# Transportation Infrastructure Precast Innovation Center (TRANS-IPIC)

## University Transportation Center (UTC)

Condition Assessment of Transportation Infrastructure
using Space-Borne Sensors and AI

Project Number UI-25-RP-02

Quarterly Progress Report
For the performance period ending September 30th, 2026

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**Collaborators / Partners:**
- None

**Submitted to:**
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## TRANS-IPIC Quarterly Progress Report:

## Project Description:

### 1. Research Plan - Statement of Problem

The project addresses the need for more effective and continuous bridge condition assessment as transportation infrastructure continues to age under traffic loading, environmental exposure, and material deterioration. It proposes using space-borne sensing data to monitor bridge movements over large geographic regions in a scalable and cost-effective manner. The framework integrates MT-InSAR, environmental data, and structural interpretation to extract millimeter-scale displacement behavior from freely available satellite observations. The overall goal is to support bridge condition assessment at both the individual bridge and network levels.

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

The research plan for this project includes three primary tasks:

Task 1: Satellite Data Collection and Analysis:
Task 1 is devoted to acquiring and analyzing multitemporal InSAR data to evaluate the feasibility of satellite-based bridge monitoring across different geographic and climatic regions of the United States. The study considers medium- to long-span steel and precast concrete bridges and combines meteorological information with long-term satellite observations of surface displacement. MT-InSAR analysis is performed using C-band satellite data, while persistent scatterer points are identified and filtered in SARPROZ to ensure reliable deformation measurements. This task establishes the satellite-data and deformation-analysis foundation for detecting both damage-related deformation and routine thermal bridge response.

Task 2: Bridge Structural Assessment using MT-InSAR and Climate Data:
Task 2 seeks to interpret the MT-InSAR displacement time histories in terms of bridge behavior and structural condition. The observed movements will be related to thermal effects, traffic loads, and possible deterioration. Representative three-dimensional finite element models will be developed and compared with the satellite-based displacement results to identify abnormal response patterns and potential structural weaknesses.

Task 3: Automation of Bridge Analysis using Machine Learning:
Task 3 extends the framework by automating the interpretation of bridge displacement behavior using machine learning. The MT-InSAR time-series data will be organized into a structured dataset for unsupervised analysis, and methods such as K-means clustering and Isolation Forest will be used to group similar bridge responses and detect anomalous displacement patterns.

## Project Progress:

### 3. Progress for each research task

**Task 1: Satellite Data Collection and Analysis [100 % completed to date]**

Task 1 remained complete during this quarter.

**Task 2: Bridge Structural Assessment using MT-InSAR and Climate Data [100% completed to date]**

Task 2 was completed during this quarter by finalizing the interpretation of MT-InSAR measurements in relation to thermal response, traffic loading, and structural condition. The finite-element assessment of the IL-251 Bridge established a reference response for a structurally stable bridge. The analysis was based on 223 Sentinel-1A acquisitions collected over three monitoring intervals between 2015 and 2024.

The MT-InSAR measurements and finite-element simulations captured consistent seasonal deformation patterns. Line-of-sight displacements generally ranged from approximately −6 mm during warmer periods to +4 mm during colder periods. The magnitude and direction of the response remained consistent

throughout the monitoring period, with no evident long-term drift or accumulation of residual displacement. This repeatable response indicated that the observed movement was primarily associated with reversible thermal expansion and contraction.

To improve the interpretation of the satellite measurements, the acquisition dates were classified according to normal and peak traffic conditions. The displacement-temperature relationships for the three monitoring intervals are presented in **Figure 1**. Separating the observations by traffic condition reduced part of the scatter in the displacement-temperature relationship. The resulting correlation coefficients reached approximately 0.89 for the best-performing subset, confirming that traffic conditions contributed to individual deviations from the dominant thermal trend.

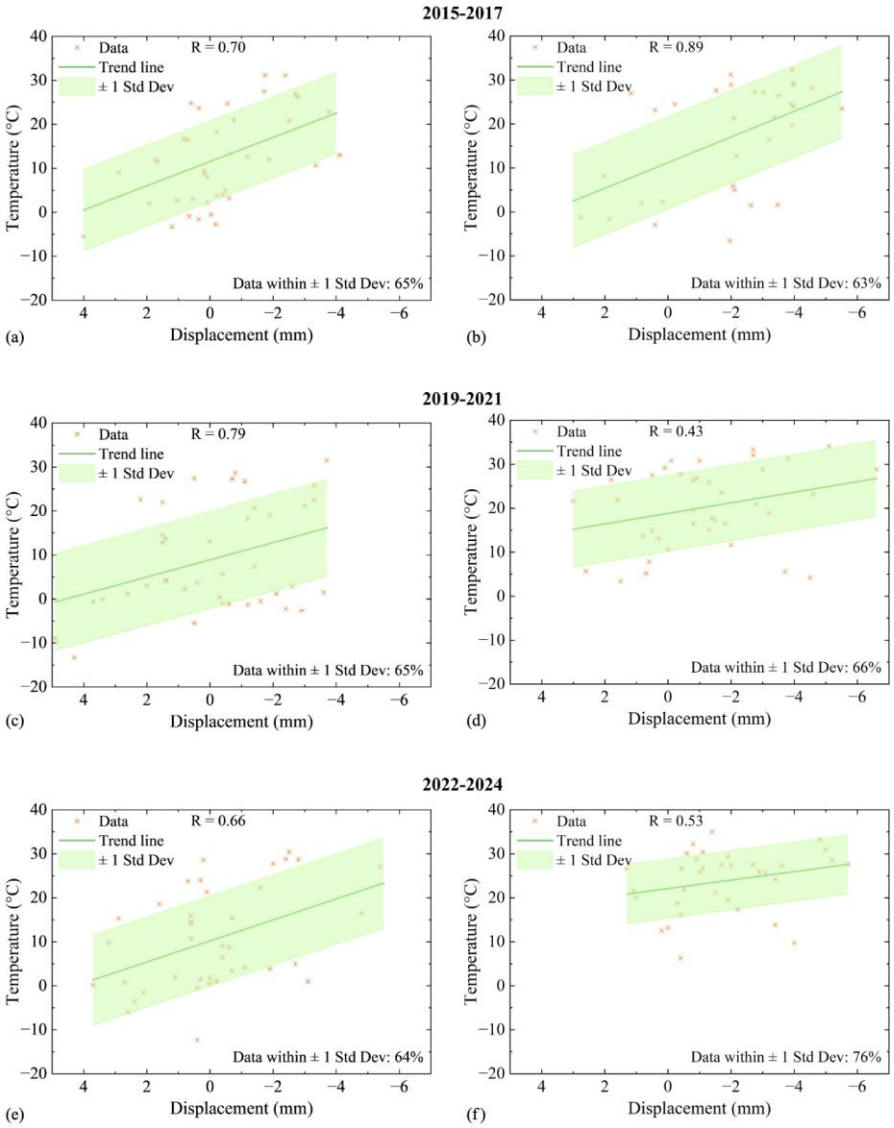



**Figure 1. MT-InSAR line-of-sight displacement versus temperature during normal and peak traffic conditions for the three monitoring intervals.**

Thermal-only finite-element simulations did not explain all differences between the predicted and satellite-derived displacements. Therefore, estimated live loads were added to selected finite-element load cases. As shown in **Figure 2**, the combined thermal and traffic-load simulations produced line-of-sight displacements that more closely matched the MT-InSAR measurements for cases with relatively large thermal-only discrepancies.

For example, for the October 8, 2019 acquisition, the measured MT-InSAR displacement was approximately +3.00 mm, while the thermal-only finite-element prediction was approximately −3.73 mm. After applying the estimated live load to the model, the predicted displacement increased to approximately +2.74 mm. Similarly, for the February 6, 2022 acquisition, the measured displacement was approximately −3.10 mm, while the thermal-only prediction was approximately −0.17 mm. Incorporating the estimated traffic load resulted in a predicted displacement of approximately −2.81 mm.

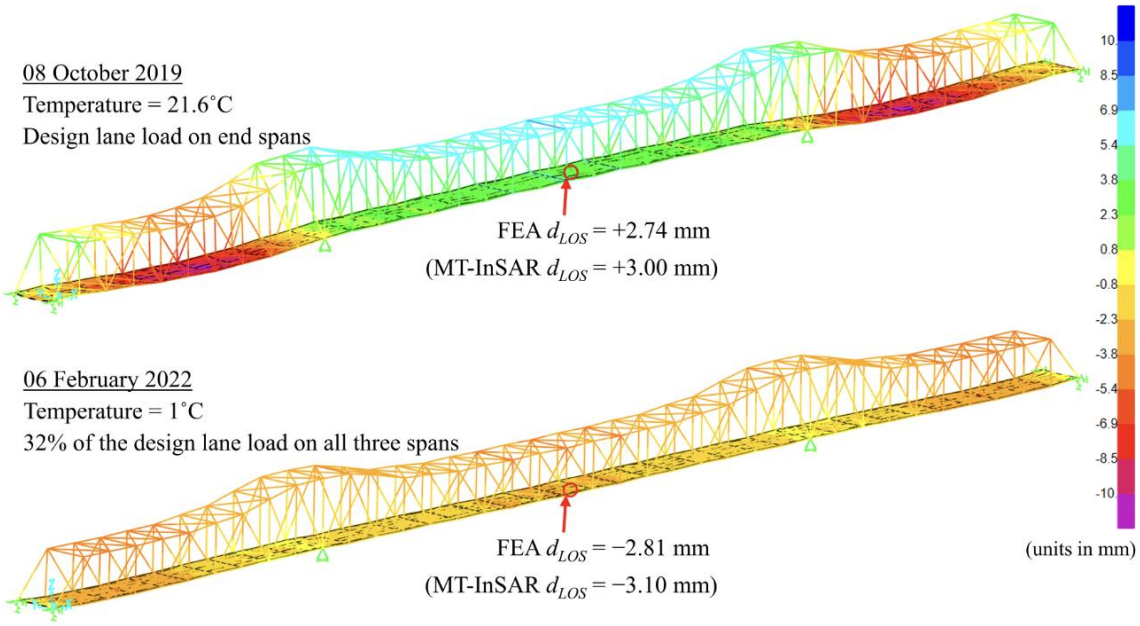



**Figure 2. Finite-element line-of-sight displacements at the bridge midspan under combined thermal and estimated live loads.**

The completed analysis confirmed that temperature was the dominant driver of the long-term bridge response, while traffic loading contributed to shorter-term variations in the satellite measurements. Based on these results, expected bridge behavior was characterized by repeatable seasonal displacement, a consistent relationship with temperature, limited residual movement, and improved agreement after accounting for traffic conditions. In contrast, progressive displacement, incomplete seasonal recovery, weak temperature correlation, or residual movement that could not be explained by traffic variation were identified as potential indicators of abnormal behavior.

These criteria completed the structural interpretation framework under Task 2 and provided the engineering basis for the automated behavioral grouping initiated under Task 3.

**Task 3: Automation of Bridge Analysis using Machine Learning [50% completed to date]**

Task 3 began during this quarter with the preparation of a structured multi-bridge displacement dataset and the initial application of unsupervised machine learning. The dataset was developed from 48 Sentinel-1A satellite acquisitions collected between January 2020 and December 2023. It included MT-InSAR displacement histories extracted at the midspan of 14 bridges along the Illinois River corridor.

The selected bridges represented multiple structural configurations, including steel truss, steel arch, composite girder, and prestressed-concrete girder bridges. Each bridge was represented by a 48-dimensional displacement vector corresponding to the satellite observations. The resulting dataset consisted of 14 bridge records and 48 temporal displacement features.

The displacement histories presented in **Figure 3** show that most bridges exhibited repeatable seasonal oscillations associated with thermal expansion and contraction. Differences in displacement magnitude were also observed among bridge types and span lengths. Steel and longer-span bridges generally exhibited larger seasonal movement than shorter concrete or composite girder bridges.

Bridge B8, identified as the Smith Bridge, displayed a displacement pattern that differed from the primarily seasonal and reversible responses observed for most of the other bridges. Its time series included sharper transitions, incomplete recovery during seasonal reversals, and a progressive displacement trend. At this stage, this behavior was treated as a preliminary indication requiring additional statistical and engineering evaluation rather than as a confirmed structural anomaly.

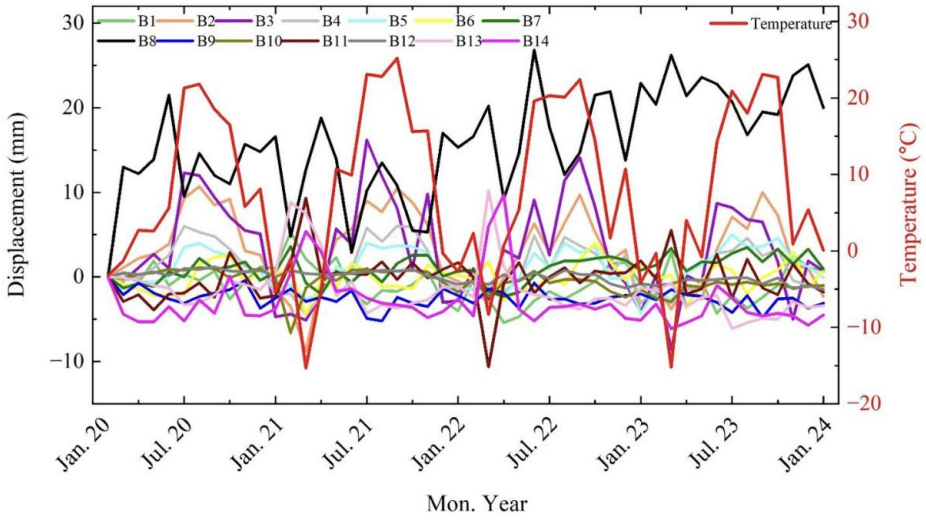



**Figure 3. MT-InSAR displacement time histories at the midspan of the 14 monitored bridges.**

Before applying the machine-learning algorithm, the displacement data were standardized using z-score normalization. This step reduced the influence of differences in absolute displacement magnitude and allowed the analysis to focus on the temporal shape of each bridge's response.

Preliminary K-means clustering was initiated using multiple cluster configurations to examine behavioral similarities among the monitored bridges. The initial analysis indicated that the bridges could be grouped according to differences in their temporal displacement characteristics. The clustering analysis and independent anomaly-detection validation remain in progress, and the detailed machine-learning results will be presented during the next quarter.

## 4. Percent of research project completed

Total project completed through the end of this quarter = [80 % completed to date]

## 5. Expected progress for next quarter

Task 3 will be completed during the next quarter by finalizing the K-means clustering analysis and applying Isolation Forest anomaly detection to the standardized multi-bridge displacement dataset. The results from the two machine-learning methods will be compared to determine whether unusual displacement patterns can be identified consistently.

Potential outliers will be further evaluated using temperature, estimated traffic conditions, bridge characteristics, and available inspection records. The findings will be used to finalize and document an automated MT-InSAR and machine-learning framework for network-level bridge screening. Final report

preparation will also be completed by integrating the results from satellite-data analysis, finite-element assessment, and machine-learning-based anomaly detection.

### 6. Educational outreach and workforce development
Nothing to report yet.

### 7. Technology Transfer
Nothing to report yet.

## Research Contribution:

### 8. Papers that include TRANS-IPIC UTC in the acknowledgments section:
*B. Andrawes, I.A. Colombani, A.Q. Khan, Using Spaceborne Sensors to Evaluate the Performance of Civil Infrastructure Systems, Journal of Performance of Constructed Facilities 39 (2025) 06025004. https://doi.org/10.1061/JPCFEV.CFENG-5114.*

*A.Q. Khan, B. Andrawes, MT-InSAR Assessment of Bridge Monitoring Using Finite-Element Analysis under Thermal and Traffic Loads, Journal of Bridge Engineering 31 (2026) 04026031. https://doi.org/10.1061/JBENF2.BEENG-7850.*

*A.Q. Khan, B. Andrawes, Multi-bridge deformation monitoring and abnormal behaviour detection using MT-InSAR and machine learning, Structure and Infrastructure Engineering (2025) 1–16. https://doi.org/10.1080/15732479.2025.2601114.*

*Bassem Andrawes "Regional-scale monitoring of bridge performance using MT-InSAR and ML" 13th International Conference on Bridge Maintenance, Safety, and Management. IABMAS 2026, Orlando, FL, July 7-10, 2026.*

### 9. Presentations and Posters of TRANS-IPIC funded research:
*Bassem Andrawes "Multi-Bridge Deformation Monitoring and Abnormal Behavior Detection using MT-InSAR and Machine Learning" 2026 Transportation Research Board Annual Meeting, Washington DC, January 11-15, 2026.*

*Bassem Andrawes "Regional-scale monitoring of bridge performance using MT-InSAR and ML" 13th International Conference on Bridge Maintenance, Safety, and Management. IABMAS 2026, Orlando, FL, July 7-10, 2026.*

### 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.
Nothing to report yet.

**Appendix 1**: Research Activities, leadership, and awards (cumulative, since the start of the project)

A. Number of presentations at academic and industry conferences and workshops of UTC findings
   - No. = 1

B. Number of peer-reviewed publications submitted based on outcomes of UTC funded projects
   - No. =

C. Number of peer-reviewed journal articles published by faculty.
   - No. = 1

D. Number of peer-reviewed conference papers published by faculty.
   - No. =

E. Number of TRANS-IPIC sponsored thesis or dissertations at the MS and PhD levels.
   - No. MS thesis =
   - No. PhD dissertations =
   - No. citations of each of the above =

F. Number of research tools (lab equipment, models, software, test processes, etc.) developed as part of TRANS-IPIC sponsored research
   - Research Tool #1 (Name, description, and link to tool) =
   - Research Tool #2 (Name, description, and link to tool) =
   - Research Tool #3 (Name, description, and link to tool) =

G. Number of transportation-related professional and service organization committees that TRANS-IPIC faculty researchers participate in or lead.
   - Professional societies
     - No. participated in = 7
     - No. lead =
   - Advisory committees (No. participated in & No. led)
     - No. participated in =
     - No. lead =
   - Conference Organizing Committees (No. participated in & No. led)
     - No. participated in = 2
     - No. lead =
   - Editorial board of journals (No. participated in & No. led)
     - No. participated in = 1
     - No. lead =
   - TRB committees (No. participated in & No. led)
     - No. participated in =
     - No. lead =

H. Number of relevant awards received during the grant year
   - No. awards received =

I. Number of transportation related classes developed or modified as a result of TRANS-IPIC funding.
   - No. Undergraduate =
   - No. Graduate = 2

J. Number of internships and full-time positions secured in the industry and government during the grant year.
   - No. of internships =
   - No. of full-time positions = 1

**References:**

*B. Andrawes, I.A. Colombani, A.Q. Khan, Using Spaceborne Sensors to Evaluate the Performance of Civil Infrastructure Systems, Journal of Performance of Constructed Facilities 39 (2025) 06025004. https://doi.org/10.1061/JPCFEV.CFENG-5114.*

*A.Q. Khan, B. Andrawes, MT-InSAR Assessment of Bridge Monitoring Using Finite-Element Analysis under Thermal and Traffic Loads, Journal of Bridge Engineering 31 (2026) 04026031. https://doi.org/10.1061/JBENF2.BEENG-7850.*

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