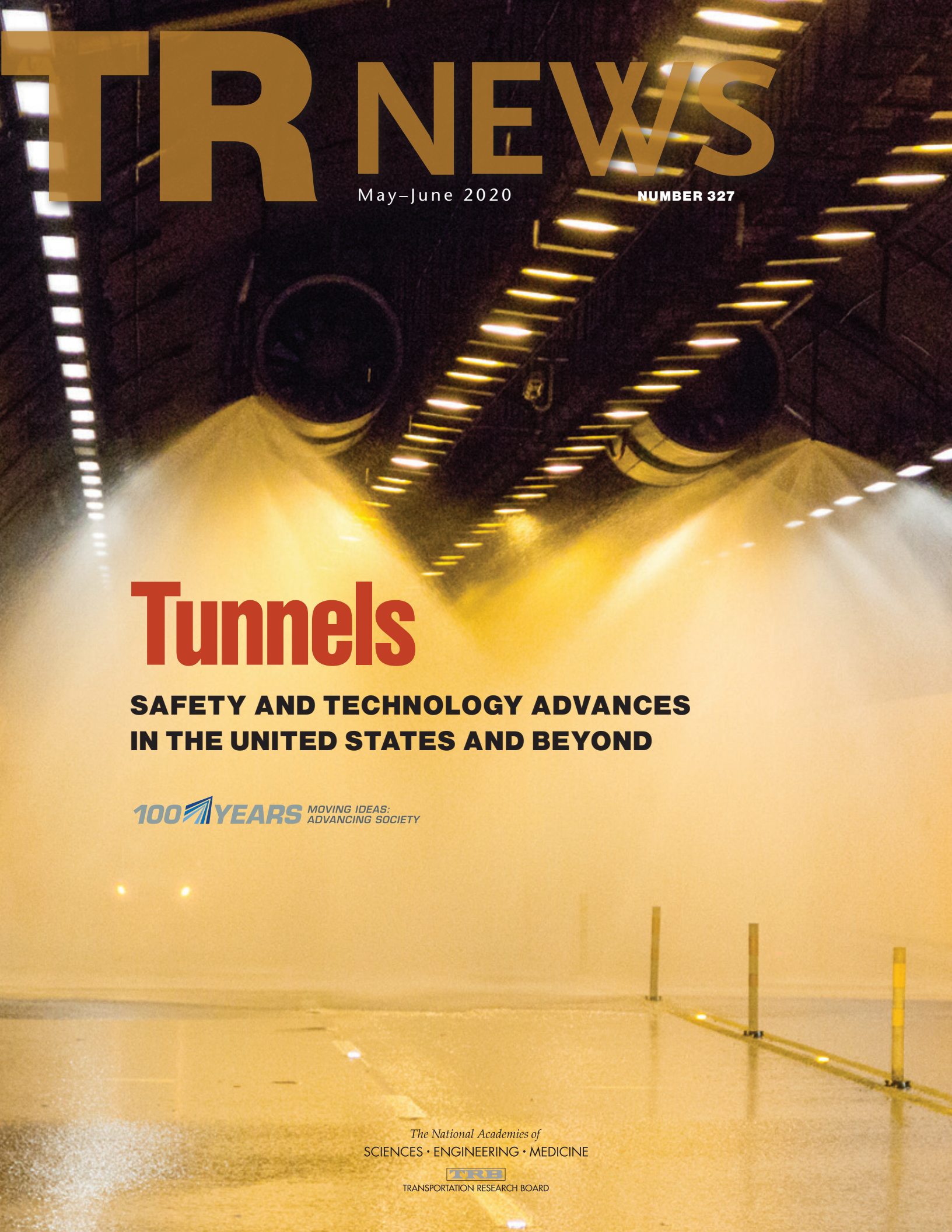

TR NEWS

May–June 2020 NUMBER 327

Tunnels

SAFETY AND TECHNOLOGY ADVANCES IN THE UNITED STATES AND BEYOND

100 YEARS MOVING IDEAS: ADVANCING SOCIETY

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The **National Academy of Sciences** was established in 1863 by an Act of Congress, signed by President Lincoln, as a private, nongovernmental institution to advise the nation on issues related to science and technology. Members are elected by their peers for outstanding contributions to research. Dr. Marcia McNutt is president.

The **National Academy of Engineering** was established in 1964 under the charter of the National Academy of Sciences to bring the practices of engineering to advising the nation. Members are elected by their peers for extraordinary contributions to engineering. Dr. John L. Anderson is president.

The **National Academy of Medicine** (formerly the Institute of Medicine) was established in 1970 under the charter of the National Academy of Sciences to advise the nation on medical and health issues. Members are elected by their peers for distinguished contributions to medicine and health. Dr. Victor J. Dzau is president.

The three Academies work together as the National Academies of Sciences, Engineering, and Medicine to provide independent, objective analysis and advice to the nation and conduct other activities to solve complex problems and inform public policy decisions. The National Academies also encourage education and research, recognize outstanding contributions to knowledge, and increase public understanding in matters of science, engineering, and medicine.

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The **Transportation Research Board** is one of seven major programs of the National Academies of Sciences, Engineering, and Medicine. The mission of the Transportation Research Board is to increase the benefits that transportation contributes to society by providing leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied activities annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

Learn more about the Transportation Research Board at **www.TRB.org.**

TRB

TR NEWS

Number 327 / May–June 2020

COVER Fixed firefighting systems and other safety advancements in road tunnels are addressed in this issue of *TR News*. (Photo: FHWA)

TRB COVID-19 Resources

Agencies and organizations can use TRB publications and online resources for useful and timely information to help address issues related to the novel coronavirus pandemic. To read about TRB's current research and activities and for a list of relevant publications, visit www.nationalacademies.org/trb/blog/transportation-in-the-face-of-communicable-disease.

Coming Next Issue

The July–August 2020 issue of *TR News* is dedicated to water and the role of transportation agencies in the stewardship of this vital resource, particularly as the way humans use water is changing dramatically. Authors will explore the evolution of stormwater regulation; how departments of transportation manage water in planning, design, construction, and operations; and more.

Alabama DOT's novel approach to construction stormwater management involves five pillars—from communications to sediment control—and has been successfully implemented in project planning and design, during construction, and while troubleshooting ongoing projects.

Photo courtesy Barry Fagan

Also in This Issue:

TR NEWS

features articles on innovative and timely research and development activities in all modes of transportation. Brief news items of interest to the transportation community are also included, along with profiles of transportation professionals, meeting announcements, summaries of new publications, and news of Transportation Research Board activities.

***TR News* is produced by Transportation Research Board Publications Staff**
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TUNNELS

Safety and Technology Advances in the United States and Beyond

STEVE ERNST AND JEFF WESTERN

Ernst is Consultant, Miami, Florida, and Western is Principal, Western Management and Consulting, Madison, Wisconsin.

Photo: Tony Webster

Free-hanging flora and decades-old patina soften the stone masonry portal of the Northwest Cornell Road Tunnel in Portland, Oregon. In 1940, laborers hired by the Works Progress Administration cut through the basalt of West Hills to build the 500-foot-long, concrete-lined conduit.

Compared with much of the world, the United States has relatively few highway tunnels. Norway—its land area approximately the same size as New Mexico—has more than 900 roadway tunnels, while the entire United States has 503. But these tunnels are important links in the transportation network, providing routes through congested urban environments and reducing travel time in mountainous regions. Tunnels provide access and offer connections that have opened social and economic opportunities beyond what their small number implies.

Driving through a tunnel is a common experience in cities like Boston or Seattle, and drivers may be unaware of the complex nature of the concrete, steel, and operations needed to make tunnel travel safe and routine.

Transition lighting makes entering the tunnel at its portal a seamless event. The motorist sees a typical roadway, tunnel walls and a ceiling, lighting fixtures and signs, and perhaps a walkway and a few doors on the side. But these are just parts of the tunnel. Beyond the walls and ceiling and below the roadway are ventilation chambers, pumping systems, mechanical equipment and emergency systems, and the other unseen infrastructure that make up the tunnel structure. In addition, operational and emergency systems and teams of response professionals at or near the tunnel ensure efficient operation and safety.

This *TR News* theme issue reveals the many hidden aspects of tunnels and illuminates the benefits of tunnel technology to modern transportation systems. The articles here show how tunnels benefit the economy and how transportation operators use the best technology to keep tunnels efficient and safe.

As with much of the nation's infrastructure, the challenges of using tunnels in a road or rail network include relatively high first costs, the need for continuing maintenance and operational expenditures, and safety matters. Highway professionals have long recognized these challenges, and entities like the American Association of State Highway Transportation Officials (AASHTO), the Federal Highway Administration (FHWA), the Transportation Research Board (TRB), and the National Fire Protection Association—as well as firefighters, emergency responders, and the private-sector engineering community—are working to make sure tunnel technology addresses the needs for the growing and congested road network. Indeed, tunnels will be an increasing part of the solution to improved freight and passenger mobility.

Real-Life Examples

A good example of the potential of tunneling is the new Port of Miami tunnel in Florida, which removed port truck traffic from downtown Miami and allowed the port to renew and expand while relieving traffic congestion. Another is the Eisenhower–Johnson Memorial Tunnel on I-70 in Colorado, which eliminated the need to traverse Loveland Pass and opened commercial and recreational opportunities for a large portion of the western United States.

Tunnels in Boston, famously known as the Big Dig, restored the city by removing aboveground viaducts and by including 27 acres of green space and millions of square feet of commercial development. The new Alaskan Way Viaduct Replacement Tunnel (SR-99 tunnel) opened the Seattle waterfront and relieved crosstown congestion while removing a double-decker viaduct that was unsightly and vulnerable to earthquakes. The SR-99 tunnel is one of the most technologically advanced tunnels in the world, utilizing the latest innovations in fixed firefighting, emergency response, lighting, and operations.

The articles in this issue will elaborate on the newest, most advanced topics in tunnel design, construction, operation, and maintenance and will describe some of the groundwork that led to the best in tunnel science. For example, as part of Boston's Big Dig, the tunnel community undertook the Memorial Tunnel Fire Ventilation Test Program. A decommissioned tunnel in West Virginia was converted into a test laboratory, and the results from extensive testing were used by researchers around the world to advance the understanding of ventilation systems and smoke control in tunnels. This study is recognized as a landmark in tunnel technology—another legacy of the Big Dig.

Tunnels can be beautiful and—as with the Waterview Tunnel in Auckland, New Zealand—can be built with community involvement that improves the long-term benefit to users. This tunnel features skate parks at each portal, improvements to surrounding landscape and buildings, and other community-driven features that increased public willingness to pay for the expensive project.

International Research

In 1999, a tragic fire in the Mont Blanc Tunnel on the border of France and Italy in the Alps took 39 lives. This event prompted a European and worldwide effort to improve tunnel operations and advance technology for tunnel signing, areas of refuge, firefighter training, emergency operations, and human-factor engineering. In June 2006, FHWA, AASHTO, and TRB undertook a study and published the report *Underground Transportation Systems in Europe: Safety, Operations, and Emergency Response* to bring these advancements to the United States. Shortly thereafter, AASHTO established a technical committee on tunnels.

The U.S. tunnel community has responded to this information by incorporating safety technology in new construction, and they have refurbished many tunnels with improved lighting, signing, camera systems, and operational improvements. Several research studies have been completed and new ones initiated.

Recently, a joint global benchmarking study for highway tunnel fixed firefighting systems (FFFS) discovered that New Zealand and Australia are established world leaders in the use of FFFS in road tunnels, demonstrating an example of best practices for the safe operation of highway tunnels. Even before this study, several U.S. tunnel owners had incorporated similar systems, both new and retrofitted. The New Zealand and Australian experiences offer the exciting opportunity to incorporate operational excellence into U.S. tunnels to improve reliable long-term functionality of transportation systems.

Transportation researchers and policy makers must "think big" to justify expensive tunnels, knowing the potential of transformative commercial development to bring lasting economic benefit. Tunnels can be a cornerstone for effective community engagement and prosperity, can improve quality of life, and—most importantly—must be reliable and safe.

Photo: Pietro

Daylight-bright lighting, a fenced raised sidewalk, and maintenance doors line the Port of Miami Tunnel. It includes the latest safety features available in the United States, including automatic incident detection, active sprinkler fire suppression systems, and a system of 105 closed-circuit TV cameras along with a 110-foot video wall that displays the tunnel's entire interior in less than 15 seconds.

The *TR News* Editorial Board thanks Waseem Dekelbab, TRB, for his work assembling and developing this issue.

Role of Tunnel Organizations

Crews inspect Oregon's 827-foot Tooth Rock Tunnel for damage after the 2017 Eagle Creek fire that swept over more than 34,000 acres in the Columbia River Gorge. FHWA and TRB work in coordination with state transportation agencies via AASHTO on tunnel safety.

Photo: Oregon DOT

Tunnels are key elements of the nation's transportation infrastructure. The amount of traffic congestion and economic opportunities afforded by air-rights structures help promote future opportunities for the innovative use of underground space and tunnels. Tunnels and underground structures play an increasingly important role in current infrastructure sustainability and resiliency programs; at the same time, these vitally important structures contribute to the quality of life of traditionally vulnerable and disadvantaged communities. Rather than introducing aboveground bridges or roadways that historically have divided cities and often have contributed to urban blight, tunnels free up open space and allow for parks and recreational facilities and other development that improve quality of life and economic opportunity.

Three organizations share vital roles in promoting tunnel technology and safety to the highway community. The Federal Highway Administration (FHWA), the American Association of State Highway and Transportation Officials (AASHTO), and the Transportation Research Board (TRB) collaborate at the national and international levels to serve the broader transportation community. They advance policies, specifications, guidance, and technologies through cooperative meetings, workshops, webinars, and publications, as well as through strategic planning and research to foster innovation, technology transfer, and the accelerated deployment of cost-effective safety technologies.

The mission of FHWA is to support state and local governments in the design, construction, and maintenance of the nation's highway system and various federal-and tribal-owned lands. Through financial and technical assistance to state and local governments, FHWA ensures that America's roads and highways continue to be among the safest and most technologically sound in the world. The agency's strategic priorities include national leadership in transportation policy and innovation, effective delivery of federal highway programs, improved safety and performance of highway systems, and enhancement of FHWA's corporate capacity to achieve its mission.

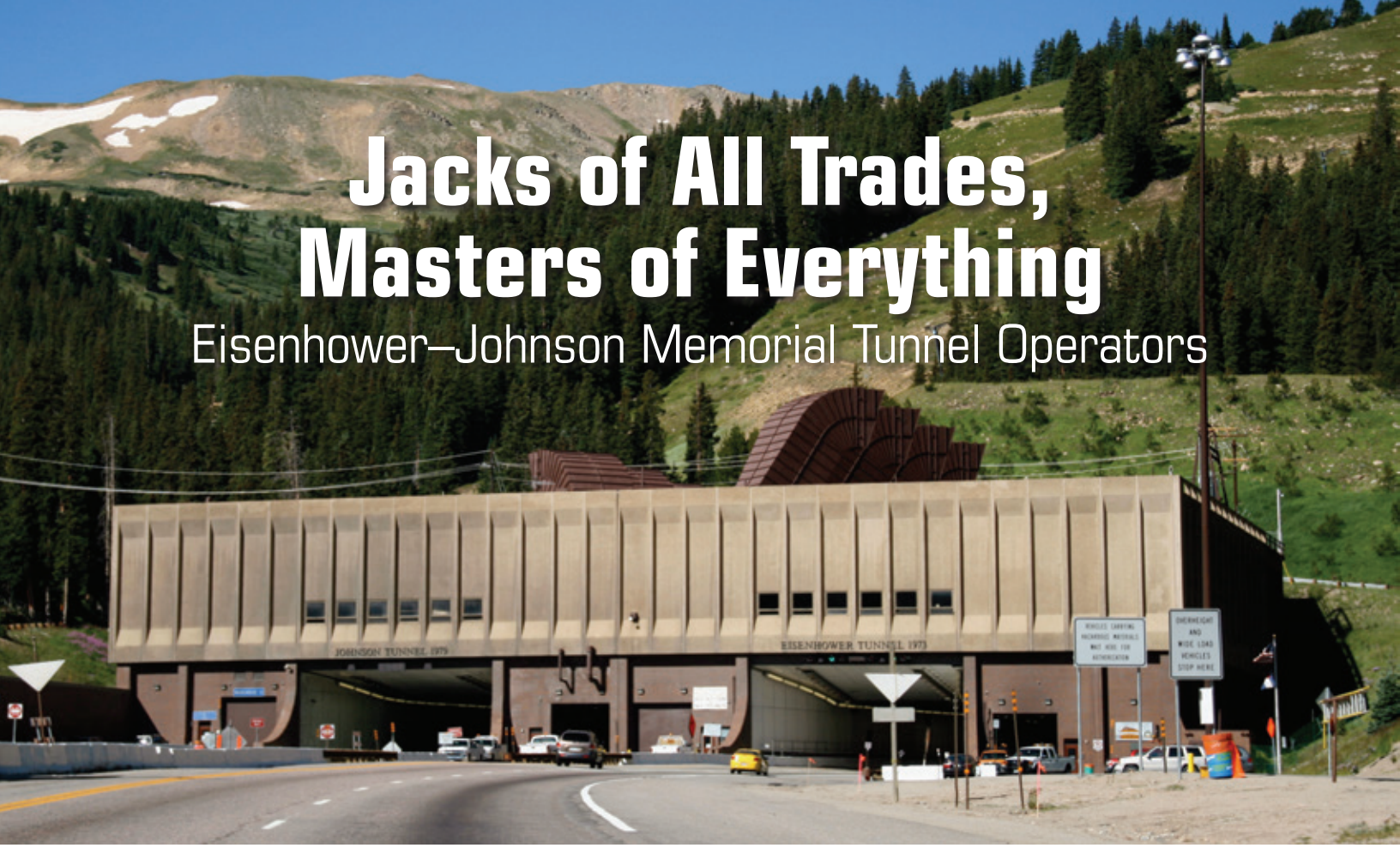
Photo: Conrad Felice

Standing Committee on Tunnels and Underground Structures Chair Brian Zelenko presents former chair Anthony "Tony" Caserta with an Emeritus Member certificate at the 2014 TRB Annual Meeting in Washington, D.C.

An international leader in setting technical standards for all phases of highway system development, AASHTO serves as a liaison between state departments of transportation (DOTs) and the federal government. Standards are issued for the design and construction of highways and bridges, materials, and many other technical areas. The AASHTO Bridges and Structures Tunnel Committee, T-20, was created in 2006 and is comprised of 10 voting members from various state DOTs, two nonvoting associate members from state tolling agencies, and a single nonvoting liaison from FHWA. Although membership in AASHTO is limited to employees of state DOTs, members of the transportation community are welcome to contribute as friends of the T-20 committee.

TRB is a division of the National Academies of Sciences, Engineering, and Medicine, which adheres to the highest standards of integrity and peer review and provides access to the foremost scientists, engineers, and medical professionals in the world. The TRB Standing Committee on Tunnels and Underground Structures is part of the Transportation Infrastructure Group and focuses on planning, design, construction, inspection, operations and systems, and maintenance related to underground structures and components. Appointed members to this committee represent the full range of perspectives from federal, state, and local governments to consultancies, academia, research organizations, associations, and industry. Although membership to the committee requires a formal process, as with the AASHTO T-20 committee, anyone with an interest is welcome to participate as a committee friend. Members and friends of the committee contribute to committee activities such as paper reviews and TRB Annual Meeting sessions. More information on how to get involved in TRB committees is available at www.trb.org/AboutTRB/GetInvolvedCommitteesTF.aspx.

—Steve Ernst, Consultant, and Jeff Western, Western Management and Consulting



Jacks of All Trades, Masters of Everything

Eisenhower–Johnson Memorial Tunnel Operators

Photo: Patrick Pelster

STEPHEN HARELSON

The author is Chief Engineer, Colorado Department of Transportation, Denver.

Above: All day, every day, Colorado's Eisenhower–Johnson Memorial Tunnel is staffed by 52 full-time employees dedicated to maintaining service and keeping drivers safe.

Plumber, electrician, traffic control supervisor, firefighter, geologist, mechanic, public relations professional, and "water witch" are only some of the roles that a tunnel employee must play in a typical week on the job at Colorado's Eisenhower–Johnson Memorial Tunnel (EJMT). Piercing the continental divide at 11,000 feet above sea level, the tunnel requires a special type of worker to keep it going.

EJMT was first opened in 1973, the culmination of decades of planning, engineering, and construction. The tunnel complex is located 50 miles west of Denver, nearly 15 miles from the nearest town. Aside from the remote location, the alpine climate at the tunnel provides between 20 and 30 feet of snow most winters, freezing temperatures in July and August, and subzero temperatures from November through March. The people who work in such an environment must be self-reliant, smart, and tough to keep traffic moving. Even though the physical infrastructure at the tunnel is amazing, the work of the tunnel staff shows that they are the heart and soul of this facility.

Mystery Leak

The most legendary experiences at the tunnel have occurred during winter blizzards, but some of the most interesting experiences have occurred during more moderate weather. One such instance happened one year in early June—known as mud season in the high country of Colorado, when the snowmelt peaks and rivers run high. Ken Martinez, the tunnel superintendent at the time, was taking a training class in Denver, about 50 miles east of the tunnel complex. His cellphone rang with the news that the water supply tank was dangerously low. The water supply tank provides the entire water supply for the tunnel, for firefighting, and for domestic use.

Martinez hurried up to the tunnel to try to help crews find the leak. An investigation showed that the tank was losing between 200 and 300 gallons per hour. Unfortunately, however, the groundwater seeping into the tunnel that time of year is

about 1,000 times that amount, distributed throughout the mountain, so any small pipe leaks were dwarfed by the natural flow. The tunnel team was looking for a moist needle in a haystack, not a geyser the size of Old Faithful.

The water supply for EJMT is diverted from Straight Creek, a small mountain stream that flows near the west portal of the tunnel. Colorado, like many arid Western states, employs a prior appropriation water-right system to govern water use. Under this system, the EJMT has a right to divert only about 800 gallons per hour. With this water right, it takes about 31 hours to fill the tank. Knowing that the tank was suffering a net drainage of 200 gallons per hour, Martinez realized that the leak was in the neighborhood of 1,000 gallons an hour.

Working from the supply tank on down through the pump room and the rest of the stand pipe system in both bores, Martinez and his team closed the entire pipe network from the storage tank and then methodically opened it up, section by section. The storage tank contains 25,000 gallons—and although 1,000 gallons per hour is a serious leak, it also is small enough to take a bit of time to see if the tank is recovering or still leaking.

Over many hours, valves on the pipe network were opened, one by one, until the leaking section was identified. The leak was isolated to a 500-foot section—much better than an 18,000-foot pipe network, but still not great given the groundwater conditions. After nearly 36 hours, the leak was located in a small tap in the pipe, which was used to supply electrical power to heat tape strung inside the pipe to keep it from freezing. A very small hole caused a very big headache.

Groundwater Challenges

The same groundwater problems that disguised the pipe leak also create challenges in winter. EJMT was constructed through a mountain containing two types of competent rock separated by the Loveland fault, which is 1,000 feet of heavily fractured material. Even in the depths of winter, this fractured zone carries liquid groundwater to the tunnel, where it meets the subzero air and promptly freezes. Thankfully, in January, the groundwater flow and subsequent freezing is manageable, and over the years tunnel staff have built groundwater drains and collection systems to minimize the icebergs that form.

Groundwater seeps can be unpredictable, however, and collection systems built several years ago can lose their utility when the seep moves 100 feet. It is a continual game of whack-a-mole—or, in this case, whack-an-iceberg—when the seeps jump around. Even when the drains collect water as expected, the groundwater carries considerable minerals. These minerals deposit in the drain pipes, ultimately clogging them. The groundwater at EJMT is relentless in the challenges it brings.

Photo: Stephen Harelson

Winter temperatures in the Colorado mountains mean that a small leak can become a large iceberg. Tunnel staff are adept at building—and rebuilding, as groundwater seeps migrate—drains and collection systems to minimize these icebergs.

Adaptable, Specialized Workforce

Because EJMT is so remote, tunnel operators must be willing to do almost any job, at any time. Several winters ago, an overheight vehicle passed through the tunnel and struck half a dozen variable message signs (VMSs), as well as about 10 smaller lighted lane-use signs. The tunnel was closed to traffic, and tunnel staff immediately began inspecting the sign brackets to ensure they were not damaged and would not cause the heavy VMSs to fall on traffic.

Brackets were inspected, damaged signs were removed, and undamaged signs were relocated to provide adequate sign coverage—all by a crew of eight people, six of whom had likely never even touched a VMS before that evening. They recognized the job that had to be done, jumped in, and got the tunnel reopened in less than 3 hours—about the same amount of time it would have taken to get a repair crew mobilized from Denver. All this work was completed in zero-degree weather.

Photo: Stephen Harelson

Springtime temperatures bring groundwater challenges at EJMT.

VENTILATION SYSTEM

The ventilation system at EJMT pulls an incredible amount of electricity and requires the services of skilled electricians and mechanics to keep in action. Half of the tunnel's 28 600-horsepower fans exhaust air from the tunnels, and the other half supply air. Because they were designed in the age of cars with leaded gasoline and V-8 engines without emission controls, much of their original utility is no longer necessary in the day-to-day operations of the tunnel. In case of fire, however, these fans are critical to the lives of motorists in the tunnel. Depending on the location of the fire, tunnel operators turn specific fans on or off to push or pull the smoke away from trapped traffic.

Like any piece of 50-plus-year-old industrial equipment, the ventilation motors and fans need ordinary maintenance, like bearing replacements, new belt drives, and lubrication. More challenging is interfacing this old equipment with the modern control systems. It takes a knowledgeable and resourceful electrician to maintain and upgrade the control systems on equipment first constructed in the 1960s.

FIREFIGHTERS AND SUPPRESSION SYSTEM

On average, EJMT has experienced about one vehicle fire per year throughout its history. In 2015, the Colorado Department of Transportation (DOT) installed a fire suppression system in the tunnel. Firefighting crews have long been onsite at EJMT 24 hours a day, 7 days a week, to address fires that occur at the tunnel's remote location. These trained firefighters do other jobs at the tunnel but are ready to don bunker gear when the need arises. The nearest fire stations are in Georgetown or Dillon, each 15–20 minutes away from the tunnel.

The fire suppression system was installed to make firefighters' jobs easier. Tunnel operators must understand how to activate and manage this fire suppression system and must work with the firefighters in the tunnel. The system has been activated twice since it was completed, and both times it helped the tunnel operators provide a tenable environment for firefighters to extinguish the fire and for trapped motorists to safely escape the tunnel.

Photos: Colorado DOT

Massive fans provide ventilation in EJMT. When working together, the multiple motors in each fan can reach up to 600 horsepower, enough to keep air circulating at a healthy level.

SNOW SAFETY

With the heavy snows at the continental divide, tunnel staff must always be aware of avalanche risk. The west portal building sits at the base of a steep mountain slope, which holds multiple avalanche paths. Tunnel staff monitor this slope and bring down snow slides using specialized long-range tools before snow grows to a magnitude that could threaten the building or the emergency turnaround loop road. The timing of this avalanche mitigation work is related to snowfall, wind, and the resultant snow drifting that loads the avalanche chutes. It is very much an art and a science.

EJMT is located in a truly beautiful spot, with gorgeous views at both the east and west portals. Many people stop to enjoy the views, others stop to let their overheated cars cool down, and some just take advantage of the parking lots at each portal to take a break from driving and stretch their legs. In one memorable instance, two motorists involved in a fender-bender inside the tunnel started a fistfight in the parking lot.

(*Continued on p. 10*)

Photo: Steve Harelson

Operated from a safe distance, the pipe structure on the ridge line (*upper left*) ignites a propane explosion and directs the explosion concussion toward the start zone of the avalanche path. This action knocks down the accumulated snow in a controlled manner while the area below is clear of people. Such active control brings down small avalanches and prevents large slabs from forming and causing catastrophic uncontrolled avalanches.

National Tunnel Inventory Guidelines and Standards

Following the tragic ceiling collapse in Boston's I-90 Connector Tunnel on July 10, 2006, the National Transportation Safety Board (NTSB) accident report identified several safety issues, including "inadequate regulatory requirements for tunnel inspections" (*1*).

On July 6, 2012, President Barack Obama signed the Moving Ahead for Progress in the 21st Century Act (MAP-21), which required the U.S. Secretary of Transportation to establish national standards for tunnel inspections. To meet MAP-21 requirements—and in recognition of the importance of tunnel safety and security—the Federal Highway Administration (FHWA) established the National Tunnel Inspection Standards (NTIS) and created corresponding manuals and guides to implement the program.

Three references are key for bridge owners to facilitate management of tunnel inventory and tunnel inspections: the Federal Register National Tunnel Inspection Standards, FHWA's *Specifications for the National Tunnel Inventory* report, and the FHWA Bridges and Structures Standards and Guidelines.

National Tunnel Inspection Standards

This final rule, published in July 2015, establishes NTIS for highway tunnels (*2*). These standards require tunnel owners to establish a program for the inspection of highway tunnels, to maintain a tunnel inventory, to report the inspection findings to FHWA, and to correct any critical findings found during these inspections. Critical findings are any structural or safety-related deficiencies that require immediate follow-up inspection or action.

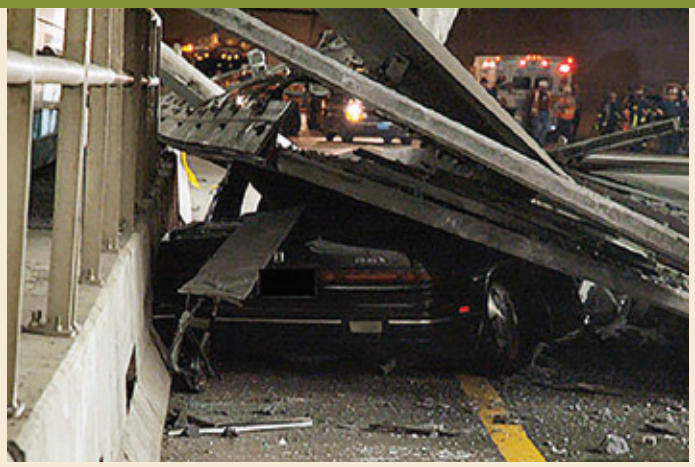


Photo: National Transportation Safety Board

Tragedy struck on the night of July 10, 2006, when concrete ceiling panels in Boston's I-90 Connector Tunnel collapsed on a car, injuring the driver and killing the passenger. The National Transportation Safety Board's investigation ultimately resulted in the establishment of nationwide safety standards.

The standards apply to all structures defined as highway tunnels on all public roads, both on and off Federal-Aid highways, as well as tribally and federally owned tunnels.

Specifications for the National Tunnel Inventory

This document supplements NTIS and provides specifications for the coding data that are required to be submitted to the National Tunnel Inventory (NTI) (*3*). Data in NTI will be used to meet legislative reporting requirements and will provide information on the number and condition of the nation's tunnels to tunnel owners, FHWA, and the general public.

NTI was developed by FHWA and the American Association of State Highway and Transportation Officials T-20 Tunnel Committee to comply with NTIS regulations and with the *Tunnel Operations, Maintenance, Inspection and Evaluation Manual*.

Bridges and Structures Standards and Guidelines

Comprehensive information about tunnel inspection, inventory, and reporting, along with manuals and other guidance documents, examples, and more, can be found on the FHWA tunnel inspection website (*4*).

—Steve Ernst, Consultant, and Jeff Western, Western Management and Consulting

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4. Tunnel Inspection. Federal Highway Administration, U.S. Department of Transportation. www.fhwa.dot.gov/bridge/inspection/tunnel.

Photo: Colorado DOT

Majestic views of mountains prone to rock and snow slides surround EJMT's west portal.

(*Continued from p. 8*)

Because so many people stop, tunnel staff have considerable opportunity to talk to these travelers, help them with vehicle or medical issues, or just answer questions about the tunnel in particular or Colorado in general. Tunnel staff members must be prepared each day to be chamber of commerce agents, first-aid experts, amateur mechanics, and boxing referees—along with their normal job of maintaining and operating the tunnel infrastructure.

The work at EJMT is highly specialized for a state DOT; because of that, many people have worked at the tunnel complex for decades. Aside from the knowledge that can only be gleaned from working at one facility for 30 or 40 years, an interesting culture develops in such a place. It is a culture based on shared experiences, past battles fought together, and a camaraderie that can only be developed after many years of working alongside one another. The best part of working with the staff at EJMT is participating in that culture.

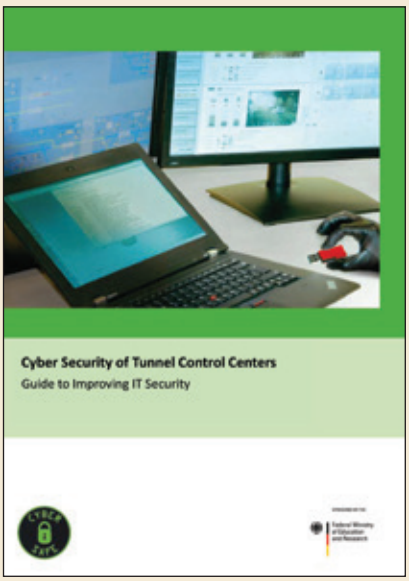
Tools for Assessing the Cybersecurity of Tunnel Control Centers

SELCUK NISANCIOGLU AND INGO KAUNDINYA

Nisancioglu is Civil Engineer and Kaundinya is Tunnel Engineering and Operation Section Head, Federal Highway Research Institute (BASt), Bergisch Gladbach, Germany.

Digitalization has already reached the transport sector. This is particularly true for tunnel control centers, which centrally monitor and control tunnels—with the support of IT systems—to guarantee safe and secure operation.

Along with this technological progress, however, the danger of cyberattacks is growing. As part of the Cyber-Safe Project, funded by the German Federal Ministry of Education and Research, research partners developed a guide and three software action tools to make it easier for tunnel control center operators to evaluate and improve their IT security. The guide accounts for industry-specific framework conditions and describes the special features of tunnel control centers in this context.



As part of the Cyber-Safe Project, research partners developed *Cyber Security of Tunnel Control Centers: Guide to Improving IT Security*. The guide is available in English, and a PDF file can be requested by e-mailing Cyber-Safe@bast.de.

In addition, the action tools can help traffic control center operators to become familiar with cybersecurity, as comparable boundary conditions can be found in many areas of organization, personnel, and technology.

Investigations and Analyses

To identify existing weak points, IT security measures that had already been implemented were analyzed for their efficiency and effectiveness using a hazard and status analysis, supplemented by a penetra-

For example, many years ago, while working on a pipe project at the west portal, I needed to know some water and gas line locations to get my project constructed. Several tunnel staffers came out to help me; each had worked at the tunnel from its very beginning. They talked about where they thought old water lines were located and, off the tops of their heads, described when the line to the old concrete batch plant that had been used during construction was abandoned and argued about when it was replaced, how deep it was, and whether the line was still active.

I was amazed at what they could remember and at how many utility lines had been built, moved, and replaced in such a relatively small space over the previous 30 years. The workers knew the history because they had been unclogging, unfreezing, and unsticking valves, and reconstructing tunnel elements for 30 years. Even more amazing, however, was when it came time to locate the lines. Each staffer pulled out a bent welding rod—also known as a witching stick—and went to work. Ever the skeptical engineer, I humored them, but I didn't believe that witching worked.

After 15 or 20 minutes, the crew of "water witches" converged on a location—and, as it turned out, they were pretty close. I am not sure whether the witching truly worked or their communal memory had found the waterline location—but I was thankful. So thankful that, a few weeks later, I asked one of the crew, a 38-year tunnel employee, to help me find a gas line. His response is one I will remember forever: "Any fool knows that witching doesn't work on gas lines; only water." Any fool, indeed.

tion test of a tunnel and a tunnel control center for insights into the IT systems. A virtual control center also was developed to simulate cyberattacks and countermeasures under laboratory conditions.

Two workshops with tunnel control center managers, providers, and planners ensured the appropriate and immediate implementation of the developed measures. Needs and requirements for action aids were developed to evaluate the current quality of IT security and to increase resilience against cyberattacks. These valuable findings regarding user requirements have been processed and are included in three end-user-oriented action tools.

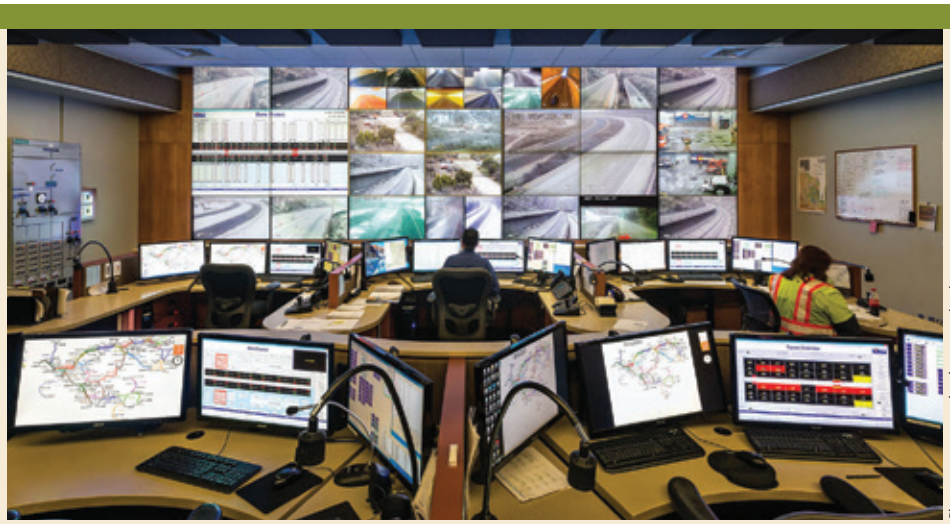


Photo: www.soundandcommunications.com

A massive video wall designed to display sequential views dominates the Hanging Lake Tunnels Command and Control Center in Colorado's Glenwood Canyon. Located above one of the 4,000-foot tunnel bores, the distributed control system provides enhanced situational awareness and visual detail to operators and first responders.

Cyber-Safe Action Tools

During the expert interviews and workshops with tunnel control center managers and operators, valuable information about the demand and user requirements were gathered to develop the action tools, designed to enable operators to identify weaknesses in their IT systems and organizational structures. The action tools' content and depth of detail are tailored to the following three target groups.

Action Tool 1: Checklist for Upper Management

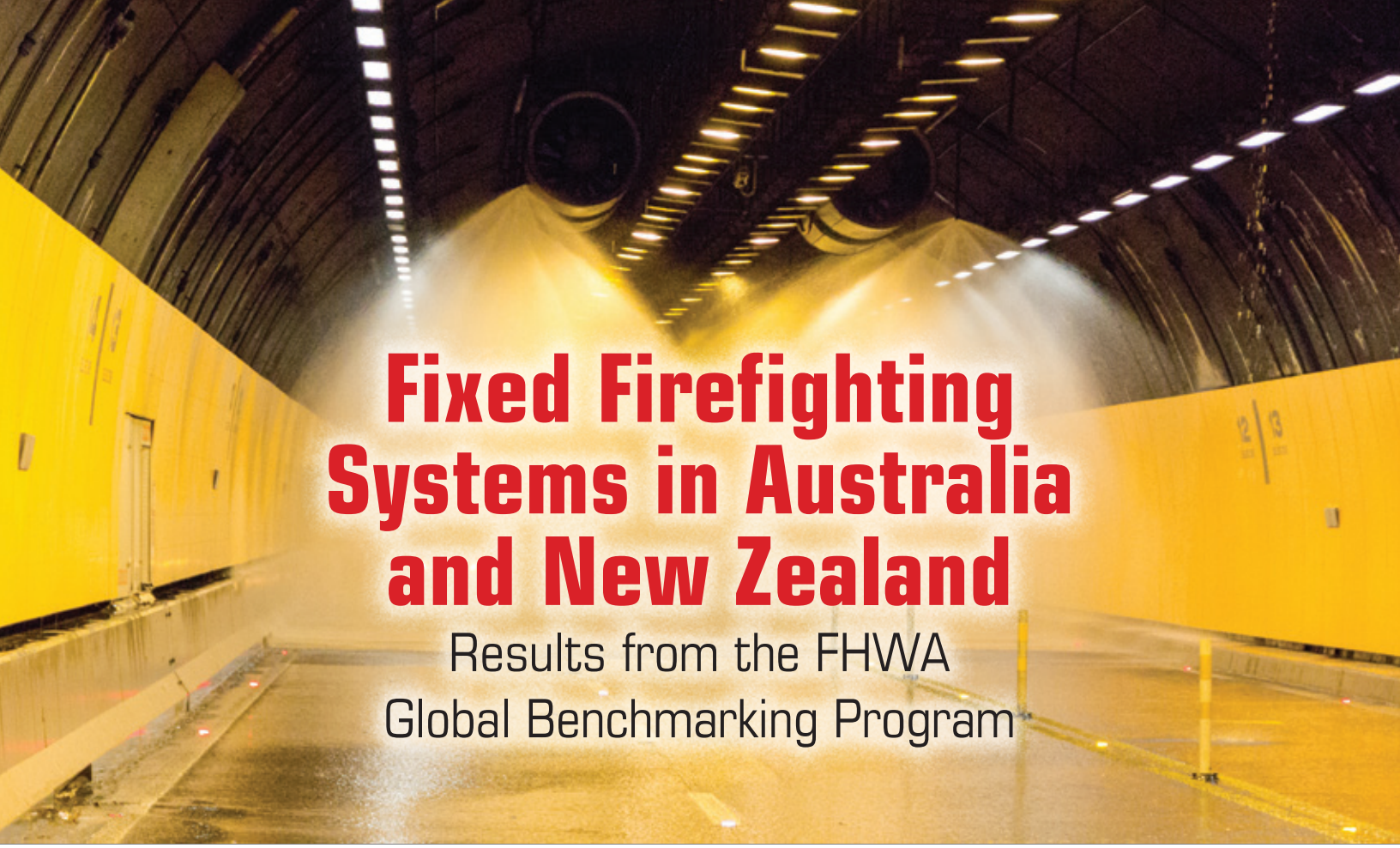
The upper-management level provides the required financial and human resources. As a rule, these people are not IT experts. They depend on the support of IT managers when assessing existing IT security, as well as when deciding on the implementation of measures. For this level, a checklist in the form of compact, browser-based software—using 24 questions about measures already taken—verifies that important high-level topics were implemented.

Action Tool 2: Guide and Evaluation Software for Middle Management

The middle-management level largely is concerned with specific organizational and personnel aspects. For this target group, the research partners developed an evaluation software tool and a guide that allows review of measures in the organization, technology, and personnel areas. The analysis distinguishes between control, automation, and field levels.

Action Tool 3: Risk Management Tool for IT Managers

The comprehensive security analysis and assessment of a networked IT system consisting of many components is difficult without technical support. For this reason, software is provided for the security-related analysis of control centers. With this action tool, the technical structure of a control center can be analyzed, potential threats identified, and already-taken measures evaluated. Suitable measures for implementation are also proposed on the basis of identified potential weaknesses.



Fixed Firefighting Systems in Australia and New Zealand

Results from the FHWA Global Benchmarking Program

Photo: FHWA

MATT BILSON AND STEVE ERNST

Bilson is Senior Supervising Engineer, WSP USA, New York, and Ernst is Consultant, Miami, Florida.

Above: Fixed firefighting works in tandem with ventilation systems to provide a workable environment for evacuation or rescue. For the sake of safety, operators must understand the intricacies of these system interactions.

Today's tunnel owner is faced with protecting life and the facility against potentially catastrophic fire events caused by heavy-goods freight vehicles. The hazards from these large fires may not be effectively mitigated by emergency ventilation and egress alone, so now the industry is turning to using water-based sprinklers, or fixed firefighting systems (FFFS), to help mitigate the risk (*1*).

Fire-suppression technology is widely accepted and required by building codes, but less commonly used in highway tunnels. By controlling the fire—thus improving the environment for evacuation, rescue, and firefighting—FFFS in highway tunnels can save lives and protect the facility. In addition to improving tunnel safety, the use of FFFSs also can improve the design performance of other safety systems, including emergency ventilation and passive structural fire protection materials.

Through the Office of International Programs Global Benchmarking Program (GBP), the Federal Highway Administration (FHWA) commenced an international study to understand effective practices and practical experience from long-term use of FFFS in countries that have successfully deployed these systems in highway tunnels. Based on findings from a desk review, the study largely focused on Australia and New Zealand, where these systems have been used with success for many years. This article is based on the published summary report (*1*).

As part of the GBP study, representatives from FHWA, the Colorado Department of Transportation, and the Maryland Transportation Authority conducted technical field visits and discussions with representatives from national transportation agencies and tunnel owners and operators in Australia and New Zealand, May 7–12, 2017. Representatives identified effective practices for applying and operating FFFS and learned from the international experience regarding the selection, performance criteria, design, operation, and maintenance of the systems.

Photo: FHWA

In the NZTA Operations Room at Auckland's Smales Farm, operators monitor, facilitate, and manage the response to incidents in various tunnels. New operators can learn the systems, and retraining can be done in emergency procedures in the glassed-in training facility (*far left*). The Smales Farm facility also provides testing for new tunnels and for new systems and processes.

History of Fire Safety and FFFS in U.S. Highway Tunnels

The National Fire Protection Association (NFPA) Standard for Road Tunnels, Bridges and Other Limited Access Highways, NFPA 502, is the governing standard for highway tunnel fire safety (*2*). NFPA 502 defines an FFFS as a "system permanently attached to the tunnel that is able to spread a water-based extinguishing agent in all or part of the tunnel."

An FFFS is not a mandatory requirement of NFPA 502, and its inclusion is subject to agreement with the authority-having jurisdiction (AHJ) on the most appropriate fire safety strategy for a tunnel. The use of FFFS in tunnels within the United States varies between jurisdictions, although it should be noted that many jurisdictions do not presently require such a system.

Fires in highway tunnels can have major consequences. For example, the 1999 Mont Blanc Tunnel fire on the border of France and Italy resulted in the loss of 39 lives, and in California's Newhall Pass tunnel, a 2007 tractor-trailer fire caused major damage to the structure when the fire spread to and destroyed an additional 30 trucks trapped behind the collision (*3*). Neither tunnel facility was equipped with an FFFS, and both facilities were closed for repairs for an extended period—months to years.

In contrast, the heavy-goods vehicle fire in the Burnley Tunnel in Australia was a major event that could have been as serious as incidents like the Mont Blanc or Newhall Pass fires. Although there was loss of life, the FFFS in the Burnley Tunnel mitigated what might have been a much more serious incident. The tunnel was safe for opening in a matter of days after the fire, since the damage to the structure was minimal (*3*).

In part as a response to fire events like these, for the past decade or so the road tunnel industry in the United States and Europe has been moving to include FFFS in tunnels (*4*). Until recently, only the City of Seattle, Washington, required the installation of FFFS in its road, transit, and bus tunnels. This began in 1952 with the construction of the SR-99 Battery Street Tunnel. Since then, FFFS have also been installed in the Mount Baker Ridge and Mercer Island tunnels along I-90, as well as in the I-5 Convention Center Tunnel. The new, 2-mile Alaskan Way Viaduct Tunnel incorporates an FFFS.

The trend in other U.S. jurisdictions is toward inclusion of FFFS in road tunnels, thus there is significant experience with road tunnel FFFS in the United States. Many recently constructed tunnels are fitted with an FFFS, including the Presidio Parkway Tunnel in San Francisco, California; the Elizabeth River Midtown Tunnel in Norfolk, Virginia; and the Port of Miami Tunnel in Florida.

Several older U.S. road tunnels have recently been refurbished and upgraded—or are planned to be. So far, however, these refurbishments have not included the addition of an FFFS. The reasons include existing spatial constraints, insufficient drainage systems, and cost. The Eisenhower–Johnson Memorial Tunnel in Dillon, Colorado, recently was retrofitted with an FFFS after the tunnel owner determined that such a system was necessary, considering the traffic mix, location, and criticality of the route.[1]

[1] To read more about the Eisenhower–Johnson Memorial Tunnel, see the article on page 6 of this issue.

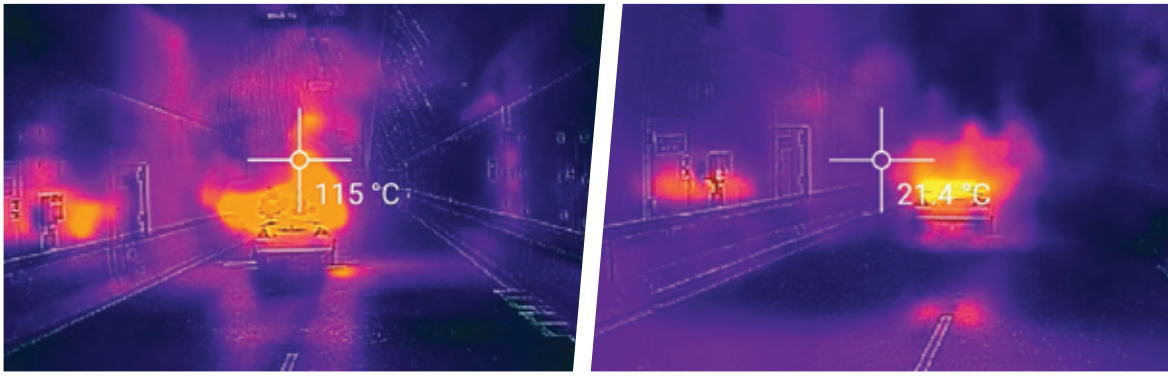


Photo: FHWA

During a car fire exercise, the temperature just as the sprinkler system is activated is 115°C (*left*), compared with the thermal image after a minute of water application (*right*). Water suppression may not always extinguish the fire, but it keeps the fire smaller and cooler to make a tenable environment for escape and firefighting.

Photo: Matt Bilson

Under the famous opera house and harbor is the Sydney Harbour Tunnel, a facility that led the way for Australia and New Zealand to become world leaders in tunnel operations and the use of FFFS in road tunnels.

Photo: FHWA

Urban area tunnels, such as Terrace Tunnel in Auckland, New Zealand, provide more room for green space. Some tunnel facilities in New Zealand share space with a school and others have included skate parks. This helps build public acceptance for the facility and provides tangible benefits to the community.

Global Benchmarking Study

In general, road tunnels of a certain minimum length in Australia, New Zealand, and Japan have required installation of an FFFS. Tunnels in Japan have required FFFS since the 1960s and 1970s (*5*). The Sydney Harbour Tunnel, Australia's first major road tunnel, opened in 1992 with an FFFS installed (*6*). This set a precedent that has been followed in Australia ever since.

New Zealand followed the approach taken by Australia and has included FFFS in its road tunnels. As a result, Japan, Australia, and New Zealand have developed significant experience with FFFS in road tunnels. Tunnels and facilities visited in New Zealand and Australia as part of the GBP included new-build tunnels and rehabilitation projects, including the following:

- Auckland Traffic Operations Center, Smales Farm, Auckland, New Zealand;
- Victoria Park Tunnel, Auckland, New Zealand;
- Waterview Tunnel, Auckland, New Zealand (rehabilitation);
- Terrace Tunnel, Wellington, New Zealand (rehabilitation);
- Mount Victoria Tunnel, Wellington, New Zealand;
- Austroads, Sydney, Australia;
- M2 Tunnel, Sydney, Australia (rehabilitation);
- Sydney Harbour Tunnel, Sydney, Australia; and
- M5 East Tunnel, Sydney, Australia.

Global Benchmarking Program

The Federal Highway Administration (FHWA) Global Benchmarking Program (GBP) is a tool for accessing, evaluating, and implementing proven global innovations that can significantly improve highway transportation in the United States. Instead of recreating advances already developed by other countries, GBP acquires and adopts technologies and best practices already available and used abroad. This is accomplished through studies that connect FHWA and state transportation agency representatives with advances and experts around the world.

Ultimately, the goal of the GBP is to improve safety, avoid duplicative research, reduce overall costs, accelerate improvements, and ensure a world-class transportation system.

Study Findings

Several topics were investigated during the site visits, including:

- Design (new tunnels and rehabilitations),
- Construction (system installation and testing),
- Operation and operator training,
- System maintenance, and
- Incident experiences.

Operational practice and experience with FFFS in Australia and New Zealand were a key area of investigation during the site visits. These were recognized as an area with the most potential differences with the United States in thinking and practice. Study participants also wanted to collect real incident

experiences from the operations staff. Notable observations regarding FFFS in Australia and New Zealand included the following:

- Consistent and formally recognized training programs for tunnel operations staff,
- Approach to integration of FFFS operations with fire brigade operations,
- Incident response planning and policy on when to activate an FFFS during a fire, and
- Accounts of real incidents demonstrating the performance of an FFFS.

Training

Australia and New Zealand use formal training, known as the Certificate IV qualification, for their tunnel operators. Implementation of the training program in Australia and New Zealand was a challenge, and it took about 6 years to formalize. Through this certification process, tunnel operators have a formal qualification that is recognized in facilities and industries beyond the tunnel at which they are employed.

The Certificate IV qualification gives tunnel operators broader opportunities for development and future employment. Agencies and owners also benefit because they have a formal measure of experience and qualification for their staff, and the objective of protecting the life safety of the tunnel-using public is arguably better achieved. In all the tunnels visited, reliance was placed on the operator to activate the FFFS, and training was an essential part of this approach.

Live Exercises

Tunnel operators in Australia and New Zealand regularly conduct exercises with emergency services agencies. These exercises usually are desktop-based but occasionally are conducted in the field and, in some cases, include a controlled fire. Training and live exercises are especially important when an FFFS is involved because of the role the operator plays in activating the system.

Operators consider a live exercise beneficial because it allows them and emergency services workers to experience the conditions in the tunnel and control room. When the FFFS is operational, visibility in the tunnel is reduced, and CCTV coverage of the tunnel likely will be obstructed. The training experience helps prepare participants response to an actual event, refine procedures, and train staff.

During the GBP study visit to the Sydney Harbour Tunnel, a live car fire demonstration was conducted. The team witnessed the FFFS being deployed to control the fire. This sort of exercise is regularly conducted in the Sydney Harbour Tunnel; the tunnel's general manager noted that it helps all stakeholders gain experience of fires in the tunnel and the systems used to make the tunnel safe.

Photos: FHWA

A lot of water can be delivered in a short time to help control a fire, as demonstrated in a test of the fire suppression system in Sydney's M2 Tunnel.

TUNNEL OPERATIONS GROUP

Australia and New Zealand tunnel operators collaborate through the Australasian Tunnel Operators Group. This group of operators holds regular meetings to share experience and lessons learned in the operation of the tunnels. Key participants include staff that supervise the facility.

Photos: FHWA

Operators, firefighters, and other emergency responders are all in the heat of the action during a Sydney Harbour Tunnel live fire exercise, demonstrating before water is applied to the fire (*left*) and at the beginning of FFFS deployment (*right*). Even the news media are included, which helps to bring awareness to the public about tunnel safety protocols.

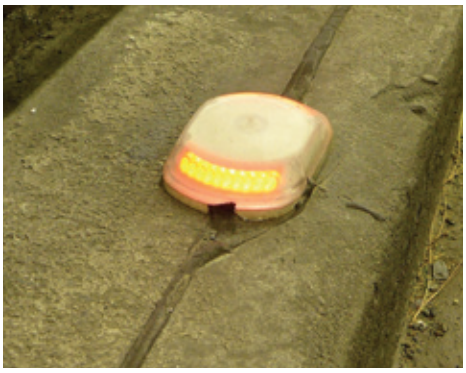


Photo: FHWA

Hallmark of the many safety features that accompany FFFS, LEDs illuminate the way inside Mount Victoria Tunnel.

FIRE-LIFE SAFETY REHABILITATION GUIDELINES

Tunnels in New Zealand deploy a specific legislative requirement framework for rehabilitations. Guideline documents spell out the basic requirements, which include a cost–benefit analysis, risk assessment, development of a business case, consideration of "do nothing" as an option, and a clear nomination of the New Zealand Transport Agency (NZTA) as the final decision maker.

In the United States, NFPA 502 does not set specific requirements for the process of fire-life safety system rehabilitation in a road tunnel. Rather, the standard permits modification of requirements by the local authority when application of a certain requirement would be impractical. In New Zealand, a process is identified for the rehabilitation—such as risk assessment or cost–benefit analysis—and the AHJ is NZTA.

> By controlling the fire—thus improving the environment for evacuation, rescue, and firefighting—FFFS in highway tunnels can save lives and protect the facility.

Conclusion

The Global Benchmarking Study identified several worthwhile practices related to design, operation, and maintenance of tunnels in Australia and New Zealand. FHWA has released a report that provides an in-depth account of the study and the findings, which contains materials that can help implementation in the United States (*5*). The findings on operation, staff training, and incident experience planning are particularly useful—not just for tunnels but also for highway system emergency operations.

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Photo: FHWA

Cutting down on confusion, directional and wayfinding signage in the Sydney Harbour Tunnel can make all the difference for drivers in an emergency. Signs such as "You are in the Sydney Harbour Tunnel" are particularly helpful. Sydney has many tunnels, and (according to operators) some motorists who have called emergency services—for a car breakdown, for example—have not been certain of their exact location.

SAFETY IN HIGHWAY TUNNEL OPERATIONS

Photo: San Francisco Fire Department

GARY ENGLISH

The author is CEO, Underground Command and Safety, and former Assistant Fire Marshal, Seattle Fire Department, Seattle, Washington.

Above: Once the scene of a July 2019 car fire in San Francisco's MacArthur Tunnel was deemed safe, firefighters worked with California Highway Patrol and the California Department of Transportation to evaluate tunnel overhaul and removal of the burned vehicle.

Highway tunnels in the United States are some of the most critical elements of national, regional, and local transportation infrastructure. Newly commissioned U.S. tunnels are setting international benchmarks in safety thanks to research, advanced engineering, the involvement of emergency responders, and an emphasis on an integrated safety approach. Research and incidents identify potential safety gaps, which necessitate changes to design, operations, and improvements to fire and life safety systems. Most tunnels might present significant safety challenges, however. This article will identify safety gaps and offer recommendations for future research needs.

The enclosed nature of tunnels increases the danger from typical roadway hazards by concentrating fire effects, limiting the rapid evacuation of motorists, and restricting responders' ability to reach an incident quickly. Safety levels also are directly affected by many factors, such as physical geometry, vehicle types, freight classes, and traffic directions. Regulations, guidelines, design standards, safety systems, and emergency operation procedures have been developed specifically to improve overall safety.

Early Tunnel Research and Fire Suppression

In 1927, New York's Holland Tunnel pioneered a new transverse mechanical ventilation system to protect motorists from vehicle exhaust; specifically, carbon monoxide (CO). Unfortunately, in 1949, a truck caught fire in that tunnel and the ventilation designed to protect against CO emissions was unable to protect motorists from the fire and its heat and smoke—resulting in one firefighter death and 66 motorist injuries, as well as severe damage to the tunnel itself.

The 1949 Holland Tunnel fire led to efforts to adapt automatic fire suppression systems, successfully used in buildings, for use in tunnels. The first of these fixed firefighting systems (FFFS) was installed in 1954 in the new Battery Street Tunnel in Seattle, Washington.

State of the Art in Tunnel Boring Machines

MICHAEL MOONEY

The author is Grewcock Chair and Professor of Underground Construction and Tunneling, Colorado School of Mines, Golden.

Today's tunnel boring machines (TBMs) can excavate through any soil and rock formation that urban transportation environments possess. A fundamental advancement in TBMs has been the effective balancing of in situ water pressure and earth pressures during tunneling, made possible by closed-mode, pressure balance shield TBMs. The majority of transportation tunnel projects take place in urban areas, in soils and soft or fractured rock and below the groundwater table.

Pressure balance shield TBMs are, therefore, like submarines—completely sealed from outside pressure. More than 90% of these TBMs are earth pressure balance machines, in which the conditioning agents—such as foams, polymers, water, and bentonite slurry—are mixed with the excavated ground at the cutterhead and in the excavation chamber and then used to counterbalance the water and lateral earth pressure at the excavation face. The excavated material is removed via pressure-dissipating screw conveyors, followed by belt conveyors.

Photo: Gary English

At 7,000 tons, 57.4 feet in diameter, and 368 feet long, Bertha was the largest-ever earth pressure balance TBM. Built by the Japanese firm Hitachi Zosen, it had a total thrust of 392,000 kN and a maximum torque of 147,000 kNm.

Less than 10% of pressure balance TBMs use bentonite slurry as a face support mechanism. Pressurized slurry counterbalances the water and lateral earth pressure and serves as a transport medium for the excavated material through return pipes.

Design Advancements

Introduced in the past 5 to 10 years, convertible and hybrid TBMs combine earth pressure balance mode and slurry

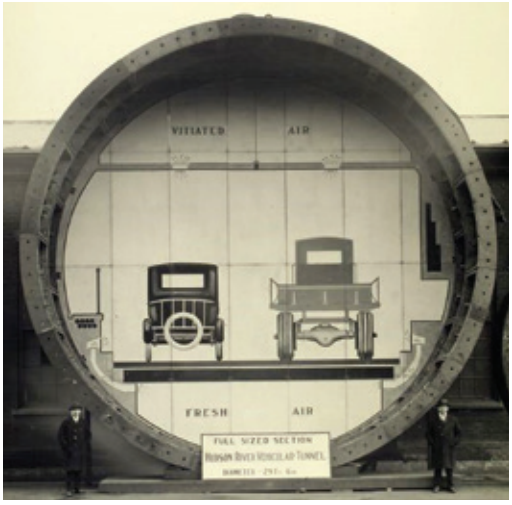

Photo courtesy of New York Public Library Digital Collections

Called the Hudson River Vehicular Tunnel when it opened in 1927, the Holland Tunnel circulated fresh air below and vitiated air above for the safety of motorists of the day.

Japan followed quickly with an FFFS in 1963; that country now has more than 100 tunnels equipped with FFFS. Switzerland's Ofenegg FFFS tunnel tests in 1965, however, produced faulty results (excess steam and explosions), which were published and codified as "facts" in many regulations, such as those of the National Fire Protection Association. These incorrect facts halted tunnel sprinkler installation for decades in many countries until new tests proved that steam and explosions do not occur if FFFSs are operated correctly.

Fire Sizes, Ventilation, and FFFS

Tunnels without FFFS historically have protected motorists from fire heat and toxic gases and have ensured visibility via emergency ventilation systems. These were initially sized to manage an expected heat release rate of 20 megawatts (MW). Tests conducted in 1995 confirmed longitudinal tunnel emergency ventilation

Photo: Herrenknecht AG

Beating out Bertha, this 58-foot-diameter slurry pressure balance tunnel boring machine is the largest such borer in the world. The machine recently was used to excavate a three-lane road tunnel in Hong Kong.

pressure balance mode—and sometimes open mode used in rock tunneling—into the same TBM. Such a configuration provides the flexibility needed to traverse alignments through varying ground types.

TBMs today routinely install a permanent lining system during excavation. Very high-quality steel rebar or steel fiber–reinforced concrete lining segments or both are precast in manufacturing facilities before tunneling. Gaskets sandwiched between segments during installation provide a watertight seal at very high water pressures.

Pressure balance TBM tunneling has been extremely effective at maintaining face stability and minimizing overlying ground and structural deformation. The Federal Highway Administration's *Technical Manual for Design and Construction of Road Tunnels*, published in 2009, indicated that 1.0% ground volume loss was "typical" practice; therefore designers used an assumption of 1.0% volume loss to perform structural impact analysis. Today, however, pressure balance TBMs consistently achieve 0.1–0.4% volume loss performance, so designers now use 0.5% volume loss to perform preliminary structural impact analysis.

Bertha and Other Big Machines

Driven by underground roadway demand, TBMs have grown in size. Bertha, the world-record earth pressure balance TBM, was 57.4 feet in diameter (that is, excavated diameter). It was used to build the double-decker, two-lane Seattle SR-99 tunnel, completed in 2019. The world-record slurry pressure balance TBM is 58 feet in diameter and was most recently used to construct a three-lane road tunnel in Hong Kong.

The success of these large-diameter TBM projects has motivated many transportation agencies to pursue larger tunnels, for both transit and roadway projects. For example, transit agencies in Toronto, Canada, and San Jose and Los Angeles, California, are considering large-diameter tunnels in lieu of twin tunnels.

Digitalization

Another recent development in TBM technology is digitalization, sensing and control, partial automation of some TBM functions, and the development of full automation technology. TBMs are outfitted with hundreds to thousands of sensors, monitoring everything from pressures at the face and around the shield to mass, volume, and density of the excavated material traveling through slurry return pipes and belt conveyors. Data are collected and streamed to project stakeholders in real time. Some data are used to automate TBM functions, such as face pressure control, soil conditioning, grout injection, and segment installation.

TBM data fueled by artificial intelligence (AI) are also being used to improve TBM performance in areas where the mechanics are complicated, such as the TBM advance rate. The use of data, AI, and automation will continue to grow and advance TBM performance in the years to come.

systems could handle a 100-MW fire; this subsequently became the new design fire size for most new tunnels.

The tradeoff of this ventilation system is that motorists downstream from the fire can be exposed to heat and smoke. The new Seattle SR-99 Tunnel uses a newer form of ventilation—point extraction—which protects motorists on both sides of a fire.

Further tests conducted in the Runehamar Tunnel in Norway showed that a truck loaded with common freight can produce a rapidly growing fire well above 100 MW. This larger fire size was proven in the analysis of the 1999 Mont Blanc Tunnel fire, which produced a 190-MW fire from margarine and flour freight.

Clogged with rush-hour traffic, in spring 1949 New York's Holland Tunnel went up in flames when a barrel of hazardous chemicals fell off a truck and sparked a raging fire. The ventilation system proved inadequate in protecting motorists from the flames, toxic fumes, and burning heat. One firefighter died, and 66 motorists were injured that morning.

The study of larger fires indicate that many of the existing tunnels rely on emergency ventilation systems for safety from fires of up to 20 or 100 MW. These may not fully protect motorists from much larger fires. Even worse, hazardous materials (hazmat) such as gasoline in flammable liquid tankers—common on roadways—is a source of fire that has exceeded even the Runehamar tests. A 1982 tanker fire in Caldecott

Tunnel in California was 400 MW, and a 2015 fire in Skatestraumen, Norway, was estimated to have reached 440 MW in the first 7 minutes. These fires are well beyond the capability for emergency ventilation systems, or even FFFS without foam additives. Adding foam to water can suppress flammable liquid spill fires, which can protect motorists and prevent possible tunnel collapse.

Firefighters have great difficulty with these fires. As a result, tankers and some other types of hazmat trucks commonly are banned from tunnels unless the tunnels have foam/deluge FFFS, as do the I-90 tunnels in Seattle.

If correctly designed, installed, tested, maintained, and activated quickly, tunnel FFFSs also could prevent exceedances of existing emergency ventilation design capacity. In Australia, tunnel operators activate the FFFS extremely quickly. In 2007, this practice helped to successfully and quickly suppress what could have been a very large fire in the Burnley Tunnel, resulting in only a short closure and no significant damage.

In buildings, FFFS are so reliable that automatic reductions in passive fire resistance and longer exit distances are accepted in current building design standards. If similar reliability of FFFS in tunnels can be proven, resulting in changes to tunnel design standards, this could lead to significant cost savings in passive fire systems and emergency ventilation, as well as improved motorist safety.

Swift FFFS activation in Melbourne, Australia's Burnley Tunnel quickly suppressed what could have been a significantly larger, more damaging—and more deadly—fire, where three people died in 2007.

Conclusion

The newest U.S. tunnels are some of the safest in the world, but many existing tunnels lack effective safety systems to address the larger, faster fires now expected. Also, lacking incident data, training, or best practice documents, the designers, tunnel operators, and responders are neither fully informed nor prepared for the larger fires that will eventually occur.

Safety Gaps

Current safety gaps and future challenges in tunnels include the following:

- Many existing tunnels lack adequate ventilation for minimum safety.
- Tunnel operators and emergency responders are not all reasonably trained on tunnel challenges.
- In some cases, tunnel emergency response guidelines for operators and responders are insufficient.
- Tunnel responders lack training facilities.
- Responder self-contained breathing apparatus systems are inadequate for extended rescues in smoke.
- Alternative fuel fires in tunnels create unknown and potentially significant challenges.
- Lack of FFFSs forces reliance on potentially undersized ventilation.

Research Directions

Among the possible research directions for tunnel safety are the following:

- Establish a tunnel safety assessment program;
- Compare and adapt effective international best practices;
- Develop a U.S. Tunnel Center of Excellence, similar to that of several other countries;
- Develop a national tunnel incident database to improve design, prevention, and response; and
- Identify tunnels with inadequate ventilation systems.

The 1949 Holland Tunnel fire led to efforts to adapt automatic fire suppression systems, successfully used in buildings, for use in tunnels.

Tunnel Fire Life Safety in the United States

Comparing Vintage Under-River Highway Tunnels to Modern Counterparts

JOSEPH M. ENGLOT

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Recent developments in the design and construction of modern under-river highway tunnels in the United States have significantly improved fire life safety features, consistent with the latest international standards. This positive trend has led to the need to reexamine the fire life safety features in a distinct class of older U.S. tunnels. These vintage under-river highway tunnels—constructed between 1927 (Holland Tunnel, New York and New Jersey) and 1964 (Chesapeake Bay Bridge and Tunnel, Virginia)—were specifically designed to mitigate the carbon monoxide exhaust from the earliest generation of gasoline-powered vehicles (Table 1, below). But how do their safety levels compare to modern highway tunnels?

Vintage Under-River Highway Tunnels

Older, under-river highway tunnels—commonly found in the northeastern and mid-Atlantic regions of the United States—provide a horizontal roadway surface that is wide enough for at least two lanes of traffic. They feature a roadway slab that is suspended off the tunnel bottom to create a void, which then is used for a ventilation plenum and other utilities (Figures 1 and 2, page 22) (*1*). Their transverse ventilation systems—required for longer tunnels—make use of mechanical fans for air movement but do not use the roadway envelope itself as the ductwork. A separate plenum or ductwork with flues that allow uniform air distribution into or out of the tunnel typically is located above a suspended ceiling or below a structural slab in bored or submersed tube tunnels with a circular cross-section. For cut-and-cover tunnels, the plenum is located in a rectangular or box section.

These tunnels are characterized by a common type of exhaust ventilation

TABLE 1 Vintage Under-River Highway Tunnels in the United States

VINTAGE TUNNEL	YEAR OPENED TO TRAFFIC (2 TWO-LANE TUBES UNLESS NOTED)	POSTED VEHICLE HEIGHT LIMIT	POSTED VEHICLE HORIZONTAL WIDTH LIMIT	TRAFFIC VOLUME, BOTH DIRECTIONS (M PER YEAR)
Holland Tunnel, NY–NJ	1927	12' 6"	8' 0"	30.1 (2018)
Detroit Windsor Tunnel, MI	1930 (1 two-lane tube)	12' 8"	8' 6"	4.4 (2018)
Sumner Tunnel, MA	1935 (1 two-lane tube)	12' 6"	8' 6"	11.0 (2015)
Lincoln Tunnel, NY–NJ	1937, 1945, 1957 (3 two-lane tubes)	13' 0"	8' 6"	37.9 (bus/HOV lane, 2018)
Queens Midtown Tunnel, NY	1940	12' 1"	8' 6"	26.8 (bus/HOV lane, 2016)
Hugh Carey Tunnel, NY	1950	12' 1"	8' 6"	19.7 M (2016)
Downtown Tunnel, VA	1952	13' 6"	8' 6"	33.9 (2002)
Hampton Roads, VA	1957 (1 two-lane tube) 1976 (1 two-lane tube)	13' 6" 14' 6"	8' 6" 10' 6"	36.0 (bus routes, 2019)
Baltimore Harbor, MD	1957	13' 6"	8' 0"	27.6
Callahan Tunnel, MA	1961 (1 two-lane tube)	12' 6"	8' 6"	14.0 (2015)
Midtown Tunnel, VA	1962 (1 two-lane tube) 2016 (1 modern two-lane tube)	13' 6"	8' 6"	14.6 (bus/HOV lane, 2013)
Chesapeake Bay Bridge Tunnel, VA	1964 (1 two-lane tube)	13' 6"	8' 6"	4.0 (2017)

Note: HOV = high-occupancy vehicle.

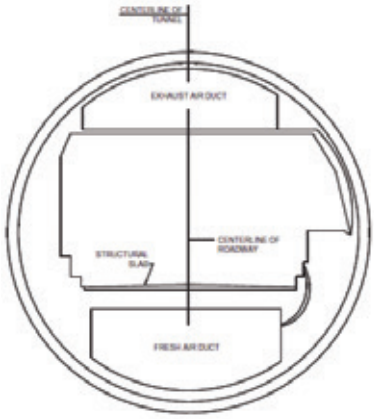

FIGURE 1 Circular tunnel with a structural slab provides space for an air plenum below.

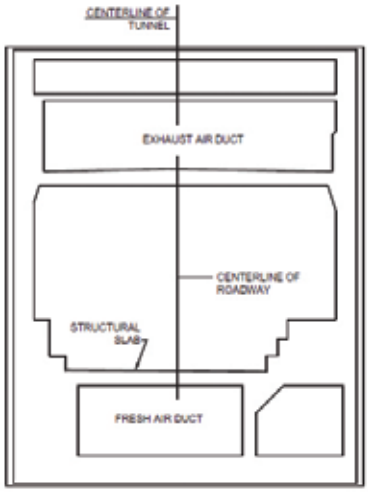

FIGURE 2 Single box tunnel with a structural slab provides space for an air plenum below.

system, low vehicle headroom and the narrow travel lanes that accommodated smaller vintage vehicles of their era, and very narrow and constrained egress paths. They included fire suppression systems that initially relied entirely on buckets of sand in the tunnel and a fire brigade response or on the installation of a fire standpipe in the tunnel.

These longer vintage under-river tunnels utilize full-transverse ventilation, incorporating supply air and exhaust air over the same length of tunnel (Figure 3, at right). This method is used primarily for longer tunnels with large amounts of air that need to be replaced or for heavily traveled tunnels that produce high levels of contaminants. The presence of supply and exhaust ducts allows for a pressure difference between the roadway and the ceiling; therefore, the air flows transverse to the tunnel length and is circulated more frequently. This system may also incorporate supply or exhaust ductwork along both sides of the tunnel instead of at the top and bottom.

All of these vintage tunnels are critical to the populations they serve, which is evident in the high traffic volumes. All are heavily used in peak rush hours and—in most cases—become congested, bringing vehicles to a crawl for significant periods. A few of the most heavily traveled vintage tunnels have a high percentage of buses traveling along express bus lanes. At peak hours, these tunnels have a calculated exposed population of up to 4,000 passengers between portals, based upon a representative mix of automobiles, buses, and trucks. During this time, the highest vehicle throughput that can be achieved in these tunnels has been measured at 2,000 vehicles per lane per hour.

These tunnels were constructed as a means to cross beneath navigable waterways. If they are closed for any reason, the available detours are very long, compounding traffic congestion and possibly leading to traffic gridlock at peak travel hours.

Because they are critical structures that have undergone heavy wear and deterioration from the elements, these tunnels have all undergone major rehabilitation at various times, including in some cases the replacement of ceiling slabs, roadway pavements, and supporting slabs; rehabilitation of drainage systems; and rehabilitation of bench walls and catwalks. Many have had major repairs to their electric motors and ventilation system fans and rehabilitation of their ventilation buildings.

Comparison of Vintage Tunnels and Modern Tunnels for Fire Analysis

When it comes to fire life safety, a stark contrast exists between the vintage highway tunnels represented here and modern highway tunnels, briefly touched on by using the following qualitative comparisons.

The Second Midtown Tunnel (Figures 4 and 5, page 23) across the Elizabeth River between Norfolk and Portsmouth, Virginia, is an example of modern tunnel design and construction (*2*). Owned and operated by the Virginia Department of Transportation (DOT), it opened to traffic in August 2016

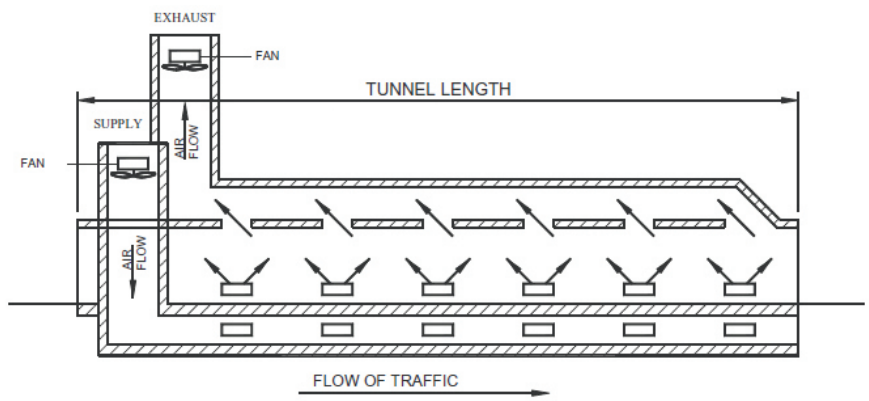

FIGURE 3 Commonly used in longer tunnels, full-transverse ventilation incorporates supply air with exhaust air over the same length of tunnel.

FIGURE 4 The Second Midtown Tunnel's precast immersed tubes are aligned in a Virginia dry dock.

FIGURE 5 Cross-section of the Second Midtown Tunnel's precast immersed tube, which spans the Elizabeth River between Norfolk and Portsmouth, Virginia.

and currently accommodates 38,000 vehicles per day. A comparison between this tunnel and vintage tunnels is not intended to serve as a risk assessment for the new tunnel, but it does show significant differences in physical tunnel parameters. And the characteristics of the ventilation and fire life safety systems—representative of current trends in tunnel design—in comparison with the antiquated design of vintage tunnels make it a safer environment.

Seattle, Washington's new Alaskan Way Tunnel, a 2-mile deep-bore tunnel that replaced the Alaskan Way Viaduct (an elevated highway that ran along the city's waterfront), is a second example of a modern highway tunnel (Figures 6 and 7, page 24). The new tunnel features a fixed fire suppression (FFS) system, pressurized egress passageway for tunnel evacuation, and modern self-evacuation egress signage.

A side-by-side correlation shows how vintage and modern highway tunnels compare in traffic lane width, vertical clearance, fire smoke control, and fire suppression (Table 2, at right). As tunnel design has evolved, economic analysis for initial construction cost and operating costs has shown that the ventilation systems designed in vintage tunnels were too expensive. Providing the full-length supply and exhaust ducts—with zoned intake and exhaust shafts and fan—were found to be unnecessary once engineers had the ability to design ventilation systems using computerized computational fluid dynamics.

By increasing the vertical clearance and lane widths to comply with minimum Interstate Highway clearances of 16 feet, 6 inches, and American Association of State Highway and Transportation Officials roadway widths of 12 feet, 0 inches, analysis showed that normal ventilation quality standards could be achieved with jet fans. Separate passenger egress corridors with positive pressure and water deluge systems to extinguish vehicle fires before they become fully developed was a safe and more economical way to deal with fire and smoke conditions.

The risk of fire hazard is much lower and the provisions for safe evacuation are much higher for modern tunnels than for vintage tunnels. This leads to another example of what can be done with vintage tunnels to improve their safety in fire events.

Older Tunnel Retrofitted with FFS System

The Eisenhower–Johnson Memorial Tunnel in western Colorado is the first highway tunnel system retrofitted with an FFS

TABLE 2 Comparison of Clearances and Fire Life Safety Features in Vintage and Modern Highway Tunnels

TUNNEL CATEGORY	CLEARANCES AND FIRE LIFE SAFETY FEATURES
Vintage tunnel	• Lane width: two 10' 6"–11' 0" lanes without offsets • Vertical clearance: 12' 6"–13' 6" • Ventilation system: full-transverse ventilation incorporates supply air and exhaust air together over the same length of tunnel • Fire smoke control: vent fans on high speed to exhaust smoke and heat • Fire suppression: standpipe for manual firefighting
Modern tunnel	• Lane width: two 12' 0" lanes with 2' 0" offsets • Vertical clearance: 16' 6" • Ventilation system: longitudinal jet fans within the roadway • Fire smoke control: separate egress corridor with positive pressure ventilation to exclude smoke (note separate passageway in Figure 5, above) • Fire suppression: water deluge system

FIGURE 6 With a 57.5-foot excavated diameter, Seattle's Alaskan Way Tunnel was the world's largest soft-ground bored tunnel upon completion.

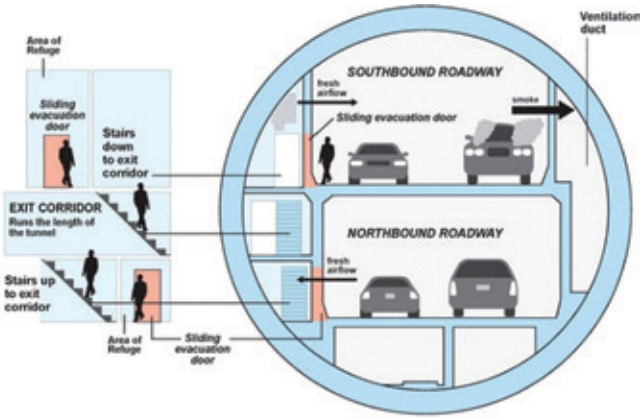

FIGURE 7 Cross-section of the Second Midtown Tunnel's precast immersed tube, which spans the Elizabeth River between Norfolk and Portsmouth, Virginia.

(Figure 8, at right). Also known as the I-70 Tunnel, the 1.7-mile-long twin tunnels are owned and operated by the Colorado DOT. More than 30,000 vehicles a day travel through them. Fires have been known to break out inside the tunnels two or three times a year. The FFS system (Figure 9, at right) has heat-detection capabilities with a deluge mechanism that can suppress a large fire within the first 2 minutes of its start. The nozzles are installed in a grid pattern in the existing air plenum, providing water for 60 minutes and up to 500 gallons per minute through a standpipe system. Because of ambient freezing temperatures most of the year, the supply water is heated. Tunnel drainage improvements were also required.

Given the heavy use of and dependence upon this class of vintage tunnels by their local U.S. communities, the question remains: why shouldn't they, too, be retrofitted to improve their fire life safety?

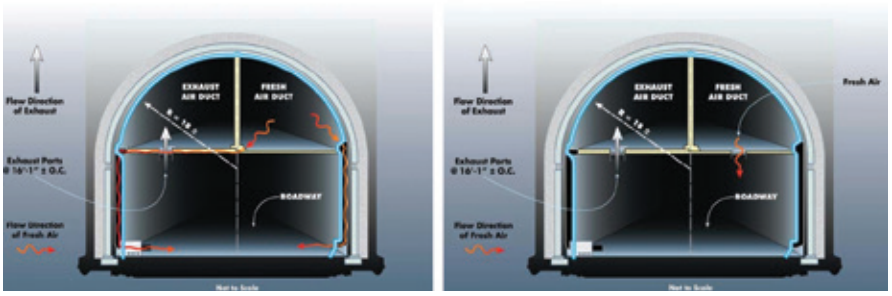

FIGURE 8 A cross-section of the I-70 Eisenhower–Johnson Memorial Tunnel system shows the roadway and ventilation ducts of the twin tunnels.

FIGURE 9 FFS system components were installed in the Eisenhower–Johnson Memorial Tunnels plenums.

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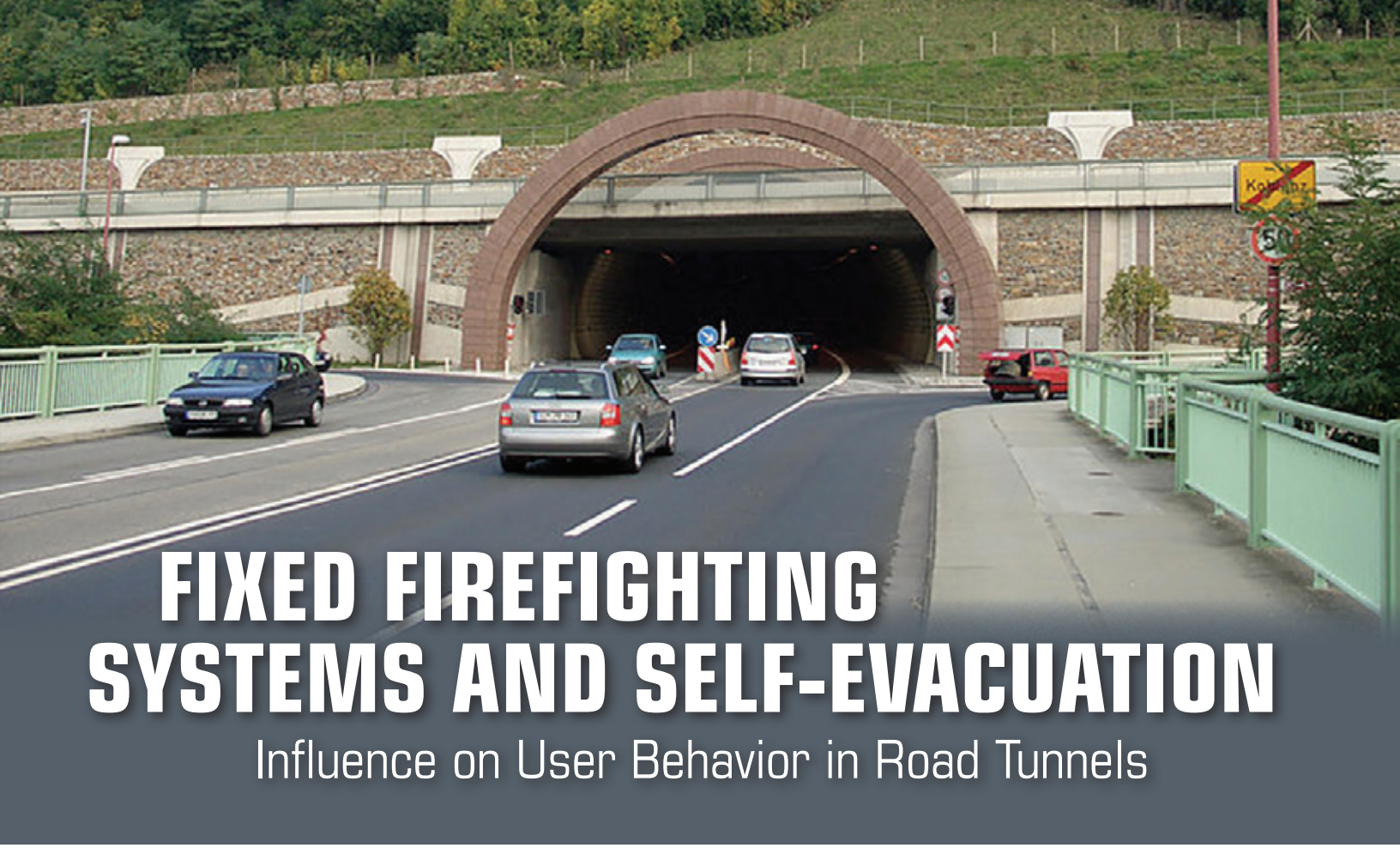

FIXED FIREFIGHTING SYSTEMS AND SELF-EVACUATION

Influence on User Behavior in Road Tunnels

Photo: Holger Weinandt

INGO KAUNDINYA AND ANNE LEHAN

Kaundinya is Tunnel Engineering and Operation Section Head and Lehan is Research Associate, Federal Highway Research Institute (BASt), Bergisch Gladbach, Germany.

Above: Masonry arches frame one of three portals of the Glockenberg Tunnel in Koblenz, Rhineland-Palatinate, Germany. Every year, European tunnels are inspected for structural integrity, equipment operations, and fire safety.

As the number of tunnels equipped with automatic fixed firefighting systems (FFFS) has increased in the past few years, researchers have examined the effects of these systems on the self-rescue of road tunnel users and how the systems interact with existing tunnel safety equipment.

Several completed research projects conducted at Germany's Federal Highway Research Institute (BASt) have studied the influence of FFFS on human behavior in an emergency and evacuation situation in road tunnels (*1–2*). This article offers an overview of the most important results of these studies.

Fixed Firefighting Systems

Automatic FFFS in road tunnels are meant to ensure the suppression of a vehicle fire as early as possible to prevent the development of a major fire. By limiting the development of a fire and its spread, FFFS can limit the effective heat release rate. They also facilitate rescue conditions for emergency services and firefighters, as well as protect the tunnel structure from high-temperature stress. These effects are clear and well-proven by fire tests and studies (*1, 3*).

So far, however, there have been no systematic studies of the effect of an activated FFFS on the behavior of tunnel users during self-rescue. It might be expected that an activated FFFS would delay or even prevent the self-rescue of tunnel users, both from seriously impaired visibility and because the water or foam from the activated FFFS may deter people from leaving their vehicles. Two types of FFFS are used in road tunnels: high-pressure water and compressed-air foam systems. They are different with respect to their interaction with human behavior.

Human Behavior in Recent Incidents

To understand the behavior of road tunnel users during an incident and to support self-rescue, it is necessary to consider

various aspects of how humans process information: perception, evaluation of information, and decision making. Several models have attempted to integrate the relevant processes in case of an incident (*4–5*).

Human escape behavior has been studied in some recent fire events in road tunnels (*1, 6*). These examples show that road users do not always follow the recommended behavior during a fire, despite many information campaigns. If new technical systems (like FFFS) are used in a road tunnel, it is important to investigate the effects of such systems on the reaction and escape behavior of road users.

Virtual Reality Research

As an alternative to real trials with limited possibilities and high availability requirements, virtual reality (VR) has evolved considerably as a research method for examining human behavior in recent years. It offers multiple advantages: for example, repeated presentation of standardized scenes and of dangerous situations, which ethical and logistical concerns prevent from being researchable in the real world (*4*).

STUDY PROCESS

As a first step, one research project used VR to examine the influence of an activated FFFS on the behavior of tunnel users (*1*). The study randomly divided 50 participants into two groups. Group A experienced a scenario in which FFFS was activated, and Group B served as a comparison and experienced the same scenario without activation of FFFS.

A heavy water mist obscured Group A participants' view immediately after hearing an evacuation announcement (*left*). Group B experienced the same scenario without FFFS (*right*).

Every participant in both groups took part in a virtual drive through a tunnel, playing the role of a driver (see photo, below), then encountering a virtual accident involving a burning truck with smoke slowly spreading toward the participant. After stopping the vehicle, an announcement instructed the participants to evacuate the tunnel. In Group A, the FFFS was activated as the announcement played for the first time, and the participant's virtual car was entirely covered in water mist (see photo, above).

Researchers observed whether participants left the vehicle and measured the reaction time until participants got out of the car. Once they left the vehicle, the experiment was paused. Upon resuming the simulation, participants had the opportunity to continue their escape using a gamepad until they reached an escape location, such as the nearest emergency exit (see photo, below). The location and duration of the escape also were observed. This research was conducted in a 3-D multisensory laboratory at the University of Würzburg (*7*).

FINDINGS

This VR experiment provides the first valuable insights on how an FFFS affects the experience and behavior of tunnel users. Although the activated FFFS had a distinct impact on the participants' visual perception—a considerable reduction of vision inside and outside the car—it had only a small effect on participants' escape

Photos: University of Würzburg

Steering wheel with gas and brake pedal provide a close-to-real experience in the VR laboratory.

Surveying the scene, a driver looks for the closest emergency exit in this VR escape scenario.

behavior. Participants of both groups left their vehicle within half a minute of the beginning of the announcement and mostly chose to escape via the nearest emergency exit.

Participants differed in their escape routes to the emergency exit, however. Whereas participants in Group A kept rather close to the tunnel walls, those in Group B evacuated directly through the middle of the tunnel. The announcement that asked them to leave the tunnel was equally well understood in both conditions and was not muffled by the sound of the FFFS.

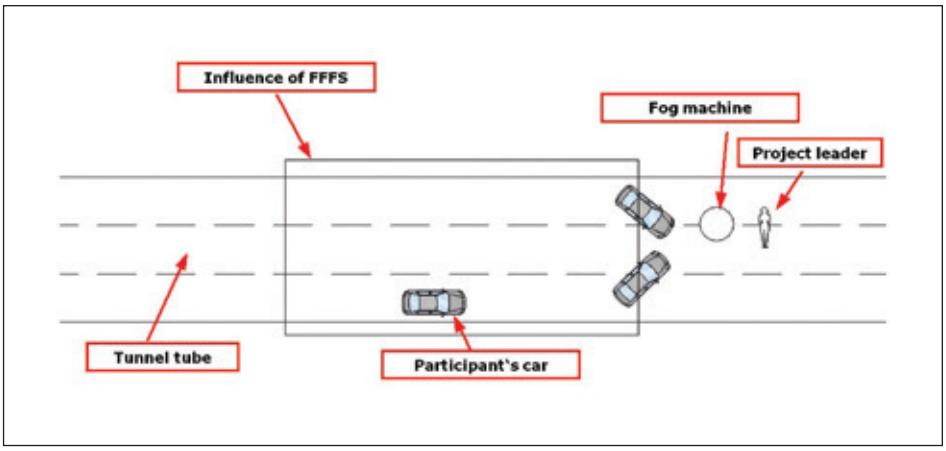

FIGURE 1 Test layout.

Research in Real Tunnels

To gain further insights into haptic effects, field tests were conducted with test participants and two types of FFFS (high-pressure foam and water mist) (*2*). The objective of these field tests was to determine the influence of stimuli from an activated FFFS (e.g., humidity and coldness, which cannot be simulated in VR) on the behavior and experience of tunnel users and to validate the findings of the VR experiment.

FIELD TEST 1

The first field test was conducted in the newly built Jagdberg Tunnel on Highway A4 near Jena, Germany, before it was opened to traffic. In a random yet controlled setup, researchers observed the escape behavior of participants inside and outside the car. Participants drove a car into the tunnel and were confronted with a simulated accident with smoke propagation. After approaching the accident and stopping the vehicle, they heard an announcement asking them to evacuate (Figure 1, above). The photos below show the activation of FFFS for both sets of participants.

Special focus was placed on analyzing the participants' reaction and escape behavior and their choice of the escape location (*8*). As in the VR experiment, participants in Group A reported restricted vision because of the foam (especially when sitting in the car without activating the windshield wipers). The loudspeaker announcement in the tunnel was less comprehensible compared with that in the VR experiment.

Participants reported hardly any fear of negative effects of the foam and reported no irritation of mucous membranes. They reported feeling slightly influenced in their escape behavior because they assumed the foam was slippery so they had watched their step. Behavior analysis shows that most participants left their vehicle even with the activated FFFS, and in both groups most participants evacuated to the nearest emergency exit. These findings suggest that most participants complied with the loudspeaker announcement's request to leave the tunnel.

Foam shrouds an FFFS experiment in Germany's Jagdberg Tunnel (*left*). A second test in Austria's Citytunnel Bregenz used water mist (*right*).

FIELD TEST 2

After the field test with the foam-based FFFS, a second field test was conducted in realistic conditions with a water mist–based FFFS (*2*). The objective and experiment setup was similar to the previous field test, the only change being that the FFFS used water mist. With the support of Austrian road operator ASFINAG, this field test took place in the Citytunnel Bregenz (Austria), which was closed to traffic during the research period for nighttime maintenance (*9*).

In accordance with the previous findings, participants in the activated FFFS condition (Group A) reported that the water mist–based FFFS considerably restricted their vision inside and outside the vehicle. As with the first field test, loudspeaker announcements were less comprehensible because of the FFFS activation. A particularly meaningful finding of this field test was that about 40% of the Group A participants did not leave their vehicles (Figure 2, below).

With regard to the time participants took to leave their vehicle, there was no statistically significant difference between the experiment groups, even though participants in Group A of the Jagdberg Tunnel field test had a longer reaction time (Figure 3, above).

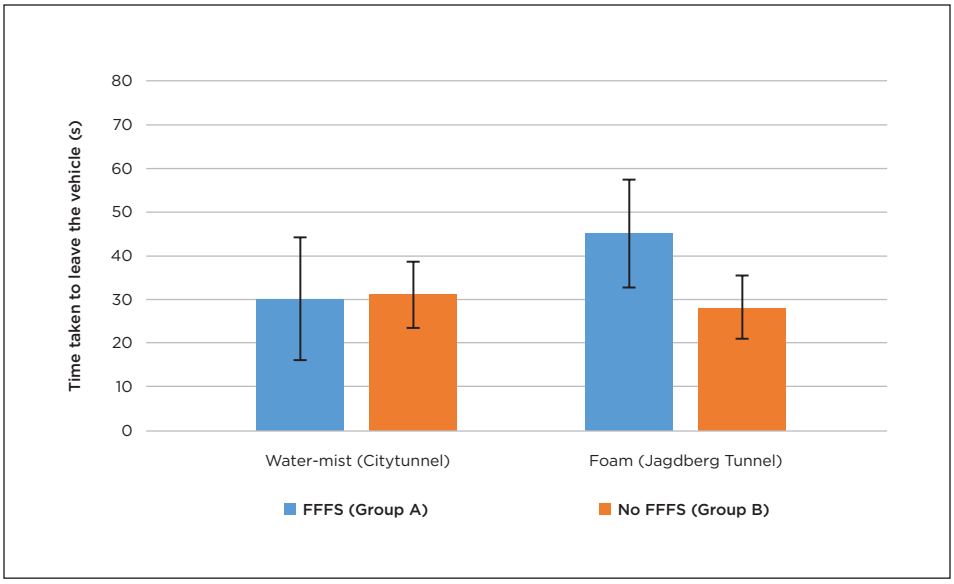

FIGURE 3 Time taken to leave the vehicle with (*blue*) and without (*orange*) activated FFFS.

Conclusion

Even though the three FFFS studies only covered one possible scenario and the transfer of the findings to real fire scenarios must be handled very carefully, it seems that activating an FFFS in a tunnel might indeed limit vision considerably but has no decisive negative impact on tunnel users' escape behavior—as long as relevant parts of the tunnel infrastructure are suitably adapted to FFFS activation.

A comprehensible announcement referring to the FFFS activation is very important so that tunnel users in the immediate area of influence of the FFFS can understand the urgency of the situation and leave their vehicle. This has also been revealed by analyzing real tunnel fires, in which little panic occurs after an accident takes place but in which people need clear instructions to initiate evacuation and to be persuaded to leave their vehicle behind (*6*).

Interestingly, in all studies at hand, a considerable percentage of participants prompted to evacuate via loudspeaker announcements (real and VR) initially evacuated toward an emergency call station. In the case of fire and thick smoke, this is not correct behavior and could be dangerous, as the emergency call station is not necessarily a safe place. Having heard the announcement, tunnel users should be able to deduce that operators and emergency services are already involved. This raises the question of whether measures

(*Continued on p. 30*)

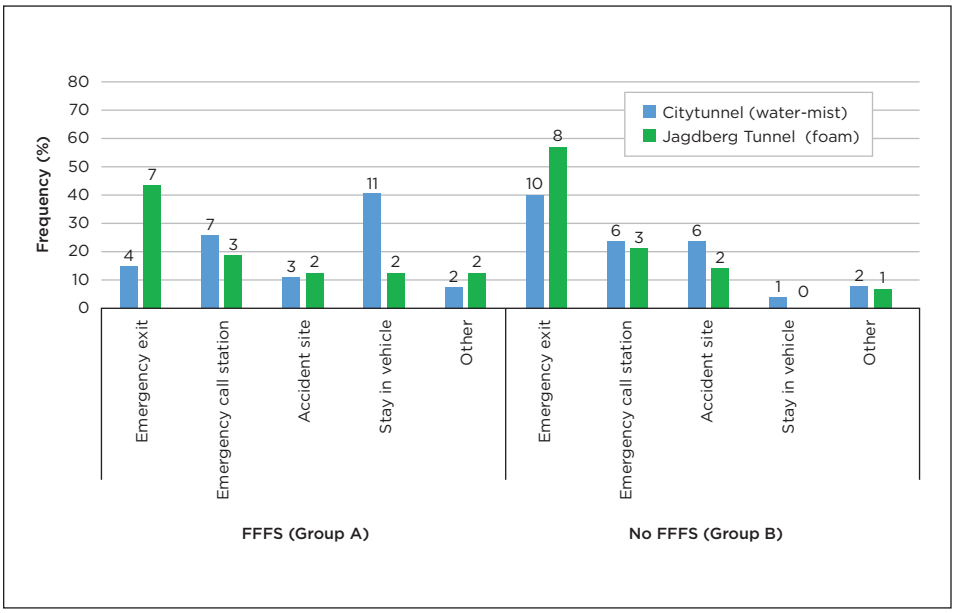

FIGURE 2 Behavior of participants and escape location behavior (%). (Note: Numbers over the columns indicate actual numbers.)

Human Behavior in Tunnels

International Perspective on Educational Strategies

JÜRGEN KRIEGER AND INGO KAUNDINYA

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Information for tunnel users is an important way to show people correct behavior during a regular tunnel passage and in case of incidents in a tunnel, such as vehicle breakdown, collision, or fire. It is important that tunnel users know the safety installations that could support their self-evacuation in case of incidents.

Many people do not know that most tunnels are supervised 24/7 and that it is very easy to contact a tunnel control center via an emergency call station. It is particularly important to memorize the emergency exit locations while driving through a tunnel so that users may safely self-evacuate, if necessary.

To better spread the knowledge about correct behavior in road tunnels, various strategies have been implemented in Germany:

- Educational videos, such as "What's my correct behaviour in a road tunnel?" on the BASt YouTube Channel (available in English at www.youtube.com/watch?v=c_NTgskzmHM), show correct behavior during a regular tunnel passage and also in the different scenarios a tunnel user could encounter.
- Tunnel quizzes and apps can help tunnel users to learn correct behavior in a playful and interactive way.
- Flyers and brochures that explain the safety installations in a road tunnel and the correct behavior in different scenarios are distributed at various locations (e.g., highway service stations).
- Tunnel-related safety questions on the German driving license test.
- An interactive tunnel model that shows all the safety installations in a road tunnel on a smaller scale. The model is permanently available for visitors in the BASt lobby and is regularly shown in various exhibitions and events, such as German Road Safety Day.
- A walk-in tunnel that shows life-size tunnel equipment. People may walk in and test all of the components, which function as they would in a real tunnel. Made from two sea containers, the walk-in tunnel is used for various exhibitions and events.
- Regular field tests in real tunnels or VR studies with test candidates to study human behavior under different scenarios in a road tunnel environment. These help to validate numerical escape simulations and to improve tunnel safety installations and organizational safety measures.

Photo: NABK

Signs and signals mimic a real experience for visitors to an interactive walk-in tunnel.

Photo: BASt

Human behavior is documented in field tests inside real tunnels.

Image: BMVI/BASt

German brochures and flyers promote road tunnel safety, including how to locate emergency equipment within a tunnel.

(*Continued from p. 28*)

could be taken to change this behavior (for example, topic-related user education and information).

Moreover, the VR and the field test comparison suggests that VR research is an appropriate means of researching behavior of tunnel users in an incident and of gaining valuable insights into infrastructure requirements for tunnels with specific safety systems. VR not only is an adequate method to investigate behavioral data, it also can provide targeted training in dealing with exceptional situations—for road users and for emergency and rescue services or operators (*10*). Furthermore, these findings show the importance of researching user behavior from a psychological perspective.

Such investigations make an essential contribution to the prevention of dangerous situations. In principle, it is possible to uncover improvement potentials by carrying out behavioral studies in connection with the use of VR. Therefore, VR is a suitable tool for investigating the interaction between road users and the infrastructure.

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Virtual reality has evolved considerably as a research method for examining human behavior.

Economic Importance of Seattle's Alaskan Way Highway Tunnel

Photo: Washington State DOT

BIJAN KHALEGHI

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Above: Future lanes and ramps take shape in 2017 at the SR-99 tunnel's south portal.

The 2001 Nisqually earthquake in Washington State caused extensive damage to the 1953-built Alaskan Way Viaduct's bridge structure and foundation, which resulted in a months-long closure and emphasized the structure's seismic vulnerability. Because of its age, design, and location, officials decided in 2009 to replace the roadway with a bored tunnel. The project replaced the Alaskan Way with a new road and is a key component to the redesign of Seattle's central waterfront.

The Alaskan Way Viaduct portion of SR-99 is critically important to local and regional transportation. Since it opened in 1953, the Alaskan Way Viaduct has been one of the main north–south highway corridors through Seattle and, until its closure in 2001, had carried an average of 100,000 vehicles per day.

Project Beginnings

Shortly after the earthquake, the Washington State Department of Transportation (DOT) launched efforts to identify and implement a solution to address this critical public safety and mobility liability, recognizing that it also offered an opportunity for the city to restore access between downtown and the waterfront and to revitalize the waterfront area. Completed in 2019, the 1.756-mile Alaskan Way Viaduct is the largest earth pressure balance bored tunnel in diameter in the world. The tunnel is designed to withstand a 2,500-year earthquake and features smart transit technology, including more than 300 cameras that monitor traffic, safety conditions, and security.

The Alaskan Way Viaduct Replacement Program was led by Washington State DOT in partnership with the Federal Highway Administration, King County, the City of Seattle, and the Port of Seattle. The budget for the tunnel, interchanges, viaduct demolition, and rebuilt waterfront totaled $3.3 billion, covered mostly by $2 billion in state gas taxes. The federal government contributed $787 million, and the Port of

Seattle contributed $268 million. Tolls are expected to pay off about $200 million in construction debt and to fund an account for long-term maintenance.

Project Details

The subsurface tunnel includes two stacked freeways, with southbound traffic on the top deck and northbound traffic on the lower deck. Each freeway deck is 30 feet wide, including an 8-foot shoulder for use by emergency responders and two 11-foot lanes. Replacing the viaduct opened enormous opportunities to improve quality of life in Seattle by increasing mobility through downtown while making the waterfront more accessible to the public.

The surface streets, transit, and waterfront improvements ensured that the project's social and economic benefits extended to all in the community. The Alaskan Way Viaduct replacement project is more than simply a solution to local congestion issues. It is also a means of improving the region as a whole. From new parks and pathways to a new pedestrian walkway and a bicycle track, a sequence of urban development projects scheduled to be completed in 2024 are now following the old viaduct's route since its demolition in 2019.

Because it was bored under streets and highways, rather than using the conventional cut and cover technology, the Alaskan Way Tunnel was built with minimal disruption to the existing highway system. The tunnel improved the commute through the city's downtown and paved the way for 9 acres of revitalized open public space adjacent to the downtown Seattle waterfront, scheduled to be completed in 2023 or 2024.[1]

Photo: Washington State DOT

Filling the crevices of a cutterhead that ground through rock and earth, workers pose with Bertha, the boring machine that dug the SR-99 tunnel.

Waterfront Seattle

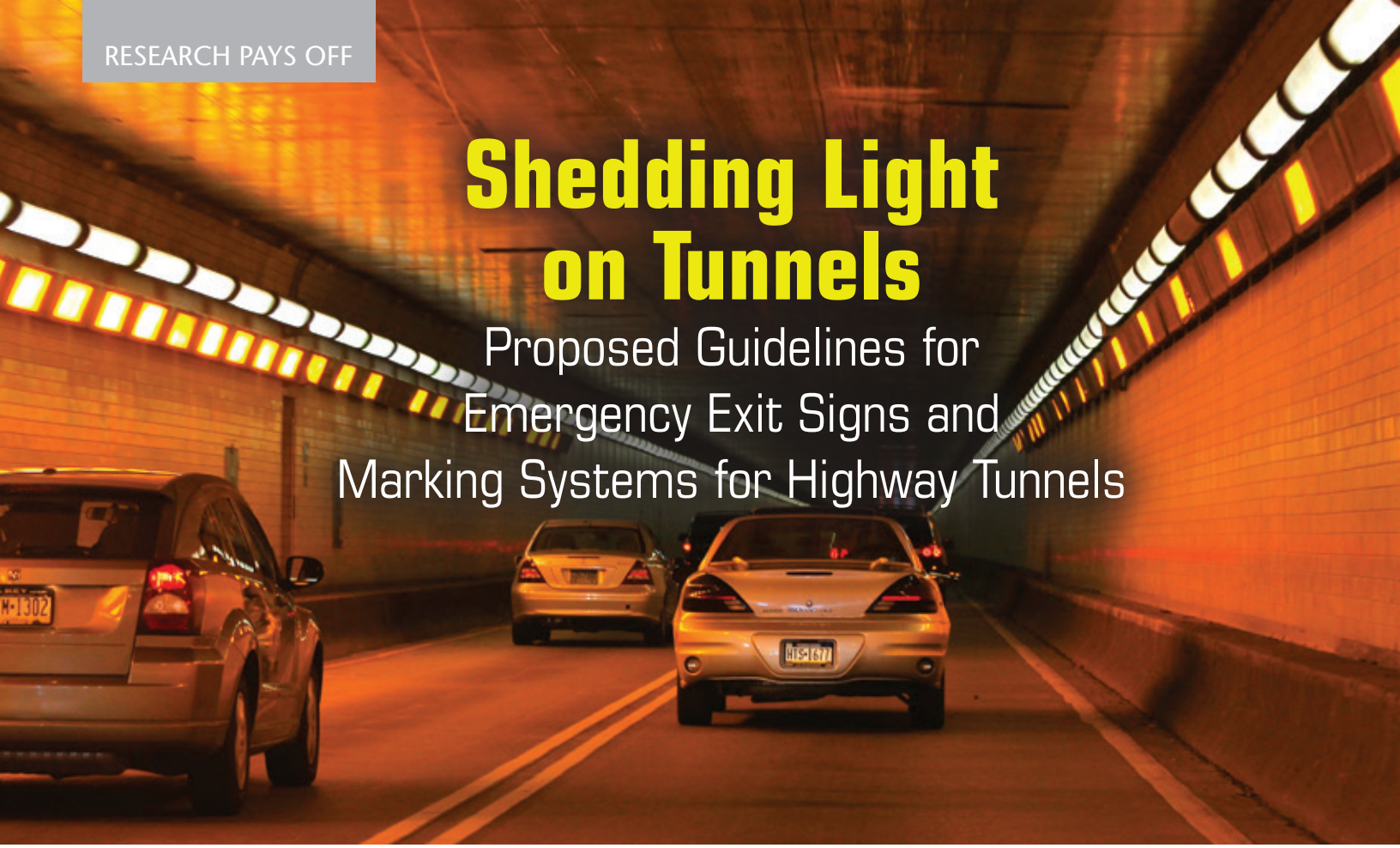
With the tunnel completed, attention focused on the demolition of the viaduct and construction of a new Alaskan Way surface street along the waterfront that connects SR-99 to downtown. The removal of the massive piece of infrastructure will substantially reduce traffic noise and will make the neighborhood more attractive and welcoming for residents and visitors to the future waterfront. Properties within the shadow of the old viaduct have been renovated and expanded at a cost of more than $1 billion. More than 10,000 new apartments and condos have opened within blocks of the project in anticipation of a large park, planned with massive community input. Business owners along the waterfront have spent more than $250 million to renovate their businesses.

When the waterfront park is finished, economic and quality-of-life benefits are estimated to be in the billions of dollars, with far and away the most significant effects coming from attracting and retaining workforce talent. The park will have water access, concert space on one of the piers, miles of gardens, a new Ocean Pavilion for the Seattle Aquarium, a connection between Pike Place Market and the waterfront, new bikeways and pedestrian paths, and a new state ferry terminal through which 17 million residents and visitors pass each year. Above the tunnel, the waterfront should be quieter. A rebuilt surface on Alaskan Way will feature a 12- to 40-foot-wide waterfront promenade; trees, flowers, and grasses; a bike trail; bus stops; and curbside parking. With the SR-99 tunnel, Seattle will enjoy a vastly improved transportation corridor through which drivers can bypass downtown traffic.

[1] For more, see www.friendsofwaterfrontseattle.org/timeline.

Photo: Washington State DOT

Running-man figures add a sense of urgency to wayfinding markings inside the tunnel.



Shedding Light on Tunnels

Proposed Guidelines for Emergency Exit Signs and Marking Systems for Highway Tunnels

Photo: Jon Dawson

LOUIS J. RUZZI AND LAURA HIGGINS

Ruzzi is District 11-0 Bridge Engineer, Pennsylvania Department of Transportation, Bridgeville, and Registered Professional Engineer in the State of Pennsylvania, and Higgins is Associate Research Scientist, Texas A&M Transportation Institute, College Station.

Above: A steady stream of traffic flows through Squirrel Hill Tunnel in Pittsburgh. It was one of the first U.S. tunnels to feature green photoluminescent running man and exit signs to aid drivers during emergencies.

The National Cooperative Highway Research Program (NCHRP) published *NCHRP Web-Only Document 216: Emergency Exit Signs and Marking Systems for Highway Tunnels* in 2015, along with a brochure titled "Proposed Guidelines for Emergency Exit Signs and Marking Systems for Highway Tunnels." Both have led to great improvements in helping direct people out of tunnels during an emergency.[1–2]

Problem

This project had its roots in the 2005 European tunnel scan, during which the U.S. scan team learned about the green "running man" signs used to mark pedestrian exits in Europe's tunnels. According to the European authorities, these photoluminescent signs—charged under ambient light and able to glow for some time after the ambient light is removed—are more easily seen when smoke and fire are present than the red, externally lighted exit signs commonly used in the United States.

Getting people safely out of tunnels during an emergency has been a priority in Europe since the 1999 fire in the two-lane Mont Blanc Tunnel between France and Italy, in which 39 people lost their lives—29 in their vehicles and 10 while trying to escape on foot. As a response to this and two other devastating tunnel fires between 1999 and 2001, the European Commission subsequently developed new safety guidelines for tunnels longer than 500 meters (1,640 feet, or 0.31 miles), including guidelines for emergency tunnel exits and signage.

Solution

Reflecting on what was learned from the 2005 European tunnel scan, the American Association of State Highway and Transportation Officials (AASHTO) T-20 Tunnel

[1] To view *NCHRP Web Document 216: Emergency Exit Signs and Marking Systems for Highway Tunnels*, visit http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w216.pdf.

[2] The brochure for *NCHRP Web Document 216* is available at http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w216_brochure.pdf.

Photo: Winsor Fireform

The AASHTO T-20 Tunnel Committee studied whether U.S. drivers understand that the running man symbol indicates an exit.

Committee proposed an investigation on the use of the photoluminescent sign technology in the United States, other potentially effective methods for evacuating people from tunnel fires, and the human factors involved in how individuals react to a fire. The objectives of the research project were to determine the most effective messages and media to advise drivers to leave their vehicles in a tunnel if necessary during an emergency, the best sign and marking system designs for guiding pedestrians to tunnel exits, and the most visible sign and marking materials and technologies for tunnel conditions during a fire.

Some of the pertinent questions the committee sought to answer included the following:

- Can individuals see green illuminated and direction signs better than red signs through smoke? Are illuminated signs more visible in smoky conditions than photoluminescent signs, or vice versa?
- Do U.S. drivers understand that the running man symbol indicates an exit?
- Is it best to have people self-direct their evacuation during a tunnel fire or to give verbal instructions to them at the time of an evacuation?
- If verbal instructions are provided, what is the best way to deliver them: short, direct sentences over a loudspeaker or cell phone or using some other method?

TESTING

The 2-year research project had a budget of $200,000 and was led by investigator Laura Higgins of the Texas A&M Transportation Institute (TTI). Testing began with focus group discussions, which provided insight into how drivers in the United States might respond to various incidents and warnings inside a highway tunnel, and helped the research team select the message and sign alternatives that subsequently were tested in a tunnel simulation in August 2014.

The tunnel simulation tested individuals' responses to an emergency scenario, emergency messaging, and a selection of sign and marking formats. Each of the 63 participants viewed a video simulation of a drive through a highway tunnel, ending with an in-tunnel traffic jam and visual and audible cues indicating a fire ahead. Some participants saw a changeable message sign or heard a recorded announcement warning them of a fire in the tunnel and instructing them to walk to exits; others did not receive a message.

More than 76% of participants who received a warning message stated that they would immediately leave their vehicle and look for an exit; by contrast, 80% of participants who received no message stated that they would remain in their vehicle until they had more information.

Exit sign and path marking formats were tested in an enclosed 60-foot-long simulated tunnel environment that was filled with artificial smoke. Running man sign formats included a symbol-only sign, viewed first in the testing sequence by each participant (Figure 1*a*, below); the symbol supplemented with the word EXIT (Figure 1*b*); and the symbol supplemented with EXIT plus an arrow and a distance in feet (Figure 1*c*).

Although 86% of participants fully or partially understood the running man symbol–only sign, adding the word EXIT to the symbol increased comprehension to 100%; 98% of participants understood that the addition of an arrow and a number of feet indicated the direction and distance to an exit.

In general, the internally illuminated signs tested in the study were visible at longer distances than their photoluminescent counterparts when smoke was present. The tested green signs were visible at slightly longer distances than the corre-

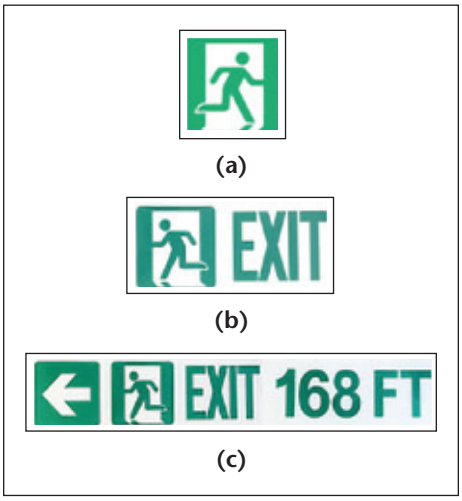


FIGURE 1 The running man sign formats tested on participants in TTI's tunnel simulation: (*a*) running man only; (*b*) running man and the word "EXIT"; and (*c*) running man, "EXIT," and directional and distance information.

sponding red signs. All were affected by smoke density, however, and were most visible at relatively short distances.

RECOMMENDATIONS

Based on the testing and analysis, the researchers recommended the use of green-and-white running man signs with EXIT text (Figure 1*b*) to mark exit doors, adding a directional arrow and distance in feet (Figure 1*c*) for signs marking the pathway to an exit. Additional recommendations included spacing signs no more than 82 feet apart along tunnel walls and using brighter illumination or white strobe lights to mark exit doors.

The research team also recommended providing messages, by any practical medium, to tunnel users in the event of an emergency, briefly identifying the nature of the emergency and providing simple, direct instructions.

Application

The first uses in the United States of the green photoluminescent running man and exit signs in this project were in the Fort Pitt, Liberty, and Squirrel Hill Tunnels in Pittsburgh, Pennsylvania (Figure 2, below). The Colorado and Virginia Departments of Transportation (DOTs), as well as the Chesapeake Bay Bridge–Tunnel Commission, have also placed the running man signs in their tunnels; it is hoped that more agencies will adopt this new technology in the future.

Photo: Virginia DOT

Virginia DOT placed the running man signs in their tunnels, including the East River Mountain Tunnel in Rocky Gap.

Pedestrian-focused exit signs will not be needed in all of the 503 tunnels in the United States; they are practical only in tunnels that have alternate exit paths available and that are long enough that pedestrians might need an exit other than the main tunnel portal (hence the 500-meter threshold specified by the European Commission). Although fires or similar large-scale emergencies are a rare occurrence in highway tunnels, they have the potential for high numbers of casualties. Proper signage along with coordinated response is increasingly recognized as an economical and effective safety measure in tunnels and continues to gain acceptance as a standard of practice.

BENEFITS

Some of the benefits in using the new technologies include 1) the likelihood of quicker rescue or escape and 2) the potential to save more lives during an emergency for a minimal cost. Although Pennsylvania DOT's tunnels have not experienced a tunnel fire in more than 15 years, based on the results of this research it is expected that the new signage and messages will help people escape tunnels faster and safer for a reasonable investment.

The cost to add the signs, messages, green cross-passage panels, and exit panels in the Liberty Tunnel was $147,000. This level of investment is small compared with the value of a life and with the total cost of the tunnel, which exceeded $75 million. The same signage system was installed for $117,000 in the Fort Pitt tunnel, a $14 million project.

For more information, contact Louis J. Ruzzi, Pennsylvania DOT, at 412-429-4893 or LRUZZI@pa.gov, and Laura Higgins, TTI, at L-Higgins@tti.tamu.edu.

FIGURE 2 Some of the emergency signs and marking systems adopted by Pennsylvania DOT: Pittsburgh's Liberty Tunnel cross passage (*left*) and Squirrel Hill Tunnel markings (*right*).

EDITOR'S NOTE: Appreciation is expressed to Stephen Maher, Transportation Research Board, for his efforts in developing this article.

International Perspective on Fire Safety in Tunnel Design, Operation, and Management

CONRAD STACEY

The author is a Director of Stacey Agnew, Australia, and Vice President of SAMJ LLC, United States.

Above: No, this is not a real incident. As a training exercise, burning a car in your tunnel gives real familiarization for operators, local responders, and fire brigades and checks the response modes.

I explore here aspects of road tunnel design and operation that can offer opportunities for improvement in risk control. I describe the impact that a focus on details and code compliance can have in masking some fundamental drivers of risk in tunnels. Although major tunnel incidents get a lot of publicity, they are rare, and, as any industrial safety expert will affirm, it is the seemingly minor indicators and near misses that can more clearly show a true level of risk. Drawing upon U.S. and Australasian practice, as well as findings from European and Japanese colleagues, I write about some of the warning signs that I have seen and suggest how they might be controlled in public underground infrastructure.

Operational Readiness

It is perhaps obvious that, for a tunnel to be operationally ready to respond to incidents, the equipment and systems must work. To that end, recent U.S. legislation led to the Federal Highway Administration mandate for National Tunnel Inspection Standards (NTIS) that all departments of transportation (DOTs) must follow. The standards require every highway tunnel in the United States to be inspected every 2 years. Where systems are not clearly understood or have never been tested, DOTs are encouraged or required to test them.

To assist with the realization of appropriate inspections, the NTIS are supplemented by the *Tunnel Operations, Maintenance, Inspection, and Evaluation* (TOMIE) manual. Tunnel inspectors are required by the NTIS to have the right background and to be trained and accredited in NTIS-compliant inspections. The training has a strong focus on the tunnel structure. Mechanical and electrical equipment are also covered. Operational systems and issues that are outside the coverage of TOMIE inspections can be more critical to safety, however. We see a gap in the safety assurance sought by the NTIS.

Most large or high-capacity tunnels are monitored 24/7. To allow the opportunity for beneficial human intervention, the response systems are semi-automatic,

with supervisory control and data acquisition (SCADA) systems assisting rather than directing the response. Tunnel operators apply the most appropriate response based on their observations of the incident. The response system includes the operator, their information streams, their training, and the written response procedures they have been trained in. It also includes the preprogrammed response modes of operation.

Although the formalized inspection of tunnel systems under the NTIS and TOMIE seems entirely appropriate, a reading of the documents shows that the mandated inspection stops short of testing the full response system, concentrating on the subsystems and the mechanics by which they are invoked. There is no clear checking of the operator's information or skills or that the modes they have been provided with are appropriate.

The operators' skills may or may not be checked at commissioning, but, as with all training, tunnel operator training and testing of acquired skills is an ongoing requirement. Not only does ongoing training sometimes get treated lightly, but staff turnover will generate a constant need for new training and testing. Of course, training without testing may not really be training at all. Unless there is verification that the skills have been acquired, you can never be really sure they will be there when needed.

Road tunnels have a training advantage over rail tunnels in that incidents requiring interaction with the SCADA system occur frequently in road tunnels, with minor accidents, broken down vehicles, spilled loads, and so on. Familiarity with the system interfaces is not the whole story, however. To give confidence in the response to a major incident, practice is required on something like the real thing. Some major tunnels may have enough minor fire incidents to test all their operators "for real," but many do not.

So, how do we test emergency response without a real emergency? The standard answer is through emergency exercises. Many tunnel operators run emergency exercises to test their systems, operator responses, and the coordination with internal and external emergency services. In Australia, the governing deeds often require these exercises every 2 years. Such exercises can be major affairs, with a hundred or more people involved, months of planning, on-site catering, and video crews. With so many people involved, the results can feel quite public, so poor performance is not an option for management of any of the parties involved. This can lead to scripting and preparation, which makes it more performance art than a testing and learning exercise and defeats much of the purpose.

For example, I once witnessed a senior fire officer complain at the hot debrief along the lines of: "The guys knew the fire was at cross passage 3, but you told them to go to cross passage 2, so they were confused." First, the officer should never have revealed the scenario, as it circumvented the important test of communicating those facts. Second, had he really been interested, he would have known that the procedure for when a cross passage is affected by the fire is to use the next one upstream. On the positive side, it was a test for the firefighters to see whether they could accept the coordination with the tunnel operator over the misdirection given as fact by their senior officer.

Response Modes

Tunnels with any ventilation, traffic control, or fire suppression systems have established plans and procedures for emergency response, ideally developed jointly between operators and system designers. With a SCADA system assisting with any response, traffic, ventilation, and suppression will have preprogrammed modes to coordinate response to different incidents at different locations in the tunnel.

Response modes can be simple or complicated, depending not only on the complexity of the tunnel network, but more on the philosophical approach taken by the designers. Long-term success depends on the ability of the construction contractor to deal with design complexity and on the ability of the operating organization to maintain and operate systems over the life of the systems, long after the design basis has faded in organizational memories. Understanding the design basis is, therefore, essential for the long-term success of facility operations and maintenance.

It is concerning how frequently a diligent end-to-end systems test turns up serious issues with the response. Rather than mitigating risk, systems with built-in mode errors sometimes make a risk severe when, if no action had been taken, the incident risk might have been minor.

OPERATIONAL MINDSET

There are many answers on how to address this mode error risk. The first is to look at the mindset of the operating organization. The organization—and that includes the senior staff—needs to own the operational response, including the

Road tunnel emergency exercise with a smoke bus.

Checking bus station ventilation response modes with a live hot smoke test.

programmed modes. Errors are far more likely to creep in where "context-free management" is applied to tunnel operation, with an external party or even the long-demobilized designers being relied on entirely by the owners and operators for assurance that all is OK. Although external experts are needed to set up and review systems, tunnel operators must be involved, follow the philosophy and reasoning, understand why all the modes are the way they are, and own the job of making sure that no adverse or unchecked changes are made.

With this level of operator engagement, the initial setup is likely to be more compatible with safe operations, and it is much less likely that the system will fail because of erroneous changes over time. European Directive 2004/54/EC on minimum safety requirements for tunnels in the trans-European road network,[1] catalysed by the Mont Blanc Tunnel fire of 1999 in which 39 people died, specifically addresses these organizational matters.

NATIONAL APPROACH

Another way to address mode error risk involves taking a national approach to the issues. Insofar as mindset can be regulated, a national regulatory approach is appropriate. Although motivation can't be regulated completely, at least it is possible to encourage some of the organizational outcomes. In the longer term, perhaps NTIS might be enhanced to include requirements for operational readiness proof tests, and perhaps even requirements on organizational matters and senior staff qualifications, as per European Directive 2004/54/EC.

REFRESHED THINKING

The third answer to mode error risk is to refresh the thinking on operational philosophy—right down to evaluating the system's detailed mode tables—every few years. This could be done by the original designers with eyes freshened by absence and other experience, or it could be done by different parties with totally fresh views. We have seen this happen to some extent when there are necessary changes to a tunnel, such as work to deal with a decaying false ceiling in a transversely ventilated tunnel. Sometimes the changes do not trigger the thought that the operating philosophy may no longer be optimal. In another example we have seen several times, fitting a deluge or misting fire suppression system may seem to be additive, with no change called for to other systems. More likely, the suppression system is a symptom of a changed appreciation of the hazards, which indicates that the operation should be revisited holistically.

TESTING AND COMMISSIONING

The fourth way to address mode error risk is testing. Exercises and tests refresh the concepts in the minds of all staff, cementing the organizational knowledge of the response modes and the philosophy behind them. Run properly, tests also show up configuration errors that may have crept in during maintenance or perhaps were present from commissioning. And yes, we have seen serious errors in response modes present in systems that have been officially commissioned, pointing to the fifth answer,

During an unannounced exercise, a train stops in a tunnel and belches smoke. The tunnel operator had no warning. Observers just happened to walk into the control room.

[1] Full directive available at https://op.europa.eu/en/publication-detail/-/publication/3681d17d-ec25-4d1a-b189-01af9633e04c/language-en.

When there was uncertainty about portal wind effects on a complicated underground bus station, portal wind was organized for recommissioning.

which is to make sure that the systems are commissioned thoroughly before a tunnel opens. For this purpose, the term "systems" includes the operating procedures and the people who will implement them; that is, the operating organization needs to be present and functional at the start of commissioning or before.

The people in the operators' seats should—as far as possible—be the operators, not the technical staff who installed the systems. If the installers operate during commissioning, problems with the tunnel may be intentionally or unintentionally hidden by their workarounds. Without the permanent operators in the hot seat, the opportunity is lost to commission the entire system, including the human element. It also means that the practice for operators would not start until live operation.

Impromptu Testing

Previously, I emphasized the central role of control room operators in the overall emergency response system. Their training is essential, and exercises to reinforce training need to be frequent. You only really know after you have an incident (the ultimate test) whether it all comes together correctly. The second-best test is an unannounced exercise. I am keen on these as I have seen improvements come out of it for the operators and the organizations in a way that would not have happened had the operators been warned and able to "brush up." The concept is simple: make as much smoke or other disturbance as safely possible, without the operations staff knowing that anything is about to happen. That is simple to say, but the practicalities of making sure that no other hazards are created can be complex and can require detailed thought, senior planning, and experience with such exercises.

Not only can unannounced exercises give more information than a semi-rehearsed major exercise, they are also orders of magnitude cheaper to run, giving a much higher return on expenditure. The low cost also means they can be more frequent. If the average stay of an operator at a tunnel is, say, 7 years, they may be lucky to be in the hot seat for one major exercise. With frequent smaller tests, the training and testing can reach everyone.

The other feature of such impromptu performance tests is that they can be so low-key that only the operations organization, the incident creators, and the test coordinator–director need know it even took place. That makes it much easier to be frank internally, and to acknowledge any shortcomings or opportunities and the underlying reasons, in a way that allows them to be best addressed.

Code Compliance

From an international perspective, the primacy of code compliance in the United States stands out as a major difference in system and operational process development. Is it appropriate to design to code minima in order to get system approval if doing so may be either inappropriate or insufficient for the specific system being designed? Although understanding codes and standards is critically important to guide safety, it is necessary to acknowledge that codes are not infallible. Owners and designers should be always trying to do the right thing (by society, clients, and others), and sometimes that means pursuing code deviations to meet the particular needs of a project.

Codes and standards should not be the only factors in making design decisions. In Australia (and elsewhere), the reasonableness of taking extra measures to reduce risk should be considered, with the risk then reduced so far as is reasonably practicable. That view of responsibilities is enshrined in rail safety national law and is also the prevailing view in road tunnels.

Conclusion

In summary:

- Tunnel owners need to "own" the whole operation, including the response modes.
- Operators are central to the response system and need to be tested as part of it.
- Commission like you really mean it, rather than just to complete the paperwork before opening.
- If you go to bed at night and wonder whether all the modes would really work if invoked, it is time for testing.
- Test the systems and the operators regularly, preferably by (benign) surprise.
- Think like an engineer about the issues, risk control, and what is right to do, rather than how others interpret the code.

José Holguín-Veras

Rensselaer Polytechnic Institute

José Holguín-Veras is William H. Hart Professor and Director of the Center for Infrastructure, Transportation, and the Environment and of the Volvo Research and Educational Foundations' Center of Excellence on Sustainable Urban Freight Systems at Rensselaer Polytechnic Institute. He received a bachelor's degree in civil engineering from the Universidad Autónoma de Santo Domingo, Dominican Republic, in 1981; a master's degree from the Universidad Central de Venezuela in 1984; and a Ph.D. from The University of Texas at Austin in 1996. He served as a faculty member at The City College of New York from 1997 to 2002 and at the Rensselaer Polytechnic Institute since 2002.

A researcher with 40 years of experience in freight transportation systems and planning and 20 years in disaster response, Holguín-Veras has received many awards for his work, including the 2013 White House Champion of Change Award. As a member of the Board of the New York State Thruway Authority—the only researcher in the board's history—Holguín-Veras helped oversee toll policy and the replacement of the $3.98 billion Tappan Zee Bridge, one of the largest construction projects in the United States. As a member of the National Academies of Sciences, Engineering, and Medicine Disaster Research Roundtable, he advised the federal government in disaster response.

Holguín-Veras's research activities focus on three major areas: freight transportation demand modeling, sustainable freight policy, and disaster response logistics. Profoundly multidisciplinary, his research melds concepts and principles from economics, operations research, supply chain management, transportation planning and policy, and the social sciences.

"I've never felt constrained by the traditional perception of what a civil engineer is or should study," he comments. "Researchers should seek out and exploit complementary perspectives and respect the knowledge of other disciplines."

Holguín-Veras's research program is guided by the belief that to improve the performance of transportation systems and disaster response, the research community must advance three key aspects: *knowledge* of the system being studied, the *mathematical models* needed to analyze the system, and *data* that characterize the performance of the system. As a result, his research activities span the entire domain from empirical to theoretical work—fieldwork, data collection, applied research, policy, real-life implementations, and mathematical and theoretical developments—which enables him and his team to develop mathematical formulations that account for the real-life patterns observed in freight systems and in disaster response operations.

"Researchers should seek out and exploit complementary perspectives and respect the knowledge of other disciplines."

In freight demand modeling, one of Holguín-Veras's most significant theoretical research contributions is the development of a closed-form freight tour flow model—a more general form of the traditional gravity model—that can estimate the flows of freight vehicles that traverse a general sequence of delivery and pickup stops. His design of the Off-Hour Delivery Project in New York City—which incentivizes receivers to accept deliveries in the off-hours—had a substantial effect on freight policy and was adopted by the City of New York in its sustainability plan.

Holguín-Veras pioneered the multidisciplinary study of disaster response logistic operations, conducting fieldwork and detailed analyses of the most prominent disasters of recent times, including Hurricane Katrina; the Port-au-Prince, Haiti, earthquake; the tornadoes in Joplin, Missouri, and in Alabama; Hurricane Irene, and the Tohoku disasters in Japan.

His research findings about the differences between disasters and catastrophes are particularly important because he demonstrated—supported by data collected during the fieldwork after the 2010 Haiti earthquake and the 2011 Japan tsunami—that relief efforts in the aftermath of catastrophic events require wholly different procedures from those taken in response to large disasters. His research also identified the deleterious effects of panic buying, uncovering the underlying behavioral determinants of these purchases and how to mitigate them.

Holguín-Veras was one of the few researchers appointed to the U.S. Department of Transportation's National Freight Advisory Committee and to the congressionally requested Transportation Research Board Truck Size and Weight Limits Research Plan Committee. He has served on many panels for the National Cooperative Highway Research Program, the National Science Foundation, and other federal and international agencies.

"My approach to research has been shaped by the influence of friends and family—particularly my mother and my wife and children—as well as my life experiences, including the political troubles my family and I endured through a dictatorial government," Holguín-Veras observes, adding that these influences allowed him to approach research as an outsider, unencumbered by disciplinary boundaries and expectations. "I will always remember the advice given to me by many well-meaning senior faculty who cautioned against ruining my career, noting, 'There is no future in freight research.'"

Bijan Khaleghi

Washington State Department of Transportation

"Engineers have got to get out and make things," observes **Bijan Khaleghi**, who has been immersed in bridge and tunnel engineering for more than 30 years. "I went into bridge engineering simply because of my love of the profession and the innovative thinking needed to create new designs that benefit people and society. I wanted to work someplace where I could apply that thinking."

That place turned out to be Washington State Department of Transportation (DOT), where Khaleghi has worked since 1991. As State Bridge Design Engineer, he administers Washington's structural design program for bridge and tunnel projects. His role includes conducting preliminary design through the final plans, specifications, and estimates and then implementing quality control and quality assurance. He also establishes the design policies for Washington State DOT designers, design consultants, design–builders, and other bridge divisions in the state.

In addition, Khaleghi manages bridge and tunnel designs and research projects, incorporating seismic requirements, accelerated bridge construction, and innovative materials and design. He also serves as Project Manager and the Bridge and Structures Office representative on complex projects related to suspension, cable-stayed, segmental, and movable bridges. "Bridge engineering involves working in multidisciplinary fields and embracing a lifetime of continuous learning," he comments. "It stimulates the mind."

Khaleghi previously served as the design unit manager for Washington State DOT and is an adjunct professor at Saint Martin's University Hal and Inge Marcus School of Engineering in Olympia, Washington, where he teaches bridge engineering and design, prestressed concrete design, and earthquake engineering and design.

He wants his students to be as enthusiastic about engineering as he is. "I encourage my students by getting them involved in classroom discussions and exciting exercises that require them to perform a task," Khaleghi shares. "They are responsible for presenting their work and ideas to the class, and I assign each student to write an article on what they have learned and achieved."

When a student is undecided about a career in bridge and tunnel engineering, Khaleghi offers sound advice. "Students who are unable to choose a career may lack motivation, goals, and vision," he explains. "To overcome these impediments, I encourage them to speak to a career counselor; interview professionals in the field; shadow consultant engineers or professionals at the government level; get an internship in the profession; and join an organization, such as Bridges to Prosperity, which builds footbridges in rural communities around the world so that residents can gain access to necessary services. Bridge and tunnel engineering is a very worthwhile profession, and the results can be incredibly satisfying."

"Bridge engineering involves working in multidisciplinary fields and embracing a lifetime of continuous learning."

Before joining Washington State DOT, Khaleghi was an Assistant Professor at Tehran Polytechnic University in Iran. He earned his master's degree and Ph.D. from the National Institute of Applied Sciences of Lyon in France. He is a registered Professional Engineer in Washington and California.

Over the years, Khaleghi's research has been recognized via multiple awards, including the Martin P. Korn Award from *PCI Journal*, publication of the Precast–Prestressed Concrete Institute; two T. Y. Lin awards from the American Society of Civil Engineers; two Charles C. Zollman awards from *PCI Journal*; and, in 2018, the PCI Fellow Award. His professional achievements also include numerous presentations, workshops, webinars, and papers, such as "Washington State Department of Transportation Plan for Accelerated Bridge Construction," published in the *Transportation Research Record: Journal of the Transportation Research Board*.

Khaleghi is an active member of the Transportation Research Board's Standing Committee on Concrete Bridges and a former member of Standing Committees on Accelerated Bridge Construction, Seismic Design, and Emerging Technology. He is also an active member of the American Association of State Highway and Transportation Officials' Technical Committees on Movable Bridges, Concrete Bridges, and Roadway Tunnels.

Khaleghi views bridge engineering as far more than the technical planning and construction of a project. For him, it is akin to art. "Bridge engineering and research are incredibly creative," he notes. "That creativity makes practical, everyday life more refined and meaningful. Bridge engineers and researchers take the vision that comes from ideas and apply the practice of science and mathematics. Then they add the heritage of the profession and knowledge of nature's materials to create a design, even a masterpiece. And when they have completed their task, everyone can see that the ideas and plans have materialized for the comfort and well-being of all."

TRANSPORTATION INFLUENCERS

Martin P. Brosnan

Martin P. Brosnan is Senior Planner, TransLink, Vancouver, British Columbia, Canada. He is a member of the TRB Light Rail Committee and Emeritus Cochair of the Young Member Council Public Transportation Subcommittee.

How did you first hear about or become involved in TRB?

I was in college, and a few of my grad student friends were presenting a paper at the TRB Annual Meeting. I didn't know much about it except that it was a conference. The following year, my grad school advisor asked me to submit two papers: one that was accepted for a poster session and one that was accepted for a presentation and publication in the *Transportation Research Record*. From the first day, I knew I wanted to come back every year. I loved seeing the areas of research being done and building connections with transportation professionals from around the world.

How has TRB informed your career so far?

When I gave that presentation my first year, I was representing the University of Minnesota, where I had just finished my master's degree. I also had just started working at CDM Smith in their Chicago office. Another CDM Smith employee from one of the Florida offices, who was the project manager for a proposed bicycle counting program, happened to attend the presentation. He came up to me after and asked if I wanted to be a part of his project team, which I gladly agreed to.

What was one of your most memorable Annual Meeting moments?

In my third year, the outgoing cochair of the Young Member Council (YMC) Public Transportation Subcommittee told me that I had been nominated to take his place. I was ecstatic to have a chance to help TRB and to represent YMC in bringing young members into the fold and helping them navigate the sometimes daunting nature of TRB and the Annual Meeting.

"Transportation Influencers" is a new section in *TR News*, highlighting the journey of young professionals active in TRB. Have someone to nominate? Send an e-mail to TRNews@nas.edu.

MEMBERS *ON THE MOVE*

Dalia Leven recently joined Cambridge Systematics as National Planning Lead for Transit and Shared Mobility. She previously worked as a consulting manager at AECOM.

Kelly McAllister, wildlife biologist at the Washington State Department of Transportation, is retiring. She served on the National Cooperative Highway Research Program project panel for Construction Guidelines for Wildlife Fencing and Associated Escape and Lateral Access Control Measures. She has been an active participant at the TRB Annual Meeting and at the International Conference on Ecology and Transportation.

Derek Nener-Plante joined the Pavement and Materials Technical Service Team at the Federal Highway Administration. He previously was the asphalt pavement engineer for the Maine Department of Transportation.

In Memoriam

Paul Jablonski, CEO of the San Diego Metropolitan Transit System and Chair of the TCRP Oversight and Project Selection Commission, has died. He was 67.

National Academies and TRB Address Diversity, Equity, and Inclusion

The following is adapted from statements made publicly and to staff in early June 2020.

The brutal killings of George Floyd, Breonna Taylor, Ahmaud Arbery, and so many more before them, along with the recent violence against peaceful protestors, have focused attention on the terrible legacy of slavery and continuing structural racism in American society. They also have led us, and many others, to reflect deeply on our own efforts to address these issues in society; in science, engineering, and medicine; at the National Academies of Sciences, Engineering, and Medicine; and at the Transportation Research Board (TRB). These events are having a tremendous impact on many of us—especially our Black and African-American colleagues.

Those of us in the transportation community are in a position to be part of the solution. Transportation can play a key role in addressing the racial disparity that exists in our society. We can and we must listen to the needs and issues—particularly the transportation-related needs and issues—of those who have been the victims of injustice and unequal treatment so we can have a better understanding of the issues that need to be addressed. We can work to provide fair and equitable access to employment, health care, education, government services, healthy food, and social and recreational opportunities. We need to ensure that our programs and activities are inclusive and meaningfully involve members of all races and ethnic groups. We need to work to develop a diverse next generation of transportation professionals, and provide opportunities to underrepresented minorities to become involved in our profession.

Those of us in the transportation community are in a position to be part of the solution. Transportation can play a key role in addressing the racial disparity that exists in our society.

At TRB, we have been actively addressing issues of equity for the past several years, but we have much more to do. TRB's Executive Committee identified equity as one of the major topic areas in the list of critical issues that TRB should be focusing on. In light of recent events, as well as equity issues that have come to the forefront during the COVID-19 pandemic, we will revisit with the Executive Committee and each of TRB's oversight committees how TRB should address equity and disparity issues in transportation in our technical activities, our research, and our advisory studies.

At the National Academies, we are taking a number of immediate actions recommended by the National Research Council (NRC) Transformation Initiative on Diversity, Equity, and Inclusion. The Office of Human Resources is sponsoring gatherings to provide direct support to our Black and African-American staff. The office is also deploying mandatory diversity and inclusion training for senior managers and accelerating implementation of a series of diversity and inclusion training modules for all staff. We are also supporting revitalization of the grassroots working group on equity, diversity, and inclusion, which can make important contributions to the NRC transformation initiative.

We recognize that these initial steps, while important, will not be sufficient, and we have many more long-term plans being developed. Creating a culture that more fully supports diversity, equity, and inclusion will require the commitment and energy of all of us at the Academies and TRB. We are grateful that our *TR News* readers are along with us for the journey.

COOPERATIVE RESEARCH PROGRAMS

Bicyclist Facility Preferences and Effects on Increasing Bicycle Trips

NCHRP Research Report 941

What infrastructure investments will be most effective in increasing cycling in communities? *National Cooperative Highway Research Program (NCHRP) Research Report 941: Bicyclist Facility Preferences and Effects on Increasing Bicycle Trips* presents findings on how current and potential cyclists respond to different types of cycling infrastructure.

Previous research has focused on places where bicycling is more prevalent, which leaves a major gap in studying the emergence of bicycling for transportation. Data for the analyses in *NCHRP Research Report 941* came from focus groups followed by a before-and-after survey. The study included three treatment neighborhoods—Anniston and Opelika, Alabama, and Chattanooga, Tennessee—in which bike infrastructure was scheduled to be opened in the study period, as well as three control neighborhoods—Talladega, Northport, and Birmingham, Alabama—in which no bike infrastructure was planned for construction over the same time frame (see Figure 1, above).

The major findings from this research included the following:

- Respondents gave infrastructure with more separation from drivers higher marks, with protected bike lanes and multiuse paths rated as the best.
- When located adjacent to bicycle infrastructure, on-street vehicle parking was a clear deterrent to comfort, perceived safety, and the willingness to bicycle. In some cases, the number of traffic lanes were a deterrent, but in others they did not affect comfort, safety, or the willingness to bicycle.
- Protected and separated bike lanes were effective in reducing the negative effects of roadway characteristics.

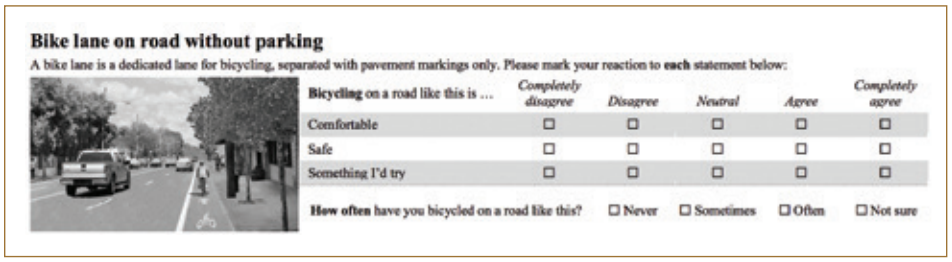
FIGURE 1 Three treatment neighborhoods (*black stars*) with bike infrastructure were scheduled to be opened, and three control neighborhoods (*red stars*) with no bike infrastructure planned in the study time frame.

In focus groups, participants were presented with digitally manipulated images of various roadway configurations and asked to express their reactions based on the bicycle facility type, the number of vehicular lanes, and the presence of on-street parking. Results included the following:

- Perceived risk from moving vehicle collisions and adjacent parked cars was a major factor in potential cyclists' willingness to use facilities. Participants expressed substantial concern about unsafe driver behavior, which may be more prevalent in places where there is not a dominant bicycling culture. Inattentive drivers, aggressive drivers, and being hit by a car door were of particular concern.
- Buffered bicycle lanes and protected, separated bicycle lanes with a physical barrier such as bollards or planters were all viewed as substantially improving comfort, but even basic bike lanes were reassuring if they were not adjacent to car parking.
- When curbed parking immediately adjacent to the bicycle lane was introduced, perceived comfort levels plummeted and only recovered with adequate buffering to place the bike lane outside the door zone or physical separation from parked cars and the door zone.

To understand impact of facilities being constructed, evaluations that include the use of surveys repeated over time are important. One method for collecting this information is a household-based survey (see Figure 2, below) with a sample that represents a cross-section of the community to assess its awareness of the facility and how the facility has changed their perceptions and attitudes toward bicycling. Using focus groups allows for more detailed exploration of perceptions and attitudes.

For more information on this report, contact Kari Watkins, kari.watkins@ce.gatech.edu.



Bike lane on road without parking

A bike lane is a dedicated lane for bicycling, separated with pavement markings only. Please mark your reaction to **each** statement below:

Bicycling on a road like this is …	*Completely disagree*	*Disagree*	*Neutral*	*Agree*	*Completely agree*
Comfortable	☐	☐	☐	☐	☐
Safe	☐	☐	☐	☐	☐
Something I'd try	☐	☐	☐	☐	☐

How often have you bicycled on a road like this? ☐ Never ☐ Sometimes ☐ Often ☐ Not sure

FIGURE 2 An example of a sample roadway setting used in the survey data collection process.

Emerging Technologies for Construction Delivery

NCHRP Synthesis of Highway Practice 534

New technologies are changing the way state departments of transportation (DOTs) deliver highway construction projects. Relatively new innovations such as 3-D and 4-D modeling, 3-D printing, virtual design and construction, and real-time kinematic GPS can improve project performance cost, schedule, and quality.

The objective of *NCHRP Synthesis 534: Emerging Technologies for Construction Delivery* was to document the use of selected advanced technologies used for highway construction projects by state DOTs. Researchers Christofer Harper, Colorado State University; Daniel Tran, University of Kansas; and Ed Jaselskis, North Carolina State University, collected and synthesized the information via literature review, a survey of state DOTs, and follow-up interviews with selected agencies for case examples. In their report, they examine visualization and modeling, interconnected technologies, safety technologies, instrumentation and sensors, and unmanned aircraft systems.

Of the 41 state DOTs surveyed, 26 (63%) have implemented visualization and modeling technologies; 18 (44%) have implemented interconnected technologies; 27 (66%) have implemented safety technologies; 31 (76%) have implemented instrumentation and sensors technologies; and 24 (59%) have implemented unmanned aircraft systems for highway construction delivery.

To download NCHRP Synthesis 534, *visit www.trb.org/Publications/Blurbs/179455.aspx.*

CENTENNIAL QUOTES

"TRB has been a major asset to my professional and career development. Not only did it allow me the opportunity to learn the most current research in my program areas, it also allowed me to network with other transportation professionals over my 34 years at FHWA. I truly am thankful for the many colleagues I've met and interacted with. Their knowledge and questions challenged me and helped me to grow a better program for FHWA. Many times, these interactions went beyond TRB into my day-to-day work activities.

—FRANCINE SHAW WHITSON
Retired Senior Advisor, FHWA, Washington, D.C.

"In early 2004, I had moved to Washington, D.C., without a job, but I was interested in transportation. I went to the TRB Annual Meeting on a student rate to look for education and connections. I listened to a panel of U.S. House Committee on Transportation and Infrastructure staffers talk about their jobs. After the panel discussion, I waited to talk to one of the panelists, who was the Railroad Subcommittee staffer at the time. I asked if her committee had interest in taking any unpaid interns. She said that unfortunately, they couldn't, but that I should contact a staffer on the Hill. Just then, a lady named Nancy—who had been standing next to me—tapped me on the shoulder: "If you're willing to be an unpaid intern, you can start tomorrow working for me at the Surface Transportation Policy Project." I arrived at 9 a.m. the next day and worked there for 2 months. Then, I used that internship to help me get a full-time job at Chambers Conlon & Hartwell, where I worked for 15 years on railroad government affairs before becoming President of the American Short Line and Regional Railroad Association.

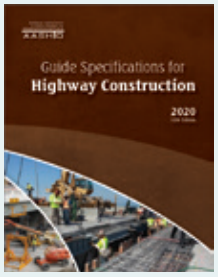
—CHUCK BAKER
President, American Short Line and Regional Railroad Association, Washington, D.C.

"TRB is how I see the progress of my career. I started attending the TRB Annual Meeting by going to sessions as a grad student. Then, I got an Eisenhower Fellowship and started presenting my work. I got my first paper published in the *Transportation Research Record*. After grad school, TRB was how I caught up with colleagues from around the globe. Now, I attend to see my students and employees present their work. Each year, I notice some other way that I am growing in the profession.

—LAUREL PAGET-SEEKINS
Assistant General Manager for Policy, Massachusetts Bay Transportation Authority, Boston

"There is a reason we all volunteer with TRB. We all contribute our unique experiences, expertise, wisdom, context, and capabilities to build an unprecedented community of expertise to lead the nation and the world to a safer, more efficient, and equitable reality. I learned that, just as I am gaining valuable knowledge from thousands of TRB volunteers, I am also bringing value to this powerful community by being myself and contributing to the best of my abilities.

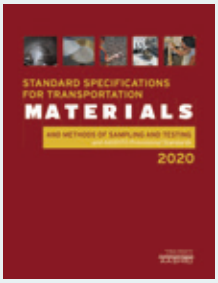
—NIKOLA IVANOV
Director of Operations, University of Maryland CATT Lab, College Park



Guide Specifications for Highway Construction, 10th Edition

The *American Association of State Highway and Transportation Officials (AASHTO) Guide Specifications for Highway Construction, 10th Edition*, provides guidance for developing transportation contract specifications and form the national standard for best practices in highway and road construction. This consensus-based guide is used by states and local agencies as a standard requirement for roadway construction contracts and is a basis for those in developing their own construction specifications. This edition focuses on electronic submittals, updated environmental requirements, and revised materials specifications.

To order a copy, visit the AASHTO Store online at https://store.transportation.org, and search by the publication's item code, GSH-10.



Standard Specifications for Transportation Materials and Methods of Sampling and Testing, and AASHTO Provisional Standards, 40th Edition

This volume, commonly referred to as the *AASHTO Materials Standards*, contains specifications, test methods, and provisional standards commonly used in the construction of highway facilities. The latest updates revise the standards and sections on hydraulic cement and lime; fresh concrete; hardened concrete; pavement measurement; bridge and pavement preservation; quality assurance and environmental; general manufactured materials, including concrete drainage structures, flexible and metallic pipe, markings and coatings, and safety devices; and geotechnical and bituminous materials and mixtures.

To order a copy, visit the AASHTO Store online, https://store.transportation.org, and search by the publication's item code, HM-40.

The titles in this section are not TRB publications. To order, contact the publisher listed.

TRB PUBLICATIONS

Transportation Research Record 2673, Issue 8

Among the topics addressed in this issue are a synthesis of glare screen use in road design, clean bus technologies and the cost-effectiveness of emissions reductions in Latin America, and a lane-by-lane analysis framework for conducting highway capacity analyses at freeway segments.

2019; 681 pp. For more information, visit http://journals.sagepub.com/home/trr.

Transportation Research Record 2673, Issue 9

Authors present research on the accessibility impacts of park-and-ride systems, an optimal platoon trajectory planning approach at arterials, the characteristics of law enforcement response to wrong-way driving events in Florida, and more.

2019; 695 pp. For more information, visit http://journals.sagepub.com/home/trr.

Transportation Research Record 2673, Issue 10

Among the topics presented in this volume are initial ridership variation on new rail transit projects, factors contributing to deer–vehicle crashes on rural two-lane roadways in Michigan, and development of a multimodal microsimulation-based evacuation model.

2019; 862 pp. For more information, visit http://journals.sagepub.com/home/trr.

To order the TRB titles described in Bookshelf, visit the TRB online bookstore, www.TRB.org/bookstore, or contact the Business Office at 202-334-3213.

Transportation Research Record 2673, Issue 11

An enhanced methodology for the identification of locations with high risk of wet crashes, understanding the use of ridesourcing services in disadvantaged New York City neighborhoods, and a new procedure to evaluate the post-crack behavior of fiber-reinforced concrete are a few of the topics explored in this volume.

2019; 924 pp. For more information, visit http://journals.sagepub.com/home/trr.

Strategic Issues Facing Transportation: Preservation, Maintenance, and Renewal of Highway Infrastructure
NCHRP Research Report 750, Volume 7

This report focuses on the issues affecting the preservation, maintenance, and renewal (PMR) of highway infrastructure, with emphasis on preparing for plausible future scenarios and develops a pathway

to guide transportation agencies in advancing the implementation of emerging PMR practices through awareness, advocacy, assessment, adoption, and action planning.

2019; 238 pp.; TRB affiliates, $73.50; nonaffiliates, $98. Subscriber categories: administration and management, bridges and other structures, construction, maintenance and preservation, materials, and pavements.

Stormwater Infiltration in the Highway Environment: Guidance Manual
NCHRP Research Report 922

This report supports the evaluation, selection, siting, design, and construction of infiltration best management practices in the highway environment. It is also intended to identify limitations on the use of infiltration and determine the need for alternative non-infiltration-based stormwater management approaches.

2019; 222 pp.; TRB affiliates, $71.25; nonaffiliates, $95. Subscriber categories: highways, environment, and hydraulics and hydrology.

Workforce Optimization Workbook for Transportation Construction Projects
NCHRP Research Report 923

This report provides state transportation agencies with guidance to identify their construction staffing needs and how to best allocate their state or consultant engineering and inspection staff and consultant resources to highway construction projects. The guidance provides 35 specific staffing strategies that may help alleviate construction staff challenges.

2019; 88 pp.; TRB affiliates, $54.75; nonaffiliates, $73. Subscriber categories: highways, administration and management, and construction.

Foreseeing the Impact of Transformational Technologies on Land Use and Transportation
NCHRP Research Report 924

This report reviews the characteristics of new transportation-related technologies and their applications in the transportation sector and explores a wide variety of potential impacts on areas such as travel and land use and planning projects.

2019; 152 pp.; TRB affiliates, $63.75; nonaffiliates, $85. Subscriber categories: administration and management, planning and forecasting, and society.

Concrete Technology for Transportation Applications
NCHRP Synthesis 544

This synthesis documents how state departments of transportation select and deploy concrete technologies in the construction of transportation facilities.

2019; 194 pp.; TRB affiliates, $ 68.25; nonaffiliates, $91. Subscriber categories: highways, and maintenance and preservation.

Incorporating Roadway Access Management into Local Ordinances
NCHRP Synthesis 549

Documented in this synthesis are regulatory tools and practices used by local governments to implement access management, as well as examples of how state transportation agencies are coordinating with local governments to advance access management objectives.

2019; 130 pp.; TRB affiliates, $61.50; nonaffiliates, $82. Subscriber categories: design, highways, operations and traffic management.

Innovative Solutions to Facilitate Accessibility for Airport Travelers with Disabilities
ACRP Research Report 210

This report outlines innovative solutions to facilitate accessibility for passengers with a variety of physical, sensory, and cognitive challenges.

2019; 206 pp.; TRB affiliates, $71.25; nonaffiliates, $95. Subscriber categories: aviation, passenger transportation, and terminals and facilities.

Guidance for Using the Interactive Tool for Understanding NEPA at General Aviation Airports
ACRP Research Report 211

This report will help airport staff from general aviation airports understand the National Environmental Policy Act, or NEPA, process.

2019; 114 pp.; TRB affiliates, $58.50; nonaffiliates, $78. Subscriber categories: aviation, and planning and forecasting.

Estimating Market Value and Establishing Market Rent at Small Airports
ACRP Research Report 213

This report offers airport management, policymakers, and staff a resource for developing and leasing airport land and improvements, methodologies for determining market value and appropriate rents, and best practices for negotiating and reevaluating current lease agreements.

2019; 84 pp.; TRB affiliates, $51.75; nonaffiliates, $69. Subscriber category: aviation.

Airport Risk Identification and Prioritization Practices
ACRP Synthesis 106

This synthesis provides information about the existing tools that airports use for identifying common hazards and the processes used for measuring, monitoring, and prioritizing the associated risks.

2019; 80 pp.; TRB affiliates, $51.75; nonaffiliates, $69. Subscriber categories: aviation, administration and management, and vehicles and equipment.

Strategic Communications to Improve Support for Transit-Priority Projects: Report and Toolkit
TCRP Research Report 208

This report analyzes the communication approaches used by cities and transit agencies in the delivery of transit-priority projects and the factors that make certain approaches more or less effective. Some of the best practices found include identifying key stakeholders early in the project planning process, developing a coordinated strategic communications plan that targets stakeholder groups, and committing to strategic communications throughout a project's life cycle.

2019; 72 pp.; TRB affiliates, $51.75; nonaffiliates, $69. Subscriber categories: public transportation, education and training, and passenger transportation.

MEETINGS

June

23–24 **Aviation Group Midyear Meetings: Business Aviation Subcommittee, Plenary Economic Outlook Discussion, Commercial Airlines Subcommittee, and Helicopters Subcommittee**
Online
To register, visit http://bit.ly/TRBAVIATION2020.

24–26 **U.S. Coast Guard Maritime Domain Awareness Study**
Washington, D.C.
For more information, e-mail Michael Covington, TRB, mcovington@nas.edu.

July

27–30 **Automated Vehicles Symposium**
San Diego, California

*TRB is cosponsor of the meeting.

UPCOMING WEBINARS

June

29 A Research Roadmap for Transportation and Public Health

30 Forecasting Zero Emission Vehicles Fleet Scenarios and Emissions Implications

July

7 Smooth Road Ahead: Applying Pavement Condition Data for Airports

8 When to Use Fully Grouted Piezometer Installations

9 Enhance Work Zone Safety with New Technologies

16 Seismic Design Basics

21 How Performance and Data Informs Transportation Decision Making

23 Looking Ahead: Strategic Issues Facing Highway Infrastructure

For more information, contact Elaine Ferrell, TRB, at 202-334-2399 or eferrell@nas.edu.

UPCOMING DEADLINES

National Cooperative Highway Research Program (NCHRP) FY 2021 panel nominations are due **Tuesday, June 30**.

For more information, visit www.trb.org/NCHRP/NCHRPOverview.aspx.

NCHRP Synthesis Program 20-05 panel nominations are due **Tuesday, June 30**.

For more information, visit www.trb.org/SynthesisPrograms/SynthesesNCHRP.aspx.

The deadline for submitting letters of interest for Airport Cooperative Research Program Synthesis topics has been extended. The new deadline is **Wednesday, July 15.**

For more information, visit www.trb.org/SynthesisPrograms/ACRPSynthesisNewStudies.aspx.

To subscribe to the TRB E-Newsletter and keep up to date on upcoming activities, go to www.trb.org/Publications/PubsTRBENewsletter.aspx and click on "Subscribe."

Please contact TRB for up-to-date information on meeting cancellations or postponements. For Technical Activities meetings, please visit www.TRB.org/calendar or e-mail TRBMeetings@nas.edu. For information on all other events or deadlines, inquire with the listed contact.

INFORMATION FOR CONTRIBUTORS TO **TR NEWS**

TR News welcomes the submission of articles for possible publication in the categories listed below. All articles submitted are subject to review by the Editorial Board and other reviewers to determine suitability for *TR News*; authors will be advised of acceptance of articles with or without revision. All articles accepted for publication are subject to editing for conciseness and appropriate language and style. Authors review and approve the edited version of the article before publication. All authors are asked to review our policy to prevent discrimination, harassment, and bullying behavior, available at https://www.nationalacademies.org/about/institutional-policies-and-procedures/policy-of-harrassment.

ARTICLES

FEATURES are timely articles of interest to transportation professionals, including administrators, planners, researchers, and practitioners in government, academia, and industry. Articles are encouraged on innovations and state-of-the-art practices pertaining to transportation research and development in all modes (highways and bridges, public transit, aviation, rail, marine, and others, such as pipelines, bicycles, pedestrians, etc.) and in all subject areas (planning and administration, design, materials and construction, facility maintenance, traffic control, safety, security, logistics, geology, law, environmental concerns, energy, technology, etc.). Manuscripts should be no longer than 3,000 words. Authors also should provide tables and graphics with corresponding captions (see Submission Requirements). Prospective authors are encouraged to submit a summary or outline of a proposed article for preliminary review.

MINIFEATURES are concise feature articles, typically 1,500 words in length. These can accompany feature articles as a supporting or related topic or can address a standalone topic.

SIDEBARS generally are embedded in a feature or minifeature article, going into additional detail on a topic addressed in the main article or highlighting important additional information related to that article. Sidebars are usually up to 750 words in length.

POINT OF VIEW is an occasional series of authored opinions on current transportation issues. Articles (1,000 to 2,000 words) may be submitted with appropriate, high-quality graphics, and are subject to review and editing.

RESEARCH PAYS OFF highlights research projects, studies, demonstrations, and improved methods or processes that provide innovative, cost-effective solutions to important transportation-related problems in all modes. Research Pays Off articles should describe cases in which the application of project findings has resulted in benefits to transportation agencies or to the public, or in which substantial benefits are expected. Articles (approximately 750 to 1,000 words) should delineate the problem, research, and benefits, and be accompanied by the logo of the agency or organization submitting the article, as well a one or two photos or graphics. Research Pays Off topics must be approved by the RPO Task Force; to submit a topic for consideration, contact Stephen Maher at 202-334-2955 or smaher@nas.edu.

OTHER CONTENT

TRB HIGHLIGHTS are short (500- to 750-word) articles about TRB-specific news, initiatives, deliverables, or projects. Cooperative Research Programs project announcements and write-ups are welcomed, as are news from other divisions of the National Academies of Sciences, Engineering, and Medicine.

BOOKSHELF announces publications in the transportation field. Abstracts (100 to 200 words) should include title, author, publisher, address at which publication may be obtained, number of pages, price, Web link, and DOI or ISBN. Publishers are invited to submit copies of new publications for announcement (see contact information below).

SUBMISSION REQUIREMENTS:

- **Articles** submitted for possible publication in *TR News* and any correspondence on editorial matters should be sent to the *TR News* Editor, Transportation Research Board, 500 Fifth Street, NW, Washington, DC 20001, 202-334-2986 or 202-334-2278, and lcamarda@nas.edu or cfranklin-barbajosa@nas.edu.
- Submit **graphic** elements—photos, illustrations, tables, and figures—to complement the text. Images must be submitted as TIFF or JPEG files and must be at least 3 in. by 5 in. with a resolution of 300 dpi. Large photos (8 in. by 11 in. at 300 dpi) are welcomed for possible use as magazine cover images. A detailed caption must be supplied for each graphic element.

Note: Authors are responsible for the authenticity of their articles and for obtaining written permissions from publishers or persons who own the copyright to any previously published or copyrighted material used in the articles **as well as any copyrighted images** submitted as graphics.

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