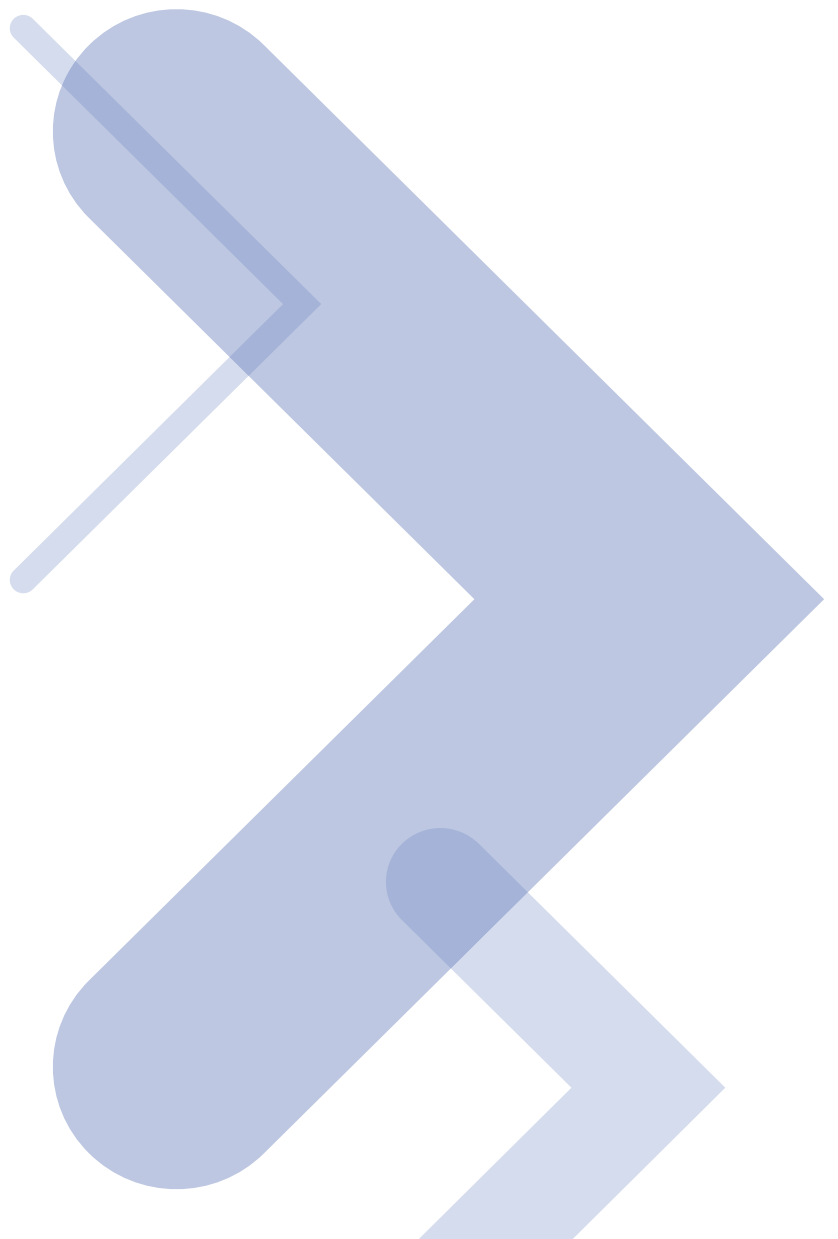




# Structural Monitoring: Making Bridges Safer Across the United States



# High-Speed Wireless Networks are Helping State and Local Departments of Transportation Remotely Monitor Highway Bridges to Increase Safety While Keeping Traffic Moving Smoothly.

During rush hour on the evening of August 1, 2007, the 8-lane I-35W steel truss arch bridge over the Mississippi River in Minneapolis, Minnesota, experienced a catastrophic failure. The bridge collapsed into the river and onto the riverbanks below, killing 13 people and injuring more than one hundred. An interim report from the National Traffic Safety Board identified undersized gusset plates as the main cause of the collapse.

In the aftermath of this tragedy, bridge safety has taken on a new urgency in the United States. There are currently more than 700 bridges in the country that are of similar construction to the I-35W span<sup>1</sup>. To address these and other potentially catastrophic circumstances, structural health monitoring enabled by wireless networks is playing an increasingly crucial role in the identification of conditions that could lead to failures.

Bridge structures are key elements of the U.S. roadway system and vital assets for the nation's economy and security. Their functioning is critical, but opportunities for failure are many, including deteriorating materials, underlying construction issues and improper load ratings. At any given point in time, bridges may also be threatened by natural disaster, man-made events, defective materials or simply by long-term "wear and tear." Today, continuous structural health monitoring solutions that combine embedded sensor systems with wireless communications networks are helping to identify potentially dangerous structures, and to pinpoint conditions that can be repaired well before a bridge fails.

## **An Indispensable Asset**

Bridges are an essential element of the nation's transit system, directly affecting both passenger car and truck traffic on regional and national levels.

In 2003, figures show that passenger vehicles represented about 57 percent of overall highway traffic.<sup>2</sup> Problems with aging and substandard bridges clearly affect millions of drivers and passengers both in terms of safety and convenience.

Although significantly smaller than passenger car numbers, commercial truck traffic affected by potentially unsafe bridges can cause substantial upheaval to the country's economy. Examining international trade with Mexico and Canada further illustrates this relationship.

## **Bridging Commercial Traffic**

In 2006, approximately 62 percent of the value of all goods traded with Mexico and Canada was carried by truck, while only 15 percent was carried by rail.<sup>3</sup> Most truck traffic crosses the border between the United States and Canada at three principle locations: Detroit, MI; Buffalo-Niagara, NY; and Port Huron, MI. Between Mexico and the United States, there are three principle border crossings at Laredo, TX; Otay Mesa/San Ysidro, CA; and El Paso, TX.<sup>4</sup>

Truck traffic is concentrated on major routes surrounding hubs of activity such as border crossings, ports, airports and population centers. As shown in Figure 1, that means there is a heavy reliance in the United States on bridge and roadway infrastructure to distribute goods to their final destinations.

Figure 2 shows a very different view of the United States in 2020 where, due to an increasing demand for goods and services, truck traffic is expected to increase by nearly 75 percent from 1998 levels.<sup>5</sup> This data clearly shows that commercial traffic will continue to rely even more heavily on the U.S. bridge infrastructure in the future.

<sup>1</sup> U.S. Department of Transportation, Office of Public Affairs. (August 2, 2007). U.S. Secretary of Transportation Mary E. Peters Calls on States to Immediately Inspect All Steel Arch Truss Bridges. U.S. Department of Transportation Press Release. <http://www.fhwa.dot.gov/pressroom/fhwa0712.htm>

<sup>2</sup> U.S. Department of Transportation, Federal Highway Administration, Office of Freight Management and Operations, Freight Analysis Framework.

<sup>3</sup> U.S. Department of Transportation, Federal Highway Administration, January 2008.

<sup>4</sup> Freight Facts and Figures, 2005, FHWA.

<sup>5</sup> U.S. Department of Transportation, Federal Highway Administration, Office of Freight Management and Operations, Freight Analysis Framework.

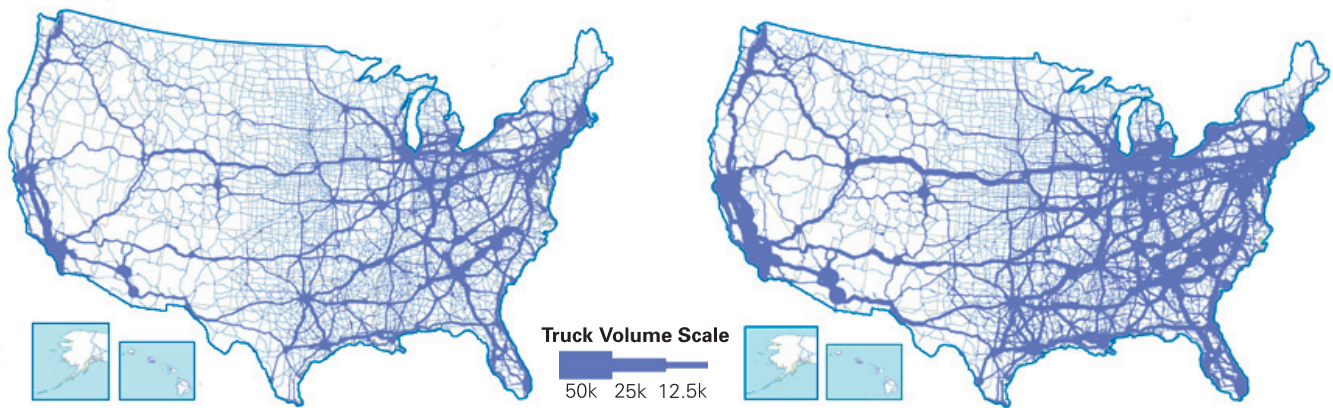


Figure 1. Estimated Average Daily Truck Traffic in 1998 <sup>5</sup>

Figure 2. Estimated Average Daily Truck Traffic in 2020 <sup>4</sup>

### Bridge Health

The U.S. Department of Transportation's (DOT) bridge inventory indicates the immense scope of the challenge in protecting the country's bridge assets. Much of this infrastructure is aging, a factor that contributes significantly to the degradation of a great many bridges.

The Federal Highway Administration has three different classifications of bridge health: healthy, structurally deficient, and functionally obsolete. In December 2007, estimates suggest that greater than 150,000 or 25 percent of bridges were deficient, falling into either the "functionally obsolete" or "structurally deficient" categories.<sup>6</sup>

A "structurally deficient" rating is given when part of the bridge is determined to be in poor condition. A deficient rating, however, does not prevent the bridge from continuing to be used. These structurally deficient bridges do, however, require significantly more maintenance and are restricted to lightweight vehicles. Bridges rated "functionally obsolete" do not sufficiently meet deck geometry criteria such as clearance, lane width or load carrying capacity. Although differentiations are made between these two categories of deficient bridges, most structurally deficient bridges are also functionally obsolete.

Management of this infrastructure inventory is complicated by the fact that many bridges are located in remote areas with limited power and communications connectivity. This significantly affects the efficiency of the inspection process.

Furthermore, the remoteness of these bridges reduces visibility as to the amount and type of traffic that uses them. This lack of information impacts the load rating of bridges as well as their construction, potentially resulting in constriction of commerce across the transportation network and unnecessarily high construction costs. Figures 3 and 4 provide a breakdown of U.S. bridges by inventory and health status.

### Inspection Regulation Issues

The United States boasts an enormous transit system, and bridges are some of its most important and most vulnerable assets. One of the questions raised by the enormity of the U.S. bridge inventory is: How to provide resources that will allow bridges to be inspected in a timely and frequent manner? Federal law requires all bridges be inspected every two years. In 2006, however, more than 7,900 state-owned bridges had not received an inspection in the last 24 months. The number is only slightly better for local bridges, with more than 6,200 not being inspected for over two years. Finally, federal agencies own about 3,000 bridges that were also past due for inspection.<sup>7</sup> Given the constraint on resources felt across the entire spectrum of transportation management entities, there is a real need to focus inspections on the bridges that are most at risk.

### Remote Monitoring Solutions

Continuous monitoring of bridges via sensors and wireless technology networks is proving to help transportation asset owners utilize their structures

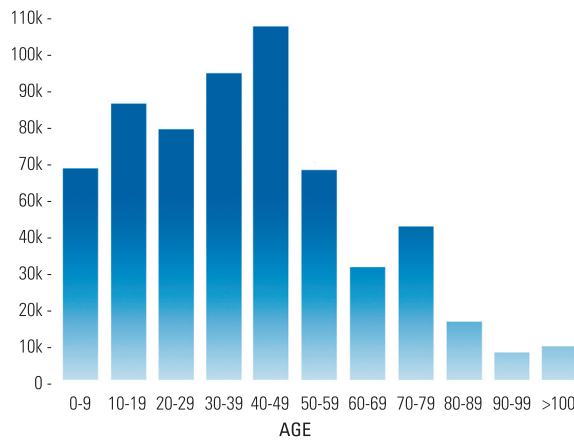
<sup>6</sup> U.S. Department of Transportation, Federal Highway Administration, Office of Bridge Programs, State and Highway System.

<sup>7</sup> MSNBC analysis of 2006 National Bridge Inventory, January 30, 2008.

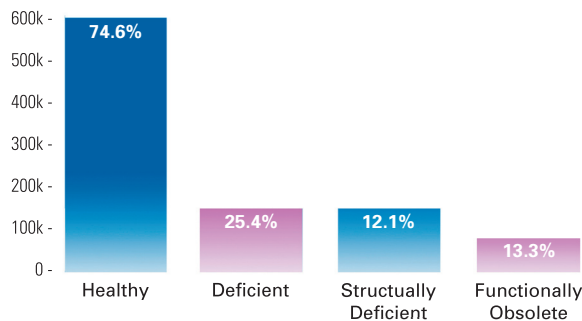
more safely and efficiently. The benefits of widespread deployment of bridge monitoring include:

- More accurate rating of bridge capacity to maximize the safe utilization of the transportation infrastructure and improve the flow of commerce.
- Measured data can be compared against computed values.
- More efficient utilization of bridge maintenance and inspection resources.
- Increased safety through early detection of structural abnormalities.
- Increased safety through monitoring and communication of icing and other conditions on bridge decks.
- Findings can be transferred to future bridge construction projects.

In addition, continuous monitoring of bridge infrastructure can help in early fault detection and protection against man-made threats. The remote location of many bridges makes them especially vulnerable to security issues, which could lead to dangerous consequences in terms of the economy and public safety. Remote monitoring enables



**Figure 3. Summary of U.S. DOT Bridge Inventory<sup>8</sup> (U.S. Bridges #)**



**Figure 4. Summary of Health Rating for All U.S. Bridges (U.S. Bridges #)**

<sup>8</sup> U.S. Department of Transportation, Federal Highway Administration, Office of Bridge Programs, Bridges Built by Year.

authorities to check for intrusions without having to deploy manpower to the location in question.

### Structural Testing Technologies

In most cases, cost-effective sensing technologies—including strain gauges, accelerometers and displacement gauges—are readily available for bridge monitoring. Taking maximum advantage of these sensors, however, requires a reliable and flexible communications infrastructure. In the past, communications infrastructure design was centered on the idea of local collection and storage of acquired data. While this method provides a satisfactory historical view, it makes crucial real-time monitoring difficult if not impossible.

### Wireless Network Monitoring Solutions

With the increased availability of wide-area wireless data networking, sensors can now be networked to provide for centralized data collection, which in turn allows for more efficient monitoring of multiple bridges or bridge segments across large areas. In general, there are two different types of communication designs. The first is based upon a public/private system design; the second is based completely on a private communications system design.

### Public/Private Communications Network

A public/private design requires several levels of communication: local sensor connectivity, on-bridge communications and wide-area communications connectivity. Figure 5 depicts a public/private communications network.

**Local Sensor Connectivity.** Depending on the use case, multiple sensors may be required to implement a bridge monitoring solution. A communications link is required between each sensor and data aggregation point. This communication link may be wired (analog or digital) or wireless. If analog, the data aggregation point will be responsible for converting this signal to a measurable value. Emerging technologies are beginning to allow for the last link of the sensors to be wireless, helping improve timeliness and cost-effectiveness by eliminating the long lengths of expensive cable and installation used to connect sensors. Low power wireless and local data collection capabilities will eventually allow for untethered sensors to operate on battery or other local power sources for years.

**On-Bridge Communications.** In addition to providing a link to each individual sensor, the data aggregation point also acts as a gateway to the communications layer established across a bridge. Connecting a data logger to a wireless device, such as a radio, enables this capability. The gateway functionality converts the analog and serial data streams from sensors to IP streams for delivery

across the wireless link. A multi-hop wireless network may serve as the communications layer because it can deliver cost-effective coverage across longer bridge structures. If wired internet access is available on the bridge, these devices can also connect directly to the wired Internet.

**Wide-Area Connectivity.** In cases where local wired Internet access is not available, point-to-point wireless backhaul links can extend the bridge networks to remote wired points of presence and enable access to the Internet.

One key benefit of this public/private type of architecture is that the data is converted to IP traffic as close to the sensors as possible as compared to the private communications system design that often uses proprietary protocols to carry the data.

**Private Communications Network**

Private communications networks may be owned and operated by a local or state agency, and generally consist of numerous radio-based towers linked together to form a wide-area network. Primarily, these systems support voice communications for

first responders, but they also provide an important data transport capability. Figure 6 illustrates the dynamics of a private communications network. In most instances, private communications networks provide wireless coverage at the bridge structure, eliminating the need for additional backhaul equipment that is required by public/private networks. For this reason, private networks require fewer levels of communication to implement a bridge monitoring solution, such as local sensor connectivity and wide-area connectivity.

**Local Sensor Connectivity.** Local sensor connectivity is also required in a private communications network. The functionality, however, of the data aggregation point can be implemented with a Remote Terminal Unit (RTU). Typically, an RTU is more closely integrated with the private communications network and can be programmed to behave as a data-logging device.

**On-Bridge Communications.** A separate on-bridge communication layer is not required in this design. Since the private communications network is based on a wide-area design, it will also provide

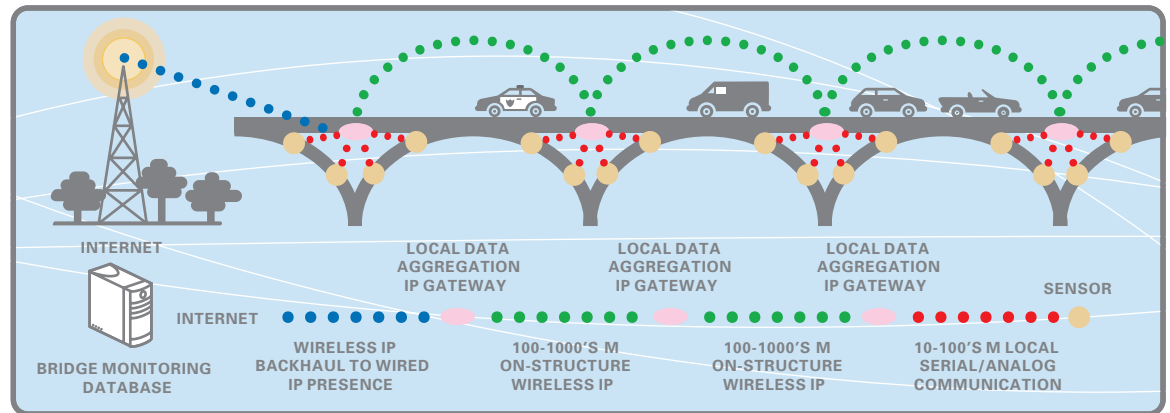


Figure 5. Public/Private Communications Network

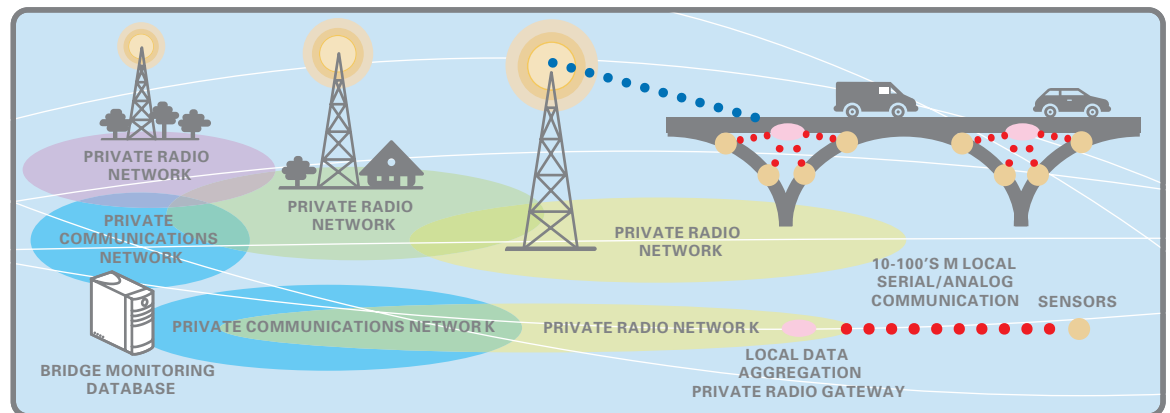


Figure 6. Private Communications Network

communications across the bridge, enabling the deployment, if necessary, of multiple RTUs. In addition to providing a link to each individual sensor, the RTU inherently acts as a gateway to the entire network. This gateway functionality consists of converting the analog and serial data streams from sensors to IP streams or, in some cases, proprietary protocols for delivery across the wireless link.

**Wide-Area Connectivity.** As shown in Figure 6, point-to-point wireless backhaul links are not required in private communications networks. Wide-area data connectivity is provided by the private radio network, which also handles routing of data to a central site.

Although this design requires fewer layers of communications than a public/private network, there are some trade-offs. The first is data rate. Private radio networks typically operate at rates less than 500 Kbps as compared to public/private networks that may operate at rates greater than 1 Mbps. Second, capacity should be considered when designing a private network since these networks are typically sharing-radio infrastructures. In this case, it is recommended that data be pre-processed and intelligently filtered at the RTU prior to transmission over the network.

#### **Bridging the Inspection Gap**

Whichever type of communications network is ultimately selected, preserving the integrity and improving the efficiency of U.S. bridges is of the utmost importance. The economic vitality of the

country depends on a smoothly functioning transportation system. The safety of the traveling public requires well-maintained infrastructure. Continuous monitoring of bridges can help meet both of those goals. The benefits of widespread deployment of bridge monitoring include:

- Effective rating of bridge capacity to maximize the flow of commerce and the safe utilization of the transportation infrastructure.
- Efficient scheduling and deployment of maintenance resources.
- Increased safety through early detection of structural abnormalities.
- Increased safety through monitoring of bridge deck conditions.
- More access to the data by multiple disciplines, sources and responders.
- More data to use for validation of historical and future bridge designs.
- Security and threat detection.
- Increased public confidence in bridge infrastructure.
- Establishes a baseline of data for existing structures should future structural events occur.

Modest investments in sensing and monitoring of transportation assets will pay dividends far into the future through the preservation and more efficient use of expensive infrastructure.



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