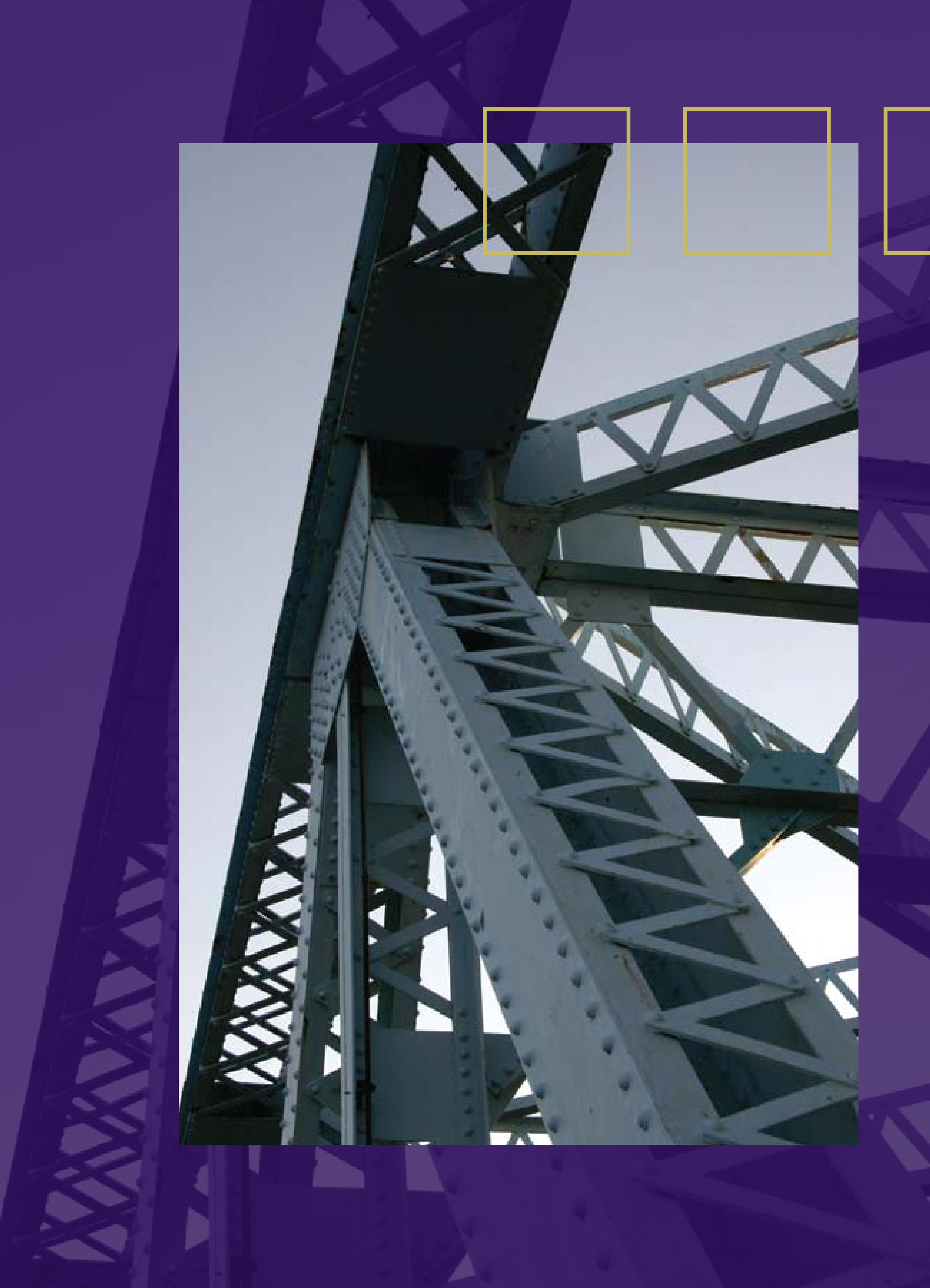

Our Aging Infrastructure: A Perspective on Bridge Safety

By Michael C. Ascher, P.E.

Editor's note: The following article was adapted from a speech given by the author last December to the Men's Club of the New City Jewish Center in Rockland County, N.Y.

The tragic collapse last August of the westbound Interstate-35 bridge over the Mississippi River in Minneapolis has raised many questions about the health of our aging infrastructure. How many power failures and brownouts, water-main breaks, steam leaks, levee and dam failures, building collapses, sidewalk-grating electrocutions, subway floods, sewage spills, and highway and bridge failures will it take for us to *truly* recognize that our infrastructure is in desperate need of repair and modernization? It takes a prudent public official to anticipate these needs before a tragedy strikes, not just react to it with hearings and admonitions afterward.

In my prior career in the nuclear industry, the term "half-life" was used to define the time required for half of the atoms of a radioactive substance to disintegrate. This term has become an everyday metaphor for anything that decays with time, including interest in issues that often confront us. But we ignore the issue of infrastructure at our own peril.

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Long-Span Bridge Structures

New York State has tens of thousands of bridge structures, more than 2,000 of which are in New York City alone. Most of these structures are relatively simple cantilevered spans such as you encounter as roadway overpasses and highway viaducts. While the discussion below entails more-complex, long-span bridge structures, many safety implications and maintenance and inspection requirements are applicable to all bridges.

A long-span bridge is a structure that is constructed without intermediate supports (piers and pier columns) over its length, which can range from several hundred feet to several thousand feet. These structures are most often required when it is necessary to meet the clearances required by navigable waterways.

Very often, engineering solutions result in the application of combinations of different structures that are needed for the approach ramps, viaducts, and causeways leading to and from the long span. These are typically a series of interconnected short spans that are supported on piers. A good example of this is the Tappan Zee Bridge, spanning the Hudson River between Rockland and Westchester counties in New York. While its overall length is about three miles, the distance between the towers of its longest span is 531 feet, and the span has a clearance of 138 feet over the shipping channel below. By comparison, the Verrazano-Narrows Bridge, the longest suspension bridge in North America, is 4,260 feet between towers, and its deck is 228 feet above mean high water.

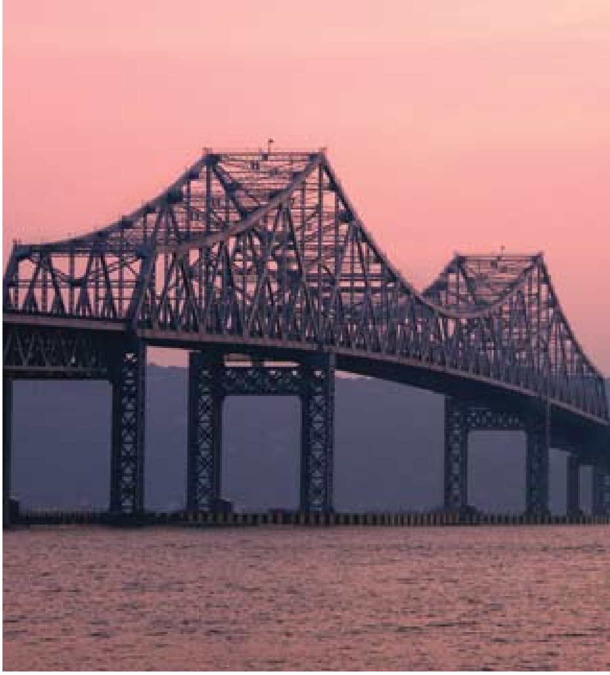
In designing any bridge span, engineers must create a structure that can handle combinations of loads, including the bridge's own weight, the weight of the traffic it must support, and other factors, such as wind, seismic activity, and fatigue. This must be accomplished with minimal deflections or bending, achieved on short-span bridges with the use of deep girders. To support long-span decks, however, one must use a lighter-weight truss section or a suspension or cable-stayed supporting system.

Truss sections. A truss section is built of individual steel members that act together to provide the needed strength and stiffness to accommodate a bridge's design loads. The I-35W bridge and the Tappan Zee Bridge employ this design. The roadway is called the deck structure and is typically constructed as a reinforced-concrete slab supported by subfloor stringers, beams, and braces.

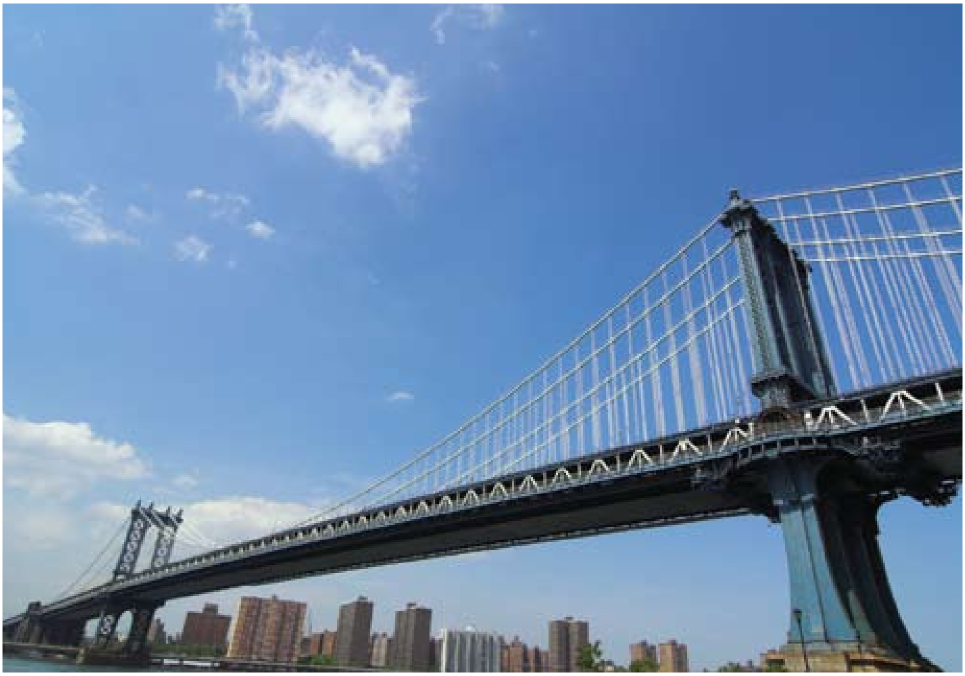
The structural members that form the truss and subfloor system are tied together via riveted, bolted, and welded connections. Pins, bearing wear plates, and expansion joints are utilized to accommodate movement between structural members. The design loads are ultimately transferred to reinforced-concrete piers through pier columns. The bottom line is that *all* of these components are subject to wear and require various degrees of inspection and maintenance.

Suspension systems. A suspension bridge differs from the truss span in that its deck structure is supported by steel ropes or suspenders that are hung from main cables. The main cables take on the appearance of a catenary as they run gracefully from massive reinforced-concrete anchorages over the top of supporting towers constructed of steel. The anchorages and towers ultimately support the entire load of the bridge.

Another variation of a suspension bridge is the cable-stayed deck span. It can be identified by its cables, which take on the appearance of harp chords or a fan distribution of cables coming off of its towers. These bridges may have one or more towers (also called pylons), which take the entire load of the bridge because they do not require anchorage structures. Although cable-stayed spans appear modern in design, their application dates back well over 100 years.



The deck structure found on suspended spans is generally similar to that found on a truss-framed bridge; however, it is not unusual for the deck elevation on a suspension bridge to change by as much as 12 feet as the cables expand and contract due to the temperature difference between summer and winter. The maintenance and inspection requirements of a suspension bridge must address such features as the



anchorages, towers, main cables, and suspender ropes, which are not found on a truss span.

Operations and Maintenance

It is often said that with proper maintenance, there is no limit to the life of a bridge. There is much truth to this theory. However, useful life is also driven by such factors as original design basis (that is, how long the bridge was intended to last) and the bridge's ability to safely handle the growing demands of traffic. Components at or near the end of their useful life must, of course, be replaced in the interest of public safety and service reliability, but life extension doesn't necessarily result in the best overall economic solution for a region, particularly when the bridge is functionally obsolete and serious traffic-capacity issues remain.

The most basic form of bridge maintenance is painting. The cost of painting a typical long-span bridge can run between $50 million and $100 million. The objective is to deter steel corrosion. Unfortunately, modern-day coatings don't offer the same corrosion resistance as lead-based paints, which today are prohibited. The resulting painting cycles are therefore about 12 years apart, and even then, intermediate touch-ups and repairs are required.

Over the years, it is not unusual to find some steel structures that have received multiple coats of paint without the original paint having been removed to bare metal through sandblasting. This technique, unfortunately, can mask certain defects, such as stress corrosion cracking, greatly challenging even the most seasoned bridge inspector. Thus, even bridge painting can, over time, produce some unintended results.

Stress corrosion cracking is perhaps the most potentially serious defect affecting bridge structures. It can affect steel structures that are exposed to a combination of high tensile stresses and a corrosive environment. The resulting cracks can propagate rapidly if not detected and repaired. Such a problem led to the tragic collapse of the Silver Bridge in 1967 in West Virginia. The entire bridge, a suspension span, went down in under a minute, resulting in 46 fatalities. This catastrophe led to an immediate review of all bridge structures across North America. Sound familiar?

Suspension cables present their own set of challenges. To understand them, it is important to know how they were built in the first place. The main cables actually consist of individual steel wires about the thickness of a number 8- or 10-gauge electrical wire. Groups of these wires are bundled into strands that are several inches in diameter. The strands are then compressed into what is visible to us as the main cable, which can be one to several feet in diameter depending on the loads it must carry.

The individual wires are typically galvanized to limit corrosion, but, additionally, they are saturated with slushing oil (a mixture of graphite and linseed oil) before being wrapped with wire and protective lagging. Maintenance and inspection require the construction of elaborate scaffolding along the length of the cable. The cables must be unwrapped and spread apart with wooden wedges to reveal the interior wires. Broken wires can be spliced in some cases, and the slushing oil must be renewed before rewrapping. Fortunately, this is not a frequent occurrence, as such service is usually performed after about 35 to 40 years of use.

Stress isn't the only factor affecting corrosion in bridges. Bird droppings, if left unchecked, can also be a cause of significant corrosion in bridge structures. Indeed, park statues aren't the only victims of potential damage from our fine-feathered friends.

Bird droppings pose an ongoing challenge particularly in urban and coastal areas that have large populations of pigeons and seagulls. Nesting areas in the structures must be humanely displaced along with regular cleanup of the areas. The droppings must be handled as a potentially hazardous material by bridge workers.

Enclosed areas such as the anchorages on suspension bridges present their own unique challenges. For decades, these structures have been pretty much open to the environment. Condensation can form on steel components such as the eyebars that carry the loads from the cable strands deep into the massive concrete structure. This, coupled with the potential for birds nesting inside these cavernous structures, can cause corrosion and result in costly and complex repairs. There is a growing trend now to have these structures well sealed and equipped with humidity-control systems.

Roadway decks present yet another set of challenges. They literally form the surface where the "rubber meets the road." The decks are most often constructed of reinforced concrete, but lighter-weight steel decks with an epoxy or asphalt wearing surface are also being used today. The decks and their subfloor structural steel form a system that not only carries the loads imposed by traffic, but also fulfills an important function in adding stiffness to the bridge structure. This is particularly important in combating the effects of wind on the bridge.

The Tacoma Narrows Bridge in Washington State collapsed in November 1940, only four months after it opened. It was commonly referred to as "Galloping Gertie" because it twisted and swayed in moderate winds. In fact, its failure occurred in winds of only 42 mph because the deck span lacked sufficient stiffness. Since then, bridge engineers have been subjecting their designs to aerodynamic modeling and testing. During such testing, models are subjected to the maximum sustained winds anticipated in the region where the bridge is to be constructed. In the Northeast, for example, that would be Category 2 or 3 hurricane levels.

Roadway decks receive the most wear of any bridge component. They are not only exposed to the stress of traffic, but they must endure the harsh environment in which they operate as well. That means salt-laden air in coastal areas and the effects of ice and snow and the chemicals used to help melt them. It is therefore essential that maintenance crews keep roadway scuppers and drains clear of debris so that rainwater and the salts that may accumulate are directed away from the deck and the subfloor structures.

Over time, even the best-maintained deck will show signs of cracking from fatigue as well as the many freeze–thaw cycles to which it is exposed. These cracks can lead to potholes and corrosion of the reinforcing steel used in the deck's construction.

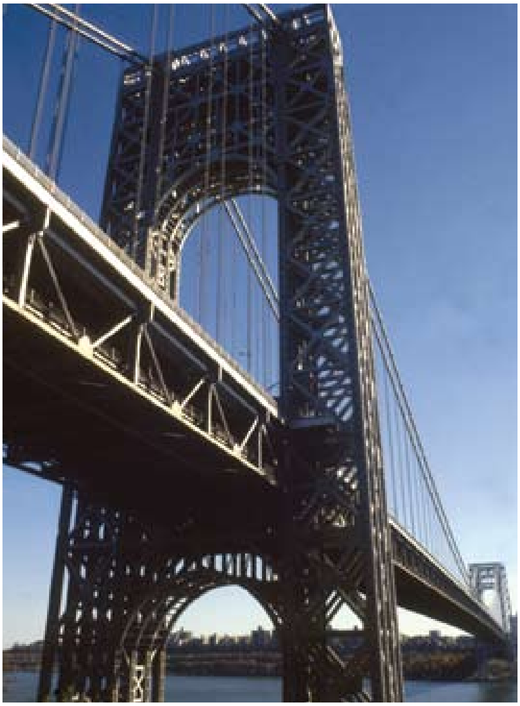
The repair and replacement of a deck structure is complicated by the fact that engineers must make these changes while often maintaining, to the extent practicable, the safe flow of traffic. This can be likened to performing open-heart surgery while the patient is running a marathon. As a result, the repair and replacement of deck structures is often the most capital-intensive recurring aspect of bridge maintenance.

Inspection Requirements

The need for bridge maintenance, repair, and replacement is driven in part by a regular calendar of scheduled servicing as well as comprehensive inspections that must be performed every two years under state law throughout the U.S. The cost to inspect a large suspension bridge can run about $1 million. In New York, all publicly owned, operated, or maintained bridges that are open to vehicular traffic under the jurisdiction of state, city, municipal, or public authority must follow the New York State Uniform Code of Bridge Inspection. Other states have similar requirements.

U.S. bridges are subdivided into their individual sections and given a unique bridge identification number. A long-span bridge and its approach ramps typically have many such sections, each of which is inspected and rated under a seven-part numerical rating system. The ratings range from a high of 7 for a bridge in new condition with no deterioration present to a low of 1 for a bridge that is totally deteriorated or in a failed condition. The worst element of the bridge section drives the rating for the entire section; no averaging is used.

Inspectors must meet rigorous state certification requirements, and the inspections must be performed under the supervision of a licensed professional engineer. The inspection teams also require the use of divers to inspect underwater structures, particularly those that are subject to the scouring action of fast-moving tides, river currents, and ice floes. The process must also address fender systems that are constructed of combinations of timber, steel, and reinforced concrete. These systems protect the piers by absorbing energy from collisions with marine traffic. Such collisions have had tragic consequences, including those that occurred on the Sunshine Skyway Bridge in Tampa, Fla., in 1980 (35 dead), the CSX Transportation Big Bayou Canot rail bridge near Mobile, Ala., in 1993 (47 dead), and the I-40 bridge in Webbers Falls, Okla., in 2002 (14 dead).



When a defect is flagged during an inspection, it may require *immediate* remediation and is subject to a plan for regular monitoring until a permanent repair is completed. In some cases, load reductions or lane closures may result.

The Northeast is home to some of the oldest bridges in the nation. We are fortunate that in states such as New York, bridge inspections have evolved in their sophistication and comprehensiveness, often exceeding the requirements under the mandate of the Federal Highway Administration (FHWA). In New York, the results of state inspections are maintained in a bridge inventory and inspection database and incorporated into the federal reporting system, as well. All other states, too, must report such results to the FHWA.

A very important distinction should be made here. The federal system may label a bridge as “deficient” if it is indeed structurally deficient, or “obsolete” if it is out of compliance with current standards (including those for lane width and overhead clearance) or simply unable to handle current traffic conditions. This system is used in helping to establish spending priorities under federal grants. Because the ratings don’t necessarily indicate that the structures are unsafe or that a collapse is imminent, state transportation officials nationwide are seeking to have the nomenclature changed to less sensationalized terminology. Nonetheless, of the more than 600,000 bridges nationally, 12 percent are presently described as “deficient” and 4 percent as “obsolete.” While the deficiency rate of the 16,000 bridges in New York State compares favorably with the national average, the number of structures that are functionally obsolete is six times the national average because of the bridges’ age and the amount of traffic they handle.

Competition for Funding

Transportation agencies that have dedicated funding sources, such as through tolls or a dedicated state gasoline tax, generally have better-maintained highways and bridges than states that lack these advantages. As our national infrastructure continues to age, there will be increasing competition for the funds needed to maintain it and to keep up with growing transportation demand. The American Association of State Highway and Transportation Officials (AASHTO) estimates that we will need $5.3 trillion during the first quarter of the 21st century to overcome the effect of decades of underinvestment and to meet these needs. The notion that there are such things as free roads is a fallacy.

So how, then, are we going to pay for this? To answer this question, we must step back to the 1950s and the development of the federal Interstate Highway System under President Eisenhower. Eisenhower appointed a commission under General Lucius Clay to recommend how to finance construction of this Herculean task. The commission felt strongly that federal bonds, backed by revenues from tolls, would not only provide for the resources needed to build the highways and retire the debt, but also meet the needs of long-term maintenance. One didn't have to look far beyond toll roadways such as the Pennsylvania Turnpike to reach that conclusion.

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Politics prevailed, however, and contrary to the commission's recommendation, Congress established that there would be no federal bonds or tolls on the interstate system. This meant that funding would be on a pay-as-you-build basis through the federal appropriations process with some small contribution at the state level. It was envisioned that a federal motor-vehicle fuel tax would meet the needs of long-term highway maintenance.

And so, here we are 50 years later, faced with the frustration that the interstate highways and bridges were underbuilt to save on construction costs, along with the economic reality that the fuel tax has failed to provide for adequate maintenance or address the impact of increased traffic, including heavy trucks. Congress has recently recognized this situation, and, as a result, it is now permissible to put tolls on the existing interstate system. This, coupled with an increase in the fuel tax, is our only remedy. Such solutions, however, are often easier said than done.

Tolls are a more stable source of revenue than taxes. They are the economic engine that facilitates paying for general operating and maintenance needs on a pay-as-you-go basis and, more importantly, enable the enormous capital needs of our infrastructure to be financed over long periods of time. Bonds, backed by future toll revenues, permit the debt to be retired generally over a period of 30 years and generate the needed capital. Covenants, however, are essential to protect investors and to enable the issuing entity to receive a favorable bond rating, which minimizes the cost of debt service.

We already have the technology (electronic toll collection) needed to implement tolling on a national scale, but to do so we must be able to integrate the various systems that are already deployed. This means that we must be able to bridge the institutional, political, and parochial interests of the states and public authorities that already have systems operating that may not be compatible across some geographic boundaries.

Beyond the issue of technology integration, we must also find common ground regarding a sensible pricing structure for the use of these highways and their interconnecting bridges and tunnels. The days of building new highways, bridges, and tunnels to handle increases in traffic are becoming very limited. We must therefore find ways to use our existing infrastructure more efficiently through pricing structures that encourage off-peak and HOV travel and the use of mass transit, which would help solve the challenges of congestion and regional mobility. Unless such initiatives are adopted across geographic and institutional borders, however, motorists will seek alternative routes and create even more localized congestion.

These kinds of initiatives require continuity in leadership and the courage and long-term commitment to pull them off. Unfortunately, the revolving door of federal, state, and local government officials doesn't necessarily allow this requirement to be met. Public–private partnerships and other privatization options will become an important part of meeting these challenges in the future. Realistically, one can only hope for a prompt and spirited debate on this subject by public officials. This brings to mind a corollary and point of reference on how long it can take to formulate such public policy: Sadly, we are no closer today to meeting our goal of "energy independence" than we were during the oil embargo of 1973.

Challenges in the 21st Century

The growth in heavy-truck traffic in the past 25 to 30 years has had a major impact on the U.S. highway system. Highways and bridges are by federal standards designed to handle trucks up to a maximum gross weight of 80,000 pounds. These standards, promulgated by the FHWA, include guidelines on the loads that are permissible by groups of axles and the allowable spacing of the axles. The standards are used in the design of highways and bridges as well as the design of trucks.

Shortly before my retirement from the New York Metropolitan Transportation Authority, I became concerned over the need to replace part of the subfloor structural steel system on the approach ramps of the Throgs Neck Bridge, which had been replaced only about 15 years earlier and well before the end of its typical life span. Something was causing cracks to develop in the right lanes that couldn't be explained by the design of the structure alone. These lanes are frequented by trucks, and upon further examination and police intervention, we found that a significant number of trucks were operating well above the legal loads—some as much as 100,000 pounds over the legal limit.

Some truck operators presented a certificate to our officers called a "Divisible Load Permit." State transportation officials promulgated the use of these permits in the 1980s as a means of assisting with the transport of certain materials, such as dairy products and gravel and other construction materials *within* the county of their origin. They were explicitly invalid across county lines.

It didn't take long for truckers to figure out that with the limited truck-permit enforcement that was being performed, they could stretch the geographic limits of their permits to their economic advantage. The greatest abuse came from aggregate haulers between upstate New York and Long Island. (Aggregate is a crushed stone that is used as an admixture in concrete.) Remarkably, when we trained our own officers and began performing truck-permit enforcement to augment the work of the New York Police Department, the truckers, with the support of certain construction industry lobbyists, filed a lawsuit. Simply stated, their logic appears to be that because they have been getting away with abusing their permits for many years, it is now an economic entitlement to do so.

Overweight and oversized vehicles can be safely escorted over bridges at night. That policy has been in place for many decades and is consistent across the region. We recognize the importance

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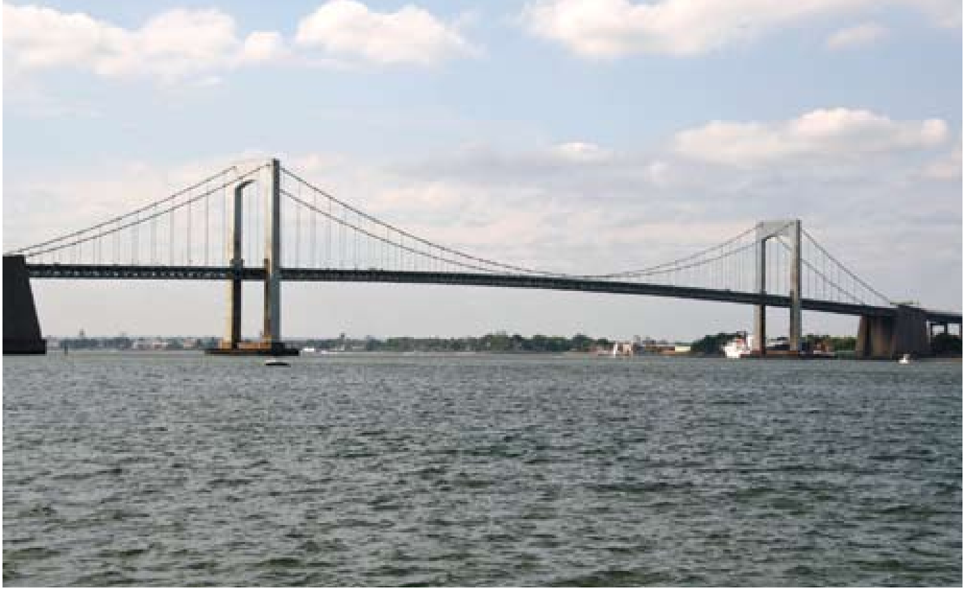

of helping to improve regional mobility by upgrading the design of the national and regional infrastructure to handle higher payloads. We even offered to start that process by working with other transportation entities to create a heavy-truck corridor from the upstate counties to Long Island. This initiative would have taken years to complete, however, which was unsatisfactory to the truckers. They cited economic hardship to the construction industry. But what about public safety and the economic hardship to the region if a major bridge became compromised? (I have no doubt that some of the structural challenges faced by engineers at the Tappan Zee Bridge are a product of this abuse.)

And if you think the only challenges to the safety of our bridges are age, underinvestment, politics, financing, and special interests, you are mistaken. Another 21st-century issue—and perhaps the granddaddy of them all—is protecting them against potential acts of terrorism.

Bridge engineering standards mandate the application of prudent factors of safety or design margins in meeting the design loads under which the structure is intended to be used. These standards have served us well, but let there be no misunderstanding: they *do not* provide for the protection of a structure from deliberate acts of terrorism or sabotage. Since the attacks on America on September 11, 2001, public officials have embarked upon several actions, including increased police surveillance along with the introduction of special features to provide enhanced perimeter protection and the hardening of certain vulnerable bridge structures. Such initiatives are costly but very necessary, particularly in those geographic areas that are considered to be targets of interest to terrorists.

Bridges and tunnels are the gateway to major cities. In the open society that we so proudly enjoy, we must strike a reasonable balance between preserving the freedom of movement of people and goods and protecting life, property, and economic prosperity. Passive and active protective devices and a stepped-up police presence will help reduce the potential for an attack on these structures and mitigate the resulting effects from one should it occur. These measures cannot, however, be expected to completely eliminate the risk of attack.

Meeting the Needs to Come

Hopefully, we now have a better understanding of the daunting challenges before us in rebuilding and protecting our infrastructure and in providing for a viable national transportation system that is safe and able to meet the needs of generations to come. Having recently passed into the twilight of my own career, I envy those who will now become the custodians of these invaluable resources. They, with the support of policymakers with the political fortitude to do the right thing, may prove to be the cavalry that arrived just in time.

Acknowledgments

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