

**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]*

Quarterly Progress Report

**Performance period:** *January 1- March 31, 2024*

**Submitted by:**

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 Dr. Tyson Rupnow, Associate Director (Research), Louisiana Transportation Research Center [advising on the project]. A private company will be contracted soon for data collection.

**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 supply channel of the precast process begins with the procurement of the 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 whole process involves different steps that can happen one after the other or at the same time, and they affect the cost, time, and reliability of the final product.

**Research Goal:** This research aims to develop 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 supply system to save money and still be reliable and sustainable.

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

The costs, sustainability, reliability of the systems and components related to the transportation- are the three main ingredients that need to be addressed in this research. This one-year research output will include:

1. **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, and the reliability and manufacturing cost of precast concretes.
* A *diagraph* representation with variables and corresponding factors will provide the precedence and parallel relationships of general understandings of the system.
* Interrelationships and dependencies of variables, factors, and their related variants will be constructed for information of DOT and the construction community.
1. **Task 2:** *CRS Problem:* A cost-reliability-sustainability (CRS) modelwill be formulated to determine the optimal process path that will 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 different 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.
1. **Task 3:** UPV (*Uncertainty & 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.

**Project Progress:**

1. Progress for each research task

**Task 1 Progress (95% Completed):**

The network of organizations and infrastructure linked together to meet customer demand through the movement of goods, information, and finances is known as a supply chain (Papapostolou *et al.*, 2011). Supply chain systems drop their sustainability objectives while coping with these unexpected disruptions (Mari *et al*., 2014). From manufacturing of a product to the delivery, there are some significant factors which have vital impacts on the whole supply chain system efficiency and the quality of the products or services which have been delivered through this supply system. Thus, there are several factors which have a great impact on cost-effectiveness, reliability, and sustainability of a precast concrete supply system which consists of all the process including manufacturing of these prefabricated concrete to the delivery of those concrete to the construction sites. The main purpose of Task 1 was to develop a hierarchical framework and classify the factors based on their Interrelationships. We followed some steps to build the diagraph:

**Step 1**: To identify and define factors to represent the contextual relationships among them.

**Step 2**: To Interpret the relationships and developing the Structural Self-Interaction Matrix (SSIM).

**Step 3**: To develop Reachability matrix and check all transitivity.

**Step 4**: Level partitions on reachability matrix.

**Step 5**: To develop the hierarchical framework or diagraph representing the significant factors of precast concrete (PC) supply system.



Figure 1. Methodology

1. Identifying Factors:

Some factors related to these three main ingredients (cost, reliability, and sustainability) have been addressed in this research. Several factors existed in some previous research works and the other factors have been identified through further research. These factors are presented below in Table 1:

Table 1. Factors affecting the cost-effectivity, reliability, and sustainability of PC

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Factors** | **Cost** | **Reliability** | **Sustainability** | **Description** |
| Quality Control **(QC)** | √  | √ | √ | High-quality standards ensure product reliability and contribute to overall system sustainability. |
| Price Volatility **(PV)** | √ |  |  | Price fluctuations or other unexpected incidents can include some additional costs. |
| Transportation Infrastructure Quality **(TIQ)** | √ | √ |  | High quality infrastructure reduces transit time which affects reliability and cost.  |
| Rate of RM Usage and Replenishment **(RMRUR)** | √ | √ |  | Efficient management reduces stockouts optimizing cost affecting reliability. |
| Mean Time Between Failures **(MTBF)** |  | √ | √ | Regular maintenance ensures operational reliability and sustainability. |
| Frequency and Duration of Delays **(FDD)** | √ | √ |  | Proactive management minimizes impact, maintaining schedule adherence and cost control. |
| Accuracy of Real-Time Tracking System **(ARTTS)** |  | √ | √ | Enhances the ability to make informed decisions, improving operational reliability and sustainability.  |
| Cement content **(CC),** Amount of Steel **(AS),** Water-cement ratio **(W/C),** Cover on reinforcement **(COR).**  | √ |  | √ | (Koskisto and Ellingwood, 2006) |
| Transporting the precast component **(TPC),** Shipping the precast component **(SPC),** Price difference for externally purchased concrete **(PDEPC)** | √ | √ |  | (Chen *et al*., 2018) |
| Hardness of Cement Paste **(HCP),** Structural Porosity **(SCP),** Aggregates and Reinforcements **(A&R),** Chloride and Carbonation Resistance **(CCR)**  |  | √ | √ | (Mackechnie and Alexander, 2009) |

2. Developing Structural Self-Interaction Matrix:

After identifying these 18 factors, a *structural self-interaction matrix,* which an interactive learning process where a set of elements are structured into a comprehensive system model, was developed to present the interrelationships among all these factors. The existence of a relation R between two elements or factors was identified. Four symbols were used to represent the type of relation that exists between two factors under consideration:

1. *F* means that element i depends on element j (only Forward).
2. *R* means that element j depends on element i (only Reverse).
3. *B* for both the direction relations from element i to j and j to I (Both ways).
4. *0* if the relation between the elements does not appear valid (Sushil, 2012).

After performing these operations, we have developed our matrix in Table 2.

Table 2. Structural Self-Interaction Matrix (SSIM)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Factors** | **QC** | **PV** | **TIQ** | **RMRUR** | **MTBF** | **FDD** | **ARTTS** | **CC** | **AS** | **W/C** | **COR** | **TPC** | **SPC** | **PDEPC** | **HCP** | **SCP** | **A&R** | **CCR** |
| **QC** | 1 | 0 | 0 | 0 | 0 | 0 | 0 | F | F | F | F | 0 | 0 | 0 | 0 | F | F | F |
| **PV** | 0 | 1 | 0 | F | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | B | 0 | 0 | 0 | 0 |
| **TIQ** | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | F | F | 0 | 0 | 0 | 0 | 0 |
| **RMRUR** | 0 | R | 0 | 1 | F | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **MTBF** | 0 | 0 | 0 | 0 | 1 | F | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **FDD** | 0 | 0 | 0 | 0 | 0 | 1 | F | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **ARTTS** | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **CC** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | B | 0 | 0 | 0 | 0 | F | 0 | 0 | 0 |
| **AS** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | F | 0 |
| **W/C** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | B | 0 | 1 | 0 | 0 | 0 | 0 | F | F | 0 | 0 |
| **COR** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | F |
| **TPC** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | B | 0 | 0 | 0 | 0 | 0 |
| **SPC** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | B | 1 | 0 | 0 | 0 | 0 | 0 |
| **PDEPC** | 0 | R | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| **HCP** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | F | 0 | 0 |
| **SCP** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | F |
| **A&R** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | F | 1 | 0 |
| **CCR** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | R | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

In this case, the relationships were defined based on consensus that emerged from expert opinions and interviews, and literature reviews (Chandramowli *et al*., 2011). Here, for example, if we take an entry (SCP, CCR) from this matrix we get *F* i.e., Structural Porosity (SCP) depends on Chloride and Carbonation Resistance (CCR), but CCR does not depend on SCP. High chloride permeability can make the concrete less dense and leaves air voids. This can also lead to a high corrosion rate. Also, if we take another entry (TPC, SPC) we get a *B i*.e., Transportation of the PC (TPC) and Shipping the PC (SPC) both factors depend on one another. Similarly, from the table, Water-Cement-Ratio (W/C) and Cement Content (CC) both depend on each other as if water cement ration gets higher cement content gets lower.

After developing this structural self-interaction matrix (SSIM), we were able to detect any kind of interdependency with any two factors or variables. But to approach our further research, we developed a *Reachability Matrix* from this SSIM.

3. Developing Reachability Matrix and checking all transitivity relations

The main purpose of generating this reachability matrix is to cluster these factors in different groups according to their precedence and parallel relationships. By converting the data in each SSIM entry into 1s and 0s, the SSIM format is converted into the reachability matrix format (Sushil, 2012).

Let, $S$ = Structural Self-Interaction Matrix (SSIM) and $R$ = Reachability Matrix. Both matrices have $i$ rows and $j$ columns. Therefore, $S$ = [$s\_{ij}$] and $R$ = [$r\_{ij}$]. The SSIM format then was converted to reachability matrix by using following rules:

1. If $s\_{ij} $= F, then $r\_{ij}$= 1 and $r\_{ji} $= 0
2. If $s\_{ij} $= R, then $r\_{ij} $= 0 and $r\_{ji} $= 1
3. If $s\_{ij} $= B, then $r\_{ij} $= $r\_{ji} $= 1
4. If $s\_{ij} $= 0, then $r\_{ij} $= $r\_{ji}$= 0

Thus, SSIM was transformed into an initial reachability matrix (IRM) by replacing the variables with 0 and 1 (Chandra and Kumar, 2018). After that, by going through some continuous revisions, we got our final reachability matrix in Table 3.

Table 3. Revised Reachability Matrix

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Factors** | **QC** | **PV** | **TIQ** | **RMRUR** | **MTBF** | **FDD** | **ARTTS** | **CC** | **AS** | **W/C** | **COR** | **TPC** | **SPC** | **PDEPC** | **HCP** | **SCP** | **A&R** | **CCR** | **Driving Power** |
| **QC** | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | **1** | 1 | 1 | 1 | **9** |
| **PV** | 0 | 1 | 0 | 1 | **1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | **4** |
| **TIQ** | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | **3** |
| **RMRUR** | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **1** | 0 | 0 | 0 | **3** |
| **MTBF** | 0 | 0 | 0 | 0 | 1 | 1 | **1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **3** |
| **FDD** | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **2** |
| **ARTTS** | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **1** |
| **CC** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | **1** | 0 | 0 | **4** |
| **AS** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | **1** | 1 | 0 | **3** |
| **W/C** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | **1** | **5** |
| **COR** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | **2** |
| **TPC** | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | **3** |
| **SPC** | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | **3** |
| **PDEPC** | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | **2** |
| **HCP** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **1** | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | **1** | **5** |
| **SCP** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **1** | 0 | 1 | 0 | 0 | 0 | 0 | **1** | 1 | 0 | 1 | **5** |
| **A&R** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **1** | 0 | 0 | 0 | 0 | 0 | 1 | 1 | **1** | **4** |
| **CCR** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | **1** |
| **Dependence Power** | **1** | **2** | **3** | **2** | **3** | **2** | **3** | **5** | **2** | **6** | **2** | **3** | **3** | **2** | **6** | **7** | **3** | **7** | **62** |

In this reachability matrix, all transitivity relationships have been revised. i.e. for any elements A, B, and C in set S, given that A is related to B and B is related to C, it necessarily follows that A is also related to C. Here, Dependence Power is the sum of all column values and Driving Power is the sum of row values. Both values of dependence power (column-sum) and driving power (row-sum) should be the same, and in our case, it is 62. After incorporating all the transitivity relationships, the final reachability matrix is obtained on which we had performed the level partitions of these 18 factors.

4. Level Partitions:

After developing the final reachability matrix, we carried out the level partition process to know the placement of elements of factors level wise. This process of level partitioning is an iterative and requires the comparison between the reachability set and the antecedents set.
The reachability set includes the factor in question along with all factors affected by it, while the antecedent set comprises the factor and all factors influencing it. Thereafter, the intersection of these sets is derived for all the factors and levels of different factors are determined. The factors for which the reachability and the intersection sets are the same occupy the top level in the hierarchy. The top-level factors are those factors that will not lead the other factors above their own level in the hierarchy. Once the top-level factor is identified, it is removed from consideration. Then, the same process is repeated to find out the factors in the next level. These levels help in building the diagraph (Attri *et. al.,* 2013). This process continues until each factor is assigned a level. Table 4 illustrates the partitioning process for level 1 specifically, just as the methodology for determining subsequent levels is similarly applied and detailed in Table 5. Thus the reachability and antecedent sets for all factors were determined (Warfield, 1974).

Table 4. Partitioning of Level 1

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Serial | Factors | Antecedent Sets | Reachability Sets | Intersection Sets | Level |
| 1 | QC | 1,8-11,15-18 | 1 | 1 |  |
| 2 | PV | 2,4-5,14 | 2,14 | 2,14 | 1 |
| 3 | TIQ | 3,12,13 | 3,12,13 | 3,12,13 |  |
| 4 | RMRUR | 4,5,15 | 2,4 | 4 |  |
| 5 | MTBF | 5-7 | 2,4,5 | 5 |  |
| 6 | FDD | 6,7 | 5,6 | 6 |  |
| 7 | ARTTS | 7 | 5-7 | 7 | 1 |
| 8 | CC | 8,10,15,16 | 1,8,10,15,16 | 8,10,15,16 | 1 |
| 9 | AS | 9,16,17 | 1,9 | 9 |  |
| 10 | W/C | 8,10,15,16,18 | 1,8,10,15,16,17 | 8,10,15,16 |  |
| 11 | COR | 11,18 | 1,11 | 11 |  |
| 12 | TPC | 3,12,13 | 3,12,13 | 3,12,13 | 1 |
| 13 | SPC | 3,12,13 | 3,12,13 | 3,12,13 | 1 |
| 14 | PDEPC | 2,14 | 2,14 | 2,14 | 1 |
| 15 | HCP | 8,10,15,16,18 | 1,4,8,10,15,16 | 10,15,16 |  |
| 16 | SCP | 8,10,15,16,18 | 1,8-10,15-17 | 8,10,15,16 |  |
| 17 | A&R | 10,16-18 | 1,9,17 | 17 |  |
| 18 | CCR | 18 | 1,10,11,15-18 | 18 | 1 |

Table 5. Level Partitioning of Factors

|  |  |
| --- | --- |
| **Factors** | **Levels** |
| TIQ, ARTTS, CC, TPC, SPC, PDEPC, CCR | 1 |
| FDD, W/C, COR, HCP, SCP | 2 |
| MTBF, A&R | 3 |
| RMRUR, AS | 4 |
| QC, PV | 5 |

After leveling all our factors, we could develop the diagraph which would provide representation of all the factors and their hierarchical relationships with the other factors.

5. Developing a Hierarchical Framework:

The diagraph (*figure 2*) is constructed by graphically organizing the factors according to their levels and illustrating their interactions as indicated by the final reachability matrix, using directed arrows. Dashed lines denote transitive relationships among the factors, while solid arrows indicate direct links. A factor positioned at an elevated level signifies its capacity to impact a greater number of other factors (Yadav and Samuel, 2022). This visual representation serves as a map, outlining the hierarchical organization and the intricate web of interconnections between various elements within the system. By clearly illustrating how different factors relate and interact with

one another, the diagraph becomes an invaluable tool in the system's analysis phase. The factors which are situated in level 5 are highly dependent on the other factors which can affect the cost-effectiveness, reliability, and sustainability of precast concrete production and supply chain. As per figure 2, there are two factors in Level 5, they are: Quality Control (QC) and Price Volatility (PV). If we take QC, we can identify the factors on which QC is highly dependent. For example, there are some solid arrows which go out from QC and enter several rectangular boxes like; CC (Cement Content), W/C (Water-cement ratio), CCR (Chloride and Carbonation Resistance) etc. Because quality of precast concrete is highly related to the cement content, water-cement ratio, and the resistance properties against chlorides and carbonates, such as:

1. Cement content (CC) is a crucial component in a concrete mix, influencing key characteristics such as workability, compressive strength, drying shrinkage, and durability. As cement undergoes hydration, its particles interact with water, leading to the bonding of the aggregate and the formation of the strength matrix. Therefore, cement content can have a high impact on the concrete quality.
2. The formula for the water-to-cement ratio significantly impacts the concrete's strength and durability. This ratio usually ranges from 0.40 to 0.60 across various concrete mix grades. Selecting the appropriate proportions for concrete mixing is essential for the longevity and resilience of any given structure.
3. Carbonation destroys the passive film of steel bars and chloride ions are a major contributor to localized corrosion and damage to the passive layer. Moreover, there is a dashed line according to figure 2 which comes out of the box of QC (Quality) and goes in HCP (Hardness of Cement Paste). This relation here is a transitive relationship. As Quality of precast concrete depends on Cement content (CC) and according to the figure this cement content depends on the hardness of the cement paste or mixture (HCP), so indirectly quality of the precast depends on the hardness of cement mix.

Through this graphical depiction, critical elements emerge as focal points due to their significant influences and roles within the hierarchy. These key components are identified not just by their position but also by the number and nature of their connections to other elements. This enables a deep dive into the dynamics at play, revealing which elements are drivers of change and which are outcomes of complex interactions. Moreover, the diagraph exposes the underlying structure of the problem or system being examined. It highlights direct and indirect relationships that might not be apparent without this structured representation. This transparency allows for a more nuanced understanding of the precast concrete, and its supply chain.



Figure 2. Digraph representing the Dependence Relationships of the Factors

However, the development of the diagraph is not a one-time task but rather a cyclic process. It is inherently iterative, demanding continuous refinement and validation. This iterative process requires soliciting and incorporating feedback from experts or stakeholders who are familiar with the nuances of the system. Their insights can lead to adjustments in the diagraph, such as reevaluating relationships or reassessing the placement of elements within the hierarchy. As the model evolves, it provides a more accurate and structured interpretation of complex issues. This, in turn, facilitates more informed decision-making and effective problem-solving.

**Task 2 Progress (5% Completed)**

All the factors which affect our three main enablers: cost, reliability, and sustainability; have been identified and clustered according to their influence in overall efficiency of precast concrete manufacturing and supply system. It will further help to build up the optimal supply system with the minimization of precast concrete supply system’s cost and improvement of reliability and sustainability of precast concrete.

**Task 3 Progress (0% Completed)**

As the individual material’s price volatility and supply uncertainty play a vital role, total process variability and expected cost should be considered as well. We will need some expert’s opinions to figure out some variables related to this total process to consider the price volatility and uncertainty in our optimization problem.

1. Percent of research project completed:

As out research project for this year has been divided into three parts, so, percentage of the research project completed,

= (95%×33.33%) + (5%×33.33%) + (0%×33.33%) = 33.33%.

1. Expected progress for next quarter:

For next quarter, we will use these factors to formulate our CRS (Cost-Reliability-Sustainability) model to 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.

1. Educational outreach and workforce development

*None (As yet).*

1. Technology Transfer

*None (As yet).*

**Research Contribution:**

1. Number of papers

Mazumder, A. and Sarker, B. R. (2024), “Developing an interpretive structural model for factors affecting cost effectiveness, reliability and sustainability of precast concrete,’ working paper (for first quarter, January 1-March 31, 2024).

1. Number presentations (when, where)

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

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