Final Report:
Project Number and Title: Thrust #1 Distributed Fiber Optic Sensing System for Bridge Monitoring
Research Area: Thrust #1
PI: Xingwei Wang, Electrical and Computer Engineering Department, University of Massachusetts Lowell
Co-PI(s): TzuYang Yu, Civil Engineering Department, University of Massachusetts Lowell.
Reporting Period: *06/05/2018-09/30/2025*
Submission Date: *09/30/2025*

******IMPORTANT: Please fill out each section fully and reply with N/A for questions/sections with nothing to report. For ease of reporting to the USDOT, please do not remove, or change the order of, any sections/text. You may remove/add each row in tables as needed. Thank you! ******
The report is due on the last day of the reporting period in .doc format to tidc@maine.edu.

Summary of the project:

The fabricated sensing textile was installed on three bridges: Salmon Falls Bridge in New Hampshire, Grist Mill Bridge in Maine, and a pedestrian bridge at UMass Lowell (UML).

- Salmon Falls Bridge (NH): Strain responses were collected for both baseline conditions and during train crossings.
- Grist Mill Bridge (ME): Frequency and strain responses were measured under different truck loads and compared with baseline data.
- UML Pedestrian Bridge: Distributed strain responses were recorded for various human activities, including walking, running, and jumping, under different load conditions.

Field tests on each bridge were conducted over several years. The collected data demonstrated the sensing textile's capability for long-term structural health monitoring. Results from these studies have been published in journals and presented at conferences.

Overview:

- The sensing textile design incorporated a U-shaped fiber for use with the BOTDA system.
- It was installed on the Grist Mill Bridge in Hampden, Maine, where baseline tests were carried out over a six-year period, complemented by measurements taken during truck passages.

Meeting the Overarching Goals of the Project:

How did the previous items help you achieve the project goals and objectives? Please give one bullet point for each bullet point listed above.

- Discussions with the Saint-Gobain team and vendors provided valuable insights into the sensing textile fabrication process, as well as key considerations such as insurance, project timelines, and the availability of fabrication equipment.
- A sample measuring 2 m in length and 33 cm in width was sent to Arachne Labs LLC to verify the fabrication machine's capability to produce the sensing textile.
- In the laboratory, the FBG wireless demodulator was tested to evaluate remote screen connectivity and software functionality.
- The U-shaped fiber BOTDA design enabled effective strain sensing with high spatial resolution, directly advancing the goal of developing reliable distributed sensing technologies.
- Field deployment of the sensing textile on the Grist Mill Bridge in Hampden, Maine, using a custom installation cart, ensured efficient installation and validated system performance in a critical infrastructure setting.
- Over six years of baseline monitoring and truck-loading tests demonstrated the long-term durability, stability, and responsiveness of the sensing system, fulfilling the objective of ensuring robustness for field applications.

Accomplishments:

- Held a meeting with Saint-Gobain and vendors to discuss fabrication process and project requirements.
- Verified proper operation of the mini-PC and software for the FBG wireless demodulators.
- Completed development of a U-shaped fiber BOTDA sensing textile for high-resolution strain monitoring.
- Successfully deployed the sensing textile on the Grist Mill Bridge in Hampden, Maine, using a custom installation cart to enable efficient installation.
- Conducted six years of baseline and truck-loading tests, demonstrating the durability, stability, and reliability of the sensing system under field conditions.

Task, Milestone, and Budget Progress:

Complete the following tables to document the work toward each task and budget (add rows/remove rows as needed, make sure you complete the Overall Project progress row and include all tasks even if they have ended or have not been started)…

Table 1: Task Progress

Task Number: Title	Start Date	End Date	% Complete
Task 1-1: Sensor development	1/1/2019	6/30/2019	100%
Task 1-2: Signal processing and sensor characterization on sensors before installation	1/1/2019	12/30/2019	100%
Task 1-3: Preliminary field tests on bridge	10/1/2019	9/30/2021	100%
Task 2-1: Algorithm optimization for temperature compensation	9/30/2021	12/2022	100%
Task 2-2: Algorithm development for color coded temperature and strain reconstruction	9/30/2021	12/2022	100%

Task 2-3: Sensor signal response to different weather conditions throughout a year of study.	1/1/2020	12/2022	100%
Task 2-4: Implementation of FBG sensors for newly constructed bridges assessment	1/2022	12/2022	100%
Task 3-1: Signal Processing for sensors on different bridges	01/01/2023	06/30/2023	100%
Task 3-2: Explore OFDR interrogation system	07/01/2021	12/31/2023	100%
Task 3-3: Long-term monitoring for more than 1 year of study	01/01/2021	09/30/2025	100%
Phase 1 Overall	1/1/2019	9/30/2021	100%
Phase 2 Overall	9/30/2021	12/2022	100%
Phase 3 Overall	1/2023	9/302025	100%

Table 2: Milestone Progress

Milestone #: Description	Corresponding Deliverable	Start Date	End Date
Milestone 1: Signal processing	• Understand the effects of Brillouin peaks on the signal. • Study the effects of spatial resolution on the Signal to Noise Ratio. • Develop a complex matrix on how different parameters affect the signal.	01/01/2021	06/30/2021
Milestone 2: Strain gauge comparison	• Comparison between distributed optical sensors and strain gauge data	07/01/2021	11/30/2022
Milestone 3: Temperature compensation scheme	• A prototype of a smart textile with tubing embedded for temperature compensation.	07/01/2021	10/30/2022
Milestone 4: Explore OFDR interrogation system.	• Analysis of the dynamic responses of the OFDR measurement on bridges.	01/01/2022	3/1/2025
Milestone 5: Hardware smart textile improvement	• Provide a system to connect fiber to the sensing textile.	07/01/2022	9/30/2025
Milestone 6: Software	• Software capable of integrating the data from the BOTDA to a 3D model.	01/01/2023	9/30/2025
Milestone 7: Long term monitoring	• Study of the effect of weather conditions on the BOTDA data. • Procedure to characterize the sensors for temperature and strain.	01/01/2023	9/30/2025

Table 3: Budget		
Project Budget	**Spend – Project to Date**	**% Project to Date***
Phase 1: $102.1k	$102.1k	100%
Phase 2: $103K	$103 k	100%
Phase 3: $167k	$167k	100%
Complete Project: $ 372,338K	$ 372,338k	100%

Include the date the budget is current to.

Match part expenditure:

Table 3: Budget Progress			
Cost Share budget	**Xingwei Wang course release**	**RA tuition and fees**	**%Percentage to Date**
$310k	$200,233	$200,059	129%

Is your Research Project Applied or Advanced?

☒ **Applied** (*The systematic study to gain knowledge or understanding necessary for determining the means by which a recognized and specific need may be met.)*

☐ **Advanced** *(An intermediate research effort between basic research and applied research. This study bridges basic (study to understand fundamental aspects of phenomena without specific applications in mind) and applied research and includes transformative change rather than incremental advances. The investigation into the use of basic research results to an area of application without a specific problem to resolve.)*

Education and Workforce Development:

Answer the following questions (N/A if there is nothing to report):

- Did you provide any workforce development or training opportunities to transportation professionals (already in the field)? If so, what was the training? When was it offered? How many people attended? (i.e. The research team provided an in the field training for the SAR technology for 3 maintenance crew members of the , on 3/31/2021. The members learned how to use the technology and interrupt the data.)

N/A

- Did you hold meetings with any transportation industry organizations or DOTs? If so, what was the meeting's purpose? When was it offered? How many people attended? (i.e. The research team held a meeting with MaineDOT to update them on the progress of the research findings and how the findings can be implemented on 3/31/2021. 15 DOT maintenance members were present at the meeting.)

- N/A

- Did you host/participant in any K-12 education outreach activities? If so, what was the activity? What was the target age/grade level of the participants? How many students/teachers attended? When was the activity held? (i.e. 25 8th graders and 2 teachers visited the concrete lab and created small concrete trinkets like Legos on 3/31/2021. They learned about the different types of fibers that can be used in the concrete.)

In 2025 summer, a summer outreach program was hosted in the Optics Lab for middle and high school participants. Four students took part in the program, contributing to sensor preparation and testing activities. Through this experience, they gained hands-on exposure to optical fiber sensors and were introduced to foundational concepts in photonics and sensing technologies. Some conference papers are expected.

Technology Transfer:

Complete all of the tables below and provide additional information where requested. Please provide ALL requested information as this is one of the most important sections for reporting to the USDOT. ***ONLY provide information relevant to this reporting period.***

Use the table below to complete information about conference sessions, workshops, webinars, seminars, or other events you led/attended where you shared findings as a result of the work you conducted on this project:

Table 4: Presentations at Conferences, Workshops, Seminars, and Other Events

Type	Title	Citation	Event & Intended Audience	Location	Date(s)
i.e Conference, Symposium, DOT/AOT presentation, Seminar, etc.	Presentation Title	Full Citation	Name of event (i.e. TIDC 1st Annual Conference) or who was the presentation given to?		
2025 TIDC Annual Conference	Long-term Structural Health Monitoring on Grist Mill Bridge	Full Citation	Guoqiang Cui	UMaine Wells Conference Center	August 6-7, 2025

Use the table below to report any publications, technical reports, peer-reviewed articles, newspaper articles referencing your work, graduate papers, dissertations, etc. written as a result of the work you conducted on this project. Please list only completed items and exclude work in progress.

Table 5: Submitted/Accepted Publications, Technical Reports, Theses, Dissertations, Papers, and Reports

Type	Title	Citation	Date	Status
i.e. Peer-reviewed journal, conference paper, book, policy paper,	Publication title	Full citation		**i.e. Submitted, accepted, under review (by org. submitted to)**

magazine/newspaper article				
Conference	Long-Term Monitoring on a New Composite Bridge Girder Based on a Fiber Optic Sensing Textile	Wu, R., Biondi, A., Cao, L., Cui, G., Abedin, S., Wang, X., HarshNareshkumar, G. and Yu, T., 2025, July. Long-Term Monitoring on a New Composite Bridge Girder Based on a Fiber Optic Sensing Textile. In International Conference on Experimental Vibration Analysis for Civil Engineering Structures (pp. 590-597). Cham: Springer Nature Switzerland.	2-4 July 2025	Published

Answer the following questions (N/A if there is nothing to report):

- Did you deploy any technology during the reporting period through pilot or demonstration studies as a result of this work? If so, what was the technology? When was it deployed?

N/A

- Was any technology adopted by industry or transportation agencies as a result of this work? If so, what was the technology? When was is adopted? Who adopted the technology?
  - N/A

- Did findings from this research project result in changing industry or transportation agency practices, decision making, or policies? If so, what was the change? When was the change implemented? Who adopted the change?
  - N/A

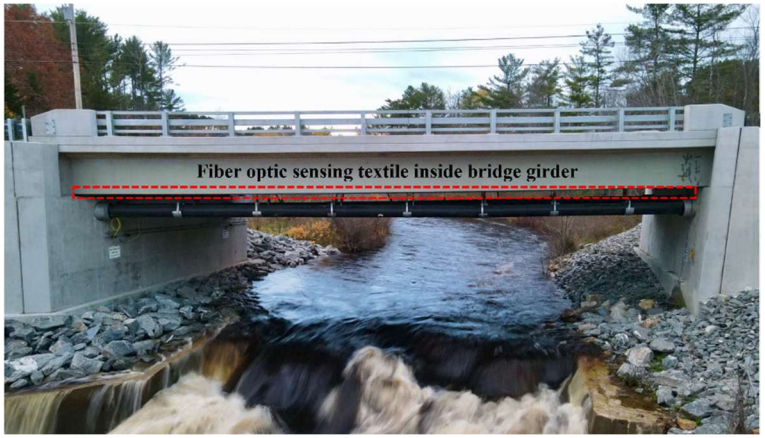
- Were any licenses granted to industry as a result of findings from this work? If so, when? To whom was the license granted?
  - N/A

- Were any patent applications submitted as a result of findings from this research? If so, please provide a copy of the patent application with your report.
  - N/A

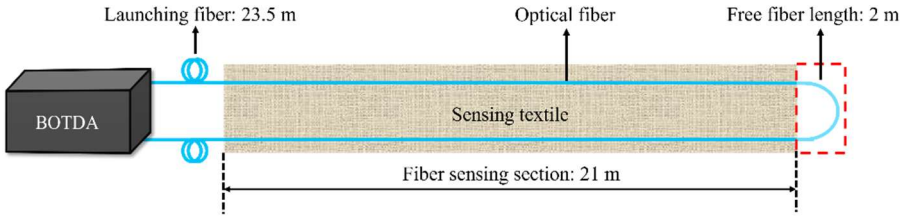
- Did industry organizations or DOTs provide cost-share (cash or in-kind) to your research during the reporting period? Who was the organization? Please provide an in-kind support invoice from the organization with your report (this is kept confidential and used for record keeping purposes only).

  N/A

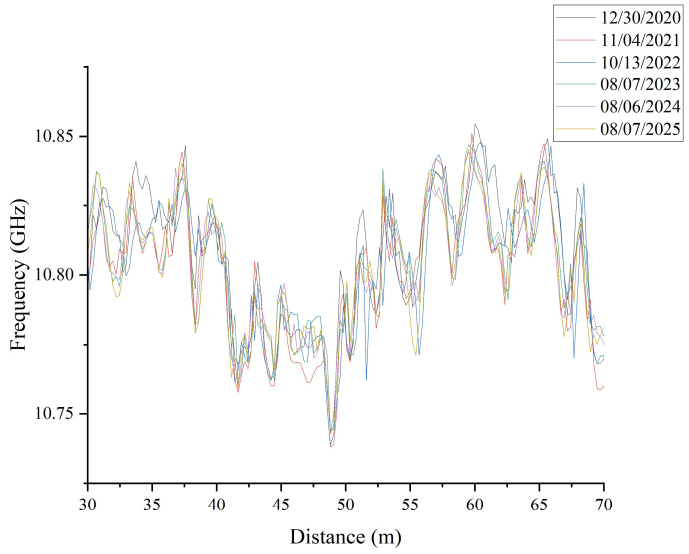
Please add figures/images that can be included on the website and/or in marketing/social media materials to further clarify your research to the general public. This is very important to our Technology Transfer initiatives.



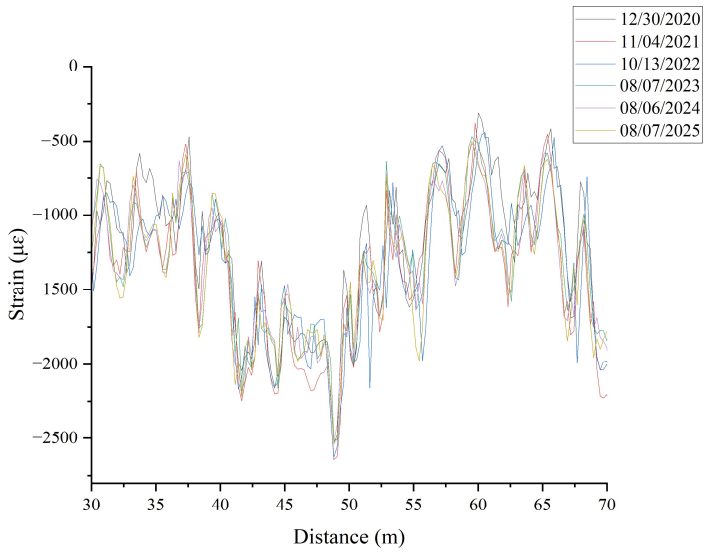
(a)



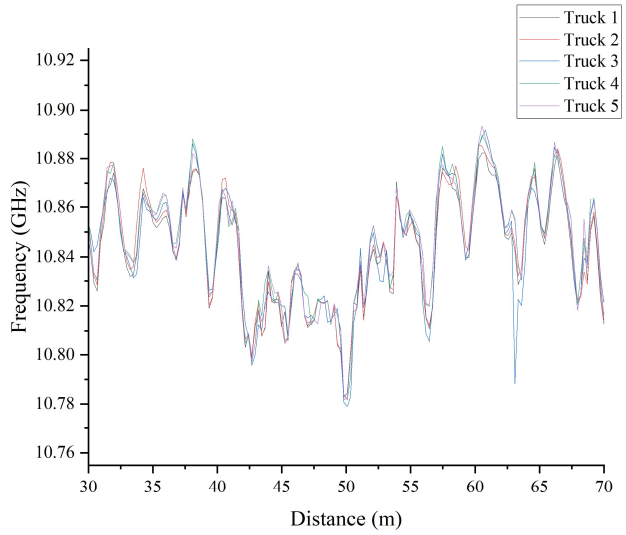
(b)


12/30/2020
11/04/2021
10/13/2022
08/07/2023
08/06/2024
08/07/2025
Frequency (GHz)
10.85
10.80
10.75
30
35
40
45
50
55
60
65
70
Distance (m)

(c)


12/30/2020
11/04/2021
10/13/2022
08/07/2023
08/06/2024
08/07/2025
Strain (με)
0
−500
−1000
1500
−2000
−2500
30
35
40
45
50
55
60
65
70
Distance (m)

(d)


Truck 1
Truck 2
Truck 3
Truck 4
Truck 5
Frequency (GHz)
10.92
10.90
10.88
10.86
10.84
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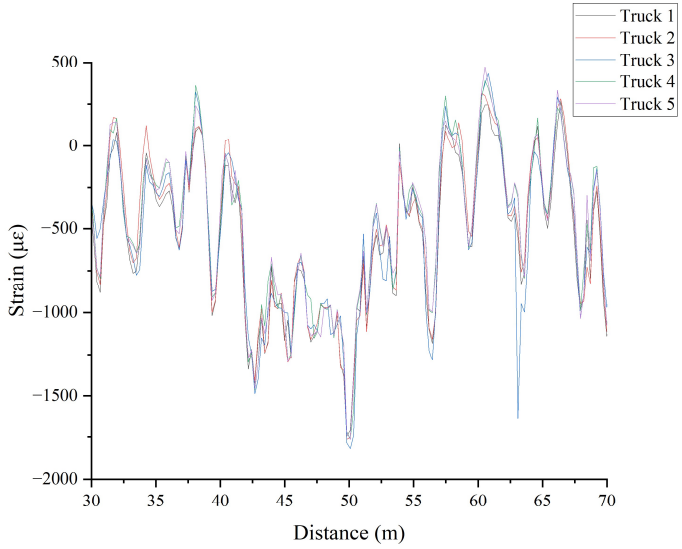
10.78
10.76
30
35
40
45
50
55
60
65
70
Distance (m)

(e)


Truck 1
Truck 2
Truck 3
Truck 4
Truck 5
Strain (με)
500
0
−500
−1000
−1500
−2000
30
35
40
45
50
55
60
65
70
Distance (m)

(f)

Figure 1. Project photos and results. (a) Grist Mill Bridge and sensing section. (b) Sensing textile pattern. (c) Baseline frequency over six years. (d) Baseline strain over six years. (e) Truck frequency responses in 2025. (f) Truck strain responses in 2025.

Describe any additional activities involving the dissemination of research results not listed above under the following headings:

Outputs:

Definition: Any new or improved process, practice, technology, software, training aid, or other tangible product resulting from research and development activities. They are used to improve the efficiency, effectiveness, and safety of transportation systems. List any outputs accomplished during this reporting period:

- A U-shaped fiber BOTDA sensing textile was developed for high-resolution, distributed strain monitoring. This technology provides enhanced capability for structural health monitoring of bridges, improving detection of localized strain and long-term degradation.
- A custom installation cart was designed and used to deploy the sensing textile efficiently on the Grist Mill Bridge in Hampden, Maine. This output simplifies installation procedures and reduces labor and time required for field deployment.
- A data set from six years of bridge monitoring, including baseline and truck-loading tests, was generated. This long-term field data demonstrates durability of the sensing textile and provides a valuable resource for advancing bridge health monitoring practices.
- A K–12 outreach module was created through the summer program, introducing middle and high school students to photonics and fiber-optic sensing. This training aid contributes to STEM education and workforce pipeline development in transportation-related technologies.

Outcomes:

Definition: The application of outputs; any changes made to the transportation system, or its regulatory, legislative, or policy framework resulting from research and development activities. List any outcomes accomplished during this reporting period:

- Example: The developed sensing technology was installed in Bridge A in town, state on 1/1/2021. This installation will… The UAV was successfully used by ___ Organization to inspect ___ Bridge in in town, state on 1/1/2021… The newly created college course was taken/completed by __ students in the 2021 fall semester.

- The U-shaped fiber BOTDA sensing textile was successfully installed on the Grist Mill Bridge in Hampden, Maine. This installation enables continuous, distributed strain monitoring of the bridge and demonstrates the technology's feasibility for long-term deployment in critical transportation infrastructure.
- Six years of baseline and truck-loading tests were completed on the Grist Mill Bridge. These tests confirmed the sensing textile's durability, stability, and responsiveness, providing validated data to inform bridge health monitoring and maintenance strategies.

- A summer outreach program was conducted in June 2025 at UMass Lowell's Optics Lab, where three middle and high school students participated in hands-on activities with optical fiber sensors. This outcome broadened STEM engagement and introduced students to photonics and sensing technologies relevant to transportation safety.
- Graduate and undergraduate students gained practical experience in sensor fabrication, deployment, and long-term field monitoring, directly contributing to workforce development in transportation-related sensing technologies.

Impacts:

Definition: The effects of the outcomes on the transportation system such as reduced fatalities, decreased capital or operating costs, community impacts, or environmental benefits. The reported impacts from UTCs are used for the assessment of each UTC and to make a case for Federal funding of research and education by demonstrating the impacts that UTC funding has had on technology and education. NOTE: The U.S. DOT uses this information to assess how the research and education programs (a) improve the operation and safety of the transportation system; (b) increase the body of knowledge and technologies; (c) enlarge the pool of people trained to develop knowledge and utilize technologies; and (d) improves the physical, institutional, and information resources that enable people to have access to training and new technologies. List any outcomes accomplished during this reporting period:

- **Improved Transportation Safety and Monitoring**
  The successful deployment of the sensing textile on the Grist Mill Bridge in Hampden, Maine, demonstrated long-term durability and reliability in field conditions. This validates the textile's capability to provide continuous, distributed strain monitoring, supporting safer operation and maintenance of bridges.
- **Contribution to Knowledge and Technology Development**
  The U-shaped fiber BOTDA design advanced high-resolution strain sensing methods, contributing to the body of knowledge in distributed sensing technologies. Publications in journals and conferences will disseminate these findings to the broader research community, enabling adoption and further innovation.
- **Education and Workforce Development**
  A K–12 summer outreach program hosted in June 2025 introduced middle and high school students to optical fiber sensors and photonics, enlarging the pool of students exposed to STEM fields relevant to transportation safety and sensing technologies. Graduate and undergraduate students also gained hands-on experience with field deployment and long-term monitoring techniques, preparing a workforce skilled in advanced sensing technologies.
- **Enhanced Research Infrastructure**
  Collaboration with Saint-Gobain, Arachne Labs LLC, and vendors provided access to specialized fabrication equipment and installation tools, strengthening institutional capabilities to develop, test, and deploy distributed sensing systems for critical transportation infrastructure.

Participants and Collaborators:

Use the table below to list individuals (compensated or not) who have worked on the project other than students.

Table 6: Active Principal Investigators, faculty, administrators, and Management Team Members				
Individual Name & Title	**Dates involved**	**Email Address**	**Department**	**Role in Research**
Xingwei Wang		Xingwei_wang@uml.edu	Electrical and Computer Engineering	PI
TzuYang Yu		Tzuyang_yu@uml.edu	Civil Engineering	Co-PI

*Use the table below to list **all** students who have participated in the project during the reporting period. (This includes all paid, unpaid, intern, independent study, or any other student that participated in this project.) **ALL FIELDS ARE REQUIRED.***

Table 7: Student Participants during the reporting period								
Student Name	**Start Date**	**End Date**	**Advisor**	**Email Address**	**Level**	**Major**	**Funding Source**	**Role in research**
Lidan Cao	*07/01/2025*	*09/30/2025*	Xingwei Wang	lidan_cao@student.uml.edu	Ph.D.	ECE	TIDC	Conducted field test preparation and analyzed signals.
Sabrina Abedin	*07/01/2025*	*09/30/2025*	Xingwei Wang	Sabrina_Abedin@student.uml.edu	Ph.D.	ECE	TIDC	Conducted field test preparation and analyzed signals.
Guoqiang Cui	*07/01/2025*	*09/30/2025*	Xingwei Wang	guoqiang_cui@student.uml.edu	Ph.D.	ECE	TIDC	Conducted field test preparation and analyzed signals.

Use the table below to list any students who worked on this project and graduated or received a certificate during this reporting period. Include information about the student's accepted employment during the reporting period (i.e. the student is now working at MaineDOT) or if they are continuing their students through an advanced degree (list the degree and where they are attending).

Table 8: Students who Graduated During the Reporting Period			
Student Name	**Degree/Certificate Earned**	**Graduation/Certification Date**	**Did the student enter the transportation field or continue another degree at your university?**

Rui Wu	Ph.D.	5/2025	Fiber Optic Manufacturer

Use the table below to list any students that participated in Industrial Internships during the reporting period:

Table 9: Industrial Internships			
Student Name	**Degree/Certificate Earned**	**Graduation/Certification Date**	**Did the student enter the transportation field or continue another degree at your university?**
NA			Please list the organization or degree

*Use the table below to list **organizations** that have been involved as partners on this project and their contribution to the project during the reporting period.*

Table 10: Research Project Collaborators during the reporting period						
Organization	**Location**	**Contribution to the Project**				
		Financial Support	**In-Kind Support**	**Facilities**	**Collaborative Research**	**Personnel Exchanges**
		List the amount	List the amount	Mark with an "x" where appropriate		
Saint Gobain	MA. USA			x	x	
OFS	GA, USA		x		x	

*Use the table below to list **individuals** that have been involved as partners on this project and their contribution to the project during the reporting period. (**List your technical champion(s) in this table.** This also includes collaborations within the lead or partner universities who are not already listed as PIs; especially interdepartmental or interdisciplinary collaborations.)*

Table 11: Other Collaborators				
Collaborator Name and Title	**Contact Information**	**Organization and Department**	**Date(s) Involved**	**Contribution to Research**
NA	For internal use only			(i.e. technical champion, technical advisory board, test samples, on-site equipment, data, etc.)

Number of active industrial partners involved in this research project
Two

Number of technical Champions actively involved in this project:

Dan Kominsky, Ph.D.

Senior Research Scientist

Luna Innovations Incorporated

3155 State Street, Blacksburg VA 24060

(540) 553-0865

Dan.kominsky@lunainc.com

Use the following table to list any transportation related course that were taught or led by researchers associated with this research project during the reporting period:

Table 12: Course List

Course Code	Course Title	Level	University	Professor	Semester	# of Students
i.e. CE 123		Grad or undergrad?	Where was the course taught?	Who taught the course?	Enter Spring, Fall, Summer, Winter and the year	How many students were enrolled in the class?

Changes:

List any actual or anticipated problems or delays and actions or plans to resolve them (list no-cost extension requests here)…
N/A

List any changes in approach and the reasons for the change…
N/A

Planned Activities:

List the activities planned during the next quarter.
N/A