Fiber Optic Sensing Association
Connect and Protect

Utilizing Distributed Fiber Optic Sensing to Improve Infrastructure Safety, Reduce Congestion, and Enable Autonomous Vehicles

This paper contains four sections outlining how distributed fiber optic sensing (DFOS) can be used to improve the safety of our nation's infrastructure assets, such as highways, bridges and tunnels, reduce congestion from the increase in urban populations, and leverage investments in fiber optic infrastructure with the multi-use of advanced sensing with broadband expansion. The first section explains the technology behind DFOS; the second section outlines the safety and capacity challenges for U.S. infrastructure; the third section explains how DFOS can provide solutions to address these challenges; and the fourth section outlines recommendations for Congress and the Executive Branch.

I. What is Distributed Fiber Optic Sensing (DFOS)?

Distributed fiber optic sensing (DFOS) systems are sensor technologies used around the world to constantly and consistently monitor roads, bridges, railways, pipelines, power stations, terrestrial and subsea power cables, international borders, critical infrastructure, and telecom networks. DFOS systems connect laser interrogator units (IUs) to a fiber optic cable converting the optical fiber to an array of distributed sensors. The fiber becomes the sensor when the interrogator units inject laser light into the fiber to detect events along the fiber over very long distances.

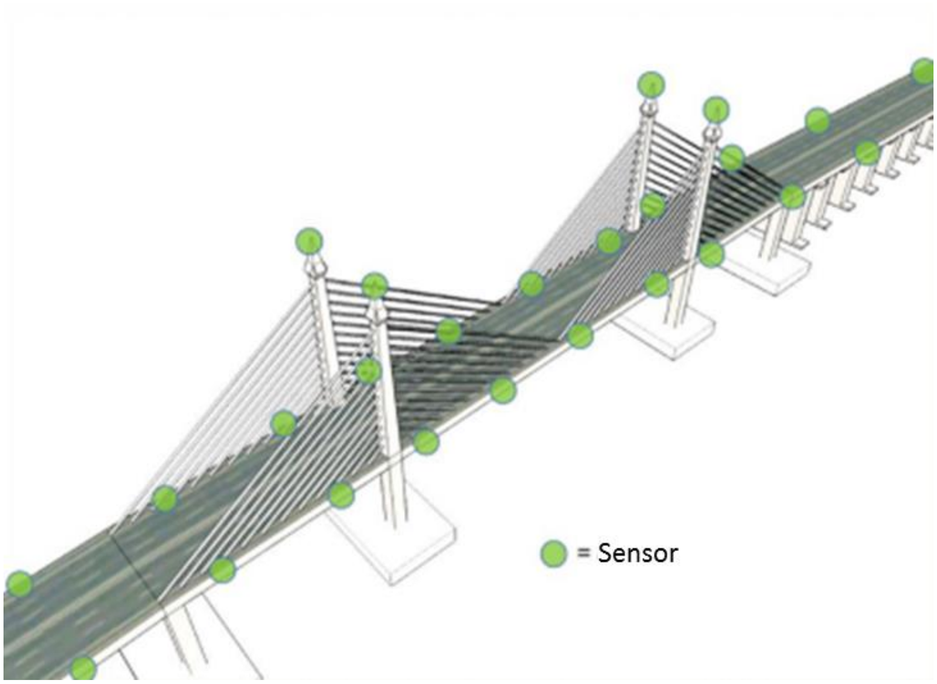
More specifically, DFOS systems consist of a fiber optic cable, IUs, and intelligent monitoring software. The IU pulses light around 10,000 times/second down the fiber optic cable. Changes in vibrations/acoustics, temperature, or strain at or near the fiber optic cable are identified and classified in real time by intelligent monitoring software, which then alerts the operator of the system with what the disturbance is and precisely where it is located. These technologies can span hundreds of miles and provide real-time readings at roughly three-foot (one-meter) intervals along the entire span.

There are three basic types of DFOS systems:

1. **Distributed Acoustic Sensing (DAS)**
   DAS systems convert fiber optic cable into a series of thousands of sensitive microphones or vibration sensing locations. Using specially developed algorithms it is possible to listen to, track, detect, and pinpoint various activities and events along assets, including vehicle and foot traffic, digging, excavation, tunneling, seismic activity, rock falls, anchoring of ships, and landslides. DAS can also be used for asset condition monitoring by detecting events such as cable faults, broken rails, damaged rolling stock, pipeline liquid and gas leaks, and much more.
2. **Distributed Temperature Sensing (DTS)**
   DTS is a fiber-optic sensing technology for measuring temperature profiles along fiber-optic sensor cables installed near linear assets as well as on two- or three-

dimensional objects. Major applications of DTS are power cable and overhead line temperature monitoring; fire detection in fuel storage facilities, tunnels and buildings; monitoring of industrial equipment such as ovens and reactors and oil and gas in-well production, as well as leak detection at pipelines and storage tanks.

3. **Distributed Strain Sensing (DSS)**
   DSS is a fiber optic sensing technology that measures changes in strain at any point along the length of a fiber optic cable. DSS is commonly used for monitoring large structures where changes in strain may be indicative of impending failure. Aging and modern infrastructure like bridges, tunnels, roadways, power cables, pipelines, dams, and levees are all assets that can benefit from DSS monitoring. Similarly, industrial process monitoring, as well as pipeline deformations, tunneling, subsidence, and landslides can be detected by DSS measurements.



DFOS technology is not constrained by line of sight or remote power access, and can be deployed in continuous lengths over hundreds of miles with detection at every point along its path. Electricity is only required to power the interrogator equipment while the fiber optic cable installed along the assets to be monitored is completely passive, requiring no electricity and immune to the effects of radio frequency and electromagnetic interference. The technology can even use existing dark telecommunication fibers. Oftentimes and preferably, the fiber cable used is located within conduit pathways which enable rapid and easy repairs to the fiber cable if required, in addition to possibly desired future fiber cable additions or replacement.

II. Infrastructure Safety, Capacity, and Future Technology Challenges in the United States

Aging Infrastructure

The U.S. has over 617,000 bridges, of which 42% are 50 years in age or older and 7.5% are considered structurally deficient, meaning they are in “poor” condition. There are 167.5 million daily crossings on 43.578 structurally deficient U.S. bridges in poor condition. In 2007, the I-35W Mississippi River Bridge in Minneapolis, MN had a catastrophic failure during the evening rush hour on August 1, 2007, killing 13 people and injuring 145. While the number of bridges in the U.S. that are in such poor condition as to be considered structurally deficient is decreasing, the average age of America’s bridges keeps going up, as does structural fatigue. And many of the nation’s bridges are approaching or exceeding the end of their design life. The estimated cost to replace all the structurally deficient bridges based on average price data from the USDOT is over $58 billion. The potential of widespread failures in bridges highlights the importance of effective monitoring systems that can identify structural problems at an early stage and ensure public safety.

Risk of Tunnel Fires

While only two major fires (the 1949 Holland Tunnel fire in New York and the 1982 Caldecott Tunnel fire in California) have occurred during the history of tunnels in the United States, major tunnel fires can be catastrophic with the scale of lives lost and property damaged, and disruptions can last months and even years. More than 30 people died in 2017 after an explosion and fire engulfed dozens of vehicles in the Yanhou Tunnel in China, and the 2008 Channel Tunnel fire in the UK required £60 million in repairs. The horrific Mont Blanc Tunnel fire on the France/Italy border in March 1999 claimed 39 lives and resulted in multi-million Euro fines for the companies involved and custodial sentences for senior executives responsible for safety. And the Kaprun disaster was a fire that occurred in an ascending train in the tunnel of the Gletscherbahn Kaprun 2 funicular in Kaprun, Austria on 11 November 2000 and killed 155 people. The naturally occurring draft within tunnels can act as chimneys encouraging smoke to engulf entrance portals and oncoming vehicles. Tunnel fires are particularly challenging for fire engineers, health and safety professionals, and emergency services. Avoidance of such fires is imperative.

Increase in Urban Populations

The urban population of the United States has grown rapidly. In 2000, 79.9% of the U.S. population lived in urban areas. This grew to 83% in 2021, and is projected to grow to 89.2% by 2045. This increase in urbanization will intensify the stresses placed on city road networks. Optimal use and predictive maintenance of road infrastructure will be vital to managing the impact of rapidly increasing traffic volumes and minimizing congestion and travel times.

III. How Can DFOS Help Solve These Challenges?

Aging Infrastructure

DFOS is an effective means of monitoring the structural health of transportation infrastructure, including roads, bridges, and tunnels. Cracks and structural deformation can be detected rapidly, with early warning of potential incidents and the ability to pinpoint areas of concern to operators. This extends the life of infrastructure, can mitigate lengthy repair or replace projects and avoid incidents, which are costly and a threat to public safety. As a long distance and highly reliable technology, DFOS lends itself to 24/7 / 365 monitoring in remote environments, where the multi-use sensing cable can also be leveraged for datacom transmission to get broadband to rural locations. In this way, both existing and new installations driven by increased broadband and datacom needs can also be a key asset for providing desperately needing monitoring of ongoing resilience.

DFOS monitors bridges, tunnels and dams and levees to provide early warning of structural issues, extend infrastructure life and protect the public from tragic incidents such as the collapse at Florida International University in 2018

Tunnel Fires

Distributed Temperature Sensing (DTS) is routinely used in Europe and Asia for fire detection in tunnels. Temperature changes are detected rapidly with high locational accuracy, easily integrating fiber optic systems with other incident mitigation solutions to protect the public and limit the devastating potential of these events.

Fire detection within a tunnel

Congestion Monitoring in Urban Locations

Distributed Acoustic Sensing (DAS) function as intelligent traffic sensors, delivering spatially rich and timely traffic management information. DAS can detect and measure vehicle movements as well as traffic patterns, such as congestion or queuing, directly and in real-time at any point along the fiber installation. DFOS can often be activated on pre-existing roadside fiber. It allows faster, less disruptive and more economical deployments of traffic management solutions, enabling city authorities to intelligently manage traffic flow, reduce emissions, leverage fiber optic cable and broadband rights-of-way for sensing. In addition, data gathered by DAS complements other traffic management solutions through data integration. Through integration of this technology within the current portfolio of existing sensors, transportation owners and operators might realize signicant operational expense reduction due to reduction of other maintenance-intensive technologies. Fiber optic sensing is also platform technology that provides multiple benefits to the development and deployment of autonomous vehicles, including integration for flow monitoring, volume counting and the tracking of individual vehicles.

DFOS leverages pre-existing roadside fiber to provide high resolution and real time traffic monitoring, enabling operators to reduce congestion and emissions, manage their roads more efficiently and provide a better experience to the public, all leveraging fiber optics that can be used for broadband distribution

IV. FOSA Recommendations

To encourage the increased implementation of DFOS systems to monitor our nation's infrastructure assets, reduce congestion, alert and alarm for disturbances, and enable autonomous vehicles, FOSA supports and encourages adoption of the following initiatives:

- U.S. DOT to prioritize funding for projects incorporating advanced sensing technologies that provide real-time monitoring of physical infrastructure and pinpoint events such as structural integrity failures, fires in tunnels and/or road congestion.
- U.S. DOT to ensure that the Broadband Infrastructure Deployment ("Dig Once") final rule (FHWA-2019-0037-0032) is implemented by state DOTs, and that state DOTs certify that they are meeting the four new requirements required in the regulation prior to receiving federal highway funding.
- U.S. DOT to prioritize funding for infrastructure projects that "minimize repeated excavation that involve broadband infrastructure installation in a ROW" and lay the groundwork for "smart roads" and other emerging or future applications.
- Funding and language in the FY2024 Transportation HUD Appropriations bill to establish a database at FHWA that can track the percentage of federal-aid highways with broadband conduit and fiber enabled rights-of-way

About the Fiber Optic Sensing Association (FOSA)

The Fiber Optic Sensing Association (FOSA) is a non-profit organization composed of organizations that manufacture, install, test, evaluate, support or use fiber optic sensing systems and equipment. FOSA's mission is to educate industry, government, and the public on the benefits of fiber optic sensing and how it can be used to secure critical facilities, enhance public safety, and protect the environment.