

# SEMI-ANNUAL PROGRAM PROGRESS REPORT

# FOR

# **UNIVERSITY TRANSPORTATION CENTERS**

| Project Title:                    | Center for Integrated Asset Management for Multimodal<br>Transportation Infrastructure Systems (CIAMTIS)  |
|-----------------------------------|---|
| Submitted to:                     | U. S. Department of Transportation<br>Office of the Assistant Secretary for Research and Technology   |
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| Center Partners:                  | Pennsylvania State University (lead), George Mason University,<br>Lehigh University, Morgan State University, University of<br>Delaware, Virginia Tech, and West Virginia University                  |
| Submission Date:<br>DUNS:<br>EIN: | October 30, 2020<br>00-340-3953<br>24-6000376   |
| Recipient Organization:           | Thomas D. Larson Pennsylvania Transportation Institute<br>Pennsylvania State University<br>201 Transportation Research Building<br>University Park, PA 16802  |
| Reporting Period:                 | April 1, 2020 through September 30, 2020  |

#### I. ACCOMPLISHMENTS

#### A. Major Goals of the Program

The vision of the Center for Integrated Asset Management for Multimodal Transportation Infrastructure Systems (CIAMTIS) Region 3 University Transportation Center (UTC) is to improve integrated asset management through research, education, and outreach activities that will enable transportation agencies to invest infrastructure funds when and where they are most critically needed. This will lead to improved ability of such agencies to deliver enhanced safe and cost-effective infrastructure management, and thereby gain the most benefit from available funds. The UTC activities will support multiple modes of transportation, including highways, rail, transit, air, maritime, and inter-modal transportation, with emphasis on highways and rail.

CIAMTIS addresses the following FAST Act priority area related to *Improving the Durability and Extending the Life of Transportation Infrastructure*. Within this priority area, CIAMTIS research, education, and outreach activities focus on the following three thrust areas:

- Application of Innovative Materials and Technologies, including research on development and deployment of new materials and technologies with potential high impact on transportation infrastructure needs.
- Condition Assessment and Health Monitoring, including development of automated, remote access (e. g., using drones), and remote-controlled inspection and monitoring technologies, as well as novel imaging, nondestructive evaluation, and self-sensing and health monitoring techniques, to provide rapid, repeatable, and reliable assessment of the present condition and rate of degradation of aging infrastructure facilities.
- Infrastructure Management and Innovative Financing, to advance infrastructure asset management at the project, network, and system decision levels. The goal is to support informed collaborative and multi-objective decision making on investments and address societal needs for safe, reliable, and resilient transportation infrastructure systems.
- B. Accomplishments During the Reporting Period

This semi-annual progress report covers the period of April 1, 2020 through September 30, 2020, which is the fourth reporting period for the regional center. The following center-wide activities have been accomplished during the reporting period.

# Center Website and Social Networking

The CIAMTIS website (available at: <u>https://r3utc.psu.edu)</u> is regularly updated and includes research project reports and technical briefs for several research projects that were completed during the reporting period. In addition to the CIAMTIS website, a website for the second annual TAIM conference was developed and updated regularly during the reporting period – this website can be found at the following link: <u>https://www.taim.psu.edu/</u>.

The CIAMTIS Facebook and Twitter social networking accounts are regularly updated to communicate CIAMTIS activities to interested stakeholders. The Facebook site is: <u>https://www.facebook.com/PSUR3UTC</u> and the Twitter account is: <u>https://twitter.com/psur3utc</u>

# CIAMTIS Newsletter

The CIAMTIS marketing and communications team began preparing content for the fall/winter 2020 newsletter during the reporting period. The upcoming issue will feature the following content: story about the 2<sup>nd</sup> annual TAIM conference; summaries/links to final research project reports; list of on-going projects with associated abstracts; education and outreach news; and highlights of a graduate student and post-doctoral scholar group that has been created among the CIAMTIS consortium. The newsletter will be disseminated to stakeholders throughout the mid-Atlantic region, including professional associations, state and federal transportation agencies, and academic institutions, during the next reporting period. It will also be posted on the CIAMTIS website.

# Center-wide Outreach and Technology Transfer Activities: Transportation Asset and Infrastructure Management Conference

Planning for the second annual TAIM conference continued throughout the reporting period. The conference will be held virtually using the Accelevents platform. The planning committee consists of more than 20 professionals from public and private sector organizations, as well as educational institutions – the committee has met at least monthly during the reporting period to develop the conference program. The program consists of the following activities:

- Two pre-conference workshops on Asset Management: these workshops are 150 minutes in duration and are planned for Monday, October 19, 2020.
- Twelve (12) concurrent technical sessions: the sessions are 90 minutes in duration and are planned on Tuesday, October 20, and Wednesday, October 21, 2020.
- A graduate student research exhibition: this session is planned for 60 minutes and will feature "lighting" talks from graduate students in the CIAMTIS consortium, on Wednesday, October 21, 2020.
- A keynote address by Leslie Richards, General Manager of the Southeastern Pennsylvania Transportation Authority (SEPTA) and former Pennsylvania Secretary of Transportation.

The following is a list of topics/sessions that are included in the conference program:

- Innovative materials, with a focus on asphalt and concrete transportation infrastructure applications
- Risk-based prioritization
- Local and transit agency asset management examples
- Asset resource allocation and trade-off analyses
- Deterioration modeling of transportation infrastructure assets
- Software utilization in asset management applications
- Financial planning for transportation asset management plans
- Automated condition assessment and structural health monitoring methods

The conference will be delivered during the next reporting period. At the time that this progress report was prepared, more than 120 participants had registered for the event.

#### **Research and Education Activities**

All research, education, and outreach activities undertaken by CIAMTIS consortium universities are allocated in two funding pools. Each partner university receives core funding that must support at least one education or technology transfer activity, as well as one or more research activities annually. This amounts to approximately one-half of the federal funds awarded to CIAMTIS. The remaining funds are awarded on a competitive basis via response to an annual call for proposals.

#### Year 1 Funds

The competitive proposal process resulted in 14 projects being awarded using Year 1 competitive funds. These projects are summarized in Table 1 below. The rows that are shaded are projects that were completed during the reporting period. Final reports for each of the research projects are currently under editorial review or are posted on the CIAMTIS website. Completed research reports were submitted to various repositories per UTC grant deliverables requirements.

In addition to the competitive proposals awarded using Year 1 funds, a collection of research and educational activities using core funds were awarded. These 16 projects are shown in Table 2. The shaded rows identify projects that were completed during the reporting period – final reports for the research projects are either under editorial review or are posted on the CIAMTIS website.

| Project   | Ы                                    | Thrust<br>Areas | PI Univ.               | Partner<br>Univ. | Performa | ance Dates | Activity<br>Type |
|---|--------------------------------------|-----------------|------------------------|------------------|----------|------------|------------------|
| Efficient Service Life Extension of Bridges<br>through Risk-based Life-cycle<br>Management and High-performance<br>Construction Materials: Emphasis on<br>Corrosion-resistant Steel | Frangopol,<br>Dan                    | A               | LU                     |                  | 3/1/19   | 9/1/20     | R                |
| Fatigue Life Estimation of Bridges with<br>Smart Mobile Sensing   | Pakzad,<br>Shamim N.                 | С               | LU                     |                  | 3/1/19   | 6/1/20     | R                |
| Life Extension of Fatigue-Damaged<br>Highway, Rail, and Transit Bridges   | Sause,<br>Richard                    | А, С            | LU                     |                  | 3/1/19   | 6/1/20     | R                |
| Numerical and Experimental<br>Investigation of Efficient Geometric<br>Arrangement of Metal Fin Tube<br>Foundations for Transportation<br>Applications                               | Qiu, Tong;<br>Laman,<br>Jeffrey      | A               | PSU                    |                  | 3/1/19   | 6/1/20     | R                |
| Time-Based Modeling of Concrete Bridge<br>Deck Deterioration Using Probabilistic<br>Models  | Guler, Ilgin                         | I               | PSU                    |                  | 3/1/19   | 2/1/20     | R                |
| Railroad Track Performance Monitoring<br>by Advanced Sensor Network & Big Data  | Huang, Hai                           | С               | PSU-<br>Altoona        | UDel             | 3/1/19   | 3/1/21     | R                |
| Use of SmartRock Sensors to Monitor<br>Pavement Performance for Supporting<br>Rehabilitation Decision Making  | Shen,<br>Shihui;<br>Wang,<br>Linbing | A               | PSU-<br>Altoona,<br>VT |                  | 3/1/19   | 3/1/21     | R                |
| Improved Methods to Assess Corrosion<br>Damage in Prestressed Concrete Beams  | Roberts-<br>Wollman,<br>Carin        | С               | VT                     |                  | 3/1/19   | 6/1/20     | R                |

Table 1. Projects Funded in Year 1 Competitive Program.

| Project   | Ы   | Thrust<br>Areas | PI Univ. | Partner<br>Univ. | Performa | ance Dates | Activity<br>Type |
|---|---|-----------------|----------|------------------|----------|------------|------------------|
| Development of a Practical Risk<br>Framework for Railway Bridge Stiffness<br>Transition Maintenance and Upgrade   | Palese,<br>Joseph                                 | С               | UDel     |                  | 3/1/19   | 3/1/20     | R                |
| Planning for the Inevitable: Readying<br>DOTs for Disaster Debris Management  | McNeil, Sue                                       | I               | UDel     |                  | 3/1/19   | 3/1/20     | E, TT            |
| Strategic Prioritization and Planning of<br>Transportation Infrastructure<br>Maintenance, Rehabilitation, and<br>Improvements Incorporating<br>Continuously-Sensed Data   | Miller-<br>Hooks,<br>Elise;<br>Lattanzi,<br>David | I               | GMU      | PSU,<br>UDel     | 3/1/19   | 3/1/21     | R                |
| Bridge Load Rating and Evaluation Using<br>Digital Image Measurements   | Head <i>,</i><br>Monique                          | С               | UDel     | GMU              | 3/1/19   | 3/1/21     | R                |
| Optimized Performance of UHPC Bridge<br>Joints and Overlays   | Mondal,<br>Paramita                               | А               | UDel     | PSU              | 3/1/19   | 3/1/21     | R                |
| Development of Low-Cost Weigh-In-<br>Motion (WIM) and Response Spectra<br>Techniques: "Development of Cost-<br>Effective Sensing System for Integrated<br>Traffic and Pavement Response<br>Monitoring in Support of Pavement<br>Management" | Wang,<br>Linbing                                  | С               | VT       | WVU              | 3/1/19   | 3/1/21     | R                |

Legend:

**Universities: GMU** is George Mason University; **LU** is Lehigh University; **MSU** is Morgan State University; **PSU** is Penn State University; **PSU-Altoona** is Penn State-Altoona; **UDel** is University of Delaware; **VT** is Virginia Tech; **WVU** is West Virginia University

**Thrust Areas:** A is application of innovative materials or technologies; C is condition assessment or structural health monitoring; I is infrastructure management and innovative financing

Activity Type: R is research; E is education; TT is technology transfer

| Project                                    | DI           | Thrust  | PLUniv | Partner | Performa | nce Dates | Activity |
|--|--------------|---------|--------|---------|----------|-----------|----------|
| Toject                                     | ••           | Areas   | TTOMV. | Univ.   | Beg.     | End       | Туре     |
| Residual Compressive Strength of Partially |              |         |        |         |          |           |          |
| Confined Concrete Column Retrofitted Using | Aslan, Kadir | А       | MSU    |         | 4/1/19   | 4/30/20   | R        |
| CFRP Wrap                                  |              |         |        |         |          |           |          |
| The Impact of Accessing Public Credit      | Gifford,     |         | CMU    |         | 1/25/10  | 2/24/20   | р        |
| Support on Public Private Partnerships     | Jonathan     | I       | GIVIO  |         | 1/25/19  | 3/24/20   | ĸ        |
| Imagine the Future: Exercises on           | Miller-      |         |        |         |          |           |          |
| Conceptualizing Infrastructure Systems for | Hooks,       | I.      | GMU    |         | 3/18/19  | 6/18/19   | E        |
| an Interconnected World                    | Elise        |         |        |         |          |           |          |
| CIAMTIS Graduate Fellowship at University  | McNeil,      |         | UDal   |         | 1/1/10   | 9/21/20   | F        |
| of Delaware                                | Sue          | A, C, I | obei   |         | 1/1/19   | 8/31/20   | E        |
| Enhancing Fundamentals of Engineering      | Zaniewski,   |         |        |         | 2/1/10   | 2/1/20    | E        |
| Program                                    | John         |         | 0000   |         | 5/1/19   | 5/1/20    | E        |
| Condition-based Inspection and Restoration | Millor       |         |        |         |          |           |          |
| Scheduling of Pavement and Bridge Systems  | Niller-      |         | CNUL   |         | 2/11/10  | 2/11/21   | р        |
| for Improved Post-disaster Infrastructure  | Flico        | I       | Givio  |         | 5/11/19  | 5/11/21   | n        |
| Systems Recovery                           | LIISE        |         |        |         |          |           |          |
| Finite Element Model Updating for Bridge   | Lattanzi     |         |        |         |          |           |          |
| Deformation Measurements Extracted from    | David        | С       | GMU    |         | 3/11/19  | 3/11/21   | R        |
| Remote Sensing Data                        | Daviu        |         |        |         |          |           |          |

# Table 2. Projects Funded in Core Program.

| Project  | PI                     | Thrust | PI Univ.        | Partner | Performa | ance Dates | Activity |
|--|------------------------|--------|-----------------|---------|----------|------------|----------|
| CIAMTIS Lehigh Research Experience for<br>Undergraduates (REU) Program   | Sause,<br>Richard      | A, C   | LU              | Oniv.   | 3/11/19  | 10/11/19   | E        |
| Road Pavement Condition Monitoring by<br>Embedded Crowdsensing   | Cheng,<br>Liang        | С      | LU              |         | 3/11/19  | 5/31/20    | R        |
| Design of Anchors for Rapid and Durable<br>Strengthening of Bridges with Externally<br>Bonded Carbon Fiber Reinforced Polymers   | Head,<br>Monique       | А      | UDel            |         | 3/11/19  | 3/11/21    | R        |
| Evaluation, Beneficiation, and<br>Implementation of Alternative Concrete<br>Pozzolans for Transportation Infrastructure  | Rajabipour,<br>Farshad | A      | PSU             |         | 3/11/19  | 3/11/20    | R        |
| A Novel Trackbed Material for Stiffness<br>Transition in Bridge Approaches and Its<br>Integration in Educational Outreach  | Shen,<br>Shihui        | А      | PSU-<br>Altoona |         | 3/11/19  | 3/11/20    | R, E     |
| Integration of Innovative Sensing<br>Technology and Data Analytics in<br>Transportation Asset Management   | Wang,<br>Linbing       | C, I   | VT              |         | 3/1/19   | 3/1/23     | R        |
| Evaluation of an Innovative Erosion Control<br>on Road Embankment Using Synthetic Turf<br>with Sand Infill   | Xiao, Ming             | А      | PSU             |         | 3/18/19  | 3/18/20    | R        |
| Automated Path Tracking and Mapping for<br>Economical, Real-Time, and Knowledge-<br>Based Roller Control in Pavement<br>Compaction Operations: Phase I: Algorithm<br>Development | Dai, Fei               | A      | WVU             |         | 3/18/19  | 3/18/20    | R        |
| Calibration of WVDOH IRI-based PSI and SCI<br>Equations  | Yoon,<br>Yoojung       | С      | WVU             |         | 8/1/19   | 1/1/21     | R        |
| Legend:  |                        |        |                 |         |          |            |          |

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Activity Type: R is research; E is education; TT is technology transfer

#### Year 2 and 3 Funds

Year 2 and 3 Federal funds were made available to the consortium in August 2019. Projects awarded via the competitive program are shown in Table 3, while awards made in the core program are shown in Table 4. During this reporting period, a total of eight (8) new projects were awarded in the core program. All of the competitive and core research, education, and outreach activities shown in Tables 3 and 4 will continue during the next reporting period.

#### CIAMTIS Graduate Research and Post-Doctoral Student Consortium (GRPDSC)

The CIAMTIS-GRPDSC was established during the reporting period and is comprised of about 60 students from the consortium institutions who are working on CIAMTIS projects. The group's overall goal is to expand their network and create connections among students in the CIAMTIS consortium. Each month, the Co-Presidents organize workshops that seeks to provide for the

research or educational interests of the group while also encouraging communication and shared resources via a group chat and Google Drive.

| Project  | PI                          | Thrust<br>Areas | PI Univ.        | Partner<br>Univ. | Performance Dates |           | Activity<br>Type |
|--|-----------------------------|-----------------|-----------------|------------------|-------------------|-----------|------------------|
| Decision Support Tools for Multi-objective,<br>Multi-asset, Multi-modal Joint<br>Maintenance Programming                         | McNeil, Sue                 | I               | UDel            | GMU,<br>PSU      | 1/20/2020         | 1/19/2022 | R                |
| Passive Strain Sensing Based on Changes in<br>Retroreflectivity  | Shenton, Harry              | А, С            | UDel            |                  | 1/20/2020         | 1/20/2022 | R                |
| Developing Equivalence Tools to Control<br>Quality of Transportation Infrastructure<br>Asset Management Data                     | Stoffels, Shelly            | I               | PSU             |                  | 3/1/2020          | 2/1/2021  | R                |
| AI-enabled fiscally constrained life-cycle<br>asset management for infrastructure<br>systems                                     | Papakonstantinou,<br>Kostas | I               | PSU             |                  | 1/20/2020         | 6/20/2021 | R                |
| Smart Mobile Platform for Model Updating<br>and Life Cycle Assessment of Bridges   | Pakzad, Shamim              | С               | LU              |                  | 1/20/2020         | 1/20/2022 | R                |
| Artificial Intelligence for Advance Landslide<br>Warning along Railroad Tracks in<br>Pennsylvania and Delaware                   | Qiu, Tong                   | С               | PSU             | UDel             | 7/1/2020          | 6/30/2022 | R                |
| Development of Turnout Rail Break<br>Warning System Based on Distributed<br>Optical Fiber Sensing Technologies                   | Huang, Hai                  | A, C            | PSU-<br>Altoona |                  | 1/1/2020          | 1/31/2022 | R                |
| Evaluation of IoT-Enabled Pavement<br>Response Monitoring for Transportation<br>System Management                                | Wang, Linbing               | С               | VT              | WVU              | 1/20/2020         | 7/19/2021 | R                |
| Unmanned Aerial Vehicles for Inspection of<br>Tack Coats and Ancillary Highway<br>Structures                                     | Dai, Fei                    | С               | WVU             | GMU,<br>VT       | 1/20/2020         | 1/20/2022 | R                |
| Durability Assessment of Externally Bonded<br>Fiber-Reinforced Polymer (FRP) Composite<br>Repairs in Bridge                      | Tatar, Jovan                | A               | UDel            |                  | 2/1/2020          | 7/31/2021 | R                |
| Extending Service Life of Rigid Pavement<br>Joints with Self-Healing Sealants  | Tatar, Jovan                | А               | UDel            | VT               | 1/31/2020         | 1/31/2022 | R                |
| Price Discovery for Strategic Compensation<br>of Toll Road Operators to Relieve State<br>Maintenance Impacts                     | Gifford,<br>Jonathan        | I               | GMU             | UDel             | 1/20/2020         | 1/31/2022 | R                |
| Preparing the Next Generation of<br>Undergraduate and Graduate Engineers in<br>Autonomous Robotic System for Damage<br>Detection | Efe, Steve                  | С               | MSU             |                  | 1/20/2020         | 1/20/2022 | E                |
| Integration of traffic and structural health<br>monitoring on the Varina-Enon Bridge via<br>sensor fusion                        | Sarlo, Rodrigo              | C, I            | VT              |                  | 1/20/2020         | 6/20/2021 | R                |

#### Table 3. Years 2 and 3 CIAMTIS Competitive Project Awards.

Legend:

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**Thrust Areas:** A is application of innovative materials or technologies; C is condition assessment or structural health monitoring; is infrastructure management and innovative financing

Activity Type: R is research; E is education; TT is technology transfer

L

| Project  | PI   | Thrust<br>Areas | PI Univ.        | Partner<br>Univ. | Performa | nce Dates | Activity<br>Type |
|--|--|-----------------|-----------------|------------------|----------|-----------|------------------|
| Automated Path Tracking and Mapping for<br>Economical, Real-Time, and Knowledge Based Roller<br>Control in Pavement Compaction Operations: Phase<br>II: Prototyping and Validation | Dai, Fei                                   | А               | WVU             |                  | 3/4/20   | 3/4/22    | R                |
| CIAMTIS Lehigh Research Experience for<br>Undergraduates (REU) Program – Year 2  | Sause, Richard                             | A, C            | LU              |                  | 3/4/20   | 10/31/20  | E                |
| Finite element model updating for bridge<br>deformation measurements extracted from remote<br>sensing data (Year 2 of a two-year project)  | Lattanzi, David                            | С               | GMU             |                  | 3/1/20   | 2/28/21   | R                |
| Detecting Disruptions, Defining Causes and<br>Understanding System Stability Restoration in<br>Disrupted Traffic Networks  | Miller-Hooks,<br>Elise                     | I               | GMU             |                  | 3/4/20   | 12/3/21   | R                |
| Optimization Framework for Infrastructure<br>Management Considering Traffic Safety Costs   | Guler, S. Ilgin                            | I               | PSU             |                  | 6/1/20   | 12/1/21   | R                |
| Experimental and Numerical Investigation of<br>Recycled Fiber Reinforced Concrete for Green Bus<br>Pads  | Aslan, Kadir                               | A               | MSU             |                  | 3/4/20   | 3/4/22    | R                |
| Prioritization Framework of ITS Technologies in the context of Smart Cities  | Yoon, Yoojung                              | I               | WVU             |                  | 5/3/20   | 11/3/21   | R                |
| Use of Machine Learning to Predict Long-Term Skid<br>Resistant of Concrete Pavements   | Rajabipour,<br>Farshad                     | А               | PSU             |                  | 5/11/20  | 2/11/21   | R                |
| Optimization Framework for Infrastructure<br>Management Considering Traffic Safety Costs   | Guler, Ilgin                               | Ι               | PSU             |                  | 6/1/20   | 12/1/21   | R                |
| Transportation Infrastructure Readiness for Post-<br>Pandemic Supply Chain Transformation for greater<br>Resilience  | Miller-Hooks,<br>Elise                     | I               | GMU             |                  | 6/1/20   | 6/1/22    | R                |
| Smart Compaction for Infrastructure Materials  | Shen, Shihui                               | А               | PSU-<br>Altoona |                  | 6/1/20   | 6/1/22    | R                |
| Railroad Engineering Education & Outreach  | Shen, Shihui /<br>Huang, Hai               | А               | PSU-<br>Altoona |                  | 6/1/20   | 6/1/22    | E                |
| Life Extension of Fatigue-Damaged Highway, Rail,<br>and Transit Bridges: Identifying Actual Crack Tip  | Pessiki, S /<br>Sause, R /<br>Hodgson, Ian | A               | LU              |                  | 8/3/20   | 8/2/22    | R                |
| Video-Sensor Data Fusion for Enhanced Structural<br>Monitoring   | Lattanzi, David                            | С               | GMU             |                  | 9/1/20   | 8/31/21   | R                |

# Table 4. Years 2 and 3 CIAMTIS Core Project Awards.

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# **CIAMTIS Professional Development Webinar Series**

During the reporting period, CIAMTIS developed a plan to deliver a monthly professional development webinar series. This included a proposal to obtain continuing education units for participants for each one-hour session that they attend – Penn State has confirmed that each one-hour webinar will provide for 0. 1 CEUs. In addition, Penn State's Conferences and Institutes has

agreed to work with CIAMTIS team members to schedule the webinars, host the sessions via a virtual platform, and manage participant registrations. In addition, the CIAMTIS team began developing an initial program for the series and expects to initiate it during the next reporting period.

#### **Other Administrative Activities of CIAMTIS**

The following other administrative activities have been completed during the current reporting period:

- CIAMTIS consortium members continue participating in monthly progress report meetings via teleconference to discuss research and education activities, reporting requirements, and other matters of interest related to the Center.
- All new research projects shown in Tables 3 and 4 have been added to the Transportation Research Board's (TRB) Research in Progress (RIP) database and documented on the CIAMTIS website.

#### Specific Education and Outreach Accomplishments of CIAMTIS Consortium Members

The following are some highlights of accomplishments from education and outreach projects during the reporting period for several CIAMTIS consortium members.

#### Penn State-Altoona

Faculty were able to complete two rounds of the Women in Engineering Design Competition during the spring 2020 semester, while rescheduling the third round to the fall 2020 semester. In addition, program faculty helped advance minority student outreach through participation in a virtual college recruiting event with Transit Tech High School in Brooklyn, NY, during the reporting period.

#### Morgan State University

Faculty participated in a Baltimore County summer youth employment program to train a high school student on recycled fiber reinforced concrete (FRC) and numerical modelling of FRC beams/slabs. This student presented the summer project at STEM youth conference during summer 2020. In addition, faculty at Morgan State University (MSU) developed two capstone projects for five undergraduate students in civil engineering based on CIAMTIS research activities.

MSU also initiated an 8-week robotics training program for undergraduate and graduate students to detect cracks in concrete surfaces, and to help students develop foundational skills in machine learning and artificial intelligence methods, during the reporting period.

#### Lehigh University

Through its Institute for Cyber Physical Infrastructure and Energy (I-CPIE) and its Advanced Technology for Large Structural Systems (ATLSS) Engineering Research Center, Lehigh University ran a 10-week CIAMTIS Lehigh Research Experience for Undergraduates (REU) program during the reporting period. The REU program funded 6 students from Lehigh to participate in the program. The program's focus included the assignment of each student to an active Lehigh University CIAMTIS research project under the direction of the project Principal Investigator and graduate student mentor to help the student navigate through the research project experience. Beyond the research experience, the program exposed the students to a well-rounded professional development experience. The program's activities included professional skills development workshops. The program culminated with a final report, poster, and presentation on the research findings to program faculty in July 2020.

C. How have the results been disseminated?

During the current reporting period, several research and education project results have been disseminated – a sample of several are provided below. Additionally, research project results were disseminated via several journal and conference publications and other avenues as reported in section III Outputs below.

- Penn State-Altoona faculty have reported research and education/outreach activities to their Rail Transportation Engineering (RTE) Advisory Board, which includes 22 railroad industry professionals and executives from across the industry. These activities were held virtually at board meetings in April and early October.
- There are numerous CIAMTIS faculty and graduate student presenting their research at the 2<sup>nd</sup> annual Transportation Asset and Infrastructure Management (TAIM) Conference in October 2020.
- D. What do you plan to do during the next reporting period to accomplish the goals?

# **CIAMTIS Center-wide Core and Competitive Research and Educational Activities**

The active projects shown in Tables 1 through 4 will continue during the next reporting period. It is anticipated that several research projects will conclude during the next reporting period, so project Principal Investigators will begin publishing final reports and technical briefs of their research during the next reporting period. In addition, a third call for competitive proposals was issued in September 2020. Proposals are due in November 2020, and peer-review will then occur in December 2020. It is anticipated that competitive project awards will be made during the spring 2021 semester, and that core proposals will then be solicited from the consortium partners.

# **CIAMTIS Technology Transfer and Outreach Activities**

- Penn State will deliver the 2<sup>nd</sup> annual Transportation Asset and Infrastructure Management (TAIM) conference on October 19-21, 2020.
- CIAMTIS will begin planning for the 3<sup>rd</sup> annual TAIM conference during the next reporting period.
- CIAMTIS will launch the annual professional development webinar series. It is envisioned that research projects shown in Tables 1 and 2 will have significant technology transfer components and these will be shared via one-hour webinars.

- CIAMTIS will continue disseminating newsletters during the next reporting period, highlighting progress from several research and educational activities, as well as summarizing planned Center events and activities.
- Rail Transportation Engineering (RTE) faculty at Penn State-Altoona will reconnect with schools to promote the "City-to-the-State" program, host a Kids College railroad engineering camp for 11-14 year old students during the summer of 2021, host a Railroad Engineering Summer camp for high school students during the summer of 2021, and begin planning for the next Railroad Industry Exchange conference (RRIX) tentative date in Fall 2021.
- University of Delaware will deliver the ArtsBridge scholars program, Annual Interuniversity Symposium on Infrastructure Management (AISIM), and the Infrastructure Management "Bootcamp" in 2021, after postponing them in summer 2020.

# II. PARTICIPANTS AND COLLABORATING ORGANIZATIONS

Below is a list of organizations who have been involved as CIAMTIS partners during the current reporting period. This includes state transportation agencies, materials suppliers, professional trade organizations, and heavy highway contractors. Each partner organization's contribution to a particular activity is noted.

| Organization Name:                        | Pennsylvania Department of Transportation  |
|---|--|
| Location of Organization:                 | Harrisburg, PA   |
| Partner's contribution(s) to the project: | PennDOT executed an agreement with Penn State to offer matching funds for research activities undertaken by CIAMTIS faculty. The agreement ends on September 30, 2023 with a funding limit of \$2.5 million. PennDOT, Penn State, and the FHWA formed a steering committee to identify projects to be funded using agreement resources. The steering committee meets annually to discuss candidate matching projects. Several projects are advancing via these collaborative meetings. |
|   | PennDOT is also collaborating on Lehigh University projects by assisting to identify bridges that can be used for field research.  |
| Organization Name:                        | Delaware Department of Transportation  |
| Location of Organization:                 | Dover, Delaware  |
| Partner's contribution to project:        | Offering collaborative research support to several University of Delaware research projects.   |
| Organization Name:                        | Aegion-Fyfe  |
| Location of Organization:                 | San Diego, CA  |
| Partner's contribution to project:        | Aegion-Fyfe is providing in-kind support for the University of Delaware<br>project titled "Design of Anchors for Rapid and Durable Strengthening of<br>Bridges with Externally Bonded Carbon Fiber Reinforced Polymers"  |
| Organization Name:                        | American Concrete Institute  |
| Location of Organization:                 | Farmington Hills, MI   |
| Partner's contribution to project:        | In addition, the University of Delaware is partnering with ACI Committee 440 to identify the experimental data test gaps to advance the knowledge and  |

|  | performance of repair and strengthening existing concrete bridges with fiber reinforced polymer (FRP) anchors.   |
|--|--|
| <b>Organization Name:</b>  | High Steel Structures (in collaboration with Lehigh University)  |
| Location of Organization:  | Lancaster, PA  |
| Partner's contribution(s) to the project:  | This partner is performing collaborative research with Lehigh University by offering in-kind support of steel components for testing.  |
| Organization Name:   | University of Delaware and Delaware T2 (LTAP)  |
| Location of Organization:  | Newark, DE   |
| Partner's contribution(s) to the project:  | The University of Delaware LTAP is providing in-kind support and collaborative research with University of Delaware faculty for various education, research, and outreach initiatives  |
| <b>Organization Name:</b>  | West Virginia Department of Highways   |
| Location of Organization:  | Charleston, West Virginia  |
| Partner's contribution(s) to the project:  | This partner is providing matching funds for projects undertaken by West Virginia University and collaborating on the research.  |
| Organization Name:   | Asphalt Paving Association of West Virginia  |
| Location of Organization:  | Charleston, West Virginia  |
| Partner's contribution(s) to the project:  | This partner is working collaboratively on projects undertaken by West Virginia University faculty.  |
|  |  |
| Organization Name:   | Pennsylvania Infrastructure Technology Alliance  |
| Organization Name:<br>Location of Organization:<br>(if foreign, list country)  | Pennsylvania Infrastructure Technology Alliance<br>Harrisburg, Pennsylvania  |
| Organization Name:<br>Location of Organization:<br>(if foreign, list country)<br>Partner's contribution(s) to<br>the project:  | Pennsylvania Infrastructure Technology AllianceHarrisburg, PennsylvaniaThe Pennsylvania Infrastructure Technology Alliance (PITA) is a<br>collaboration of the Commonwealth of Pennsylvania, the Center for Advanced<br>Technology for Large Structural Systems (ATLSS) at Lehigh University, and<br>the Institute for Complex Engineered Systems at Carnegie Mellon University.PITA offers matching funds to competitive and core research projects<br>conducted by Lehigh University.  |
| Organization Name:<br>Location of Organization:<br>(if foreign, list country)<br>Partner's contribution(s) to<br>the project:<br>Organization Name:  | Pennsylvania Infrastructure Technology AllianceHarrisburg, PennsylvaniaThe Pennsylvania Infrastructure Technology Alliance (PITA) is a<br>collaboration of the Commonwealth of Pennsylvania, the Center for Advanced<br>Technology for Large Structural Systems (ATLSS) at Lehigh University, and<br>the Institute for Complex Engineered Systems at Carnegie Mellon University.<br>PITA offers matching funds to competitive and core research projects<br>conducted by Lehigh University.Norfolk Southern  |
| Organization Name:<br>Location of Organization:<br>(if foreign, list country)<br>Partner's contribution(s) to<br>the project:<br>Organization Name:<br>Location of Organization:<br>(if foreign, list country)   | Pennsylvania Infrastructure Technology AllianceHarrisburg, PennsylvaniaThe Pennsylvania Infrastructure Technology Alliance (PITA) is a<br>collaboration of the Commonwealth of Pennsylvania, the Center for Advanced<br>Technology for Large Structural Systems (ATLSS) at Lehigh University, and<br>the Institute for Complex Engineered Systems at Carnegie Mellon University.<br>PITA offers matching funds to competitive and core research projects<br>conducted by Lehigh University.Norfolk SouthernNorfolk, VA   |
| Organization Name:         Location of Organization:         (if foreign, list country)         Partner's contribution(s) to         the project:         Organization Name:         Location of Organization:         (if foreign, list country)         Partner's contribution(s) to         the project:  | Pennsylvania Infrastructure Technology AllianceHarrisburg, PennsylvaniaThe Pennsylvania Infrastructure Technology Alliance (PITA) is a<br>collaboration of the Commonwealth of Pennsylvania, the Center for Advanced<br>Technology for Large Structural Systems (ATLSS) at Lehigh University, and<br>the Institute for Complex Engineered Systems at Carnegie Mellon University.<br>PITA offers matching funds to competitive and core research projects<br>conducted by Lehigh University.Norfolk SouthernNorfolk, VAOffer in-kind support for student educational projects and made a recent gift<br>of \$20,000 for educational outreach efforts, as well as a locomotive gift to<br>faculty in Penn State-Altoona RTE program for use in teaching labs and for<br>K-12 outreach activities.  |
| Organization Name:Location of Organization:<br>(if foreign, list country)Partner's contribution(s) to<br>the project:Organization Name:Location of Organization:<br>(if foreign, list country)Partner's contribution(s) to<br>the project:Organization Name:Organization Name:   | Pennsylvania Infrastructure Technology AllianceHarrisburg, PennsylvaniaThe Pennsylvania Infrastructure Technology Alliance (PITA) is a<br>collaboration of the Commonwealth of Pennsylvania, the Center for Advanced<br>Technology for Large Structural Systems (ATLSS) at Lehigh University, and<br>the Institute for Complex Engineered Systems at Carnegie Mellon University.<br>PITA offers matching funds to competitive and core research projects<br>conducted by Lehigh University.Norfolk SouthernNorfolk, VAOffer in-kind support for student educational projects and made a recent gift<br>of \$20,000 for educational outreach efforts, as well as a locomotive gift to<br>faculty in Penn State-Altoona RTE program for use in teaching labs and for<br>K-12 outreach activities.Mission Critical Solutions  |
| Organization Name:Location of Organization:<br>(if foreign, list country)Partner's contribution(s) to<br>the project:Organization Name:Location of Organization:<br>(if foreign, list country)Partner's contribution(s) to<br>the project:Organization Name:Location of Organization:<br>(if foreign, list country)Partner's contribution(s) to<br>the project:Organization Name:Location of Organization:<br>(if foreign, list country)   | Pennsylvania Infrastructure Technology Alliance         Harrisburg, Pennsylvania         The Pennsylvania Infrastructure Technology Alliance (PITA) is a         collaboration of the Commonwealth of Pennsylvania, the Center for Advanced         Technology for Large Structural Systems (ATLSS) at Lehigh University, and         the Institute for Complex Engineered Systems at Carnegie Mellon University.         PITA offers matching funds to competitive and core research projects         conducted by Lehigh University.         Norfolk Southern         Norfolk, VA         Offer in-kind support for student educational projects and made a recent gift         of \$20,000 for educational outreach efforts, as well as a locomotive gift to         faculty in Penn State-Altoona RTE program for use in teaching labs and for         K-12 outreach activities.         Mission Critical Solutions         Alum Bank, PA  |
| Organization Name:Location of Organization:<br>(if foreign, list country)Partner's contribution(s) to<br>the project:Organization Name:Location of Organization:<br>(if foreign, list country)Partner's contribution(s) to<br>the project:Organization Name:Location of Organization:<br>(if foreign, list country)Partner's contribution(s) to<br>the project:Organization Name:Location of Organization:<br>(if foreign, list country)Partner's contribution(s) to<br>the project:Partner's contribution(s) to<br>the project: | Pennsylvania Infrastructure Technology Alliance         Harrisburg, Pennsylvania         The Pennsylvania Infrastructure Technology Alliance (PITA) is a collaboration of the Commonwealth of Pennsylvania, the Center for Advanced Technology for Large Structural Systems (ATLSS) at Lehigh University, and the Institute for Complex Engineered Systems at Carnegie Mellon University.         PITA offers matching funds to competitive and core research projects conducted by Lehigh University.         Norfolk Southern         Norfolk, VA         Offer in-kind support for student educational projects and made a recent gift of \$20,000 for educational outreach efforts, as well as a locomotive gift to faculty in Penn State-Altoona RTE program for use in teaching labs and for K-12 outreach activities.         Mission Critical Solutions         Alum Bank, PA         The partner is working with Penn State by providing matching funds and in-kind support for fabricating small-scale metal fin tube foundations and laboratory test setup. |

| Location of Organization:<br>(if foreign, list country) | Blacksburg, VA  |
|---|---|
| Partner's contribution(s) to the project:               | Sentek is providing in-kind support and collaboration with Virginia Tech faculty on the project "Integration of Innovative Sensing Technology and Data Analytics in Transportation Asset Management." |

In addition to the collaborations identified above, several international collaborations were undertaken by CIAMTIS faculty during the reporting period. Examples are provided below:

- George Mason University faculty are collaborating with Professor Eleni Chatzi from ETH, Zurich in Switzerland on journal manuscripts related to the strategic prioritization and planning of transportation infrastructure maintenance, rehabilitation, and improvements incorporating continuously-sensed data.
- George Mason University faculty have collaborated with faculty at Hong Kong Polytechnic University on topics related to condition-based inspection and restoration scheduling of pavement and bridge systems for improved post-disaster infrastructure systems recovery.
- Collaborators at NSWC Carderock (a NAVSEA research facility) have shared relevant data and helped in the conceptualization of finite element modeling approaches on George Mason University research projects.

# III. OUTPUTS

A. List any outputs resulting from the program during the reporting period. (e. g., Publications, conference papers, and presentations; New methodologies, technologies or techniques; Inventions, patents, and/or licenses)

The CIAMTIS research performance metrics, goals, and targets are shown in Table 5, while the technology transfer performance metrics, goals, and targets are shown in Table 6. The following summarizes progress toward several of these targets during the current reporting period:

- 22 journal publications were submitted or published during the current and previous semiannual reporting periods;
- 36 conference presentations were planned or delivered during the current and previous semi-annual reporting periods (several conferences or conference presentations have been postponed until 2021 due to COVID);
- One patent application was submitted during the current reporting period;
- More than 20 graduate and undergraduate students were involved in CIAMTIS research projects during most recent federal fiscal year (per annual performance indicators report).
- There were 712 website visitors during the reporting period, up 99 percent from the previous reporting period.

| Output, Outcome, or Impact | Performance Measure  | Target |
|----------------------------|--|--------|
| Output #1                  | Annual number of journal publications  | 30     |
| Output #2                  | Annual number of conference presentations  | 40     |
| Outcome #1                 | Annual number of times research changes a standard practice, guideline, or specification         | 2      |
| Outcome #2                 | Annual number of media stories referencing CIAMTIS research, faculty, or students                | 12     |
| Impact #1                  | Percentage of research projects that extend infrastructure asset life by 10%                     | 20%    |
| Impact #2                  | Percentage of research projects that reduce repair, maintenance, and rehabilitation costs by 10% | 20%    |

# Table 5. Research Performance Metrics

# Table 6. Performance Metrics for CIAMTIS Technology Transfer Activities

| <b>Performance Metric</b>                          | Assessment Measure  | Performance Targets   |
|--|---|---|
| Partnership with<br>Private and Public<br>Entities | <ul> <li>✓ Number of technologies advanced to<br/>State Transportation Innovation<br/>Councils (STIC) in each state or<br/>nominated for Every Day Counts (EDC)<br/>and Accelerated Innovation Deployment<br/>(AID) programs.</li> <li>✓ Number of adopted technologies or<br/>programs.</li> </ul> | <ul> <li>✓ One STIC technology innovation<br/>annually.</li> <li>✓ One adopted technology or program<br/>annually.</li> </ul>             |
| Patents and<br>Commercialization                   | <ul> <li>✓ Number of invention disclosures,<br/>patents, and copyright applications.</li> <li>✓ Number of license agreements.</li> </ul>  | <ul> <li>✓ One invention disclosure, patent, or<br/>copyright application annually.</li> <li>✓ One license agreement annually.</li> </ul> |
| Publications and<br>Presentations                  | Number of publications and presentations per project and per thrust area.   | One publication and presentation per project per year.  |
| Information Exchange                               | Number of website visitors, news reports, and tech-briefs.  | 500 website visitors annually, seven news reports annually, and seven technical briefs annually.  |
| Continuing Education<br>Courses                    | <ul> <li>✓ Number of courses offered annually.</li> <li>✓ Number of participants.</li> </ul>  | ✓ Three continuing education courses<br>offered annually with at least 25<br>participants per course.                                     |
| Number of students<br>supported                    | <ul> <li>✓ Number of undergraduate and graduate<br/>students supported annually by<br/>CIAMTIS</li> </ul>   | <ul> <li>✓ Support at least 20 undergraduate and 20 graduate students annually.</li> </ul>  |

#### B. Publications, Conference Papers, and Presentations

#### Journal Publications

- Zhang, C., S. Shen, H. Huang, and L. Wang. Estimation of the Vehicle Speed using Cross-Correlation Algorithms and MEMS Wireless Sensors. Submitted to *Sensors*, 2020.
- Yu, S., S. Shen, H. Huang, and C. Zhang. Engineered Semi-flexible Composite Mixture and Its Implementation Method for Mitigating Railroad Bridge Transition. Submitted to *Transportation Research Record: Journal of the Transportation Research Board*, 2020.

- Begany, M., J. Ambrosino, and B. Schlake. Railroad Trespassing on Rising Fatalities and Potential Solutions. Accepted for publication in *Joint Rail Conference Proceedings*, Virtual Conference, April 2021.
- Shokouhian, M. and T. Tsegaye. Recycled Fiber Reinforced Concrete for Green Bus Pads. Submitted to *Structure Congress 2021*.
- Zhou, W. and E. Miller-Hooks. Multi-asset roadway improvement scheduling with updated asset states for enhanced traffic network reliability. Accepted for publication in 8<sup>th</sup> *International Conference on Transport Network Reliability*, Stockholm, Sweden (originally scheduled in June 2020, but postponed to 2021).
- Lu, L., F. Dai, and J. Zanewski. Automatic roller path tracking and mapping for pavement compaction using infrared thermography. Submitted to *Computer-aided Civil and Infrastructure Engineering*, 2020.
- Gulgec, N. S., M. Takac, and S. N. Pakzad. Structural Sensing with Deep Learning: Strain Estimation from Acceleration Data for Fatigue Assessment. *Journal of Computer-aided Civil and Infrastructure Engineering*, Accepted, available online May 20, 2020.
- Sadeghi Eshkevari, S., S. N. Pakzad, M. Takac, and T. J. Matarazzo. Modal Identification of Bridges using Mobile Sensors with Sparse Vibration Data. *Journal of Engineering Mechanics*, Vol. 146(4), April 2020, 18 pp.
- Lu, M., J. Hydock, S. I. Guler, and A. Radlinska. Bayesian Monte Carlo Markov Chain Methodology for Bridge Deck Deterioration. Submitted for publication consideration to *ASCE Journal of Infrastructure Systems*.
- Pei, T., T. Qiu, and J. Laman. A Numerical Parametric Study of Laterally Loaded Steel Fin Pile Foundations in Sand. Submitted for publication consideration to *ASCE International Journal of Geomechanics*, 2020.
- Wang, Z., D. Ildefonzo, M. Abbas, and L. Wang. Pavement Fatigue Crack Detection and Severity Classification based on Deep Convolutional Neural Network. Submitted for publication consideration to *Journal of Pavement Research and Technology*, 2020.
- Ismail, H., M. Xiao, S. Salam, B. Scholl, and X. Liu. Infill Mobility through an Engineered Synthetic Turf on Steep Slopes. *ASCE Journal Hydraulic Engineering*. Revision submitted in Oct 2020.
- K. Jafari and F. Rajabipour. The performance of impure calcined clay as a pozzolan in concrete. Accepted for publication in Transportation Research Record: Journal of the Transportation Research Board, April 2020.

# Other Publications, Conference Papers, and Presentations

- Dargahi, M., S. Mohamadi, and D. Lattanzi. Life-cycle Modeling of Infrastructure Assessment Data for Predictive Analytics. Accepted for presentation at *Structures Congress 2020* (postponed to 2021).
- Dargahi, M. and D. Lattanzi. Quantifying Structural Damage via 3D Point Cloud Complexity. Accepted for presentation at *Engineering Mechanics Institute 2020* (postponed to 2021).
- Graves, W., S. Mohamadi, and D. Lattanzi. Finite Element Model Updating through Photogrammetry and Spatial Statistical Analysis. Accepted for presentation at the *European Workshop on Structural Health Monitoring 2020* (postponed to 2021).

- Lattanzi, D., S. McNeil, E. Miller-Hooks, K. Papakonstantinou, and S. Stoffels. Using Visualization and Intelligent Technologies to Manage the Transportation Infrastructure. Accepted for presentation at the *TRB Asset Management Conference*, Boston, MA (originally scheduled for July 2020, but postponed to August 2021).
- Dargahi, M., S. Mohamadi, and D. Lattanzi. Life-cycle modeling of infrastructure assessment data for predictive analytics. Accepted for *Structures Congress 2020*.
- Dargahi, M. and D. Lattanzi. Quantifying Structural Damage via 3D Point Cloud Complexity. Accepted for *Engineering Mechanics Institute 2020*.
- Graves, W., S. Mohmadi, and D. Lattanzi. Finite element model updating through photogrammetry and spatial statistical analysis. Accepted for *European Workshop on Structural Health Monitoring 2020*.
- Andriotis, C. P., K. G. Papakonstantinou, and E. N. Chatzi. Value of structural health information in partially observable stochastic environments. *Structural Safety*, also as arXiv preprint: <u>https://arxiv.org/abs/1912.12534</u>, 2020.
- Lu, L. and F. Dai. A Thermal-based technology for roller path tracking and mapping in pavement compaction operations. Accepted for publication and presentation at *Proceedings of the 2020 Winter Simulation Conference*, IEEE. December 13-16, Orlando, Florida, USA.
- Gulgec, N. S., M. Takac, and S. N. Pakzad. Multi-LSTM-Based Framework for Ambient Intelligence. Intelligent Systems Conference, 2020, Accepted.
- Gulgec, N. S., Z. Shi, N. Deshmukh, S. N. Pakzad, and M. Takac. FD-Net with Auxiliary Time Steps: Fast Prediction of PDEs using Hessian-Free Trust-Region Methods. NeurIPS Workshop on Beyond First-Order Methods in ML. Accepted for Publication, Conference planned for July 2020, Vienna, Austria (postponed to December 2020, virtual).
- Sadeghi Eshkevari, S. and S. N. Pakzad. Physics-based Neural Network for Bridge Fatigue Analysis. Accepted for Publication for EMI/PMC 2020 Conference, Planned for New York, NY, May 2021.
- Lu, M., J. Hydock, S. I. Guler, and A. Radlinska. Bayesian Monte Carlo Markov Chain Methodology for Bridge Deck Deterioration. Accepted for presentation to 100<sup>th</sup> Annual Meeting of the Transportation Research Board, Virtual Meeting, January 2021.
- Hydock, J., M. Lu, S. I. Guler, and A. Radlinska. Bridge Deck Deterioration Modeling for Pennsylvania Bridges. Accepted for presentation to 100<sup>th</sup> Annual Meeting of the Transportation Research Board, Virtual Meeting, January 2021.
- Pei, T., T. Qiu, and J. Laman. A Numerical Investigation of Laterally Loaded Steel Fin Pile Foundations. *Proceedings of the Joint-Rail Conference*, St. Louis, MO, April 2020 (postponed to April 2021).
- Ismail, H., M. Xiao, S. Salam, B. Scholl, M. Zhu, and X. Liu (2020) Experimental Study of infill Mobility through an Engineered Synthetic Turf Bed, *Proceedings of the 10th International Conference on Scour and Erosion (ICSE-10)* [conference is postponed to Oct 14-17, 2021].

Website(s) or Other Internet Site(s) (Not necessary to include the publications already specified above in this section. ): Nothing to report this period

# Technologies or Techniques:

CIAMTIS researchers are developing the following technologies or techniques as part of research projects:

- A 3D deformation measurement technique designed for use with remote sensing systems under field conditions for infrastructure inspection.
- A statistically driven interpolation technique for point cloud data, with inherent uncertainty quantification
- A technique for mapping point cloud field measurements into numerical simulations.
- Methodology to support the evaluation of a transformation in international supply chains towards a "manufactured in the U. S." approach.
- Tools for measuring post-pandemic supply chain resilience improvements for the U.S.
- Mathematical solution methods that account for endogeneity in uncertainty arising from inspections and continuous data updates on asset state for use in post-disaster roadway repair.
- Multi-asset decision-support tools for strategic planning of maintenance, repair and rehabilitation options.
- Prototyping predictive analytics methods based on feature extraction and latent feature space temporal modeling.
- Serviceability objectives and development of simulated environments for systems of pavements and bridges.
- Bilevel program using concepts of Markov Decision Processes and traffic user equilibrium to create framework for project planning and prioritization, and approximate dynamic programming techniques for their solution.
- Methodology for quantification of the value of monitoring systems through Partially Observable Markov Decision Processes.

Inventions, Patent Application, and/or Licenses (include date, and/or licenses that have resulted from the research):

Patent Application. Invention description: Automatic Roller Path Tracking and Mapping for Pavement Compaction Using Infrared Thermography, submitted to WVU Office of Tech Transfer on 10/11/2020, Invention Disclosure Completed.

# IV. OUTCOMES [WHAT OUTCOMES HAS THE PROGRAM PRODUCED? HOW ARE THE RESEARCH OUTPUTS DESCRIBED IN SECTION (III) ABOVE BEING USED TO CREATE OUTCOMES?]

A. What outcomes has the program produced? How are the research outputs being used to create outcomes?

Programmatic outcomes will be measured after completion of the initial set of research projects (see Tables 1 and 2) are completed. Examples of outcomes produced to date include the following:

- Introduced over 40 Penn State women engineering students to Rail Transportation Engineering through the WE-Design program.
- Morgan State University faculty are investigating the cause of the cracking of bus pads and developing a more sustainable design and monitoring approach. This will lead to less frequent reconstruction, thereby reducing costs to maintain transit bus pads. Use of recycled fiber extracted from used tires will also lead to reduced environmental impacts as a result of the research.
- West Virginia University developed an algorithm of a thermal image-based intelligent compaction technology has been implemented into a prototype and tested in the lab. This cost-effective technology will help the paving industry better control the quality of asphalt paving operations.
- George Mason University outcomes from CIAMTIS projects include: acceptance of work for presentation at conferences and a paper that is undergoing revision and resubmission for a journal that are expected to promote the important discussion on the federal support for transportation infrastructure sector, facing new bill amendment; and nearly-ready, open source code to be included in a newly developed source code repository (LRGpy) hosted on Github. Data hosted on Github will be shared through the UTC data hub at the end of the project.

*B.* Discuss the performance measures (a minimum of two) for research outcome and the targets (goals) for each measure: Nothing to report this period

# V. IMPACTS [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?]

# A. Impact:

Morgan State University developed a professional engineering (PE) training course to support the industry need for licensed engineers in Maryland. This professional development activity will enhance the development of engineers in the state and create a community of licensed engineers to hand the 21<sup>st</sup> century infrastructure challenges facing the transportation industry. To date, 15 professionals have enrolled in the training program.

West Virginia University is developing a new, inexpensive compaction technology which will help control the quality of asphalt concrete pavements being constructed. This will make intelligent compaction more affordable, potentially leading to wider adoption and, therefore, enhancing reliability and durability of newly-constructed asphalt concrete pavements.

The Penn State project titled "Evaluation of an Innovative Erosion Control on Road Embankment Using Synthetic Turf with Sand Infill" was co-sponsored by the industry partner Watershed Geo. Findings from the work have directly informed business decisions made by the company.

The Penn State project titled "Evaluation, Beneficiation, and Implementation of Alternative Concrete Pozzolans for Transportation Infrastructure," in collaboration with industry partner York Building Products, is working with Argos Cement company to scale-up the developed technology and produce and market the calcined clay pozzolan to the concrete industry.

Penn State is assisting with this process and helps with presenting the data to State DOTs in the region to help with DOT approval of the resulting pozzolan for use in DOT-owned concrete projects.

The George Mason-University of Delaware-Penn State project entitled, "Strategic Prioritization and Planning for Multi-Asset Transportation Infrastructure Maintenance, Rehabilitation, and Improvements: Prioritization through Optimization," advances technologies to support strategic planning of maintenance, repair and rehabilitation options (improvement actions) and their implementation prioritization for our nation's roadway systems. The work takes a multiasset approach with emphasis on pavements and bridges. It accounts for system-wide traffic impacts of postponed treatments, downtime impacts of construction work zones on traffic performance, and post-action benefits in terms of capacity and speed. It further incorporates uncertainty in system state due to stochasticity in the evolution of deterioration and its underlying physical processes. The technologies will enable a deeper understanding of the nature of sensed data and its utility specific to the perception of roadway condition and the ability to detect deteriorated conditions and ascertain relationships between sensed condition and serviceability levels across assets. Performance indices, deterioration rates and collected data are often significantly different between asset classes. Consequently, maintenance planning tools and managing practices often focus on only one distinct asset class, without integrating other asset types into their analysis, resulting in different asset classes competing for limited funds and suboptimal performance of the larger roadway network. Compatible serviceability assessments of individual asset types, as well as overall system serviceability, will be directly supported.

Research being undertaken at Lehigh University is developing a crowd sensing system that will permit for pavement condition monitoring in a low-cost, reliable, and rapid manner. Being able to identify pavement hazards in a timely manner will enable efficient maintenance and repair of the pavement.

Dr. Linbing Wang is working collaboratively with students at Virginia Tech to reimagine the way that infrastructure condition assessment and non-destructive analysis is taught in the curriculum. The existing curriculum is dated and does not reflect recent advances in the field, such as new non-destructive analysis techniques and the existence of asset management systems, such as pavement management systems (PMS). To remedy these issues, Dr. Wang and his team have solicited assistance from Civil Engineering undergraduate students to develop a new textbook as a course supplement. The team is currently editing the textbook.

B. What is the impact on the effectiveness of the transportation system?

Several research projects currently on-going in CIAMTIS involve fiber reinforced polymers, which are used in the construction or reconstruction of transportation structures. It anticipated that this research will enable updates to existing design and construction guidelines in order to make bridge construction or repairs more efficient and durable.

Other research being performed by CIAMTIS faculty and students will lead to development of elastomeric sealants for use in rigid pavement contraction joints, leading to improved durability of these pavements. Collaboration among structural and materials engineers, materials scientists, and pavement engineers has the potential to significantly reduce the maintenance cost of rigid pavements.

The project entitled, "Strategic Prioritization and Planning for Multi-Asset Transportation Infrastructure Maintenance, Rehabilitation, and Improvements: Phase 1 – Prioritization through Optimization," will support national durability and state-of-good-repair objectives, exploiting synergies through a multi-asset approach. It will further aid in making effective use of public funds for reducing congestion from construction and maintenance activities.

One of the main challenges facing bridge owners is the allocation of scarce resources for repair and maintenance of these aging structures. Because the main issue associated many bridges relates to fatigue, the availability of life-cycle information could provide very important tools for allocation of these resources for effective asset management. Lehigh University is using mobile sensors with machine learning methods to monitor bridge performance in the field. Life-cycle information can then be used to produce tools for bridge resource allocation.

The project entitled, "Bridge Load Rating and Evaluation Using Digital Image Measurements," will develop and implement a procedure for bridge load rating based on field testing using digital image measurements to capture displacements. By obtaining deformation data, bridge owners will be able to understand and evaluate a bridge's ability to carry load in a more efficient and faster way to ensure safety of bridges within the transportation network. This research will provide a simpler way to load rate bridges. Being able to provide more bridge load ratings could provide a novel and simpler to execute methods of monitoring long term fatigue and strength losses on bridges.

- C. What is the impact on the adoption of new practices, or instances where research outcomes have led to the initiation of a start-up company? Nothing to report this period.
- D. What is the impact on the body of scientific knowledge?

Novel data driven artificial intelligent (AI)-based predictive models for bridge deck deterioration are being used by research at Penn State, including the first-ever deep reinforcement learning constrained optimization framework. The framework appears to significantly outperform currently used asset management standard policies.

E. What is the impact on transportation workforce development?

Graduate students in public policy at George Mason University are being introduced to the fields of transportation infrastructure, infrastructure finance, financial markets, credit support program evaluation, p3 contracts, crisis impact on the sector, and policy remedies specific to the sector. Those in engineering are enhancing their knowledge in machine learning, data fusion, bilevel programming, multi-asset management, supply chains, multi-modal transportation, decision-making under uncertainty, multi-stakeholder competitive games, and other techniques from mathematical modeling and algorithm design for planning and real-time deployment. More generally, these efforts are training a generation of researchers in leading-edge techniques, and will support transportation decision-makers. Plans for disseminating findings through webinars designed for professionals and practicing engineers are underway for one or more of the included projects.

#### VI. CHANGES/PROBLEMS

A. Changes in approach and reasons for change:

One of the competitive research projects that was identified for funding during the year 2 and 3 peer-review competition, "Developing Design Specifications to Ensure Long-life Skid Resistant

Concrete Pavements," was unable to secure adequate matching funds to support the experimental focus of the proposed research (project PI's are asked to provide 1:1 matching for each CIAMTIS project). After consultation with the UTC grant manager, the project PI redirected the scope of the project to focus on a computational component of the research – the updated project is titled "Use of Machine Learning to Predict Long-Term Skid Resistance of Concrete Pavements." The funding level pledged to the project in the competitive program was returned to the competitive pool. The updated project was moved to the core program, and the budget and schedule for the project were both reduced to reflect the revised scope. Matching funds for the revised scope were secured. The updated project is shown in Table 4.

Dr. Kadir Aslan, key personnel from Morgan State university, accepted another position outside the academic community. Dr. Mehdi Shokouhian assumed the key personnel role from Morgan State University in June 2020.

B. Actual or anticipated problems or delays and actions or plans to resolve them:

The COVID-19 pandemic has resulted in delays to experimental research. Several universities in the CIAMTIS consortium issued directives to reduce research activities in laboratories during the previous reporting period, and this continued into the current reporting period. Most laboratory research by CIAMTIS consortium members restarted during the reporting period (May-August 2020 timeframe), but the COVID-19 temporary lab closures have resulted in delays to several active research projects due to capacity limitations in laboratory spaces.

Several universities in the CIAMTIS consortium have also reported delays to field work associated with travel restrictions during the current reporting period. For example, several projects include bridge and pavement instrumentation during construction, which was suspended in some states during the 2020 period. Several of these field activities have resumed during the current reporting period, but several research projects involving field instrumentation have been delayed.

Several CIAMTIS universities have reported that graduate student recruitment has been impacted by COVID-19, resulting in students having to delay the start of their graduate program until the fall or spring 2021 semester.

- C. Changes that have a significant impact on expenditures: Nothing to report this period.
- D. Significant changes in use or care of human subjects, vertebrate animals, and/or biohazards: Nothing to report this period
- E. Change of primary performance site location from that originally proposed: Nothing to report this period.

# **VII. SPECIAL REPORTING REQUIREMENTS**

None to report this period.