CIAMTIS
U.S. DOT Region 3 University Transportation Center

SEMI-ANNUAL PROGRAM PROGRESS REPORT

FOR

UNIVERSITY TRANSPORTATION CENTERS

Project Title:	**Center for Integrated Asset Management for Multimodal Transportation Infrastructure Systems (CIAMTIS)**
Submitted to:	U. S. Department of Transportation Office of the Assistant Secretary for Research and Technology
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Center Partners:	Pennsylvania State University (lead), George Mason University, Lehigh University, Morgan State University, University of Delaware, Virginia Tech, and West Virginia University
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Recipient Organization:	Thomas D. Larson Pennsylvania Transportation Institute Pennsylvania State University 201 Transportation Research Building University Park, PA 16802
Reporting Period:	April 1, 2021 through September 30, 2021

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 through September 30, 2021, which is the sixth 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: https://r3utc.psu.edu) 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 third annual TAIM conference was developed and updated regularly during the reporting period – this website can be found at the following link: https://www.taim.psu.edu/. The TAIM conference will be held on October 25-27, 2021.

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

CIAMTIS Newsletter

The CIAMTIS marketing and communications team distributed the spring 2021 newsletter in April 2021. The contents of the newsletter included: (1) a summary of the Transportation Infrastructure workforce development webinar series, (2) a rail transportation engineering education and outreach activity, (3) several research project summaries, (4) plans for the Transportation Asset and Infrastructure Management (TAIM) conference, and (5) announcement of new research project awards. Planning for the winter 2021 newsletter began during the current reporting period.

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

Planning for the third annual TAIM conference began during the current reporting period. The conference planning committee met virtually several times to develop the conference program. The program consists of the following activities:

- Four pre-conference workshops on Asset Management.
- Twelve (12) concurrent technical sessions on topics related to innovative materials and technologies, condition assessment and structural health monitoring, and infrastructure asset management.
- A research exhibition, including posters from several graduate students representing universities in the CIAMTIS consortium.
- A graduate student panel session related to career opportunities in transportation infrastructure asset management.
- A keynote address by Peter Stephanos, Director, Office of Stewardship, Oversight, and Management, and Acting Chief Strategy Officer, Federal Highway Administration

The conference will be held virtually on October 25-27, 2021.

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 are complete. Final reports are posted on the CIAMTIS website and are distributed to various

repositories per UTC grant deliverables requirements. It is anticipated that several projects will be completed during the next reporting period.

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 are complete. Final reports are posted on the CIAMTIS website and are distributed to various repositories per UTC grant deliverables requirements.

Table 1. Projects Funded in Year 1 Competitive Program.

Project	PI	Thrust Areas	PI Univ.	Partner Univ.	Performance Dates		Activity Type
Efficient Service Life Extension of Bridges through Risk-based Life-cycle Management and High-performance Construction Materials: Emphasis on Corrosion-resistant Steel	Frangopol, Dan	A	LU		3/1/19	9/1/20	R
Fatigue Life Estimation of Bridges with Smart Mobile Sensing	Pakzad, Shamim N.	C	LU		3/1/19	12/21/20	R
Life Extension of Fatigue-Damaged Highway, Rail, and Transit Bridges	Sause, Richard	A, C	LU		3/1/19	12/31/20	R
Numerical and Experimental Investigation of Efficient Geometric Arrangement of Metal Fin Tube Foundations for Transportation Applications	Qiu, Tong; Laman, Jeffrey	A	PSU		3/1/19	9/1/20	R
Time-Based Modeling of Concrete Bridge Deck Deterioration Using Probabilistic Models	Guler, Ilgin	I	PSU		3/1/19	8/15/20	R
Railroad Track Performance Monitoring by Advanced Sensor Network & Big Data	Huang, Hai	C	PSU-Altoona	UDel	3/1/19	9/30/21	R
Use of SmartRock Sensors to Monitor Pavement Performance for Supporting Rehabilitation Decision Making	Shen, Shihui; Wang, Linbing	A	PSU-Altoona, VT		3/1/19	12/31/21	R
Improved Methods to Assess Corrosion Damage in Prestressed Concrete Beams	Roberts-Wollman, Carin	C	VT		3/1/19	12/20/21	R
Development of a Practical Risk Framework for Railway Bridge Stiffness Transition Maintenance and Upgrade	Palese, Joseph	C	UDel		3/1/19	8/25/20	R
Planning for the Inevitable: Readying DOTs for Disaster Debris Management	McNeil, Sue	I	UDel		3/1/19	3/1/20	E, TT
Strategic Prioritization and Planning of Transportation Infrastructure Maintenance, Rehabilitation, and Improvements Incorporating Continuously-Sensed Data	Miller-Hooks, Elise; Lattanzi, David	I	GMU	PSU, UDel	3/1/19	5/21/21	R

Project	PI	Thrust Areas	PI Univ.	Partner Univ.	Performance Dates		Activity Type
Bridge Load Rating and Evaluation Using Digital Image Measurements	Head, Monique	C	UDel	GMU	3/1/19	12/31/21	R
Optimized Performance of UHPC Bridge Joints and Overlays	Mondal, Paramita	A	UDel	PSU	3/1/19	12/31/21	R
Development of Low-Cost Weigh-In-Motion (WIM) and Response Spectra Techniques: "Development of Cost-Effective Sensing System for Integrated Traffic and Pavement Response Monitoring in Support of Pavement Management"	Wang, Linbing	C	VT	WVU	3/1/19	12/1/21	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

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Table 2. Projects Funded in Core Program.

Project	PI	Thrust Areas	PI Univ.	Partner Univ.	Performance Dates		Activity Type
					Beg.	End	
Residual Compressive Strength of Partially Confined Concrete Column Retrofitted Using CFRP Wrap	Aslan, Kadir	A	MSU		4/1/19	3/31/20	R
The Impact of Accessing Public Credit Support on Public Private Partnerships	Gifford, Jonathan	I	GMU		1/25/19	9/24/20	R
Imagine the Future: Exercises on Conceptualizing Infrastructure Systems for an Interconnected World	Miller-Hooks, Elise	I	GMU		3/18/19	6/18/19	E
CIAMTIS Graduate Fellowship at University of Delaware	McNeil, Sue	A, C, I	UDel		1/1/19	7/20/23	E
Enhancing Fundamentals of Engineering Program	Zaniewski, John		WVU		3/1/19	3/1/20	E
Condition-based Inspection and Restoration Scheduling of Pavement and Bridge Systems for Improved Post-disaster Infrastructure Systems Recovery	Miller-Hooks, Elise	I	GMU		3/11/19	3/11/21	R
Finite Element Model Updating for Bridge Deformation Measurements Extracted from Remote Sensing Data	Lattanzi, David	C	GMU		3/11/19	3/11/21	R
CIAMTIS Lehigh Research Experience for Undergraduates (REU) Program	Sause, Richard	A, C	LU		3/11/19	10/11/19	E
Road Pavement Condition Monitoring by Embedded Crowdsensing	Cheng, Liang	C	LU		3/11/19	12/31/20	R
Design of Anchors for Rapid and Durable Strengthening of Bridges with Externally Bonded Carbon Fiber Reinforced Polymers	Head, Monique	A	UDel		3/11/19	9/30/21	R
Evaluation, Beneficiation, and Implementation of Alternative Concrete Pozzolans for Transportation Infrastructure	Rajabipour, Farshad	A	PSU		3/11/19	6/1/20	R

Project	PI	Thrust Areas	PI Univ.	Partner Univ.	Performance Dates Beg.	End	Activity Type
A Semi-flexible Composite Trackbed Material for Stiffness Transition in Bridge Approaches and Its Application	Shen, Shihui	A	PSU-Altoona		3/11/19	10/6/20	R, E
Integration of Innovative Sensing Technology and Data Analytics in Transportation Asset Management	Wang, Linbing	C, I	VT		3/1/19	3/1/23	R
Evaluation of an Innovative Erosion Control on Road Embankment Using Synthetic Turf with Sand Infill	Xiao, Ming	A	PSU		3/18/19	3/18/20	R
Automated Path Tracking and Mapping for Economical, Real-Time, and Knowledge-Based Roller Control in Pavement Compaction Operations: Phase I: Algorithm Development	Dai, Fei	A	WVU		3/18/19	3/18/20	R
Calibration of WVDOH IRI-based PSI and SCI Equations	Yoon, Yoojung	C	WVU		8/1/19	12/31/21	R

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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. The 2 projects that are shaded in Table 3 (core funds) are complete, while the remaining projects will continue into the next reporting period. In addition, several research project reports are currently under internal review and will be posted on the CIAMTIS website during the next reporting period.

Year 4 Funds

During the current reporting period, a competitive research project solicitation was developed and distributed in October 2020. A total of 27 proposals were received by CIAMTIS consortium members. A peer-review process was undertaken in November-December 2020. Table 5 is a summary of those projects that were awarded – several additional projects will also be awarded, following confirmation of matching funds. All Year 4 projects will continue into the subsequent reporting period. Among the awarded projects, 50 percent are collaborative among at least two consortium members. Table 6 is a summary of the project awarded using the core funds. Several other Year 4 project proposals are currently under review for the core program.

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

Project	PI	Thrust Areas	PI Univ.	Partner Univ.	Performance Dates		Activity Type
Decision Support Tools for Multi-objective, Multi-asset, Multi-modal Joint Maintenance Programming	McNeil, Sue	I	UDel	GMU, PSU	1/20/2020	1/19/22	R
Passive Strain Sensing Based on Changes in Retroreflectivity	Shenton, Harry	A, C	UDel		1/20/2020	1/20/22	R
Developing Equivalence Tools to Control Quality of Transportation Infrastructure Asset Management Data	Stoffels, Shelly	I	PSU		3/1/2020	4/30/21	R
AI-enabled fiscally constrained life-cycle asset management for infrastructure systems	Papakonstantinou, Kostas	I	PSU		1/20/2020	8/31/21	R
Smart Mobile Platform for Model Updating and Life Cycle Assessment of Bridges	Pakzad, Shamim	C	LU		1/20/2020	1/20/22	R
Artificial Intelligence for Advance Landslide Warning along Railroad Tracks in Pennsylvania and Delaware	Qiu, Tong	C	PSU	UDel	7/1/2020	6/30/22	R
Development of Turnout Rail Break Warning System Based on Distributed Optical Fiber Sensing Technologies	Huang, Hai	A, C	PSU-Altoona		1/1/2020	1/31/22	R
Evaluation of IoT-Enabled Pavement Response Monitoring for Transportation System Management	Wang, Linbing	C	VT	WVU	1/20/2020	3/31/22	R
Unmanned Aerial Vehicles for Inspection of Tack Coats and Ancillary Highway Structures	Dai, Fei	C	WVU	GMU, VT	1/20/2020	1/20/22	R
Durability Assessment of Externally Bonded Fiber-Reinforced Polymer (FRP) Composite Repairs in Bridge	Tatar, Jovan	A	UDel		2/1/2020	7/31/22	R
Extending Service Life of Rigid Pavement Joints with Self-Healing Sealants	Tatar, Jovan	A	UDel	VT	1/31/2020	1/31/22	R
Price Discovery for Strategic Compensation of Toll Road Operators to Relieve State Maintenance Impacts	Gifford, Jonathan	I	GMU	UDel	1/20/2020	1/31/22	R
Preparing the Next Generation of Undergraduate and Graduate Engineers in Autonomous Robotic System for Damage Detection	Efe, Steve	C	MSU		1/20/2020	1/20/22	E
Integration of traffic and structural health monitoring on the Varina-Enon Bridge via sensor fusion	Sarlo, Rodrigo	C, I	VT		1/20/2020	9/20/21	R

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

Project	PI	Thrust Areas	PI Univ.	Partner Univ.	Performance Dates		Activity Type
Automated Path Tracking and Mapping for Economical, Real-Time, and Knowledge Based Roller Control in Pavement Compaction Operations: Phase II: Prototyping and Validation	Dai, Fei	A	WVU		3/4/20	3/4/22	R
CIAMTIS Lehigh Research Experience for Undergraduates (REU) Program – Year 2	Sause, Richard	A, C	LU		3/4/20	10/31/20	E
Finite element model updating for bridge deformation measurements extracted from remote sensing data (Year 2 of a two-year project)	Lattanzi, David	C	GMU		3/1/20	2/28/21	R
Detecting Disruptions, Defining Causes and Understanding System Stability Restoration in Disrupted Traffic Networks	Miller-Hooks, Elise	I	GMU		3/4/20	12/3/21	R
Optimization Framework for Infrastructure Management Considering Traffic Safety Costs	Guler, S. Ilgin	I	PSU		6/1/20	12/1/21	R
Experimental and Numerical Investigation of Recycled Fiber Reinforced Concrete for Green Bus Pads	Shokouhian, Mehdi	A	MSU		3/4/20	4/29/22	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 Resistant of Concrete Pavements	Rajabipour, Farshad	A	PSU		5/11/20	8/31/21	R
Optimization Framework for Infrastructure Management Considering Traffic Safety Costs	Guler, Ilgin	I	PSU		6/1/20	12/1/21	R
Transportation Infrastructure Readiness for Post-Pandemic Supply Chain Transformation for greater Resilience	Miller-Hooks, Elise	I	GMU		6/1/20	6/1/22	R
Smart Compaction for Infrastructure Materials	Shen, Shihui	A	PSU-Altoona		6/1/20	6/1/22	R
Railroad Engineering Education & Outreach	Shen, Shihui / Huang, Hai	A	PSU-Altoona		6/1/20	6/1/22	E
Life Extension of Fatigue-Damaged Highway, Rail, and Transit Bridges: Identifying Actual Crack Tip	Pessiki, S / Sause, R / Hodgson, Ian	A	LU		8/3/20	8/2/22	R
Video-Sensor Data Fusion for Enhanced Structural Monitoring	Lattanzi, David	C	GMU		9/1/20	12/31/21	R

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Table 5. Years 4 CIAMTIS Competitive Project Awards.

Project	PI	Thrust Areas	PI Univ.	Partner Univ.	Performance Dates		Activity Type
Characterizing Fundamental Rutting Property of Asphalt Concrete from Multiscale Simulative Tests using an Inverse Approach	Wang, Linbing	A	VT	PSU Alt	3/3/21	3/2/23	R
Combined Structural Health and Traffic Monitoring using Fiber Optic Distributed Acoustic Sensing	Wang, Linbing	A	VT	WV	2/15/21	2/14/23	R
Deep reinforcement learning for multi-asset infrastructure management incorporating traffic operations adaptations and control	Papakonstantinou,K. and Shelley Stoffels	I	PSU	GMU	5/1/21	4/30/23	R
Developing Transportation Engineering Graduates for Industry	Efe, Steve	C	MSU		3/8/21	3/7/23	E
Implementing Waste Plastics in Asphalt Pavement for Both Engineering and Environmental Benefits	Shen, Shihui	A	PSU Alt	VT	3/8/21	3/7/23	R
In-situ Stiffening and Upgrading of Ballasted Rail Track Beds via Cement Grout Injection	Rajabipour, Farshad	I	PSU Alt		3/15/21	10/14/22	R
Strategic Prioritization and Planning for Multi-Asset Transportation Infrastructure Maintenance, Rehabilitation, and Improvements: Phase 2 - Data-driven Decisions from Continuous Monitoring	Miller-Hooks, Elise and Lattanzi, David	I	GMU	UDel / PSU	5/21/21	3/31/22	R
Mitigating Cracking in Ultra-High Performance Concrete (UHPC) Bridge Connections	Tatar, Jovan	A	UDel	PSU	3/8/21	3/7/23	R
Investigation of the Benefit of Using a Novel Corrosion Resistant Steel in New and Existing Steel Bridges in Pennsylvania	Frangopol, Dan	A	LU		3/1/21	6/1/22	R
Development of a Virtual Weigh-In-Motion System for Enhanced Pavement System Management	Dei, Fei; Wang, Linbing	C	WVU	VT	3/1/21	8/31/22	R
Workforce Development and Job Training Pilot	Na, Ri	A,C,I	UDel		6/1/21	5/31/22	E
Utilizing daily traffic as a sensor network for infrastructure health monitoring	Pakzad, Shamin	I	LU		3/1/21	12/30/22	R
Infrastructure Subsurface Damage Detection through Video-Based Imperceptible Vibration Measurement	Dai, Fei	C	WVU		8/31/20	8/31/22	R

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Table 6. Years 4 CIAMTIS Core Project Awards.

Project	PI	Thrust Areas	PI Univ.	Partner Univ.	Performance Dates		Activity Type
Stochastic Models for Incorporating Traffic Reliability Goals in Roadway Improvement Scheduling	Miller-Hooks, Elise	I	GMU		8/1/21	2/1/23	R

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Year 5 Funds

A call for competitive proposals was developed and distributed to the CIAMTIS consortium members in September 2021. Proposals are due November 1, 2021, which will be followed by the peer-review process. During the next reporting period, the results of the competitive proposal process will be announced, and projects will begin. In addition, CIAMTIS university partners are developing proposals for projects that will be included in the core funding program.

CIAMTIS Professional Development Webinar Series

During the current reporting period, the CIAMTIS Transportation Infrastructure monthly webinar series continued. Speakers were identified and webinars delivered during each month of the current reporting period. Continuing education credits are awarded for participation (0.1 credits per webinar) – a total of 27 participants are currently registered for the series – efforts are on-going to increase the number of registered participants. During the next reporting period, speakers will be recruited for webinars in 2022.

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 virtual platform to discuss research and education activities, reporting requirements, and other matters of interest related to the Center.
- All new research projects shown in Table 5 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.

University of Delaware

Twenty-one graduate students (including four from the University of Delaware) from 15 different universities, and 15 professionals participated in the Advanced Infrastructure Management Bootcamp between June 9 and August 11, 2021. The course included modules on economics and finance, performance, deterioration modeling, risk, reliability and resilience, optimization, sensors and instruments, and data analysis. The modules were offered by internationally recognized instructors from the University of Delaware, McMaster University, Georgia Tech, Virginia Tech, University of Texas at Austin, University of Houston, Purdue and Iowa State University. The graduate students completed team projects to develop an asset management plan for the pavement, sidewalks and bicycle facilities in the Newark business district.

In addition, seven undergraduate students from the University of Delaware participated in a research experience for undergraduate students during the reporting period. To complement the research projects, weekly professional development seminars were delivered, focused on topics related to presenting research, preparing a literature review, technical writing, graduate school applications, and research ethics. At the end to the summer all students participated in a poster session.

Five University of Delaware students participated in the Annual Interuniversity Symposium on Infrastructure Management (held virtually during the reporting period) and three other undergraduate students participated in the University of Delaware's Arts Bridge Summer program.

Morgan State University

Researchers at Morgan State University held virtual workshops and training sessions during the reporting to educate undergraduate students on problems, challenges, and potential solutions associated with transportation infrastructure design. The goal of this activity is to prepare engineering student for a career in transportation engineering by engaging them in community service-related projects and to prepare participants for the Fundamentals of Engineering exam, so that pass rates increase. In addition, Morgan State faculty conducted a Professional Engineer refresher course during the reporting period. The Baltimore City Department of Public Works and Maryland Department of Transportation expressed interest in this workforce development activity to target the next generation of professional engineers.

Morgan State continued an educational activity focused on preparing the next generation of undergraduate and graduate students on topics related to autonomous robotic systems for damage detection. During this reporting period, several undergraduate students designed the autonomous robot for concrete crack inspection, which included circuit construction using a variety of hardware, software, and sensors. At the end of the training activity, students were able to design a robust pavement or railway crash detection scheme using a sensor assembly.

C. How have the results been disseminated?

During the current reporting period, several research and education project results have been disseminated. This includes completion of research reports, submission of journal publications, and presentations at conferences – these are highlighted below in section III Outputs below. In addition, other forums to disseminate results of research include the TAIM conference, where numerous faculty and graduate students will present their research in October 2021; presentations at the CIAMTIS Transportation Infrastructure monthly webinar series; and dissemination of the semi-annual CIAMTIS newsletter.

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 6 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 be publishing final reports and technical briefs of their research. In addition, CIAMTIS partners will be encouraged to continue submitting research and education proposals for projects in the core program.

CIAMTIS Technology Transfer and Outreach Activities

- Penn State continued planning for the 3rd annual Transportation Asset and Infrastructure Management (TAIM) conference during the reporting period. The conference is scheduled to take place during the next reporting period (October 25-27, 2021).
- CIAMTIS will continue scheduling speakers for the Transportation Infrastructure webinar series during the next reporting period and seek to increase participation in the series via increased marketing efforts to stakeholders throughout the mid-Atlantic region.
- 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.

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:	Central and District Offices
Partner's contribution(s) to the project:	PennDOT and CIAMTIS have identified five collaborative research projects – one is underway and four are currently pending. PennDOT Engineering District 5-0 is collaborating on Lehigh University projects by assisting to identify bridges that can be used for field research.

Organization Name:	**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 test specimen fabrication.
Organization Name:	New Enterprise Stone and Lime Company
Location of Organization:	Roaring Springs, PA
Partner's contribution(s) to the project:	Penn State-Altoona researchers work collaboratively with paving contractor to conduct field compaction experiments.
Organization Name:	**West Virginia Department of Highways**
Location of Organization:	Charleston, West Virginia
Partner's contribution(s) to the project:	This partner is collaborating on research with West Virginia University on data collection activities to support of a project to calibrate pavement design equations.
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 with West Virginia University faculty to identify industry members to field test automated path tracking and mapping for roller control in pavement compaction operations.
Organization Name:	**Delaware Technology Transfer Center and Delaware Contractor Association**
Location of Organization:	Newark, DE
Partner's contribution(s) to project:	Provided administrative support for professional participation in bootcamp including recruiting and registering participants and providing professional development certificates.
Organization Name:	**Academic and Professional Collaborators**
Location of Organization:	USA
Partner's contribution(s) to project:	Researchers at George Mason University have undertaking the following collaborations during the reporting period: (1) University of Maryland collaborators shared a major transportation projects database in support of the project entitled "Relative Performance of Public-Private Partnerships and Conventional Project Delivery during Crises"; (2) briefing and review of models by Department of Justice, Rutgers University, and Eastern Transportation Coalition for project entitled "Price Discovery for Strategic Compensation for Toll Road Operators to Relieve State Maintenance Impact"; (3) briefing with National Academies of Science, Engineering and Medicine Committee on Supply Chain Resilience for project entitled "Transportation Infrastructure Readiness for Post-Pandemic Supply Chain Transformation for Greater Resilience."
Organization Name:	**Virginia Transportation Research Council**
Location of Organization:	Charlottesville, VA
Partner's contribution(s) to project:	Researchers at Virginia Tech are offering funding support and collaboration on research, including assistance with applying the developed technologies in practice.
Organization Name:	**FHWA Long-term Pavement Performance/Long-term Infrastructure Performance Program**

Location of Organization:	Washington, DC
Partner's contribution(s) to project:	Penn State researchers acquired publicly-available data from InfoMaterials, as well as project data form past LTPP BAA analysis project for use in project entitled "Developing Equivalence Tools to Control Quality of Transportation Infrastructure Asset Management Data."

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 6, while the technology transfer performance metrics, goals, and targets are shown in Table 7. The following summarizes progress toward several of these targets during the current reporting period:

- 16 journal publications were submitted or published during the current semi-annual reporting period;
- 10 conference presentations or other publications were accepted or delivered during the current semi-annual reporting period.
- There were 1129 website visitors and 4410 pageviews on the website during the reporting period.

Among the annual performance metrics shown in Table 8, considerable progress has been made toward the output and outcomes targets during the current semi-annual reporting period.

Table 7. Research Performance Metrics

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 8. Performance Metrics for CIAMTIS Technology Transfer Activities

Performance Metric	Assessment Measure	Performance Targets
Partnership with Private and Public Entities	✓ Number of technologies advanced to State Transportation Innovation Councils (STIC) in each state or nominated for Every Day Counts (EDC) and Accelerated Innovation Deployment (AID) programs.	✓ One STIC technology innovation annually. ✓ One adopted technology or program annually.

	✓Number of adopted technologies or programs.	
Patents and Commercialization	✓Number of invention disclosures, patents, and copyright applications. ✓Number of license agreements.	✓One invention disclosure, patent, or copyright application annually. ✓One license agreement annually.
Publications and 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 Courses	✓Number of courses offered annually. ✓Number of participants.	✓Three continuing education courses offered annually with at least 25 participants per course.
Number of students supported	✓ Number of undergraduate and graduate students supported annually by CIAMTIS	✓ Support at least 20 undergraduate and 20 graduate students annually.

B. Publications, Conference Papers, and Presentations

Journal Publications

- Zhou, W., E. Miller-Hooks, K. Papakonstantinou, S. Stoffels and S. McNeil. A Bilevel and Stochastic Model for Multi-asset Roadway Improvement Scheduling Considering Traffic Impacts. In review in *ASCE Journal of Infrastructure Systems.*
- Yu S., S. Shen, H. Huang, and C. Zhang. Engineered Semi-Flexible Composite Mixture Design and Its Implementation Method at Railroad Bridge Approach. *Transportation Research Record.* April 2021. doi:10.1177/03611981211004981
- Zhang, C., S. Shen, H. Huang, and L. Wang. Estimation of the vehicle speed using cross-correlation algorithms and MEMS wireless sensors. *Sensors*, 21(5), 1721, 2021.
- Kamranfar, P., D. Lattanzi, A. Shehu, and S. Stoffels. Pavement distress recognition via wavelet-based clustering of smartphone sensor data. In review in *ASCE Journal of Computing in Civil Engineering*.
- Andriotis, C.P., K. G. Papakonstantinou, and E. N. Chatzi. Value of structural health information in partially observable stochastic environments. *Structural Safety*, 93, 102072-1:13.
- Sujon, M. and F. Dai. Application of weigh-in-motion technologies for pavement and bridge response monitoring: State-of-the-art review. *Automation in Construction*, 130, August 2021, pp. 103844.
- Lu, L. and F. Dai. Automatic roller path tracking and mapping for pavement compaction using infrared thermography. *Computer-Aided Civil and Infrastructure Engineering*, 36(11), April 2021, pp. 1416-1434.
- Lee, J. and Y. Yoon. Hierarchy table of indicators and measures for the current status assessment of urban roads in smart cities. Under review in *Sustainable Cities and Society*.
- Lee, J. and Y. Yoon. Indicators development to support intelligent road infrastructure in urban cities. Under review in *Transport Policy*.

- Lu, L. and F. Dai. A unified normalization method for homography estimation using combined point and line correspondences. Under review in *Computer-Aided Civil and Infrastructure Engineering*.
- Han, X., Yang, D. Y., and D. M. Frangopol. Optimum maintenance of deteriorated steel bridges using corrosion resistant steel based on system reliability and life-cycle cost. *Engineering Structures*, 243, 2021, pp.112633.
- Han, X. and D. M. Frangopol. Life-cycle connectivity-based maintenance strategy for bridge networks subjected to corrosion considering correlation of bridge resistances. *Structure and Infrastructure Engineering*, submitted.
- Han, X. and D. M. Frangopol. Risk-based optimal life-cycle maintenance strategy for bridge networks considering stochastic user equilibrium. *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering*, submitted.
- K. Jafari, J. Yoon, R. Tokpatayeva, J. Olek, and F. Rajabipour. Surfactant-assisted purification of an impure kaolinite clay to improve its pozzolanic reactivity in concrete. *ASCE Journal of Materials in Civil Engineering*, Accepted: Sep. 2021.
- Pei, T. and T. Qiu. A Numerical Investigation of Laterally Loaded Steel Fin Pile Foundation in Sand. *International Journal of Geomechanics*, ASCE, under review.
- Lu, M., S. I. Guler, and V. Gayah. Random Survival Forest Model for Bridge Deck Deterioration. *Transportation Research Record: Journal of the Transportation Research Board*, submitted, August 2021.

Other Publications, Conference Papers, and Presentations

- Milev, S. and J. Tatar. Durability Assessment of Fiber-reinforced Polymers Composites Externally Bonded to a Concrete Bridge after 26-year Exposure. *Proceedings of the 8th International Conference on Advanced Composite Materials in Bridges and Structures (ACMBC VIII) Virtual Conference*, August 5-7, 2021.
- Hu, P. and S. Stoffels. Applications of Equivalence and Noninferiority Testing to Pavement Condition Data. Abstract prepared for 1st International Data Science for Pavements Symposium. Under review for presentation and possible publication in *Road Materials and Pavement Design*.
- University of Delaware faculty and graduate students made five presentations at the *Annual Interuniversity Symposium on Infrastructure Management* during the reporting period. The symposium was held at the University of Texas-Austin, July 17-18, 2021.
- Andriotis, C.P. and K. G. Papakonstantinou. Value of structural health information: Theoretical properties and connections to stochastic optimal control. Engineering Mechanics Institute (EMI) Conference and Probabilistic Mechanics & Reliability Conference (PMC), Columbia University, New York, NY, May 2021.
- Lee, N. and J. Gifford. P3 Toll Adjustments to Relieve Maintenance Impacts of Adjacent Facilities: A Repeated Game Analysis, Universities Transport Study Group (UTSG) Annual Meeting, Virtual (Loughborough, U.K.), July 2021.
- Lu, L. and F. Dai. A unified normalization method for point and line-based homography estimation. *Proceedings of the 2021 ASCE International Conference on Computing in Civil Engineering* (i3CE 2021). September 12-14, 2021, Orlando, Florida.
- Sujon, M. and F. Dai. Machine learning-enabled automatic vehicle detection for virtual weigh-in-motion applications. Accepted by the 2022 ASCE Construction Research Congress (CRC 2022), March 9-12, 2022, Arlington, Virginia.

- Lu, L. and F. Dai. Visual surveying of on-road vehicle height for over-height warning using deep learning and view geometry. Accepted by the 2022 ASCE Construction Research Congress (CRC 2022), March 9-12, 2022, Arlington, Virginia.
- Andriotis, C. P. and K. G. Papakonstantinou. Deep reinforcement learning approach to structural inspection and maintenance policy optimization subject to life-cycle reliability constraints. Proceedings of the 14th International Conference on Evolutionary and Deterministic Methods for Design, Optimization and Control (EUROGEN 2021), June 2021.
- Andriotis, C. P. and K. G. Papakonstantinou. Partially observable Markov decision processes for life-cycle inspection and maintenance planning under constraints. Proceedings of the Engineering Mechanics Institute (ASCE) and Probabilistic Mechanics and Reliability Conference, May 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:

- For the collaborative project entitled "Strategic Prioritization and Planning for Multi-Asset Transportation Infrastructure Maintenance, Rehabilitation, and Improvements," the George Mason-Penn State-Delaware team developed a new Artificial Intelligence algorithm that connects vehicle dynamics with pavement condition. The algorithm is designed to support crowd-sourced assessments that improve safety and roadway management, particularly for lower-volume roads where professional monitoring is less routine.
- George Mason University researchers developed a new algorithm for fusing remotely-sensed images with embedded sensor array systems in the project entitled "Video-Sensor Data Fusion for Enhanced Structural Monitoring." The algorithm helps to address the fundamental limitations of each sensing modality on its own and can be used to provide a more comprehensive and holistic understanding of structural system health.
- Researchers at Virginia Tech developed a framework that utilizes pavement condition, traffic data, and roadway geometry to predict crash frequencies in a geo-fenced area of interest. Validated the framework using a geographic grid with cells of varying traffic, geometric and pavement conditions, and historical crash frequencies.

Inventions, Patent Application, and/or Licenses (include date, and/or licenses that have resulted from the research): Nothing to report.

IV. OUTCOMES

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

Examples of outcomes produced during the current reporting include the following:

- Researchers at the University of Delaware completed an inspection and materials characterization of the Foulk Road Bridge in Delaware, for the CIAMTIS project entitled "Durability Assessment of Externally Bonded Fiber-Reinforced Polymer (FRP) Composite Repairs in Bridges." The results of visual inspection and materials characterization indicated that the original FRP repair had experienced significant deterioration and needs replacement – the results were shared with the Delaware Department of Transportation. The research team concluded that the primary issue that led to the FRP degradation was the lack of a protective UV coating.
- University of Delaware researchers completed preliminary work on fracture characterization of interfaces between ultra-high-performance concrete (UHPC) and high-performance concrete (HPC) in the project entitled "Mitigating Cracking in Ultra-High-Performance Concrete Bridge Connections." The adopted test method performed well, and the team successfully captured crack growth characteristics along the UHPC/HPC interfaces. The test results show that surface preparation plays a significant role in UHPC/HPC interface fracture toughness—the interfaces where HPC substrate had exposed aggregate finish has significantly greater fracture energy than those where UHPC was bonded to as-cast HPC substrate. The research results also indicate that hygric state of the HPC substrate (dry vs. saturated-surface dry) does not statistically significantly affect tensile strength or fracture energy of UHPC/HPC interfaces.
- Researchers at West Virginia University developed a unified normalization method for homography estimation using combined point and line correspondences on the project entitled "Automated Path Tracking and Mapping for Economical, Real-Time, and Knowledge Based Roller Control in Pavement Compaction Operations: Phase II: Prototyping and Validation." The method has been implemented into an executable application and will be made publicly available for broader use.
- Researchers at Virginia Tech are working on methods to change the traditional total asphalt content design method to an effective asphalt content design method, leading to more direct association of mix design objectives for durability and compactability in pavements. The methods will also allow better prediction of mixture properties using rational mechanics.
- Researchers at Morgan State University on working on research to develop implementation methods associated with recycled fiber reinforced concrete. Use of fibers in concrete materials can reduce maintenance costs in pavements. In addition, these fibers have environmental benefits. The research can help designers to implement recycled fiber reinforced concrete on a larger scale in transportation infrastructure systems.
- Researchers at Lehigh University completed life-cycle maintenance strategies for a multi-girder steel bridges using a holistic parametric analysis on a variety of factors that may exert an influence on life-cycle maintenance strategies for a carbon steel bridge subjected to corrosion. It has been proved that A709-50CR prevails over carbon steel in achieving a high reliability /low risk level when used in girder replacement actions, and is cost-effective from a perspective of life-cycle cost.
- Lehigh University researchers are developing the first database on fatigue crack-arrest holes at fillet weld toes for bridge owners and consulting engineers to use to support the engineering of these crack-arrest holes, which should lead to more reliable results. Draft crack-arrest-hole specifications for owners to maintain steel bridges within rail and highway systems is being developed.

- Penn State researchers developed an AI data-based model that can be used to predict deterioration of bridge decks, as well as a constrained optimization Deep Reinforcement Learning algorithm that can be used for large-scale infrastructure asset management. The results of this research will help improve inspection, maintenance, repair, and reconstruction decisions, such that existing budgets can be optimally-allocated under constraints and risk considerations.

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?]*

A. Impact:

The expected impact of a Leigh University project is more reliable fatigue crack-arrest holes. The development of fatigue cracks in steel highway bridges is a critical problem. Tens of thousands of steel bridges constructed in the 1960's and 1970's (or earlier) are critical components of transportation systems. These older steel bridges have welded steel details that develop fatigue cracks during their service life. If not repaired, these fatigue cracks have the potential to cause brittle fracture and bridge collapse. Crack-arrest holes are commonly used as the repair method. Current practice uses visual inspection to determine the crack geometry and to drill crack-arrest holes. Field experience, however, suggests that cracks have the potential to "re-initiate" at weld toes near these holes. The potential impact of more reliable repair of fatigue cracks is fewer instances where a previously-repaired bridge needs to be fully or partially closed as additional expensive emergency repairs are made.

The Penn State project entitled "AI-enabled fiscally constrained life-cycle asset management for infrastructure systems" will produce improved predictive models and optimization capabilities that can substantially reduce life-cycle costs, while increasing safety and reliability, of the transportation system.

Morgan State University are training undergraduate and graduate students on automated crack identification and visualization using computer vision. With an aging infrastructure, manual inspection is not efficient at identifying deterioration in order to facilitate implementation of appropriate maintenance or rehabilitation procedures. Training programs will produce opportunities to implement autonomous mobile robotic system for inspection and evaluation of transportation infrastructure.

Virginia Tech researchers are using novel sensors and sensing techniques, including distributed array and roadway surface-mounted sensors, to collect traffic and pavement response information. The data processing that is currently in progress has the potential to yield results that can change the design and management of roadway pavements; a data-rich environment is more desirable for decision-making. Further, these technologies will contribute to the promotion of connected transportation infrastructure systems, which will lead to more informed design and operations and maintenance decisions for pavements.

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.

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

Several research projects currently on-going in CIAMTIS involve fiber reinforced polymers and corrosion-resistant steel, 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 related to bridge structures in the CIAMTIS consortium will have considerable impact on the life-cycle of this critical infrastructure element. For example, there are projects focused on the application of new materials (e.g., corrosion-resistant steel); use of innovative sensing technologies (e.g., mobile sensors); and improved infrastructure management methods (e.g., probabilistic modeling, optimization of repair and rehabilitation strategies) that will collectively enable transportation agencies to improve the durability of bridges while using data to make informed construction and maintenance decisions.

In addition to bridges, there are a number of projects focused on pavements in the CIAMTIS consortium. These projects also consider the three thrusts areas of the Center, including the application of new materials and technologies (e.g., waste plastics in asphalt pavements and pozzolans in concrete pavements), condition and structural health monitoring technologies (e.g., crowd sensing to collect condition data), and infrastructure management (e.g., smart compaction during construction and optimization strategies for maintenance and rehabilitation).

Other CIAMTIS research focuses on rail transportation engineering applications (e.g., use of sensors to assess the condition of the rail infrastructure), landslide prediction methodologies in the areas of transportation assets, and use of unmanned aerial systems to assess the condition of roadside hardware and other transportation infrastructure systems.

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?

Many researchers in the CIAMTIS consortium are working on research projects that impact the scientific body of knowledge, including use of fiber-reinforced polymers in infrastructure materials, machine learning-artificial intelligence applications, life-cycle modeling, collection and analysis of various sensor data, and use of unmanned aerial systems to monitor the condition of the transportation infrastructure. Collectively, the use of innovative materials and technologies, new methods to monitor the condition and the health of the transportation, and application of methods to manage and finance transportation infrastructure will enable owners to extend the life of bridges, pavements, and railroads in the mid-Atlantic region.

E. What is the impact on transportation workforce development?

Morgan State University continued their work on a Principles and Practice of Engineering (PE) exam workforce development activity during the current reporting period. The program is aimed at building the competitiveness of the transportation infrastructure workforce in the region by impacting the ability of "at risk" engineers and other participants in the training to learn how to efficiently and successfully engage best practices or strategies for the PE exam through an active learning approach. The structured PE training course and assessment will be used to measure the

changes in the pre-training and post-training performance of the test takers. Based on responses, the PE certification training program was effective in preparing license applicants for the NCEES standards examination as there was more than a significant general improvement in pre-test scores considering the evaluated final morning and afternoon exams.

In addition, the TAIM annual conference and transportation infrastructure webinar have provided forums for researchers and practitioners to discuss and learn about opportunities to implement research into practice. Collectively, more than 150 individuals participate in these activities annually, from across the mid-Atlantic region.

VI. CHANGES/PROBLEMS

A. Changes in approach and reasons for change:

Nothing to report this period.

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 previous reporting periods (March-April 2020 timeframe). Most laboratory research by CIAMTIS consortium members restarted during a previous reporting period (May-August 2020 timeframe), but with reduced capacities. Laboratory activity has increased in the current reporting period, but past lab restrictions have resulted in delays to several research projects.

Several universities in the CIAMTIS consortium have also reported delays to field work and graduate student recruitment associated with travel restrictions during past and current reporting periods. While some travel has been approved during the current reporting period, several research projects involving field instrumentation have been delayed, while some students had to delay their graduate programs until the current reporting period.

Although the annual TAIM conference was proposed to be in-person event and rotated to various institutions in the consortium, the CIAMTIS steering committee members were unanimously in favor of Penn State hosting this education and workforce development event annually. Penn State shifted the conference to a virtual event for the last two years as a result of COVID concerns. It is anticipated that Penn State will host the TAIM conference in the future based on their institutional experience in planning the in-person and virtual versions of the event.

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.