precast concrete manufacturer can significantly influence the demand for specific precast concrete products or components.

For example, the cost of a particular material varies with time such that $c_i(t) = c_i \pm \lambda t$ where $c_i(t)$ is the cost of product i at time t, and λ is the rate of change of cost. It may be further noted that the rate λ may also be a function of time. However, the cost of materials may not always change linearly over the time. For example, the cost equation can be like, $c_i(t) = c_i e^{\pm\lambda t}$. In this equation, the cost increases/decreases exponentially over time, meaning that as time passes, the cost of the raw material grows at an increasing/decreasing rate, representing a more drastic increase/decrease than a linear or quadratic change. This type of price volatility can affect situations where prices increase rapidly due to sudden demand changes in the product or raw material market—resource shortages and/or inflationary pressures as experienced during Covid-19 are other living examples. Similar issues can be considered for demand such as $D_i(t) = D_i \pm \mu t$ or $D_i(t) = D_i e^{\pm\mu t}$ (μ = change rate of cost).

To effectively account for uncertainties in demand and material price, the team is working actively collaborating with PC with industry leaders such as Gainey's Concrete Products, Waskey, and Premier Concrete Products (PCP) to gather detailed supply and operational data from industry partners. This data will help capture trends in raw material prices and the demand for precast concrete components, enabling the development of an uncertainty budget. This framework (Figure 2) will help mitigate the risks associated with market volatility, ensuring that the supply chain remains efficient and responsive to changes in demand. The team is currently working with several PC manufacturing companies to collect sufficient information about historical price and demand to figure out the trend of fluctuations. The phases of work in progress are highlighted in orange in Figure 2.

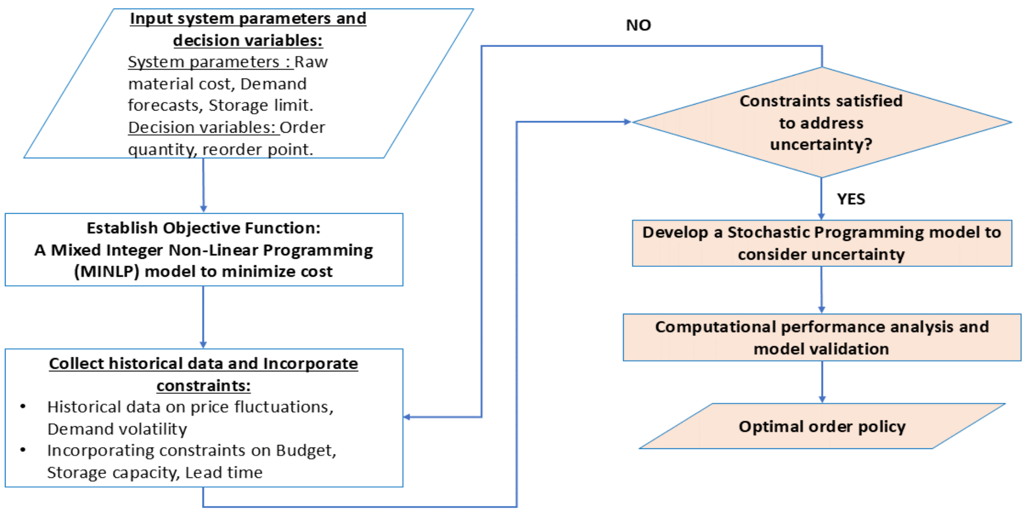

Figure 2. Model development process considering uncertainties.

The team has already visited the plants of Gainey's to study the factors that must be considered for the dynamic and often unpredictable conditions that can significantly affect both pricing and the timely delivery of precast concrete products (Figure 3). For instance, the research team will focus on products like arch bridge structures manufactured by Gainey's. We are exploring optimization techniques to develop flexible supply chain strategies that can adapt to uncertainty. Additionally, the team is investigating the potential for long-term contracts, buffer stock management, and cost escalation mechanisms in Gainey's projects, aiming to create solutions that stabilize operations in volatile market conditions.

Figure 3. Arch bridges precast products at Gainey's, LA

Visits at Premier Concrete Products (Figure 4) also provided insights into how fluctuating market demand can impact production timelines and lead to delays for which it is crucial for the company to optimize its yard layout and logistics (as experienced by *Premier Concrete Products*). An optimal ordering policy that accounts for price and demand uncertainty is crucial in this scenario because it directly impacts the efficiency of the yard layout, traffic flow, and material stockpiling. By aligning the ordering process with fluctuating prices and demand, the model can ensure that materials are available when needed without overstocking, which could lead to inefficient use of space and increased handling costs.

Figure 4. Casting product storages at Premier Concrete Products, LA

By observing plant operations firsthand during a plant tour at Rinker Materials (Figure 5), several factors were identified that can contribute to address variability in production schedules, such as equipment downtime, or supply chain disruptions in the model. For example, Rinker produces box products based on specific market demand, while pipes are manufactured for stockpiling. As a result, Rinker may encounter challenges if there are any fluctuations in demand for either of these products. Additionally, Waskey, known for their expertise in precast bridge construction, will contribute with their operational data that would help us to optimize material flow and minimize inefficiencies.

Figure 5. Precast highway box culvert at Rinker Materials, LA

The expected outcomes for this quarter aim to deliver an optimal ordering policy tailored to precast concrete manufacturing companies, enabling them to navigate challenging market conditions. By using this policy,

- the companies will be helped make informed decisions about which products should be manufactured based on demand and which should be stockpiled in advance.
- the companies can better respond to demand fluctuations, reduce costs, and improve operational efficiency, by optimizing their production and inventory strategies, which will ensure that they are well-prepared for any market volatility.

4. Percent of research project completed.

As the research project for this year has been divided into three parts, so, percentage of the research project completed is approximately (90%×33.33%) + (75%×33.33%) + (60%×33.33%) ~ 75%.

5. Expected progress for next quarter.

Several private companies are associated with production of PC components related to transportation infrastructure, are contributing with the research team for data collection and model validation. Within next quarter, the formulated model will determine the optimal process path that will minimize the expected precast concrete supply system's cost and simultaneously improve the system reliability and sustainability of the system under consideration of Price volatility and material uncertainty. Also, the two working papers under preparation currently will be modified and updated to complete the proposed research.

6. Educational outreach and workforce development

(a) A paper entitled "Exploring Interdependencies of Factors in Precast Concrete Supply System: An Interpretive Structural Modeling Approach," (Grant #LS-23-RP-04) was presented at the poster session at the DOT TRANS-IPIC Workshop, Big Ten Conference Center, 5440 Park Place, Rosemont, IL, April 22, 2024. This was the outcome of the first quarterly report QPR-1 and the audience/attendees comprised of Trans-IPIC researchers and collaborators.

(b) A paper entitled "Factors of the Precast Concrete Supply Chain: An Interpretive Structural Modeling Approach," was presented at the Graduate Research Conference (GRC), at the Students' Union, Louisiana State University, Baton Rouge, LA on April 30, 2024. The LSU Graduate Council for all LSU faculty and graduate students arranged the conference.

(c) The team is in contact with LTRC (Louisiana Transportation Research Center) representative (Dr. Tyson Rupnow, Director) to assist and advise in the project.

(d) A 13-member meeting of 4 companies and LTRC was held at Louisiana Concrete Association (LCA) on August 14, 2024, to discuss the possible collaboration with Trans-IPIC and the PI has already interacted with WASKEY, Premier Concrete Products (PPP), Gainey's Concrete Products (GCP), and Rinker Materials for corrective feedback on the project.

(e) Precast concrete plants visited/meeting (Summary):

- Louisiana Transportation Research Center Meeting (June 11, 2024)
- Louisiana Concrete Assoc. Tech. Committee Meeting (August 14, 2024)
- WASKEY, Baton Rouge, LA (August 14, 2024)
- Premier Concrete Products, Denham Spring, LA (August 12 & 14, 2024)
- Gainey's Concrete Products, Holden, LA (August 26, 2024)
- Rinker Materials Workshop, Alexandria, LA (September 23, 2024)

7. Technology Transfer

The research team is in contact with several companies through LTRC. Efforts have been given to collaborate and collect some real-life data for testing purposes and feedback on the project. The outcome is yet to achieved for technology transfer.

C. RESEARCH CONTRIBUTION

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

1. Mazumder, A. and Sarker, B. R. (2024a), "Developing an interpretive structural model for factors affecting cost effectiveness, reliability and sustainability of precast concrete," *Working Paper* #1 (outcome of QPR-1, January 1 - March 31, 2024).

2. Mazumder, A. and Sarker, B. R. (2024b), "Optimizing Pallet Capacity Utilization to Minimize Curing Cost in Precast Concrete Manufacturing," *Working Pape*r #2 (Outcome of QPR-2, April 1 - June 30, 2024).

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

1. Mazumder, A. and Sarker, B. R., "Factors of the Precast Concrete Supply Chain: An Interpretive Structural Modeling Approach," *Graduate Research Conference (GRC)*, presented at the Students' Union, Louisiana State University, Baton Rouge, LA on April 30, 2024.

2. Mazumder, A., and Sarker, B.R., "Exploring Interdependencies of Factors in Precast Concrete Supply System: An Interpretive Structural Modeling Approach," presented at the *DOT TRANS-IPIC Workshop* (Grant #LS-23-RP-04), Big Ten Conference Center, 5440 Park Place, Rosemont, IL, April 22, 2024.

10. 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.

1. Mazumder, A. and Sarker, B. R., “Factors of the Precast Concrete Supply Chain: An Interpretive Structural Modeling Approach,” Graduate Research Conference (GRC), presented at the Students’ Union, Louisiana State University, Baton Rouge, LA on April 30, 2024.

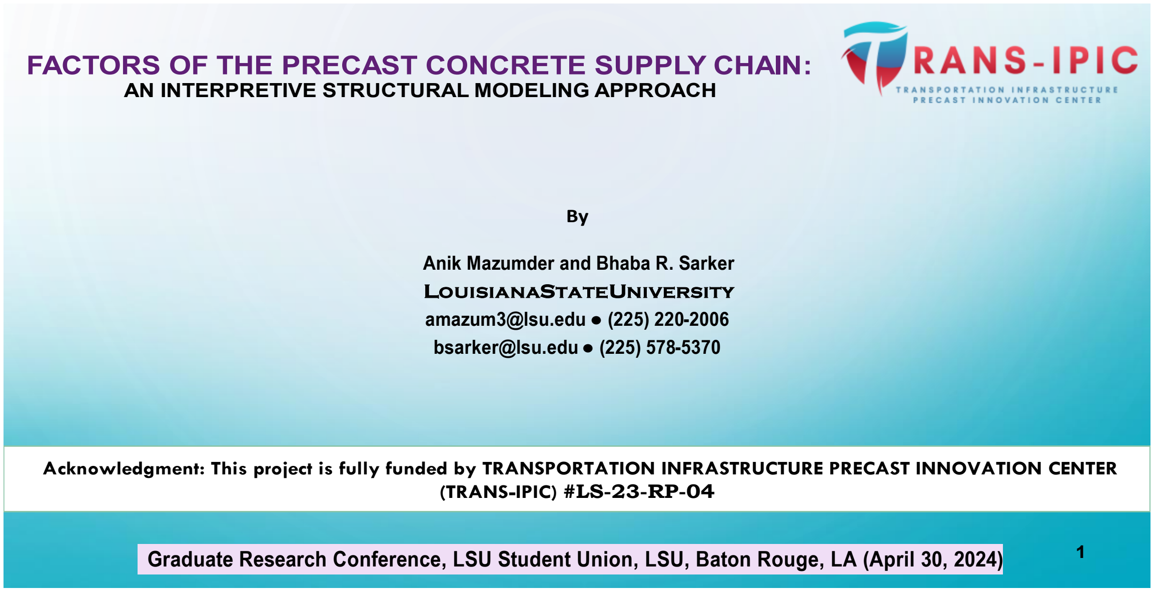

Figure 6. Cover Slide of the presentation file that was presented at GRC, LSU.

2. Mazumder, A. and Sarker, B. R., “Optimizing Pallet Capacity Utilization to Minimize Curing Cost in Precast Concrete Manufacturing,” presented at the *DOT TRANS-IPIC* online research online seminar on July 22, 2024.

Figure 7. Research online seminar presentation on July 22, 2024

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