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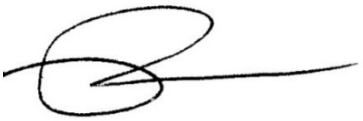


1. **ACCOMPLISHMENTS** (What was done? What was learned?)

What are the major goals and objectives of the program?
The CAIT Region 2 UTC Consortium's research vision aligns with the ongoing national dialogue on the state of the U.S. transportation infrastructure, and the emerging consensus on the need for significant investment to fill condition gaps, improve/expand existing systems, and build for the future.

The Consortium's **primary research focus** will be on "Improving the Durability and Extending the Life of Transportation Infrastructure" with additional elements of "Preserving the Existing Transportation System" such as resilience. Using Region 2 as a complex infrastructure laboratory, the Consortium will contribute to: 1) extending the life of the region's legacy systems, 2) building future systems with consideration to changes in living patterns and where people and products will move to and from, and 3) the use of technologies and better design approaches to maximize the use of both old and new transportation infrastructure assets.

The Consortium will structure its **education and workforce development activities** around a "cradle to grave" approach, developing programs that attract more people to the transportation industry, fostering skills to sustain them within the industry, and provide the workforce with professional development.

Gaining and sharing knowledge is the critical first step toward developing a transportation system that improves the durability and extends the life of transportation infrastructure. To this end, the Consortium will conduct **technology transfer** of research through implementation projects, knowledge transfer activities, and exploration of patents.

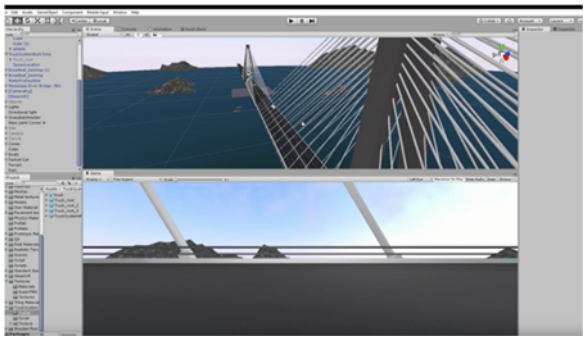
What was accomplished under these goals?
Research
The peer-review panel has approved 20 projects during this cycle. Two research projects are currently under review.

CAIT-UTC-REG1	Augmented Reality (AR) in Life-Cycle Management of Transportation Infrastructure Projects	RU
CAIT-UTC-REG2A	Sustainability and Resiliency of Concrete Rapid Repairs Utilizing Advanced Cementitious Materials – Freeze/Thaw Loads	NJIT
CAIT-UTC-REG2B	Sustainable, Rapid Repair Utilizing Advanced Cementitious Materials	SUNY Buffalo
CAIT-UTC-REG3	Large-Amplitude Forced Vibration Testing for St-Id of Bridges and Foundation Reuse Assessment	RU
CAIT-UTC-REG4	Rail Track Asset Management and Risk Management	RU
CAIT-UTC-REG6	Airfield Pavement Management Framework using a Multi-Objective Decision Making Process	RU
CAIT-UTC-REG7	MEMS Sensor Development for In-Situ Quantification of Toxic Metals in Sediment	RU
CAIT-UTC-REG8	Prioritizing Infrastructure Resilience throughout the Capital Planning Process	RU
CAIT-UTC-REG9	Delivering maintenance and repair actions via automated/robotic systems	RU
CAIT-UTC-REG10	Policies, Planning, and Pilot Testing on Infrastructure Readiness for Electrical, Connected, Automated, and Ridesharing Vehicles	RU/Columbia
CAIT-UTC-REG11	Pavement Design For Local Roads and Streets	Cornell
CAIT-UTC-REG12	Laboratory Performance Evaluation of Pavement Preservation Alternatives	Rowan

CAIT-UTC-REG13	Virtual Tour (VT), Informational Modeling (IM), and Augmented Reality (AR) for Visual Inspections (VI) and Structural Health Monitoring (SHM)	PU
CAIT-UTC-REG14	Performance-Based Engineering of Transportation Infrastructure Considering Multiple Hazards	SUNY Buffalo
CAIT-UTC-REG15	Flood Vulnerability Assessment and Data Visualization for Lifeline Transportation Network	Rowan
CAIT-UTC-REG16	Fire In Tunnel Collaborative Project	PU/SUNY-Buffalo/NJIT
CAIT-UTC-REG17	Improving Transportation Infrastructure Resilience against Hurricanes, other Natural Disasters, and Weathering: Part I - Analysis of failure of transportation signs due to Hurricane Maria	PUPR
CAIT-UTC-REG18	Improving Transportation Infrastructure Resilience against Hurricanes, other Natural Disasters, and Weathering: Part II - Analysis of pedestrian bridges failures due to Hurricane Maria	PUPR
CAIT-UTC-REG19	Improving Transportation Infrastructure Resilience against Hurricanes, other Natural Disasters, and Weathering: Part III - Analysis of motor vehicle bridges failures due to Hurricane Maria	PUPR
CAIT-UTC-REG20	Infrastructure Cybersecurity and Emergency Preparedness Academic and Non-academic Credential Development	SUNY-Farmingdale

HIGHLIGHTS

Augmented Reality (AR) in Life-Cycle Management of Transportation Infrastructure Projects (CAIT-UTC-REG1, Project Manager: Dr. Jie Gong)



This project has produced a number of products for advancing the state of practice in Virtual/Augmented Reality (VA/AR) for highway infrastructure applications. A high-level technical report has been produced on available VR/AR technologies to assist owners with proper selection. Furthermore, two VR training modules have been developed to advance the reliability of infrastructure inspection and greatly improve the safety of the personnel in the work-zone areas and in critical facilities such as pump stations due to fire and gas leak. The first training module utilized a full-scale cable stayed bridge in VR environment, modeled after the Stan Musial Veterans Memorial Bridge, which crosses Mississippi River between St. Clair County, Illinois, and the city of St. Louis, Missouri. The second VR training module utilized a full-scale critical facility in VR environment, modeled after an in-service pump station.

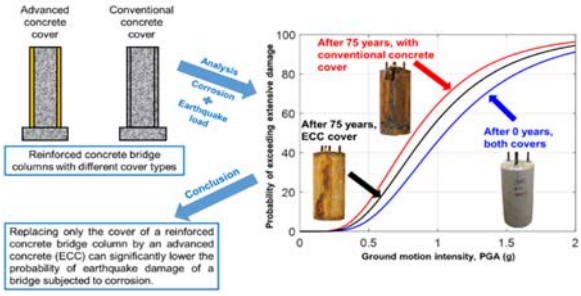
Outputs: Two full-immersive virtual environments featuring bridges and critical facilities have been developed. These virtual environments are modeled after two real facilities. The virtual training environments can greatly improve the efficiency and effectiveness of training for transportation workforce. For example, construction crews can use the bridge VR environment to simulate the setup of work zones and experience the traffic flow in a fully immersive environment. Such training can greatly enhance the safety of construction crews and the traveling public.

Outcomes: Several private companies and labor unions have expressed interests to fund the further development of these modules for their own training needs. These collaborations could potentially augment or change the current training requirements or policy framework.
Impacts: (1) Reducing the training cost and transportation related fatalities, and 2) Improving the reliability of inspection and safety of the transportation workforce.

Sustainability and Resiliency of Concrete Rapid Repairs Utilizing Advanced Cementitious Materials – Freeze/Thaw Loads (CAIT-UTC-REG2A, Project Manager: Matthew P. Adams)

Appropriate testing methods have been devised for examining degradation of the bond zone between repair materials and concrete substrate during freeze-thaw damage. To facilitate a broad understanding of repair materials and techniques, various surface preparation methods are being used to compare the bond behavior between repair materials and substrates. Further, rapid repair materials with different cementitious binder chemical compositions, and thus varying levels of durability performance, are being tested. In addition, hydrodemolition is being considered as a removal and surface preparation method, and scarification is being used to prepare the substrate surface. In the rapid repair material area, a calciumsulfoaluminate cement based binder, a calcium aluminate cement binder, and three portland cement based binders are being examined. Results will indicate which material and surface preparation technique are ideal for freeze-thaw situations. Additionally, information on the deterioration rate of the bond-zone and overlay material will be gathered.
Outputs: A guideline on how freeze-thaw damage will impact the bond and quality of overlays or repairs done with rapid repair cements.
Outcomes: The guideline developed from this study will assist the infrastructure owners to better assess the quality of their repairs and select materials that are more suitable to particular repair situations. This guideline has the potential to make changes to the current policy and largely assist in material choice decision making process.
Impacts: The results of this study will decrease the maintenance costs of concrete pavements by providing more durable, longer lasting repairs. These repairs will extend the life of infrastructure and reduce the need to replace infrastructure as frequently. Additionally, better understanding and increased use of these rapid repair materials will allow shorter lane closure times during repairs resulting in lower community impacts.

Sustainable, Rapid Repair Utilizing Advanced Cementitious Materials (CAIT-UTC-REG2B, Project Manager: Ravi Ranade)



A computational framework for systematic assessment of vulnerability of deteriorated bridges to earthquakes was developed. This was accomplished by comparing advanced cementitious materials and conventional concrete in various construction and repair strategies of deteriorated bridges (i.e., rebar corrosion as the main deterioration mechanism in columns). Damage probabilities (fragility curves) of the deteriorated bridge components (i.e., columns) were then computed by performing dynamic structural analysis under a set of ground motions. When

fully developed, this framework can be used as an assessment tool by the state departments of transportation (DOT) to prioritize structures for repair and choose between various repair strategies.
Outputs: This framework improves decision-making processes, efficiency and safety of bridges by determining corrosion and hazard vulnerabilities.
Outcomes: Bridge engineers from NY and WA State DOTs are very much in support of this framework and suggested that a more developed version of this framework can be used as an assessment tool to prioritize structures for repair, choose between various repair strategies, and determine their resiliency to earthquakes.
Impacts: Improvements in safety and resilience of bridges are expected as a result of the application of the framework developed in this research. In addition, this framework will result in life cycle cost savings and facilitate informed allocation of state DOT's annual maintenance budget for prioritizing construction and repair activities.

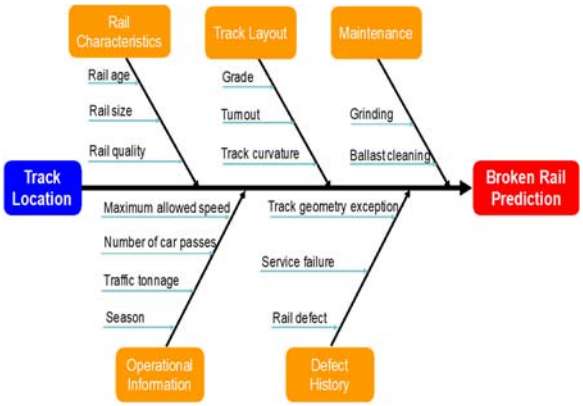
Large-Amplitude Forced Vibration Testing for St-Id of Bridges and Foundation Reuse Assessment (CAIT-UTC-REG3-Project Manager: Dr. Nenad Gucunski)

A numerical simulation of the process of evaluation of unknown foundations, and preparations for the field implementation was conducted. The numerical study dealt with the establishment of correlations between the dynamic response and bearing capacity of a bridge foundation. A FEM parametric study was conducted using COMSOL Multiphysics to correlate the dynamic response and the ultimate bearing capacity, without the knowledge of shear strength parameters. A parametric study was also accompanied to ensure the solution uniqueness, since similar responses can be obtained for multiple foundations of different geometries. A plan is being pursued for field implementation on an actual bridge using forced vibration, which will involve the use of T-Rex, a large-amplitude mobile shaker from the Natural Hazards Engineering Research Infrastructure (NHERI) at the University of Texas, Austin (UTA).
Outputs: A methodology for establishing performance of bridges by considering the effects of dynamic soil-foundation-structure. Products such as a generic guideline for dynamic field-testing considering soil-structure interactions, data analysis and visualization, and the reuse of foundation systems based on the large-amplitude shaking are anticipated as deliverables.
Outcomes: The findings will support performance-based management of highway infrastructure assets which could broadly impact the current policies for foundation reuse and allocation of resources.
Impacts: Enhancing the State of Good Repair of highway bridge structures, which will ultimately reduce life-cycle cost, and improve safety and quality of service for travelling public.

Rail Track Asset Management and Risk Management (CAIT-UTC-REG4, Project Manager: Dr. Yun Bai)

In collaboration with experts from Port Authority Trans-Hudson (PATH), the research team focused on broken rails, which is one of the most critical railroad track failures. Hence, a comprehensive review of the influencing factors of broken rails, as well as the methods to predict broken rail risk were conducted which resulted in identifying five high-level categories of influencing factors: 1) rail characteristics; 2) track geometry and layout; 3) maintenance activities; 4) operational information; and 5) defect histories. Within each category, a number of factors were identified based on the literature review, discussion with PATH, as well as engineering heuristics and discussion with subject matter experts. A preliminary

Concept of Operations (ConOps) has been developed which includes a number of sequential steps for broken rail prediction and development of asset management practice. Work is underway to further discuss and refine the preliminary ConOps, gather information, and identify resources needed for Phase 2 of the study. Research in Phase 2 will concentrate on compiling "big data" from PATH (under Non-Disclosure Agreement) to develop and test the machine-learning model, and apply the model to practical use-cases in collaboration with their engineering department.



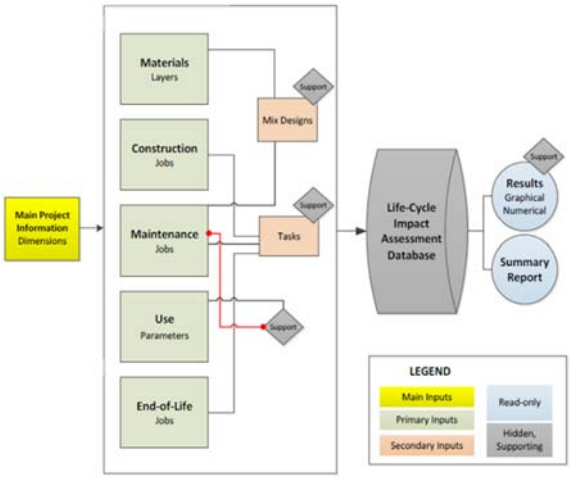
Outputs: The output of this project will be a data-centric asset management process & concept of operation (ConOps) in support of the future development of the methodology and practices for proactive maintenance and state of good repair. This includes the design of the methodology framework for predicting railroad infrastructure deterioration, with defined input data fields, type, and format, as well as how output information can be used in further asset management practices.

Outcomes: Development of a probabilistic analysis/methodology focusing on location-specific broken rail occurrence. This will support data-driven infrastructure asset management for maintenance, repair and preservation.

Impacts: Track infrastructure health condition is fundamental to rail transport safety and operational efficiency. Enhancing the State of Good Repair of track infrastructure will ultimately reduce life cycle cost, reduce accident probability, and improve the quality of service for riders. Ultimately, improved rail transportation will bring significant environmental and societal benefits.

Airfield Pavement Management Framework using a Multi-Objective Decision Making Process (CAIT-UTC-REG6, Project Manager: Dr. Hao Wang)

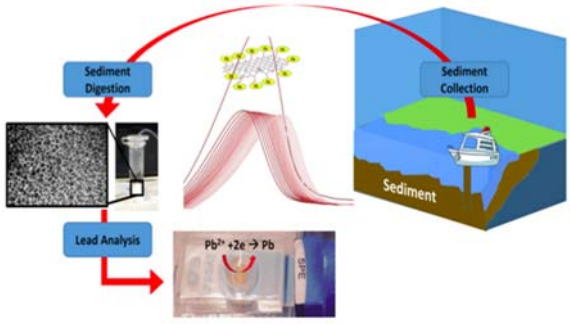
Performance Management System (PMS) database from FAA for airport performance modeling were obtained and reviewed extensively. The database includes pavement distresses (fatigue cracking, block cracking, longitudinal cracking, rutting, etc.) and foreign object debris (FOD) collected on runway, taxiway, and apron of over 2700 airports. The database also includes construction date, pavement surface type, length and width of each pavement section inspected. Beside the pavement condition, another very important component is the maintenance information, containing the distress type, its rate and severity, work type (e.g., slab replacement, crack sealing), unit cost, and total cost.



Survival analysis techniques are being used to predict the pavement life considering different failure criteria, such as the pavement condition index (PCI) and structure condition index (SCI) of airfield pavement, and FOD. The preliminary results will be used to derive life-cycle cost and environment impact of different pavement types. In addition, a flowchart of life-cycle assessment for pavement project has been developed, which will be used to be coded into an Excel-based tool for calculating energy consumption and greenhouse gas emission of airfield pavement, which will be further considered as the importance sustainability criteria in the decision making.

Outputs: The anticipated output is the life-cycle assessment tool that can compare different pavement maintenance treatments through quantitative analysis of energy consumption and Greenhouse Gas emission. The tool can be directly used by airport authorities for sustainability-related decision making.
Outcomes: The research outcome is the framework of multi-criteria decision making considering the balance between pavement life, economic cost, safety, and environmental impact.
Impacts: The research outcome will lead to the enhancement of airport sustainability through protection of the environment, conservation of natural resources, and preservation of infrastructure condition.

MEMS Sensor Development for In-Situ Quantification of Toxic Metals in Sediment (CAIT-UTC-REG7, Project Manager: Dr. Mehdi Javanmard)



During this period, the research team has developed a working prototype of highly accurate Microelectromechanical Systems (MEMS) chemical sensors, which is capable of detecting lead in sediment samples.
Outputs: A technology that can rapidly (within 5 minutes) quantify lead in sediment samples. This will significantly lower the cost and increases the speed in which sites can be mapped and assessed for identifying toxic hotspots.
Outcomes: A technology that is capable of rapid and inexpensive identification and triaging of environmental sediment hotspots in natural water sources. Rather than using brute force and costly approach to dredging everywhere, the contaminated hotspots can easily and rapidly be identified which otherwise require dredging. The result will be a more cost effective environmental remediation.
Impacts: NJDOT has been contacted to showcase this cost effective environmental remediation technology and further discuss its capabilities.

Prioritizing Infrastructure Resilience throughout the Capital Planning Process (CAIT-UTC-REG8, Project Manager: Jon Carnegie)

Conducted a literature review and practice scan that examines how transportation agencies are incorporating resilience measures and considerations in: vulnerability assessments; asset management methodologies; benefit-cost (B-C) / return on investment (ROI) methodologies; project identification/prioritization approaches; and project design and construction. The scan also documents how agencies are coordinating regionally, addressing interdependencies and how resilience is treated in the organizational structure of the agency. The next step in the process will be to conduct a series of key informant interviews to develop case studies of leading/promising practices. The leading/promising practice case studies will be presented at a peer learning exchange workshop where participants from regional transportation agencies will develop self-identified action agendas for advancing these practices at their own agencies. Outreach Activities: The Port Authority of New York and New Jersey; NJDOT.

Delivering Maintenance and Repair Actions via Automated/robotic Systems (CAIT-UTC-REG9, Project Manager: Dr. Jie Gong)

Extensive review of available robotic systems and solutions for delivering maintenance and repair actions were conducted. Based on the findings, a technical workshop is being planned on May 30, 2019 focusing on identifying use cases, characterizing research priorities in robotic systems, aligning research

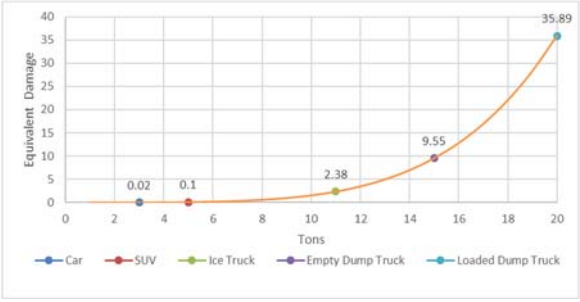
visions, and forming sub-committees on various identified research dimensions. Participants include representatives from state DOTs, industry, and academia.
Outputs: The workshop will produce research questions related to "robotic solutions" and delivering maintenance and repairing actions to physical infrastructure systems. These questions will be used to guide our search for and evaluation of tools and techniques. They will help us to understand how we can use "robotic solutions" to support the delivery of maintenance and repairing actions to physical infrastructure systems, what are the fundamental challenges hindering the design and implementation of such robotic solutions, what are the requirements in ensuring these systems to deliver quality services, what are the potential limitations of these systems, and what could be the unintended consequences of the use of these systems?
Outcomes: The workshop and its outputs will inform infrastructure stakeholders and practitioners about available robotics tools to deliver infrastructure inspection and repair actions and will provide critical projection on future jobs in infrastructure maintenance. To this end, the workshop will provide critical insights on how current legislative and policy framework need to be adjusted to enable greater innovations in infrastructure maintenance.
Impacts: The workshop outcome contributes to safer and more efficient infrastructure inspection and repair practices.

Policies, Planning, and Pilot Testing on Infrastructure Readiness for Electrical, Connected, Automated, and Ridesharing Vehicles (CAIT-UTC-REG10, Project Manager: Mohsen Jafari)

Gap analysis on available system architecture for connected vehicles in the United States and other countries were compiled. Also, several applications for system architecture were identified for further analysis, such as adaptive signal control, queue warning, safety, electric vehicle charging, V2X, and more. Work is underway to develop a detailed system architecture along with data / logic specifications of the proposed smart mobility and infrastructure which will be examined on a testbed in New Brunswick. Stakeholders from private, public, and academic sectors were engaged in the selection of the testbed. The research team has also conducted a comprehensive review of the existing V2X technologies and various use cases, with a special emphasis on 5G and mmWave technologies, in comparison to the existing DSRC framework.
Outputs: A preliminary system design, component specifications, budget, and deployment plan for the testing ground has been established. Work is underway to develop an introductory video to demonstrate the concept for the proposed testbed for further stakeholder outreaching and engagement. A technical report is under preparation and a stakeholder workshop is planned for summer 2019.
Outcomes: The research results will provide technical and policy support for the potential New Jersey legislation on ADS (Automated Driving System) testing to the New Jersey Advanced Vehicle Task Force.
Impacts: The results of this research study will target the reduction of crashes at pedestrian crossings, intersections, and highway merge, diverge, and weaving sections with connected and automated vehicle technologies.

Pavement Design for Local Roads and Streets (CAIT-UTC-REG11, Project Manager: Dr. David Orr)

A user-friendly software tool using mechanistic-empirical methods has been developed to assist local agencies to design roads for various traffic spectra associated with low-volume roads, set to 1,000 vehicles per day. Currently, additional work is

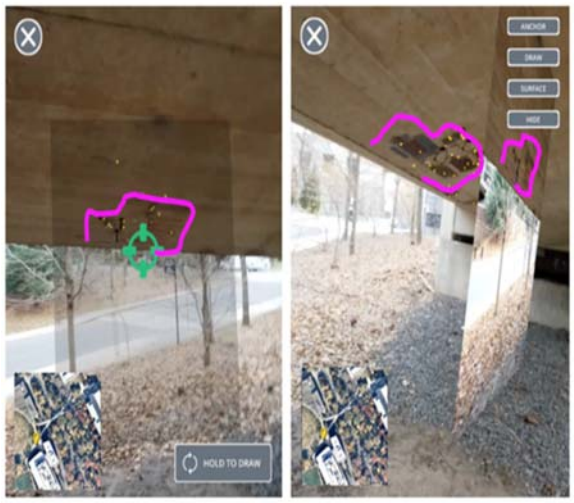


underway to expand and improve the tool. A prototype of the user interface is almost complete and should be ready by the May UTC meeting. Oswego and Erie counties in NY and PA have been contacted to test this software tool with actual project.
Outputs: Initially, it will be a spreadsheet based tool which will allow agencies to design the roads for various traffic spectra associated with low-volume roads. The long-range goal is to develop an app or nomograph depending upon the needs of the local agencies during the testing phase.
Outcomes: The tools developed under this study tool will allow local agencies to design the roads for the required loads. "Experience," budgetary constraints and inappropriate tools often conspire in forcing towns and villages to underbuild their roads, leading to premature failure and costly remediation.
Impacts: Unlike Mechanistic Empirical Pavement Design Guide (MEPDG), the tools developed under this study will require inputs, which the local agencies understand and can obtain using the limited resources of small municipalities. Ultimately, they can make the best decisions to allocate their limited resources, while serving the traveling public and tax payers.

Laboratory Performance Evaluation of Pavement Preservation Alternatives (CAIT-UTC-REG12, Project Manager: Dr. Yusuf Mehta)

The research team evaluated cracking resistance of three common overlay pavement preservation treatment types using laboratory performance testing. The three treatments evaluated include chip seal, microsurfacing, and high performance thin overlay (HPTO). The specifications for each treatment were obtained from federal and several state agencies, including the New Jersey Department of Transportation (NJDOT). The research team reached out to local plants in the area to obtain mixes for the treatments. All three preservation treatments were produced using these materials according to acquired specifications. Coordination is currently underway to produce special test specimens and plan to invite NJDOT's subject matter experts to show the testing setup and experiments. The goal is to discuss plans for NJDOT to actively consider one or more of these treatments for a pilot project.
Outputs: Texas Overlay Tester sample fabrication procedures will be modified to evaluate cracking performance of asphalt pavement preservation mixes. The application of these treatments to Texas Overlay asphalt samples will be conducted in a manner to simulate field application as closely as possible.
Outcomes: Recommendations will be made to local and federal highway agencies regarding decision-making guidelines for choosing the timing and appropriate pavement preservation treatments. Decisions will be based on the performance of materials being considered for preserving asphalt pavements.
Impacts: Evaluation of cracking performance of pavement preservation treatments will lead to improved decision-making processes, increase the effectiveness of treatments, and reduce costs.

Virtual Tour (VT), Informational Modeling (IM), and Augmented Reality (AR) for Visual Inspections (VI) and Structural Health Monitoring (SHM) (CAIT-UTC-REG13, Project Manager: Dr. Branko Glisic)



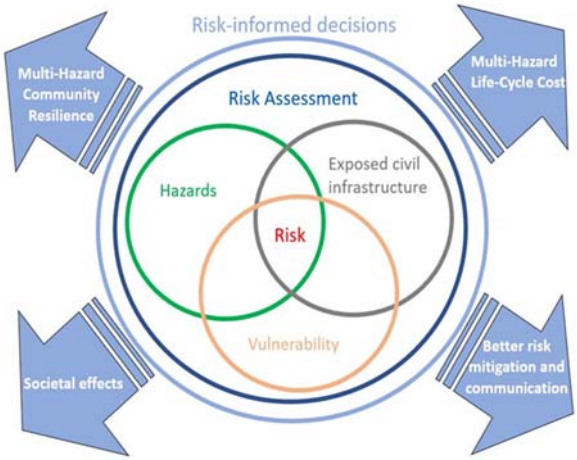
During this period, Dr. Glisic and his research team developed a method and associated software for integrating, documenting, accessing, and visualizing (i.e. managing) inspections and monitoring data and metadata using virtual tours (VT), informational modeling (IM), and augmented reality (AR). VT/IM environments were generated by "stitching" together 360° spherical panoramic photographs, taken methodically throughout the structure's interior and exterior. Users can navigate and interact using "hotspots," which are on-click conditionals that are programmed to perform a prescribed task, such as change of location or access stored SHM data (raw, processed, and analyzed) and metadata (construction drawings, sensor specifications, etc.). To ensure efficiency both on and off site, a framework using a combination of image-based documentation and AR is explored. Unity game engine was used for cross-platform development as it supports open-source programming for headsets, computers, web addresses and mobile devices. At current stage only drawing tool is enabled, while future work will include text, voice recordings, and other forms of annotations.

Outputs: Virtual Tour (VT)/Informational Modeling (IM) prototype software and Image/Augmented Reality (AR) prototype software.

Outcomes: A practical outcome of the project will be a demonstration software that can be accessed on a mobile device, laptop, desk computer, virtual reality (VR) headset, or AR headset, depending on a user's needs. Validation of the method will be performed on real structures, in particular Streicker Bridge in Princeton, NJ and/or US202/NJ23 overpass in Wayne, NJ.

Impacts: The new method and associated software will have an impact on asset durability, resilience, and preservation, as the proposed project method provides means to assist the actions that improves these three features.

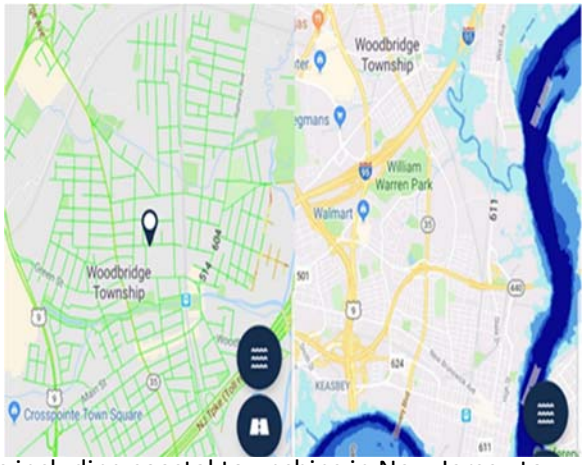
Performance-Based Engineering of Transportation Infrastructure Considering Multiple Hazards (CAIT-UTC-REG14, Project Manager: Dr. Kallol Sett)



A framework has been developed for performance-based engineering of transportation infrastructure considering multiple hazards (i.e., seismic and storm surge) which utilizes an event-based approach and considers both structural and downtime losses. The framework can be utilized to explore financial aspects of various retrofit strategies for an interdependent civil infrastructure system subjected to multiple hazards in terms of risk metrics commonly used in the field of financial engineering for portfolio optimization.

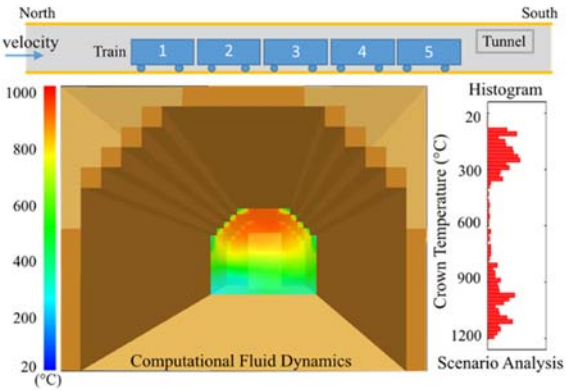
Outputs: A novel risk-informed design framework that could potentially enable a paradigm shift and enable design of resilient transportation network, moving away from the focus on individual components of a network (i.e., one bridge designed without consideration of network impact, redundancy, etc.).
Outcomes: A case-study illustrating performance-based engineering of a simple network subjected to seismic and storm surge hazards. The results show that unless all components of a network are analyzed together, risks to the network may be underestimated. Furthermore, it shows that an optimum retrofit strategy for any transportation networks depends upon the person who is making the decision: policy makers, owners, and insurance companies could potentially perceive risk from different perspectives and decide on different strategies for the same system.
Impacts: 1) Reducing the repair cost and downtime of highway infrastructure networks subjected to multiple hazards, 2) Reducing the impact to the community, and 3) designing safer and more economical transportation infrastructure.

Flood Vulnerability Assessment and Data Visualization for Lifeline Transportation Network (CAIT-UTC-REG15, Project Manager: Rouzbeh Nazari)



Developed beta version of a mobile app (currently being tested) for Street Level Flooding (SLF) to provide precise information of flood depth at street level at a very high resolution and accuracy. The app uses a framework, which combines the hydrodynamic modeling of flooding, data extraction at street level, data QA/QC and final integration within the app. Meetings have been organized with various stakeholders including coastal townships in New Jersey to discuss benefits of this app to the society.
Outputs: A state of the art flood map for New Jersey towns that offers a unique picture of flood hazards, lifeline infrastructures, vulnerability assessments, and resiliency measures.
Outcomes: The art flood map will provide more detailed, reliable and current data on flood hazards resulting in a better picture of the New Jersey towns most likely to be impacted by flooding and a better foundation from which to make key legislative decisions/changes.
Impacts: To assist decision makers and coastal communities to understand the magnitude of flood events, quantify the impact and offer assistance with mitigation and resiliency plan.

Fire in Tunnel Collaborative Project (CAIT-UTC-REG16, Project Manager: Negar Khorasani)



A traveling fire model was established for a railway tunnel to evaluate the burning behavior and the spread of fire to adjacent train cars and its potential impact on tunnel concrete lining. Uncertainties in the amount of fuel, ventilation velocity, tunnel slope, ignition point, and criteria for fire spread were incorporated to capture distribution of fire temperature and duration in the tunnel. A finite element modeling approach was developed to take effects of concrete spalling on the

structure's response into account. The spalling rate was determined based on existing test data and laboratory experiments in which concrete sections were subjected to high temperatures.
Outputs: A methodology to achieve acceptable fire safety and minimize economic losses in a tunnel subjected fire. This will lead to the development of improved guidelines and code provisions on structural safety of tunnels under fire.
Outcomes: Recommendations on preventive measures (i.e. the minimum concrete cover requirements of tunnel lining or fireproofing) for tunnel structures subjected to fire. In addition, the project outcomes can be used to inform operation/inspection strategies and post-event analysis.
Impacts: Resilience of a tunnel subjected to fire is measured by the expected downtime and loss of functionality following an event. The results of this research will allow tunnel engineers to design and evaluate new and existing tunnels subjected to fire and implement proper mitigation actions for required performance level.

Improving Transportation Infrastructure Resilience against Hurricanes, other Natural Disasters, and Weathering: Part I - Analysis of failure of transportation signs due to Hurricane Maria (CAIT-UTC-REG17, Project Manager: Dr. Héctor J. Cruzado)

This is an ongoing study to analyze the failure of transportation signs due to Hurricane María. Three types of traffic signs supporting structures that failed during Hurricane María are being studied: (1) support of steel truss cantilevered guide sign anchored to concrete pedestal, (2) traffic signs supported by I-beams with break-away system, and (3) small regulatory signs supported by a single tubular or channel post. For each type of traffic signs, different modes of failures are being documented and geolocated, and specific case studies are being selected to further investigate and determine the wind speed that caused the failure. Samples of the failed structures have been taken to determine, by experimental testing, the mechanical properties of the materials.
Outputs: Improvements in design and analysis of highway signs subjected to high wind/Hurricane.
Outcomes: Expected output will potentially be a Design guide.
Impacts: 1) Safety of the travelling public during a hurricane event, 2) Improving the resiliency of highway signs subjected to excessive wind/Hurricane.

Improving Transportation Infrastructure Resilience against Hurricanes, other Natural Disasters, and Weathering: Part II - Analysis of pedestrian bridges failures due to Hurricane Maria (CAIT-UTC-REG18, Project Manager: Héctor J. Cruzado)

The goal of this project is to analyze the failure of pedestrian bridges due to high wind in particular to Hurricane Maria. Two types of studies are being developed: (1) an inventory of failures of pedestrian bridges in the San Juan Metropolitan Area (SJMA),

and (2) the advanced analysis of a case study pedestrian bridge that experienced large deflections in the plastic range. For the first study, 34 pedestrian bridges are being visually inspected in the SJMA. The second study will be used to validate our preliminary assessment. One of the bridges that experienced damages has been selected as a case study. Several field visits have been conducted to perform visual inspections and bridge geometric data was collected using surveying instruments and drones.
Outputs: Improvements in design and analysis of highway pedestrian bridges subjected to high wind/Hurricane.
Outcomes: Expected output will potentially be a Design guide.
Impacts: 1) Safety of pedestrians during a hurricane event, 2) Improving the resiliency of highway pedestrian bridges subjected to excessive wind/Hurricane.

Improving Transportation Infrastructure Resilience against Hurricanes, other Natural Disasters, and Weathering: Part III - Analysis of motor vehicle bridges failures due to Hurricane Maria (CAIT-UTC-REG19, Project Manager: Héctor J. Cruzado)

This is an ongoing project to analyze the failure of bridges due to high wind in particular to Hurricane Maria. Bridges that experienced damages and were closed due to the hurricane were identified and geolocated. Twenty-eight bridges were identified. Four major sources of information have been identified: (1) official transportation government agencies reports, mainly from the Puerto Rico Department of Transportation and Public Works and the Puerto Rico Division of the Federal Highway Administration; (2) other technical reports, e.g., FEMA, technical conferences, etc.; (3) news outlets; and (4) social media. Several visits to the local transportation agencies have been made. The information is being collected and organized.
Outputs: Improvements in design and analysis of highway bridges subjected to high wind/Hurricane.
Outcomes: Expected output will potentially be a Design guide.
Impacts: 1) Safety of the travelling public during a hurricane event, 2) Improving the resiliency of highway bridges subjected to excessive wind/Hurricane.

Education and Workforce Development Activities

The consortium has trained 1,292 professionals during this period.

- **Developed Fatigue and Fracture of Steel Bridges Workshop.**
  This two-day workshop will provide training on designing and evaluating steel bridges for fatigue and fracture limit states according to the latest editions of the AASHTO LRFD Bridge Design Specifications and the AASHTO Manual for Bridge Evaluation. The course covers: the fundamentals of fatigue and fracture of steel structures; the background to the fatigue and fracture provisions within the AASHTO specifications; applications of the provisions for designing steel bridges for

fatigue and fracture including design examples; evaluation of existing steel bridges for remaining fatigue life and fracture resistance, including design examples; inspection, repair and retrofit of steel bridges for fatigue and fracture, both strategies and application examples.

The course is designed incorporating adult-learning principles. Hands on exercises, interactive discussions and real life examples are incorporated into the training for enhancing the bridge engineers' understanding of the subject and making informed design decisions and structural assessment. Each participant will be provided with a CD containing the course material, the examples, the training exercises, along with a workbook containing the training content. It will pilot in May 2019.

- **2nd National Summit on Rural Road Safety**
  The 2nd National Summit on Rural Road Safety was held December 4-6, 2018 in Savannah, GA. It was co-hosted by the National Center for Rural Road Safety (Safety Center) and the National Association of County Engineers (NACE). Sponsors included: AASHTO, the Center for Advanced Infrastructure and Transportation (CAIT) at Rutgers, Cambridge Systematics, and Lux Solar.

  At this second summit, our goal was to lead an action oriented event with interactive sessions that provided REAL takeaways to assist attendees on their Road to Zero. A great group of speakers, facilitators and trainers were assembled to assist and inspire attendees with the hopes that attendees would leave feeling empowered to improve the safety of the rural roadway systems within their jurisdictions. Remember, together we can make a difference in improving safety for your family, community, and all road users!

Technology Transfer

- **Engineering companies honor CAIT contributions and advances**
  The American Council of Engineering Companies New Jersey (ACECNJ) selects CAIT to receive its 2019 Distinction in Industry Advancement Award for innovative products and exceptional transportation workforce training (Presented in March, 2019 at the ACECNJ banquet).

  ACECNJ's goal for the Engineering Excellence Awards (EEA) competition is to share with the engineering field, building industry, government officials, the media, and the general public, outstanding design and construction that bring value to local communities and society at large.

  Each year a distinguished panel of judges representing a cross section of New Jersey's industry, government, academia and media, assemble to rank the project submissions on engineering excellence. Projects entered into New Jersey's EEA competition are rated on the basis of uniqueness and innovative applications; future value to the engineering profession; perception by the public;

social, economic, and sustainable development considerations; complexity; and successful fulfillment of client/owner's needs, including schedule and budget.

- **RU rail expert's research chosen for special issue of Transportation Research Record**
  A paper written by Rutgers civil engineering professor and railroad expert, Dr. Xiang Liu, was selected for a special publication by the Transportation Research Board (TRB) that was released in February 2019. Liu is a CAIT-affiliated researcher.

  TRB, through SAGE Publications, did an analysis of the most read and cited papers of 2016 and 2017, focusing on citations and mentions in articles, federal reports, and policy documents. The full text of these articles has been published in a special issue of Transportation Research Record (TRR): Journal of the Transportation Research Board (TRR Volume 2672 Issue 1S). TRB and SAGE are using this issue to raise visibility of TRR and promote access subscriptions to various libraries and online publication systems around the world.

  Risk-based Optimization of Rail Defect Inspection Frequency for petroleum crude oil transportation by Liu and his coauthor, C. Tyler Dick, P.E., was published in 2017. It is the only paper in this TRR special issue that addresses railway challenges. Dick is a senior research engineer at the University of Illinois at Urbana-Champaign, Rail Transportation and Engineering Center.

  The rapid expansion of oil production of North America, mainly from shale extraction, has led to a significant increase in rail transport of crude oil and an uptick in accidents and spills. The researchers were aware that broken rails are often the cause of train accidents, so they set out to more thoroughly assess the relationship between broken rails and crude oil train derailments.

  Instead of inspecting all track segments on a route with equal frequency, an alternative, risk-based approach proposed by Liu and Dick that would help railroads identify "hot spots" and concentrate inspection efforts—and resources—on those track segments. Skipping inspection of certain "less risky" rail segments could enable more frequent inspection of higher-risk areas, thus reduce costs and lower risk. The model they developed was used on an example route to validate this theory.

  Although the paper focused on crude oil transported in unit trains (i.e., trains composed of all the same type of car), the methodology can be adapted to other trains carrying hazardous materials.

- **NJIT hosted a Rapid-Repair Cements Seminar on February 25th, 2019**
  Rapid repair cement materials are a hot topic in concrete research and are actively being used across the industry to reduce construction times. However, the chemistry of these systems can be quite different from portland cement, and therefore the durability and constructability of concrete made with rapid repair cements is often not well understood. This seminar provided people who are familiar with standard concrete systems an overview of rapid repair cements, their chemistry, uses, durability concerns, and constructability. The seminar included a demonstration on casting with ultrafast setting cements in the laboratory environment. The presenters were Dr. Michael

Thomas from University of New Brunswick, Dr. Ted Moffatt, independent consultant and Dr. Matthew P. Adams, assistant professor of Civil Engineering at NJIT.

- **National Transportation Training Directors Executive and Conference Planning Committees**
  Staff are serving on the National Transportation Training Directors (NTTD) Executive and Conference Planning Committees in preparation for the upcoming National Local Technical Assistance Program Association/National Transportation Training Directors Joint Annual Conference in August 2019. *The outcome is participation in knowledge transfer and professional development for a nationwide group of transportation professionals within academia and the public sector.*

- **Work Zone Safety Awareness Week Legislative Resolution**
  The New Jersey Senate and General Assembly have signed a Joint Legislative Resolution acknowledging the New Jersey Work Zone Safety Conference hosted by Rutgers Center for Advanced Infrastructure and Transportation. The Resolution declares the conference as promoting work zone safety awareness in local and state roadways for a multidisciplinary audience of construction, engineering, public safety, maintenance and operations personnel. The Resolution is signed by the President of the New Jersey State Senate and the Speaker of the General Assembly. *The outcome was visibility for work zone safety awareness.*


State of New Jersey

THE SENATE AND GENERAL ASSEMBLY

JOINT LEGISLATIVE RESOLUTION

- **Representation at the NJDOT Research Showcase**
  Noah Thibodeaux, NJIT graduate student working on the "Sustainability and Resiliency of Concrete Rapid Repairs Utilizing Advanced Cementitious Materials – Freeze/Thaw Loads" project has presented his initial research and project outline at the New Jersey Department of Transportation Research showcase in a poster presentation format in October 2018. Noah interacted with DOT officials, researchers, and industry practitioners at this event. Additionally, Noah's work has had an abstract accepted for a conference paper and presentation at the June 2020 Calcium Aluminate Cements Conference.

- **New Jersey Asphalt Paving Conference**
  Rutgers CAIT researcher Thomas Bennert, PhD. presented "Use of IDT Testing for Asphalt Mixture Performance-design and Quality Control/Quality Assurance Testing" at the 62nd Annual New Jersey Asphalt Paving Conference. Staff also exhibited during the conference and served on the conference planning committee for the event, which was attended by 300+ people. *The outcome was technology transfer to more than 300 practicing professionals.*

How have the results been disseminated?

CAIT has established the Consortium internet site: https://cait.rutgers.edu/
Incorporated into earlier sections of this report

Newsletter

Nothing to report

What do you plan to do during the next reporting period to accomplish the goals and objectives?

No change to plan and process to accomplish our goals.

2. PARTICIPANTS AND OTHER COLLABORATING ORGANIZATIONS (Who has been involved?)

- ***Consortium Universities Involved***

  Rutgers, The State University of New Jersey • Piscataway, NJ 08854 (**LEAD**)
  Atlantic Cape Community College • Mays Landing, NJ 08330
  Columbia University • New York, NY 10027
  Cornell University • Ithaca, NY 14853
  New Jersey Institute of Technology • Newark, NJ 07102
  Polytechnic University of Puerto Rico • San Juan, Puerto Rico 00918
  Princeton University • Princeton, NJ 08544
  Rowan University • Glassboro, NJ 08028
  SUNY–Farmingdale State College • Farmingdale, NY 11735
  SUNY–University at Buffalo • Buffalo, NY 14260

- ***What organizations have been involved as partners?***

New Jersey Department of Transportation	Trenton, NJ	Financial support and collaborative research on multiple projects, personnel resources, knowledge exchange
Port Authority of New York and New Jersey	New York, NY,	Collaborative research on multiple projects, personnel resources, knowledge exchange, financial support
New Jersey Board of Public Utilities	Trenton, NJ	Financial support and collaborative research on multiple projects, including PHMSA State Damage Prevention Grant
New York State Department of Transportation	Albany, NY	Financial support, personnel resources, knowledge exchange
Washington State Department of Transportation	Olympia, WA	Personnel resources, knowledge exchange
Port Authority Trans-Hudson	Jersey City, NJ	Personnel resources, knowledge exchange
New York State County Highway Superintendents Association	Oneida and Chemung Counties	Personnel resources, knowledge exchange
New York Association of Town Superintendents of Highways	Canaan, NY	Personnel resources, knowledge exchange
Mistras Group	Princeton Junction, NJ	Personnel resources, knowledge exchange
Arup	New York, NY	Personnel resources, knowledge exchange
New Jersey Department of Community Affairs	Trenton, NJ	Personnel resources, knowledge exchange
Arora and Associates, P.C.	Lawrenceville, NJ	Personnel resources, knowledge exchange
Pennsylvania Department of Transportation	Bridgeville, PA	Personnel resources, knowledge exchange
Puerto Rico Highway and Transportation Authority	San Juan, PR	Personnel resources, knowledge exchange
Federal Highway Administration, Puerto Rico Division	San Juan, PR	Personnel resources, knowledge exchange
Puerto Rico Department of Transportation and Public Works	San Juan, PR	Personnel resources, knowledge exchange

- ***Have other collaborators or contacts been involved?***
  Nothing to report

3. OUTPUTS (What new research, technology or process has the program produced?)

- **Publications, conference papers, and presentations**

- A. Blyth R. Napolitano, B. Glisic. "Documentation, Structural Health Monitoring, and Numerical Modeling for Damage Assessment of the Morris Island Lighthouse under Environmental Loading," Philosophical Transactions of the Royal Society (Special Issue: Environment Loading of Heritage Structures), 2019 (accepted, in press).
- Orr, D. P.. When Should Agencies Post Weight Limits on Local Highways in New York State. Transportation Research Record, 12th International Conference on Low-Volume Roads, Kalispell, MT, TRB, Washington, DC, 2019 (will be published this fall with the conference)
- R. Napolitano, Z. Liu, C. Sun, B. Glisic, "Combination of image-based documentation and augmented reality for structural health monitoring and building pathology," Frontiers in the Built Environment, 2019, Vol. 8, art. no. 50 (14 pp).
- Hua, N., Tessari, A., Elhami Khorasani, N. (2019). "Design fire scenarios for railway tunnel fires." Proceedings of the IABSE Congress, New York City, NY, September 2-6.
- R. Napolitano, A. Moshirfar, Z. Liu, B. Glisic. "Virtual Tours and Augmented Reality for Direct Data Integration" International Association for Bridge and Structural Engineers, 4-6 September 2019.
- A. Blyth, R. Napolitano, B. Glisic. "Structural health monitoring in workflows for preservation engineering" 8th International Conference on Structural Health Monitoring of Intelligent Infrastructure, 4-7 August 2019.
- R. Napolitano, A. Moshirfar, Z. Liu, B. Glisic. "Combining image-based documentation and augmented reality to create a cyber physical system for the built environment" Engineering Mechanics Institute, 18-21 June 2019.
- A. Blyth, R. Napolitano, B. Glisic. "Damage diagnosis for historic marine infrastructure: Documentation, numerical modeling, and structural health monitoring of Morris Island Lighthouse" Engineering Mechanics Institute Conference, 18-21 June 2019.
- R. Napolitano, Z. Liu, C. Sun,B. Glisic. "Augmented and virtual reality environments for structural health monitoring" Structures Congress, 24-27 April 2019.
- R. Napolitano, Z. Liu, A. Blyth, B. Glisic. "Augmented Reality for Structural Inspection and Management", NYDOT 2019 Bridge Inspectors Meeting, 26-27 March, 2019.
- R. Napolitano, Z. Liu, C. Sun,B. Glisic. "Virtual tours, augmented reality, and informational modeling for visual inspection and structural health monitoring", SPIE Sensors and Smart Structures for Civil, Mechanical, and Aerospace Systems, 3-7 March 2019.
- A.Blyth, R. Napolitano, B. Glisic. "Integrative workflow for documentation, analysis, and structural health monitoring of marine infrastructure," SPIE Sensors and Smart Structures for Civil, Mechanical, and Aerospace Systems, 3-7 March 2019.
- R. Napolitano, Z. Liu, A.Blyth, B. Glisic. "SHM-based Virtual and Augmented Reality for Visual Inspection and Nondestructive Evaluation," Transportation Research Board (TRB) Webinar, 29 November 2019.
- Jon Carnegie, executive director of the Rutgers Voorhees Transportation Center, presented and co-facilitated a workshop at the TRB 98th Annual Meeting (January 13-17, 2019). The workshop title was "Building a Resilient Rail Transit" provided information on leading practices related to resilience adoption in the capital planning process.
- Hector J. Cruzado & Gustavo Pacheco, "General Overview and Case Studies of Damages in Puerto Rico due to Hurricane Maria", ASCE Forensic Engineering Congress 2018.
- Hua, N., Tessari, A., Elhami Khorasani, N. (2019). "Application of structural fire engineering for performance-based design of tunnels." Structures Congress, Orlando, FL, April 24-27.

- When Should We Post Weight Limits, 2018 Annual School for Highway Superintendents, Ithaca NY & 2019 Association of Towns of the State of New York, New York City, NY
- H. Wang, P. Okumus, R. Ranade, "Seismic Fragility of Bridges Subjected to Corrosion", 10th New York City Bridge Conference, New York, NY, Aug 26-27, 2019.
- H. Wang, R. Ranade, P. Okumus, "Seismic Fragility of Bridges Subjected to Corrosion", presentation to New York State Association of Transportation Engineers - Section 4, Buffalo, NY, April 3, 2019.
- Xia Luo, Bo Liu, Peter J. Jin, Yang Cao, Wansgu Hu (Ph.D. Student Advised), Arterial Traffic Flow Estimation based on Vehicle-To-Cloud (V2C) Vehicle Trajectory Data Considering Multi-Intersection Interaction and Coordination, Transportation Research Record, Accepted, 2019.
- Nasim Arbabzadeh, Mohsen A Jafari, et al., "A Hybrid Physics/Data-Driven Approach for Personalized Forward Collision Warning System," (with N. Arbabzadeh), Transportation Research – Part C – Emerging Technologies, Vol. 100, pp. 107-124, March 2019.
- Y. Huang, S. Jiang, M. Jafari and P. Jin, "Infrastructure Readiness for Transformative Changes in Transportation," Int'l Conf. on Smart Infrastructure and Construction, University of Cambridge, July 2019.
- Tianya Zhang, Peter J. Jin, A Longitudinal Scanline based Vehicle Trajectory Reconstruction Method for High-Angle Traffic Video, Transportation Research Part C, Accepted, 2019.

- **Policy Papers**
  Nothing to report
- **Website(s) or other Internet site(s)**
  https://www.facebook.com/RutgersCAIT/
  https://www.instagram.com/rutgerscait/
- **New methodologies, technologies or techniques**
  Incorporated into earlier sections of this report
- **Inventions, patents, and/or licenses**
  Nothing to report
- **Other products**

Outputs	Goal	Metric
1) a traditional or online training program.	3	3
2) a presentation and/or webinar.	10	18
3) a demonstration and/or pilot project.	3	1
4) a guidebook or similar publication in addition to an academic report.	8	4
5) a new specification.	1	1
6) new software or an app.	3	3
7) a new material and/or tangible product.	1	1
8) a potential patent or otherwise marketable product.	2	0
9) Primary or secondary customers will be tracked.	15	32
10) Implementation stakeholders will be tracked.	15	52
11) Implementation stakeholders that identify in each of the following will be tracked. *	Customer / Implementer	Customer / Implementer
a. Sponsors of research and T2	2 / 2	0 / 2
b. Researchers and/or developers	1 / 5	2 / 18
c. Early adopters and problem owners	5 / 5	14 / 25
d. Late adopters that follow the technology's development	3 / 5	5 / 9
e. Deployment team	3 / 3	6 / 6
f. Others, e.g., trade organizations, regulators, suppliers, etc.	1 / 3	1 / 13

12) Conceptual methodologies to calculate actual impact. How the PI expects to calculate the actual impact that a customer will realize by implementing the results.	15	41
13) The number of projects that help meet each USDOT Strategic Plan goal *	-	-
a. Safety: Reduce transportation-related fatalities and serious injuries across the transportation system.	5	7
b. Infrastructure: Invest in infrastructure to ensure mobility and accessibility and to stimulate economic growth, productivity, and competitiveness for American workers and businesses.	5	14
c. Innovation: Lead in the development and deployment of innovative practices and technologies that improve the safety and performance of the nation's transportation system.	5	16
d. Accountability: Serve the nation with reduced regulatory burden and greater efficiency, effectiveness, and accountability.	2	4

** Stakeholders or projects that fall under one or more category or goal may be counted more than once.*

4. OUTCOMES (What outcomes has the program produced? How are the research outputs described in section (3) above being used to create outcomes?

Outcomes	Goal	Metric
1) MOU/letters of commitment indicating a customer's commitment to adopt or that they have adopted/used	5	1 pending
2) full-scale adoption of a new technology technique, or practice, or the passing of a new policy, regulation, rule making, or legislation including commercialized or patented product	5	0

5. IMPACT (What is the impact of the program? How has it contributed to improve the transportation system: safety, reliability, durability, etc.; transportation education; and the workforce?)

Impacts	Goal	Metric
1) cost savings (time, money, or life-cycle performance)	$280k year one - $2.575M each subsequent year	0
2) durability and/or resilience and/or preservation	Zero in year one - 30 years each subsequent year	0
3) workforce proficiency or documented success stories	4 success stories	1

6. CHANGES/PROBLEMS

- ***Changes in approach and reasons for change.***
  Nothing to report
- ***Actual or anticipated problems or delays and actions or plans to resolve them.***
  Nothing to report
- ***Changes that have a significant impact on expenditures.***
  Nothing to report
- ***Significant changes in use or care of animals, human subjects, and/or biohazards.***
  Nothing to report