TR NEWS

November–December 2020 NUMBER 330

Recycled Materials Web Map

PLUS

Living with Transformational Tech

Highway Barriers that Reduce Pollution

The Importance of Freight Resilience Plans

100 YEARS MOVING IDEAS ADVANCING SOCIETY

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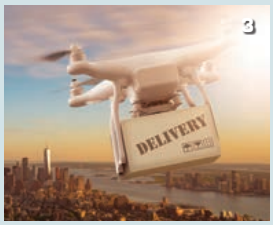

COVER Today's blast furnaces operate with efficiency in mind, even for waste. Recyclable slag produces the asphalt concrete, Portland cement concrete, granular base, embankments, and fill that are used to construct highways. (Photo: Pxfuel)

Coming Next Issue

Among the topics explored in the January–February 2021 issue of *TR News* are research trends in *Transportation Research Record* articles; truck size and weight research challenges; and a National Academies of Sciences, Engineering, and Medicine study on social isolation and loneliness in older adults.

Photo: Flickr

By grandfathering preexisting state laws, some trucks—notably Rocky Mountain Doubles, or trucks with two linked trailers—are allowed to exceed 80,000 pounds on the nation's Interstates. Along with varied regulations among different states, this complicates research into truck size and weight limits.

Also in This Issue:

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.

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.

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TR News (ISSN 0738-6826) is issued bimonthly by the Transportation Research Board, 500 Fifth Street, NW, Washington, DC 20001. Internet address: www.TRB.org.

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Subscriptions: North America: 1 year $75; single issue $19. Overseas: 1 year $100; single issue $19 plus shipping. Inquiries or communications concerning new subscriptions, subscription problems, or single-copy sales should be addressed to the Business Office at the address below, or telephone 202-334-3216, fax 202-334-2519. Periodicals postage paid at Washington, D.C.

Postmaster: Send changes of address to *TR News,* Transportation Research Board, 500 Fifth Street, NW, Washington, DC 20001.

LIVING WITH TRANSFORMATIONAL TECHNOLOGIES AND OTHER SURPRISES

Photo: Shutterstock

ANDREW C. LEMER

The author is a Senior Program Officer, Transportation Research Board, Washington, D.C.

Above: In the near future, traditional land-based modes of local freight delivery—such as panel trucks—may be joined by growing fleets of unmanned aerial systems (or drones), technology that is transforming the speed of moving goods.

It's tough to make predictions, especially about the future. The observation—attributed variously to American baseball great Yogi Berra, Danish physicist Niels Bohr, and 19th-century author Mark Twain—is well supported by experience.

Thomas Watson, then president of IBM, famously averred in 1943, "I think there is a world market for maybe five computers." Of course, a computer at the time filled a large room, used vacuum tubes, and required trained operators with substantial programming skills. Today, the microchip-laden laptops, tablets, and cell phones that even young children carry pack more computing power than these early behemoths.

Physicist Albert Einstein, whose statue graces the front of the National Academies of Sciences, Engineering, and Medicine headquarters in Washington, D.C., wrote in 1932, "There is not the slightest indication that nuclear energy will ever be obtainable. It would mean that the atom would have to be shattered at will." He later observed that "I did not, in fact, foresee that [atomic energy] would be released in my time. I believed only that it was theoretically possible. It became practical through the accidental discovery of chain reaction, and this was not something I could have predicted."

When President Dwight D. Eisenhower signed the Federal-Aid Highway Act of 1956, he and his advisors looked forward to building a system that would "eliminate unsafe roads, inefficient routes, traffic jams, and all of the other things that got in the way of 'speedy, safe transcontinental travel (*1*).'" Although the Interstate highways spanned the nation and lifted motor vehicles out of the mud, congestion and crashes are still very much with us. But even automotive innovators Henry Ford (1863–1947) and Alfred Sloan (1875–1966) probably would have been hard-pressed to imagine that in 2019 there would be nearly 285 million registered motor vehicles in the United States for our estimated population of about 329 million people (*2*, *3*).

Photos: Eisenhower Archives

During the 1919 Transcontinental Motor Truck Convoy, then-Lt. Col. Dwight D. Eisenhower saw the poor condition of U.S. roads firsthand. Faced with one gully after another as they crossed Wyoming, engineers rolled up their sleeves and reinforced unstable wood bridges with planks (*left*). Then, they held their breath as the first truck lumbered across (*right*). That arduous journey—plagued by vehicles overturned in ditches and mired in mud—inspired later President Eisenhower to sign the Federal-Aid Highway Act of 1956 into law.

Photo: Virginia DOT

Highways have come a long way since the rutted roads, precarious curves, and eroded shoulders that were the nationwide norm 100 years ago. Today, technology such as toll booth E-Z Pass that reads prepaid, dashboard-mounted sensors in cars keep traffic moving along an intricate network of smoother thoroughfares that has transformed how we get around.

Prophecy, Prediction, and Transformation

Shakespeare's Macbeth encountered witches in the woods who foretold his rise and fall. Such foretelling is perhaps prophecy rather than prediction. Austrian British philosopher Karl Popper distinguished prophecy as an unqualified and essentially untestable assertion that something will or will not occur (*4*). In Popper's view, prediction is a result of logical deduction from a scientific theory. Failure of the future to unfold as prophesied is not taken by believers as convincing evidence against their faith, but outcomes contrary to prediction may call the theory into question.

Of course, the line between faith and theory is often fuzzy. For example, Moore's Law—cited frequently with regard to progress in microelectronics—is the product of an observation in the 1960s (by Gordon Moore, one of Intel Corporation's founders) of two concurrent trends: the number of transistors that could be fit on a microchip was doubling about every year, and production costs were declining. Anticipating that these trends would continue, Moore suggested that computing power—and the market for Intel's chips—would continue to grow dramatically. The trend line, adjusted a bit to account for the actual changes in chip design, looked very convincing in a graph and came to be viewed popularly as having predictive power akin to Newtonian physics. In today's chip fabrication plants, however, size shrinkage has slowed as production technology runs up against physical limitations.

Nevertheless, decades of explosive growth in capabilities and usage of cell phones, digital industrial control systems, and the like have conditioned us to the idea that new technologies will be "transformational" in the ways they affect our lives and society and not without some justification. When English urban planner Ebenezer Howard's influential diagrams illustrating urban growth through

development of "slumless" "garden cities" at the periphery of primary urban centers was published in 1902, who would have predicted the sprawl that turned forests and pastures in many parts of the country into megaregions (*5*, *6*) (Figure 1)? And when American transport entrepreneur Malcolm McLean patented the idea of the shipping container in 1956, who would have predicted the growth of intermodal transport, huge container ships, and globalized supply chains delivering fresh South American asparagus to winter dinner tables in North America?

In surface transportation, a great deal of attention is being given to the transformational potential of connected and automated vehicles (CAV) and, more generally, connected and automated transportation (CAT) systems; CAT refers generally to all transportation modes. Proponents imagine a future of driverless cars, trucks, and transit vehicles providing safer, more reliable, and possibly less-expensive transportation services that afford travelers the freedom to read, cope with unruly passengers, and pursue other activities that today distract drivers. However, there are other technological developments under way, such as shared mobility (e.g., bicycles, e-scooters, and hourly auto rentals, as well as cellphone app–based services such as Lyft and Uber), use of unmanned aerial systems (UASs or drones) for package delivery and personal transportation, and smart cities and communities initiatives as forces for change in city living and economic activity.

An outgrowth of these discussions was National Cooperative Highway Research Program (NCHRP) Project 08-117, "Impact of Transformational Technologies on Land Use and Transportation." The project's objective was to provide guidance for state and other transportation agency decision makers on practical ways to assess the likely effect of transformational technologies on future activity centers, land use, and travel demand within their regions. The project's planners supposed that such technologies as 3-D printing, e-commerce, and UASs, as well as automated transit and other vehicles, may shift industrial supply chains and locations of warehousing, distribution, intermodal transfer facilities, and jobs in settings ranging from rural to intensely urban. Having insight into potential shifts can inform decisions and perhaps avoid—or at least defer—needless investment and regulatory obsolescence. A team led by Kittelson & Associates was engaged to conduct the research, but NCHRP's project panel also had opinions of its own. Offering guidance to transportation agency decision-makers would become a joint effort.

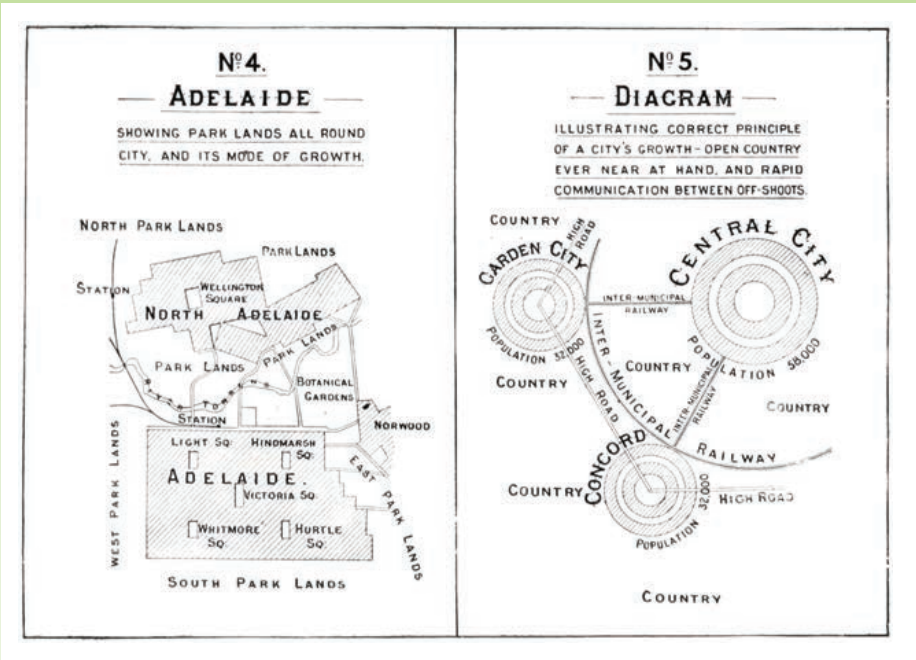

FIGURE 1 Ebenezer Howard's Garden City concepts.

It's All in the Timing

Technologies that may affect the spatial patterns of economic activity, travel, and land use potentially comprise a very large class, even if researchers imagine that only some of these technologies would qualify as transformational. Early in the NCHRP project, the research team had to address how and where to draw the line: What technologies are we talking about?

An early criterion for focusing the research was restricting consideration only to newer technologies. For example, technological advances continue to improve fuel efficiency for vehicles with gasoline- or diesel-powered engines, but the fundamental technology has been widely available for decades. Electric and other alternative-fuel vehicles, however, might qualify for attention.

NCHRP's audience inspired a second criterion. State transportation agencies—the sponsors and primary customers for NCHRP products—vary in the scopes of their responsibilities, but all of them have a substantial interest in highway-based transportation. Considering the limits of time and budget, the project panel and research team agreed that the project should focus on technologies that had a potential to significantly affect highway traffic in the not-too-distant future. Such technologies as passenger-carrying UASs, magnetic levitation trains, and hyperloop train systems were unlikely to have widespread impact within the coming two or three decades.

It makes a difference where the technology is applied in the complex system of transportation and land use, whether it be in vehicles, the infrastructure that carries and serves vehicular movement, or passenger or freight payloads. Again, the limits of time and budget motivated focusing the

Personal Communication Devices

- 5th-Generation (5G) Cellular
- Dedicated Short-Range Communications (DSRC)

"Active" Transportation Modes

- e-Bicycles
- e-Scooters

Motorized Auto, Mass Transit, and Freight Vehicles

- Alternative (combustion) Fuels
- Electric
- Autonomous (AV) Control
- Connected (CV)

Unmanned Aerial Vehicles (UAV) for Freight Delivery

Intelligent Transportation System (ITS) Applications

- Highway Operations
- Parking Systems

FIGURE 2 Potentially transformational technologies considered in NCHRP Project 08-117.

project on the road system and freight-delivery UASs as potential near-term competition for conventional delivery modes (e.g., panel trucks on neighborhood streets). Within the road system, several infrastructure-, vehicle-, and payload-embedded technologies were identified as sources of potentially significant impact in the relative near term (Figure 2).

How Impacts Become Transformational

Predicting that a technology will have any impact at all requires that we have some ideas or theories of how impact occurs and that we be able to deduce logically what the impact may be. If the theory is truly scientific (Newton's idea that gravity causes apples to fall down from the tree branch, for example), our confidence in the prediction will generally be greater than if it relies on anticipated continuation of a long-term trend (as was the case with Moore's Law). Because we are dealing with economic and social forces and systems (essentially the behavior of people as individuals and in groups or results of these behaviors), useful theories and the predictions they support may seem less certain than those of, for example, chemistry or structural mechanics.

The Kittelson research team started their prediction effort with a few fundamental but simple relationships from economic theory: when the price of transportation goes down, people use more of it. New technologies can reduce the travel times or monetary costs (or both) that users of a particular mode or service experience. New technology can offer attractive new options for travel (e.g., new modes or destinations). Anything that reduces the price of travel or offers attractive new travel options will not only shift travel patterns but also influence land use. Lower travel costs can make land more accessible and increase the land's value. The new technology that brings down travel times and monetary costs throughout a region make the region more attractive for people and businesses. Other regions without the new technology may lose out as their populations respond to these incentives by moving out.

Applying these predictive relationships to the technology cases under consideration in the NCHRP project, the research team reasoned out some general predictions about each case. CAT applications that would support self-driving trucks or truck platooning for line-haul freight transportation, for example, could shift goods from rail to highways; increase truck traffic on major routes and, thereby, pose challenges for automobile drivers; slow traffic flow on mountainous routes; and increase demand for larger warehouses and distribution centers. Although some land for larger truck-transport shipping might be made available from railyard conversions, the rural fringes of large urban centers would likely face development pressures. With fewer vehicle drivers, however, the demand for truck stops and associated commercial development might not grow at the rates previously experienced.

Surprise!

Such general predictive relationships can be valuable by themselves, helping us envision the consequences of these new technology applications. However, the specific characteristics of a particular region are likely to make a big difference as to how substantial the effects will be and how quickly they may develop. Perhaps more importantly, the consequences are uncertain. Even chemistry, structural mechanics, and similar disciplines are subject to uncertainty, and the theories for predicting the behavior of individuals and groups and the results of these behaviors are even less certain than those of other subjects of scientific and engineering study.

Various statistical methods are useful for characterizing and trying to measure this uncertainty, but we sometimes still can be surprised. Harvey Brooks—the late Harvard University professor; presidential science advisor; and member of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine (now the National Academy of Medicine)—suggested three types of surprises that can make a shambles of our predictions:

1. Unexpected discrete events that shock the system being considered (e.g., the petroleum shortages and steep fuel price increases of the 1970s),
2. Discontinuities in long-term trends (e.g., the collision between Moore's Law and the limits of photolithography for printed circuit fabrication), and
3. Sudden emergence into political consciousness of new information that shifts the balance of values in peoples' decision making (e.g., societal response to our understanding of impending climate change) (*7*).

Former options trader Nassim Nicholas Taleb asserts that surprises may come simply from our ignorance—or lack of imagination—about possibilities. He refers to Black Swan events that are far out on the extreme tail of a probability distribution, possibly one of Brooks' "unexpected discrete events" but more momentous (*8*). Taleb takes the name Black Swan from the observation

Photo: Pixabay

Stripped of its sign, a storefront closed its door for good. The COVID-19 pandemic has had a devastating effect on many sectors of the global economy, including air travel, hospitality, entertainment, individual franchises, and mom-and-pop stores. Some economists see it as a Black Swan event—extremely rare with the possibility of serious consequences.

that Europeans could not imagine swans occurred in any color except white until the Dutch explorer Willem de Vlamingh in 1697 discovered black swans in Australia.

In Taleb's terms, Black Swan events are not only very rare but also very consequential. The investment and financial communities have adopted the concept in discussing the causes and impacts of such events as the 2001 Fukushima nuclear disaster and the 2007–2008 global financial crisis. The 2020 onset of the COVID-19 pandemic will almost certainly be seen as a Black Swan for many sectors of the global economy.

Planner's Mindset

Confronted with the possibilities of small surprises and black swans, Brooks and Taleb might agree that having a good imagination and a measure of skepticism are essential in making predictions—and in relying on predictions to make decisions. These two elements are apparent in the guidance for state and other transportation agency decision makers that NCHRP Project 08-117 research developed.

That guidance is presented in *NCHRP Research Report 924: Foreseeing the Impact of Transformational Technologies on Land Use and Transportation*, the primary research product. "It has become apparent," the report's authors suggest, "that 1) public agencies have less control than they used to over the transportation system and 2) agencies cannot let five years go by between updates of their plans and procedures (*9*)." Agencies, their planners, and managers must take on a new mindset: reset their perspectives on how they think about change.

To deal effectively with the challenges of technological change, agency planners must continually be attentive to maintaining their capabilities to understand new technologies and their implications. These planners must get accurate and current data to support their work and be smart about practical options for adapting and managing the systems they oversee. Above all, planners and policy makers must be nimble, adjusting their decision making as technology continues to change. *NCHRP Research Report 924* offers advice on how to develop and maintain these four capabilities and how to develop a practical procedure and template for assessing technology impacts within a region (Figure 3).

The linearity of Figure 3 is perhaps misleading. The process is circular; in fact, it is endlessly repetitive. Being nimble means remaining aware of a region's evolving situation. To be nimble, one must have current data and use them quickly to assess and explain the current situation. Being nimble means making smart decisions on the basis of what is being observed, adapting to new technology developments as they emerge. Being nimble means adjusting course quickly when the situation seems to be changing.

Coincidentally, while the NCHRP project research team and panel were preparing their guidance to help planners deal with potentially transformational technologies' impacts on geographic regions and their transportation systems, another team working under the auspices of NCHRP's U.S. Domestic Scan Program (NCHRP Project 20-68) was preparing their Scan 18-02 report, *Leading Practices in Modifying Agency Organization and Management*

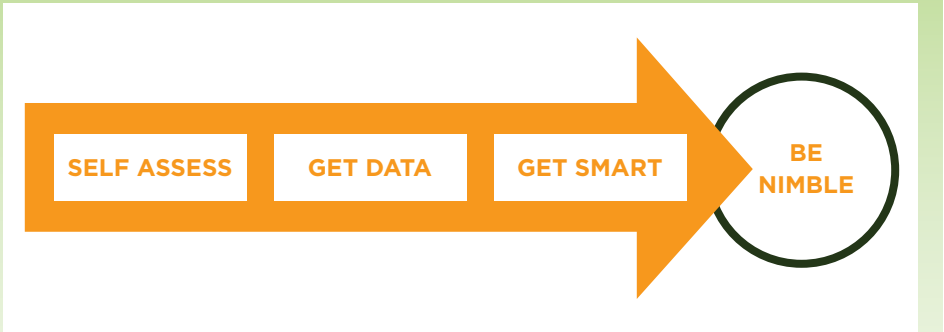

FIGURE 3 A new mindset for planning. (Source: *NCHRP Research Report 924*.)

to Accommodate Changing Transportation System Technologies (*10*). The objective of that team's work was to identify how leading government transportation agencies are changing their organizations, institutional arrangements, and management practices to improve transportation system performance through adoption of new technologies. The scan team interviewed staff at several state transportation agencies and studied these agencies' leadership, organizations, staffing, business processes, performance management, and collaboration practices to discover useful lessons that might inform their peers throughout the nation.

The team concluded that sometimes agency culture is a concern. The functional silos typically found in many agencies—insularity among business-area and geographic units within the agency—impede acquisition and retention of workforce talent; obstruct self-assessment of agency capabilities; and add to costs of data collection, maintenance, and effective use. Smart and creative management thinking and nimble response to change can flourish in more open organizations.

Inventing the Future

Like many large structures, silos are not easily dismantled. On the one hand, fear of change and our human inclination to protect our own turf feed resistance to change and paralysis in the face of change. American author Alvin Toffler came to prominence when his 1970 book, *Future Shock*, became an international bestseller (*11*). The shock associated with the perception of "too much change in too short a period of time" in one's life causes stress, disorientation, upset, and erosion of peoples' conviction that they can cope with the forces of new patterns of economic and political activity, social expectations, and interpersonal interactions. At a societal level, the result is apparent confusion and conflict of values, loss of direction, and a breakdown of decision making. After half a century, the idea of future shock continues to resonate, not least in the thought that technologies have become transformational.

On the other hand, there is the complacency that comes from overconfidence that everything is under control, that familiar trends will continue forever, and the idea that a frog placed in tepid water that is gradually brought to a boil will stay put and be cooked. Anecdotal reports suggest that experimental evidence disproves that folklore. Taleb gives a better example: a commercially raised turkey—fed reliably and well for 1,000 days—may come to look forward to old age. But as Thanksgiving draws near, the turkey learns how drastically wrong its expectations were (*12*).

We cannot afford to let shock or complacency lead to paralysis. Predictions about the future may be difficult and uncertain, but people who take on responsibility for making long-term investments to ensure the continued survival and prosperity of future generations must cope.

British–Hungarian Nobel Prize physicist Dennis Gabor wrote: "The future cannot be predicted, but futures can be invented" (*13*). Considering in a reasonable and logical way what the implications of new technologies may be and acting on our conclusions is how the future is invented. The guidance presented in *NCHRP Research Report 924* and the *Scan 18-02* report help with the tasks of invention.

Acknowledgments

The author thanks the members of the research and scan project panels and the research teams.

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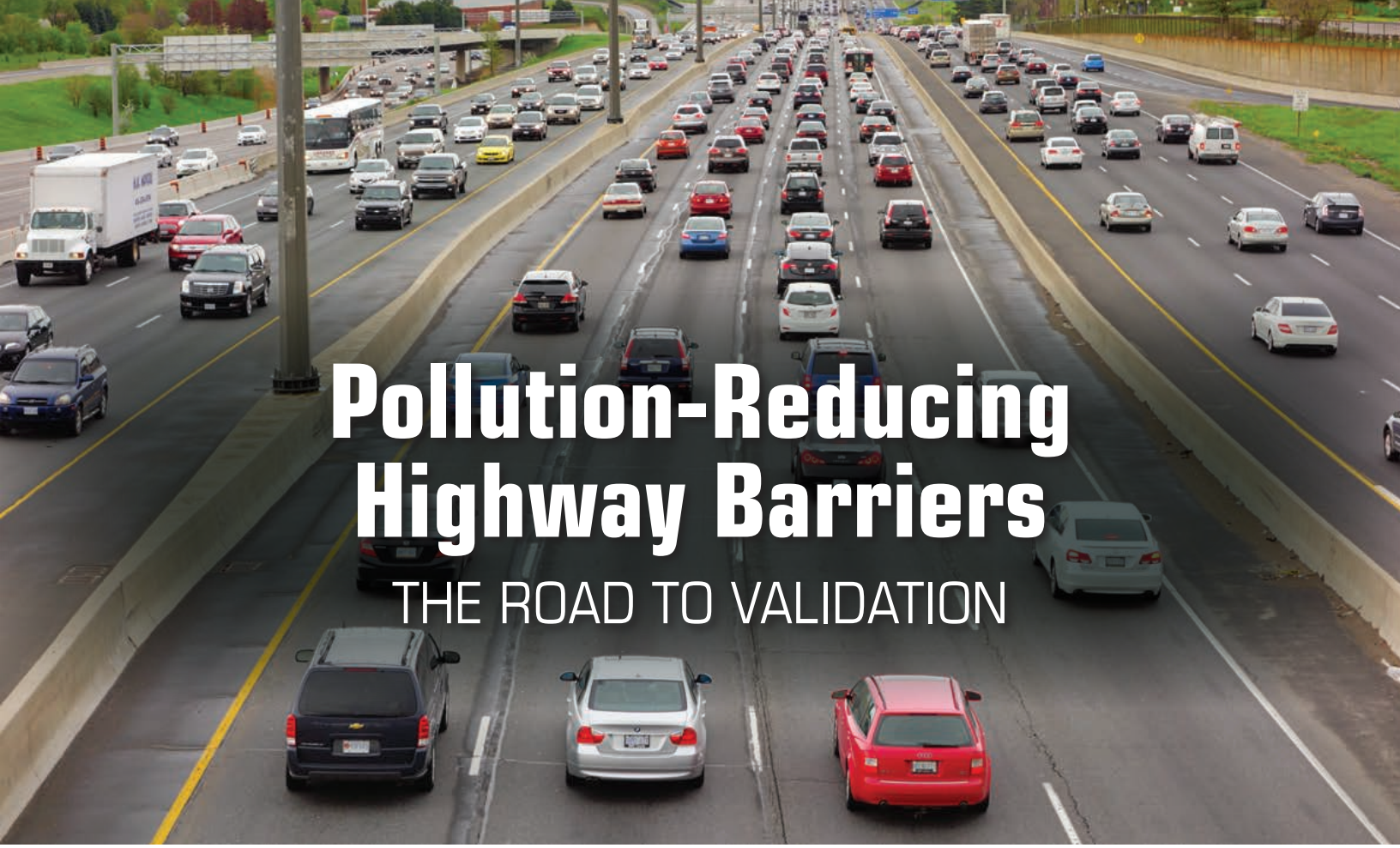


Pollution-Reducing Highway Barriers

THE ROAD TO VALIDATION

Photo: iStock

BILL VAN HEYST AND STEPHANIE SHAW

Van Heyst is Professor and Shaw is PhD Candidate, School of Engineering, University of Guelph, Ontario, Canada.

Above: Carrying more than 340,000 vehicles a day, the stretch of Highway 401 that traverses Toronto, Ontario, Canada, is North America's busiest roadway. And with anywhere from eight to 14 lanes across, it is also the continent's widest.

A new type of highway barrier is addressing one of the biggest sources of urban air pollution: traffic emissions. By incorporating "pollution-eating" photocatalytic coatings, these barriers break down the harmful compounds created by burning gasoline and diesel, as well as mitigate traffic noise. And because these photocatalysts are activated by sunlight, the barrier's extra pollution-eating benefit costs nothing to operate.

However, as several trials have revealed, simply painting a conventional barrier with a photocatalyst doesn't work. This article examines the crucial role of aerodynamics, the shortcomings of using titanium dioxide (TiO_2, currently the most common photocatalytic coating), and what it takes to bring emerging alternatives to market.

The Double-Walled Design

The University of Guelph first got involved in this area in 2011, when air quality consultants Scott Shayko and Xin Qiu approached the institution with a design concept for a novel, double-walled barrier to disperse traffic pollutants. They were looking for help to refine the aerodynamics and test the barrier's performance.

The university's research office put them in touch with the Air Quality Lab, since the lab team had expertise in air quality and in fluid dynamics. Working closely with Shayko and Qiu, the team assessed and tweaked the barrier's configuration. The end result featured an angled baffle on the top of the barrier that faced the highway and directed traffic emissions between the two walls (Figure 1). Thanks to high pressure on the traffic side of the barrier and low pressure just behind the barrier, emissions naturally flow between the two walls and out of a gap at the base of the rear wall. Meanwhile, any emissions that flow over the wall are disrupted by the baffle, which generates vortices that enhance dispersion of pollutants. The process is entirely passive, with no fans or blowers required.

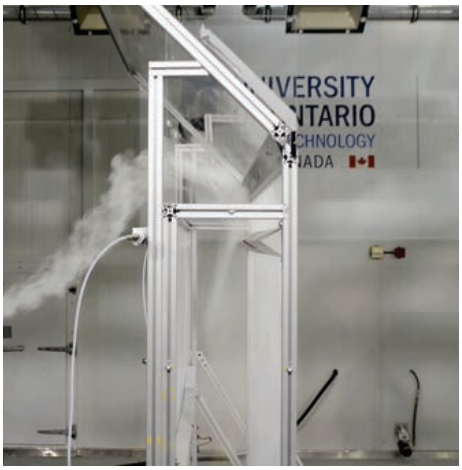


Photo: Xin Qiu, EnvisionSQ

The barrier's angled baffle directs pollution between the two walls, which ensures contact with the photocatalytic coating.

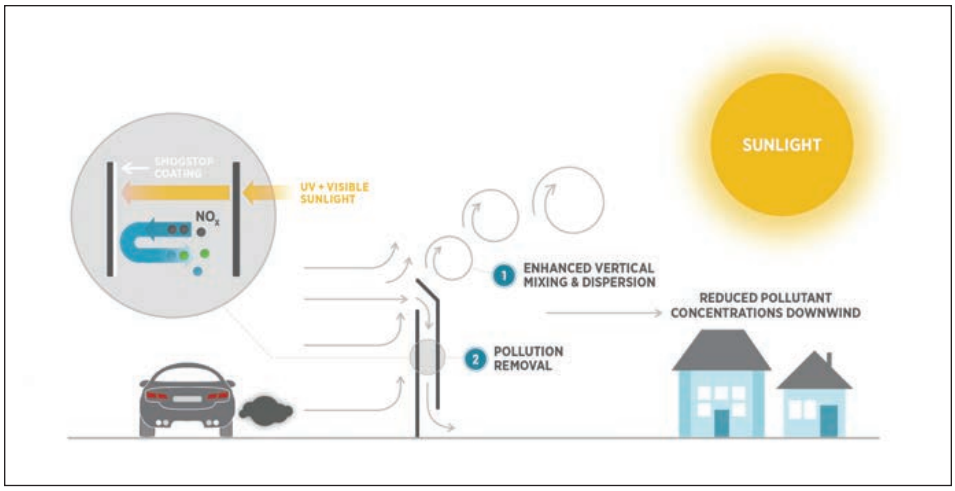


FIGURE 1 **The barrier reduces traffic pollution in two ways: using aerodynamics to disperse pollution and a photocatalytic coating to break down pollutants.**

The research team tested the design using a small-scale prototype at Western University's boundary layer wind tunnel in London, Ontario, which mimics the dynamic and turbulent character of natural wind. Using ethane as a tracer gas to simulate traffic emissions, researchers compared the double-walled barrier against a standard highway noise barrier. Hydrocarbon analyzers measured the concentration of ethane downwind to compare dispersion patterns.

When wind speeds were just 2.5 meters per second (conditions that contribute to high pollution levels), the double-walled barrier reduced downwind concentrations of ethane gas more than 50 percent compared with a standard, noncoated noise barrier (*1*).

As the computational fluid dynamics (CFD) modeling predicted, the vortexes of air created by the barrier pushed the plume of emissions up into the atmosphere. This action increases the vertical height that the plume travels before it reaches residents who live nearby. The further it travels, the more diluted it becomes, reducing the impact on communities.

Shayko and Qiu continued to develop and commercialize the barrier. However, they were not satisfied with simply dispersing traffic emissions. Because their ultimate aim was to actually break down the pollutants, the research team started looking at different options.

Initially, the team discussed the possibility of using electrostatic precipitators to remove particulates from the air. However, that would require a source of electricity, which was not practical. The team then turned to the idea of a sunlight-powered photocatalyst that could break down pollutants—including nitrogen oxides (NO_x) and volatile organic compounds (VOCs)—that contribute to local and regional air pollution.

The Promise of Photocatalysts and the Real-World Results

Certain light-activated catalysts have the ability to break down air pollutants. The best-known of these is TiO_2. Over the past few decades, lab-bench experiments have shown that when TiO_2 is exposed to ultraviolet (UV) rays, it generates strong oxidizing agents called hydroxyl radicals that can break down NO_x and VOCs.

The discovery created lots of excitement about the potential of passively reducing ambient air pollution by coating nearby surfaces with the photocatalyst. The idea is very attractive: paint building exteriors, highway barriers, and even pavement with TiO_2 (or incorporate the photocatalyst into the building materials themselves), and then stand back and watch pollution levels drop.

Although laboratory tests and simulations were very promising, real-world TiO_2 results have been mixed. A study in Manila showed that coating outdoor surfaces with photocatalyst paint could achieve average NO_x reductions of 10 percent significantly less than the numbers seen in lab tests (*2*).

In Europe, the EU-funded PhotoPAQ project tested commercially available TiO_2 products in artificial street canyons designed to mimic roadways with buildings on either side. When the researchers compared NO_x levels in a canyon coated with TiO_2 to those in the uncoated control, the difference was a mere 2 percent.

Similarly, in trials conducted by Germany's Federal Highway Research Institute, applying a TiO_2 coating to a kilometer of highway noise barrier on a six-lane stretch of the A1 Autobahn achieved only single-digit reductions in NO_x compared with an uncoated control. The biggest reductions were on the east side of the highway and were likely due to the prevailing airflow, which directed pollutants towards the eastern barrier (*3*).

Meanwhile, researchers at the University of Texas at Austin's Center for Transportation Research compared coated and uncoated barriers at a toll plaza on State Highway 45. After analyzing more than 230 days of data, they found no consistent reduction in NO_x levels (*4*).

Studies have shown the reasons for this lack of anticipated performance in real-world

situations are twofold: poor aerodynamics and the inherent limitations of TiO_2.

Shortcomings of First-Generation Pollution Barriers

For any photocatalytic surface to work, it has to have sufficient contact with the pollutants it is designed to break down. As several experiments reveal, the flat vertical surfaces of conventional barriers prevent natural airflow from achieving adequate contact (*5*). As air flows over a typical roadside noise barrier, large recirculation zones form in front of and behind the wall and force the air to move upwards. As a result, most of the pollution flows over the barrier and very little contacts its surface. Even more fundamentally, when air flows smoothly along any flat surface, there is a no-slip layer of air right next to the surface that does not move. In the case of a photocatalytic surface, this no-slip layer inhibits much of the polluted air from contacting the photocatalyst.

Based on CFD modeling and wind tunnel results, the research team knew that the double-walled design addressed this issue by enhancing air mixing between the two walls, where it would have plenty of opportunity to contact a photocatalyst on the inner surface (Figure 2). Meanwhile, the turbulent flow created between the two walls disrupted the no-slip layer. However, the team still had to address the shortcomings of TiO_2, which contributed to the disappointing results reported for first-generation photocatalytic barriers.

One problem with TiO_2 is that the reactions in the oxidation pathway it triggers do not fully break down all the pollutants. Instead of turning bigger molecules into their most basic components, they produce intermediate compounds that can be more harmful than the original pollutant. Those compounds include harmful substances such as cancer-causing formaldehyde (*6*). Moreover, TiO_2 can produce nitrate radicals that undergo further light-activated decomposition to form smog-producing ozone (*5*).

Humidity also impairs the performance of TiO_2 because water molecules in the air can block active sites on the surface of the photocatalyst (*7*).

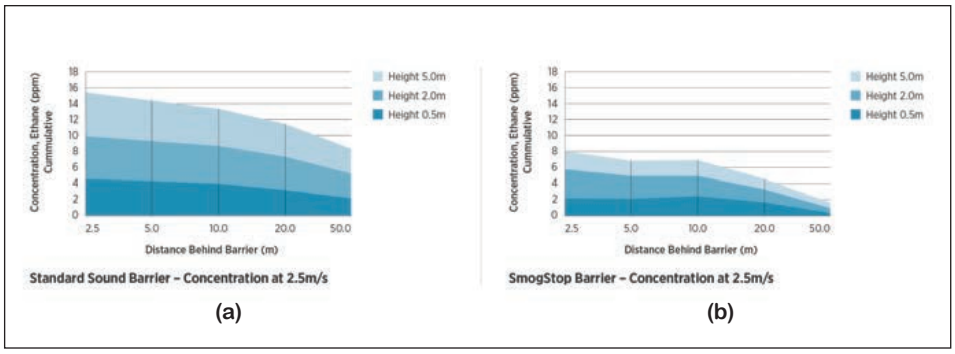


FIGURE 2 Wind tunnel tests reveal that—compared with a standard highway noise barrier (*a*)—the aerodynamic design of the uncoated SmogStop barrier (*b*) significantly reduces downwind pollution levels.

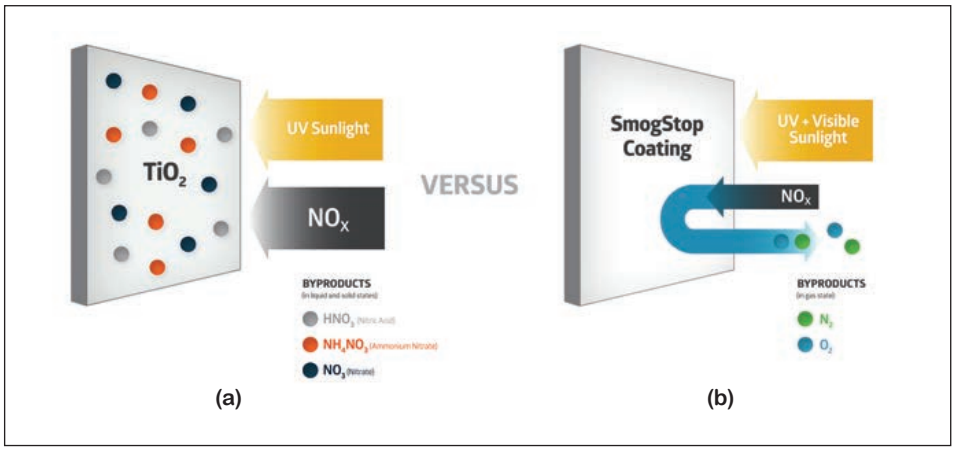


FIGURE 3 TiO_2 catalyzes a reduction reaction that can produce harmful byproducts and create a hard scale on the surface of the photocatalyst (*a*). In contrast, SmogStop's reduction reaction produces harmless nitrogen and oxygen gas (*b*).

But perhaps the biggest issue with TiO_2 is the dramatic drop in performance over time. One of the products of TiO_2-catalyzed reactions is nitric acid. It can react with basic gases in the air to form nitrate salt (*8*). Over time, nitrate salt creates a hard scale that renders the coating ineffective (Figure 3). For example, one Hong Kong study reported an 80 percent drop in NO_x removal after panels coated with TiO_2 were exposed to an outdoor environment for several months (*9*).

Creating a Different Kind of Photocatalyst

To find an alternative without those shortcomings, Shayko and Qiu's company, EnvisionSQ, worked with the University of Toronto to develop a proprietary photocatalyst that leveraged reduction reactions rather than the oxidation pathway of TiO_2.

This fundamentally different chemical approach prevents the formation of nitrate salts. It transforms NO_x into harmless nitrogen gas and oxygen gas—the basic components of air—and breaks down VOCs into carbon dioxide and water. Without the formation of the nitrates that cause scale buildup, the surface of the photocatalyst remains active and continues to remove pollutants efficiently hour after hour and month after month.

It took several years to hit on the right formula, but eventually the team succeeded. At that point, EnvisionSQ returned to the University of Guelph with the next

challenge: find a way to attach their new photocatalyst to the interior of the barrier. It was not a trivial problem.

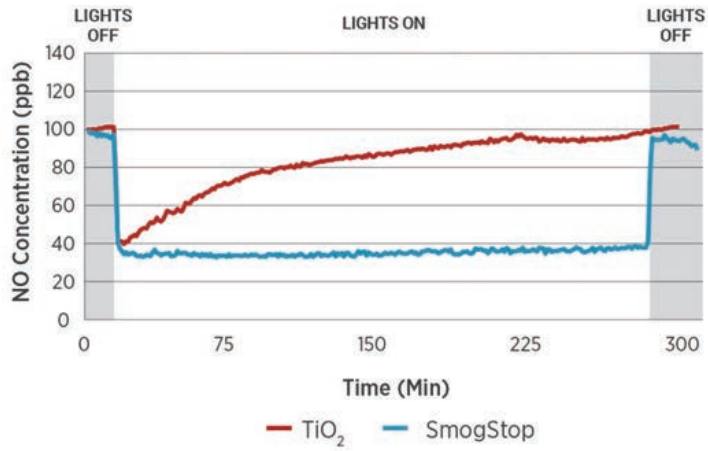
The coating had to stick reliably to the barrier's acrylic surface in the face of a broad range of weather conditions: sun, wind, snow, salt, and temperatures ranging from –20°C to +30°C. But simply mixing the particles with adhesives and slapping a layer on the barrier was not an option; researchers also had to make sure they did not block the active sites of the photocatalyst's nanoparticles. It took hundreds of trials to find the right balance between adhesion and pollutant break down, and the team has continued to refine the coating as they have moved from small test samples to full-scale barriers.

To test the coating's effectiveness, the researchers conducted a series of experiments that followed the ISO 22197-1 protocol for photocatalysts. Although the laminar flow conditions specified in the ISO standard do not reflect real-world conditions, using this widely accepted benchmark allowed the team to compare the performance of the barrier with commercial TiO_2 coatings. It also allowed the researchers to assess the improvements they made to the photocatalyst formulation and the coating procedure.

The process involved placing glass plates coated with a photocatalyst into a chamber and then passing nitric oxide over them. To activate the photocatalysts, the Guelph team simulated natural sunshine with an intensity of 350 watts per square meter (Figure 4). This was considered a worst-case scenario, representing the average daytime intensity of sunlight during the month of January in Toronto, when solar intensity is at its lowest.

Over the five-hour test, SmogStop proved 3.6 times more efficient than titanium dioxide and continued to work with no loss of performance throughout the experiment. In contrast, the TiO_2 performance quickly decreased. By five hours, it had stopped working (*10*).

In part, this was because TiO_2 is activated by UV light, which accounts for only 4 percent of total solar energy. In contrast, SmogStop takes advantage of both the UV and visible light spectrum, allowing it to take advantage of a much bigger source of energy.



Decomposition of NO at 100 ppb by SmogStop® and TiO_2 under 350 W/m² of solar light (VIS+UVA)

FIGURE 4 **In lab tests, SmogStop reduced NO_x levels further than TiO_2 and continued to perform effectively over the duration of the test, while the performance of TiO_2 dropped significantly.**

In a different set of experiments, the Guelph researchers assessed the durability of the barrier's coating in outdoor conditions. Samples of the photocatalyst were placed in a Weather-O-Meter machine, which simulates long-term exposure to light, moisture, and oxidation. At set simulated time durations, samples were removed from the Weather-O-Meter and tested using the ISO protocol to assess how well they reduced pollution levels. The results showed very little—if any—drop in performance, even after the equivalent of 10 years of weathering and use.

Putting It All Together

At this point, the Guelph team returned to the wind tunnel to see how well the coating performed on the barrier. First, the researchers ran smoke visualization tests in the University of Ontario Institute of Technology wind tunnel, which confirmed that the double-walled design channeled emissions between the two walls and created sufficient contact with the coated interior surface.

Next, the team injected NO_x gas into the barrier and then used artificial sunlight to trigger the photocatalytic reaction. Because this was a climatic wind tunnel, the researchers could adjust the amount of solar radiation to simulate actual operating conditions. When the team measured pollution concentrations at the barrier's outlet, they saw NO_x levels reduced up to 37 percent (*11*).

But to truly convince transportation authorities, governments, and other prospective customers that the barrier was effective, the researchers still had to answer a fundamental question: how does it hold up in the real world?

To find out, the team set up field tests in collaboration with the Ontario Ministry of Transportation. In March 2017, they erected a 15-meter segment of the barrier in Toronto along the north side of Highway 401, North America's busiest highway. Each day, more than 340,000 vehicles drive this 14-lane stretch of freeway (*12*).

The barrier was equipped with sampling heads to measure NO_x in the air entering and leaving the barrier at one-minute intervals. From August 18, 2017 to

Photo: Xin Qiu, EnvisionSQ

Smoke visualization tests revealed that the aerodynamics created by a standard noise barrier move pollutants over the barrier, preventing contact with the barrier surface.

February 28, 2018, researchers tracked those levels using data-logging equipment and gas analyzers housed in a trailer set up just behind the barrier. An anemometer installed on the barrier allowed us to measure wind speeds. For other meteorological data, the team relied on a weather station at the nearby Toronto Pearson International Airport. From the data collected, the team calculated the difference between inlet and outlet NO_x concentrations, which provided them with the efficiency of the barrier's pollutant removal.

The study was not without its share of hiccups. For the first several months of the field tests, there was a gap in the existing wall of conventional sound barriers directly west of the SmogStop segment. This unfinished section allowed air to escape around the side of the barriers, reducing the volume of emissions being treated. In December, the Ontario Ministry of Transportation extended the wall, which dramatically improved aerodynamic performance.

Because of that complication—and since the tests ran during the autumn and winter, when daylight is limited in Canada—the pilot results are likely conservative. Still, the findings were impressive.

Strong Results Drive Big Opportunities

In the daytime, the barrier reduced NO_x levels an average of 49 percent. During peak daylight hours, it could achieve reductions of up to 92 percent. Meanwhile, thanks to illumination from the highway's high-mast lighting, the barrier even functioned after the sun went down, although removal rates were less than half the daytime rates. (It is also worth noting that ambient NO_x levels are much lower at night.)

When these results are extrapolated, they suggest a single kilometer of the barrier can remove 43 kilograms of NO_x over the course of a day—the equivalent of taking 200,000 vehicles off that stretch of road.

Meanwhile, the field test also proved that the coating could withstand abuse from nature, backing up the Weather-O-Meter test results. For six months, the barriers endured rain, snow, ice, and high winds, as well as road salt, dust, and more with no loss of performance.

Developing any new technology is a long and complicated process, but the project presented particular challenges. This was uncharted territory in many ways, from the novel aerodynamic design of the barrier to the proprietary photocatalyst developed to overcome the limitations and drawbacks of TiO_2.

Photo: Xin Qiu, EnvisionSQ

In March 2017, the research team and a crew from the Ontario Ministry of Transportation installed several panels of SmogStop barrier along the north side of a 14-lane stretch of Highway 401, the continent's busiest highway.

Photo: Xin Qiu, EnvisionSQ

Field tests showed that SmogStop cuts NO_x levels in half during the day, and the energy provided by high-mast lighting created significant NO_x reductions at night.

Over the past nine years, the researchers have continued to iterate and refine both aspects. They also refined and expanded their CFD model, which can now handle very complex flow configurations.

The team proved that this approach works, and they look forward to the day when emission-reduction barriers line highways around the world, creating measurable improvements in urban air quality.

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Baking Resilience into Freight Mobility Planning

Photo: National Oceanic and Atmospheric Administration

KEITH J. BUCKLEW

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Above: A week after Hurricane Sandy tore through the Northeast in 2012, the *NOAAS Thomas Jefferson* launched a high-tech survey boat to check the waterways in the Port of New York–New Jersey. Resilience planning may have different meanings for different freight modes, but it is crucial to all of them.

By its very nature, freight infrastructure is a long-term investment, and its assets must serve the test of time. Time is not the real issue, however; it is how the facility responds to and recovers from the stress and shock of natural and manmade events that determines the resilience of the freight transportation system.

To ensure that resilience is incorporated into the freight planning process, freight planners must understand the following four aspects:

- The definition and meanings of resilience,
- How best to raise the awareness of the need for resilience,
- An approach to incorporate resilience in freight planning, and
- The areas where resilience best fits in the established freight planning process.

Defining Resilience

"Resilience" (and its variant, "resiliency") is a somewhat nebulous term. Derived from the Latin *resiliens*, meaning "to rebound or recoil," resilience is the capacity of a strained body to recover its form after experiencing shock or stress.

Depending upon one's experiences, needs, and modes, resilience can mean different things. To some, it may mean versatility and flexibility; for example, Minneapolis, Minnesota, converting roadway shoulders to bus lanes during peak traffic periods or Florida converting southbound Interstate lanes to northbound lanes to facilitate evacuation during hurricanes or tropical storms. Commercial airports may view resilience as the ability to recover quickly from severe weather and resume normal operations. Railroads have contingency plans to reopen rail lines that have experienced adverse weather or derailment and redundancy in their system to divert rail traffic to alternate routes as needed. A seaport may view resilience

Photo: Wikimedia Commons

The Minneapolis–St. Paul region widely deploys bus-on-shoulder travel—an example of resilience in dealing with traffic congestion.

in terms of infrastructure that is durable, tough, and always works.

Transportation system resilience often is linked to weather extremes and climate change, but this is only one of many reasons to develop a resilient freight system. Remember the old Timex wristwatch slogan "it takes a licking and keeps on ticking?" The message was that it is waterproof, dustproof, shatterproof, and shock-resistant; it works all the time (no pun intended). Transportation infrastructure needs to be resilient—a similar slogan to the old Timex ad might be "it takes a pounding but keeps on rebounding."

But what is resilience, and have we defined it? Figure 1 illustrates the many different meanings of "freight resilience." If we want to ensure the freight transportation system is ready and able to support the movement of goods, then we must plan for it and factor in the critical tenets that define resilience.

The Fixing America's Surface Transportation Act of 2015 (FAST Act) requires the consideration of projects and strategies to "improve the resilience and reliability of the transportation system" in the planning process. Although the Federal Highway Administration (FHWA) does not offer guidance for incorporating resilience into transportation planning, it provides a white paper on how states and metropolitan planning organizations (MPOs) are integrating resilience. As noted in a RAND Corporation study, FHWA's *Vulnerability Assessment and Adaption Framework* helps guide assessment of transportation infrastructure vulnerabilities but stops short of integrating resilience into planning.

FHWA incorporates resilience as a tenet of sustainability. For example, FHWA's Infrastructure Voluntary Evaluation Sustainability Tool (INVEST) is a web-based collection of best practices and is available for planning agencies to evaluate and assess sustainability and resilience of projects and programs. INVEST notes that planning and designing for infrastructure resilience supports all the triple bottom-line (TBL) principles of sustainability—environmental, social, and economic—because it provides energy savings, improves transportation system and user safety and security, and reduces future spending on infrastructure replacement.

Like the sustainability TBL, resilience also can be viewed as a stool with three legs. First, resilience is a key characteristic of the freight transportation system; however, as the word-cloud graphic in Figure 1 demonstrates, resilience possesses many attributes. Second, resilience also should be an important element of the freight planning process. As the title of this article suggests, resilience, like safety and quality, must be inherent to freight transportation infrastructure. Third, resilience must become an outcome of the freight planning process. Prioritizing projects should include criteria for reliance—infrastructure investment decisions are made for the long term.

FHWA's INVEST tool, which helps agencies evaluate and assess project sustainability and resilience, was deployed in the rehabilitation of the Going-to-the-Sun Road in Glacier National Park, Montana.

These assets are built to support the economy for future generations. In reality, resilience exists on a continuum that may be present to differing degrees depending upon the external forces exerted on the system and across the asset's lifespan. So although a particular bridge might be able to withstand heavy truck traffic today, it might not be resilient enough to withstand an earthquake tomorrow.

FIGURE 1 "Resiliency" word cloud.

Photo: Jacob W. Frank, National Park Service

Freight moves 24 hours a day, seven days a week, 365 days a year, and the multimodal freight system that provides that conveyance must always be available to perform consistently and facilitate the unimpeded movement of goods and commodities.

When freight moves freely, customer service is maximized and logistics costs are minimized—and everyone wins. Moving freight requires tough, strong infrastructure. A typical Class 8 commercial truck with a loaded trailer weighs 80,000 pounds. Forty tons of mass moving at 65 mph every day has a significant impact on roadway infrastructure. A loaded rail hopper car weighs 286,000 pounds, and although loaded tri-level auto racks and loaded double-stacked intermodal well railcars vary in weight, 170,000 pounds is typical.

Over time, the mass (by weight and volumes), speed, and frequency of goods movement exerts wear and tear on the infrastructure. The laws of physics are inescapable. As a result, even before considering climate impacts and other events, infrastructure already needs to be resilient and these factors must be incorporated into the freight planning exercise.

Planning to incorporate resilience factors into the freight transportation system is the proactive approach. Although we cannot predict the future, we can plan for it. Resilience planning must plan not only for how a facility recovers from an event but also how such an event can be avoided. Arguably, there is no such thing as being "reactive to resilience." Failing to plan is planning to fail. Events on nonresilient infrastructure lead to an overburdened, costly reaction and recovery effort.

Developing Resilient Freight Infrastructure

Understanding resilience is the first step to incorporating it into transportation system planning. Eight tenets provide the foundation for resilient infrastructure: availability, reliability, durability, redundancy, adaptability, demand, recoverability, and vulnerability. Although each tenet is an important factor, some may be more important than others (Figure 2). For day-to-day freight mobility needs, the first four tenets align with the immediate mandate for supply chains to function. Being available, reliable, durable, and redundant supports today's need for mobility to be immediately responsiveness to maximizing customer needs while minimizing transportation costs. As supply-chain needs fluctuate over time or as disruptive events occur, the other four tenets—adaptability, demand, recoverability, and vulnerability—rise in importance.

System Shocks

As 2020 has proven, supply chain disruptions do occur; suppressing the importance of any tenets is shortsighted. All tenets are important, but their relevance varies in different geographies and operational situations.

The freight transportation system reels from the effects of shock and stress every day. These factors are omnipresent and must be considered during infrastructure inspections, risk assessments, and when conducting strengths-weaknesses-opportunities-threats (SWOT) analysis. The underlying

Photo: Birmingham Photographer J.g., Flickr

A BNSF train returns to a Birmingham, Alabama, railyard after dropping off auto racks. Moving heavy freight loads requires durable infrastructure.

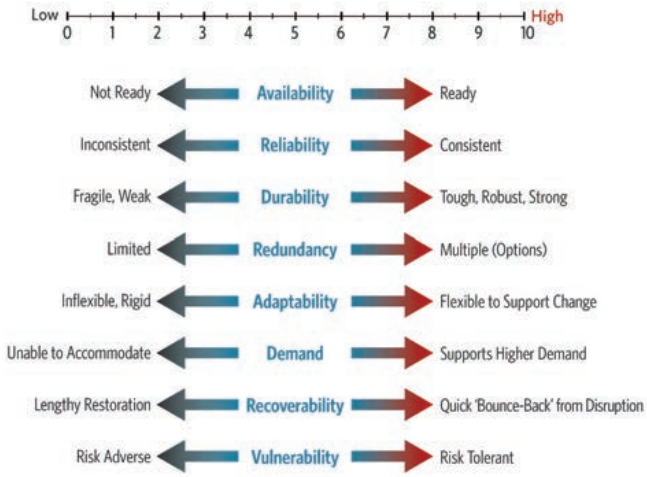

FIGURE 2 Resilience in the context of the overall multimodal freight transportation system rather than a single aspect or portion of the system.

causes of shocks and stress can be natural as the physical environment is dynamic and powerful. Similarly, human factors both intended and unintended manifest as shocks or stress, or both. Equally important are institutional factors and economics, which drive the demand for freight transportation infrastructure (Figure 3).

The adage "a chain is only as strong as its weakest link" may be appropriate for some supply chains that are lean or lack options and alternatives, but the multimodal freight system supports every supply chain in the nation. Therefore, it should be a goal to ensure that the freight transportation system incorporates multiple links to overcome expected stresses and shocks. Given the expansiveness of the freight transportation system, resilience failures will occur.

In today's parlance, freight movement is a contact sport. To be proactive, we need a strong defense: planning and preparation. Equally important, we need a robust offense: policies, programs, and projects to maintain the freight transportation system. Incorporation of resilience into the planning process and preparations for contingencies sets the conditions to establish effective polices and selection of programs and projects to develop a resilient freight transportation system.

Photo: SoulRider.222, Flickr

St. John's Bridge looms behind University Park, Oregon. Resilience considerations for mountainous regions are different from those in areas with flatter terrain and more roadway connections.

Proactive Measures

A process to assess and measure resilience needs to be developed. One way to approach this task is to develop assessment criteria to underscore each of the tenets presented above. For example, reliability factors could include consistency of peak traffic volumes and unpredictable but frequent adverse weather, such as ice or fog. Criteria for durability may include the ability of pavement to support large quantities of truck traffic or susceptibility to frequent potholes. Redundancy could include the existence of parallel or alternative roadways, inland waterway and rail options, and the like.

Different levels of vulnerability depend upon the location and situation of the asset—for example, one in a flood zone—as well as upon the criticality of the asset—for example, one that is part of the primary multimodal freight network. Once criteria are identified for each tenet, each criterion can be assigned a weight to align with its relevant importance in different geographical areas. Mountainous states with challenging terrain may not have the same redundancy of roadway routes as a state with flat topography. Some states are not connected to the inland waterway system, while others are located in climate zones that experience frequent freezing and thawing, and some states are located where major shocks occur, such as earthquakes and hurricanes.

Although all tenets of resilience must be considered, different criteria and weighting these criteria allow freight

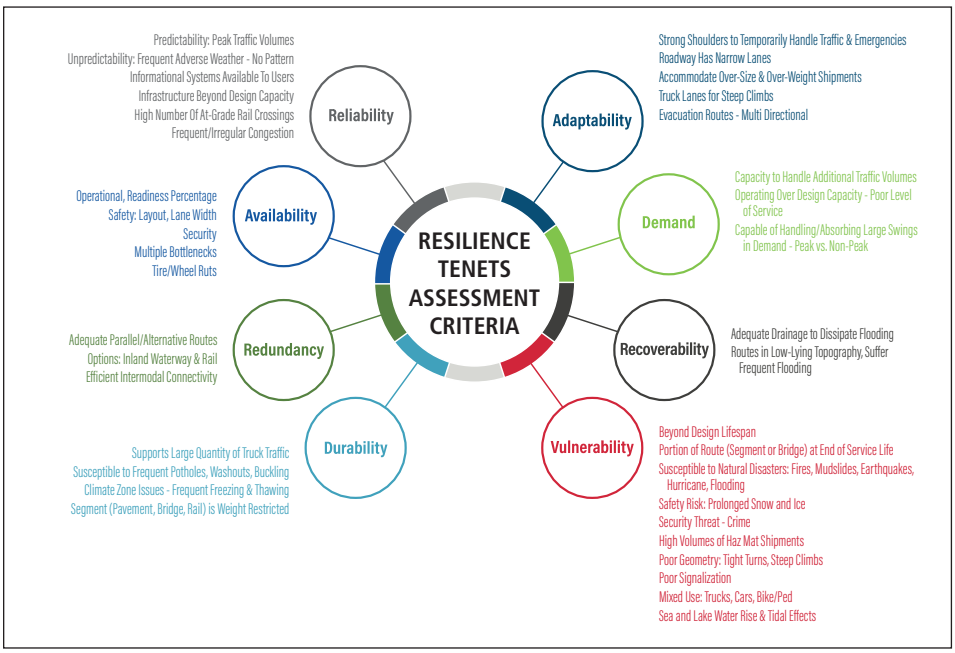

FIGURE 3 Resilience tenets assessment criteria.

planners to tailor the resilience process to fit the needs of states, regions, MPOs, and other planning agencies. Some plausible examples are shown in Figure 4.

Managing resilience for freight transportation infrastructure can be challenging and daunting, but sustainment of the economy requires it. To be effective, resilience should be considered within the current process for freight planning.

Multistep Process

Freight planning requires the development of goals and objectives first, which then provide a framework for the other elements of the freight-planning process. Therefore, it is important that resilience be integrated into the goal-setting effort. As components of the freight plan are developed, resilience is inherent in many tasks. The first four steps shown in Figure 5—assessment, determining needs, developing solutions, and selecting and prioritizing projects—are integral to the freight-planning process.

ASSESSMENT

As a first step, freight planners should focus on system resilience, which includes how well the system is performing. This process begins with the identification of the multimodal freight system and its operation. The lack of redundancy, inability to support growing demand, or a lack of reliability should trigger a warning that the freight system lacks resilience for current and future situations.

Similar to private-sector supply chains, the freight system possesses key nodes and links. These include interchanges, bridges, locks and dams, airports, pipeline junctions, intermodal facilities, seaports, and border crossings. A SWOT analysis by freight mode or by corridor may be a way to undertake a systematic approach to a SWOT analysis for the multimodal freight system. If portions of the system are unavailable or vulnerable, then there exists a resilience risk.

DETERMINING NEEDS

Next, a resilience assessment can be helpful as a component of identifying and validating needs and issues. Determining needs involves the use of data and consultation with freight stakeholders to capture

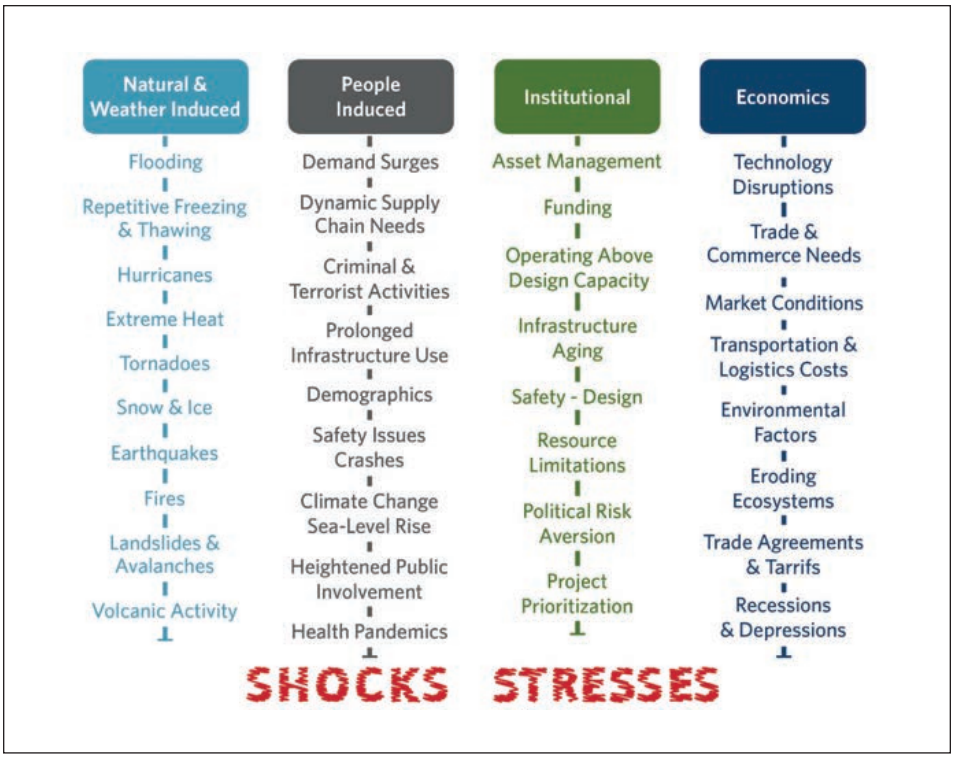

FIGURE 4 Forces affecting freight transportation resilience.

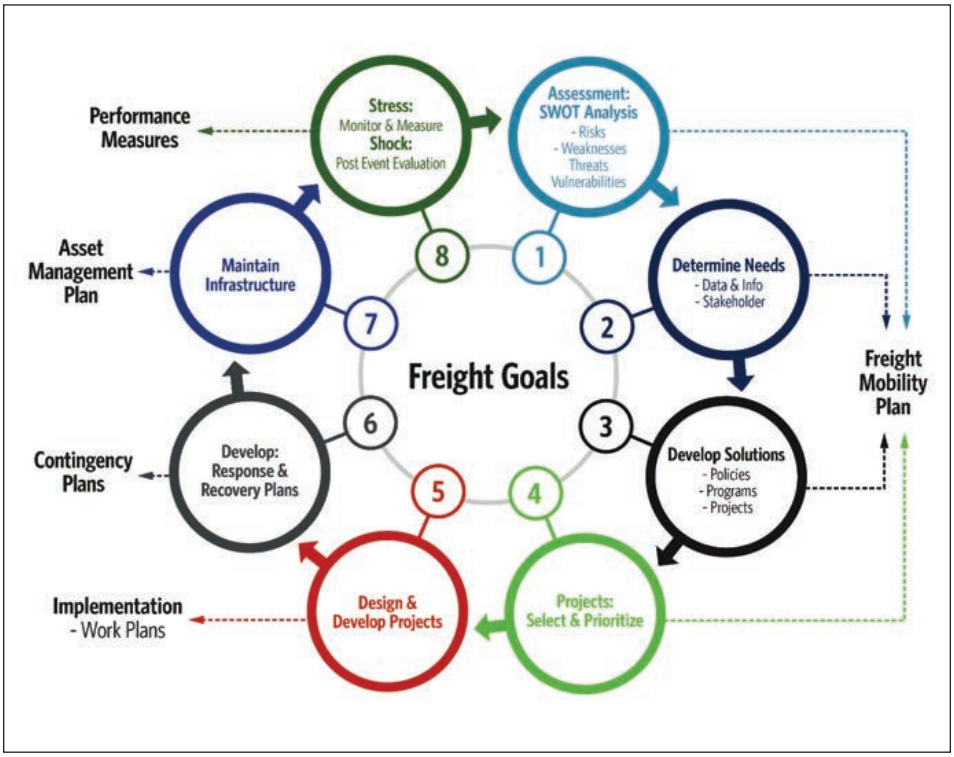

FIGURE 5 Continuous resiliency cyclic process for freight transportation planning.

Photo: Todd Kimery, U.S. Army Corps of Engineers

Lock and Dam 52 in Illinois impounds water in 2018, one year before the Ohio River dam was demolished to make way for the new Olmsted Locks and Dam. Many major components of the inland waterway system—like Lock and Dam 52—were built in the early 20th century, and their age can cause resilience risks.

objective and accurate information. One method of analysis considers the particular need in light of the eight resilience tenets. For example, a rural state highway bridge that provides a critical linkage for transporting agricultural products often may not support trucks at the maximum gross vehicle weight limit, so that bridge and the associated route would not be resilient for durability and vulnerability reasons. Similarly, a particular lock and dam on the inland waterway system may not be reliable and may need frequent maintenance and repairs. Understanding and identifying the potential risks and threats of lack of resilience can be part of identifying needs and issues.

DEVELOPING SOLUTIONS

Next, recommendations of policies, programs, and projects should be based upon objective data and information analysis and validated by stakeholders and should support the freight goals. These recommended solutions can be system enhancements or can be project-based. The solutions should have recommendations for when the project is needed—immediately, mid-term, or long-term, and should have recommended funding sources.

SELECTING AND PRIORITIZING PROJECTS

Finally, project selection and prioritization should be predicated on the greatest needs, including those that support resilience. In many cases, policies, programs, and projects are not supported by the need for resilience. In turn, if resilience is not addressed as a freight goal, then the freight plan is missing a key aspect on which the freight mobility system and choice of priority freight projects should be based.

Resilience should be factored into the project development process (shown in Step 5 of Figure 5) and then continuously assessed throughout the infrastructure's lifespan.

When plans have been assembled, the transition to implementation begins. Some post-planning actions are shown in Steps 6 to 8 (Figure 5). If the planning process is effective in articulating the need for resilience in freight infrastructure and the freight system, then it falls on agency leadership to enact policies and programs to support resilience and to prioritize projects that support resilience goals. Planners should clearly communicate the freight mobility needs and issues and provide recommendations that can be implemented.

Every day, we utilize freight transportation infrastructure that was built by the previous generation. The phrase "we are building it for the next generation" can be the lens through which we view the long-term benefits for freight transportation and then incorporate resilience into freight infrastructure and freight system performance. We need a resilient mindset to build a resilient freight transportation system.

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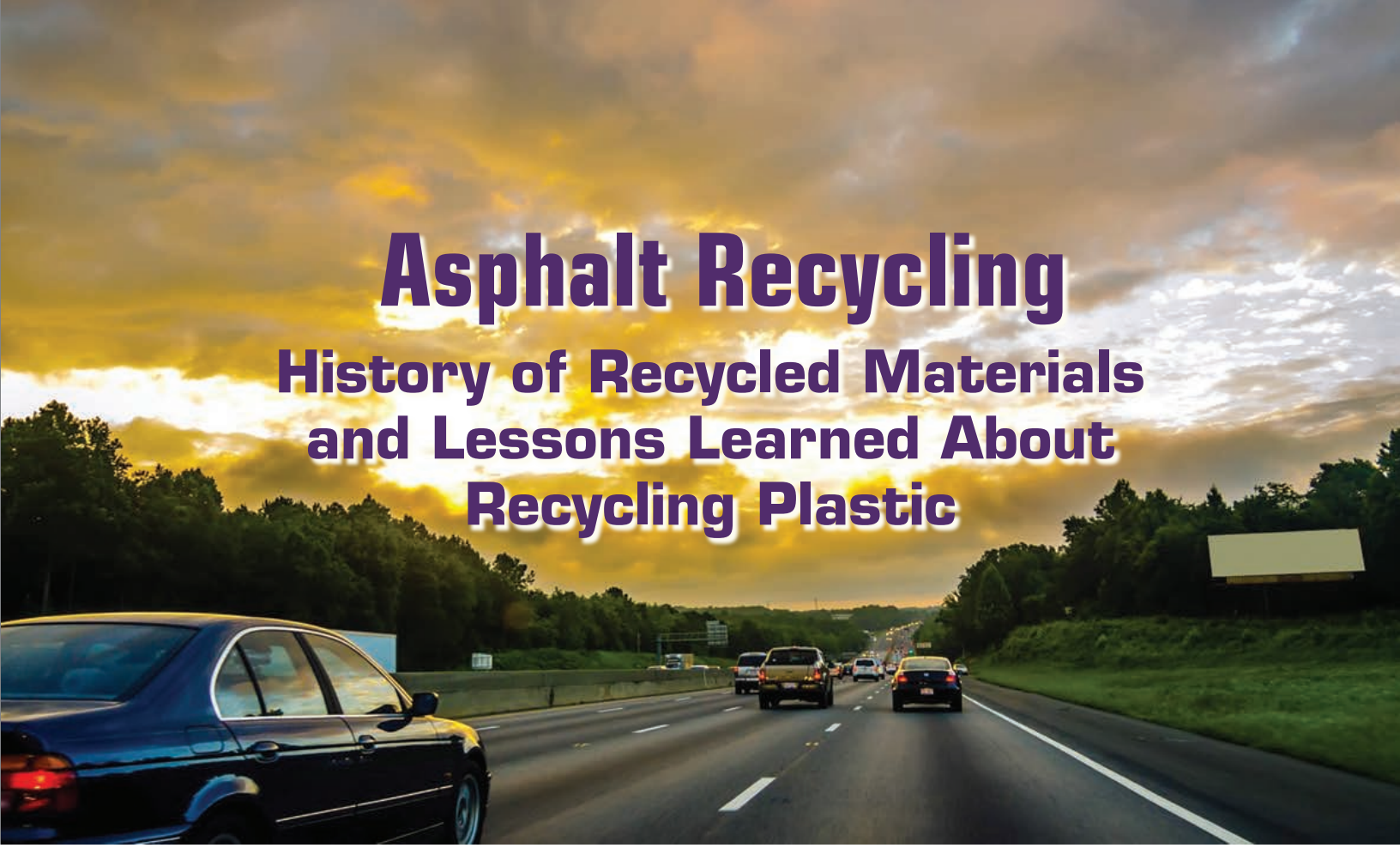

Asphalt Recycling

History of Recycled Materials and Lessons Learned About Recycling Plastic

Photo: Pixabay

J. RICHARD WILLIS AND ISAAC L. HOWARD

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Above: Traffic runs smoothly along an asphalt highway. For decades, the asphalt pavement industry has mixed asphalt with recycled materials—such as old tire rubber and roofing shingles—as a viable alternative to concrete roads. Today, it is pinning its hopes on recycled plastic.

The waste hierarchy of "reduce, reuse, recycle" is so simple and learned at a young age. As elementary students, many of us remember crushing aluminum cans at home so they could be recycled. We remember feeling good about doing our part—and making a little spending money. But it never occurred to us that someone else then had to take the crushed cans and find a responsible way to reuse that aluminum.

Recycling is a concept that most of society supports as a practice that can benefit the environment and overall well-being, as well as reduce the needs and costs associated with raw materials. However, the conversation needs to shift from just recycling to responsible recycling. People make the same mistake with other words when they sometimes unintentionally reduce the word's scope. For example, "sustainability" has been limited by some to mean just "green" or "environmentally responsible" materials. However, economics and the well-being of people are just as relevant to fully understanding whether a material is truly sustainable.

Recycling for the sake of recycling may be fine in passing conversation, but for those who design, research, and build today's infrastructure—and to the public, who often owns this infrastructure—responsible recycling is key to a more sustainable future. Some say that people are turning highways into linear landfills—and that could be the case if recycling is done without further analysis. However, research can determine whether recycled materials could add benefits to our infrastructure network. In that case, recycling is a responsible action.

The asphalt pavement industry is looking at recycled plastic as a potential new source of waste material for use in its product, and it is expected to increase the durability of the world's roadway networks.

This article describes how asphalt paving technologists have been leaders in recycling for many years, summarizes several of the materials that have been

recycled (or evaluated), and uses this history to provide some perspective on recycling plastic: a topic of worldwide interest. A prevailing theme is that logical decisions backed by engineering, science, and economics have led to successful outcomes, but recycling without doing so responsibly may not be best for the longevity of asphalt pavements.

Truly sustainable practices come in many forms but unify around the environment, economics, and social well-being. Portions of this *TR News* issue provide other ways that transportation is working to be part of a sustainable society, such as using titanium dioxide in highway barriers to facilitate oxidation of air pollutants on the barrier surface. A second example is the recently completed research on sustainable highway construction practices performed under the National Cooperative Highway Research Program (NCHRP) Project 10-91A and documented in Muench et al. (*1*). A third example is work through the Transportation Research Board (TRB) Standing Committee on Resource Conservation and Recovery and its Recycled Material Web Map, an ArcGIS warehouse of the location of various recycled materials intended to connect the supply to construction market demand.[1]

The Plastic Crisis

In 2017, China passed the National Sword policy focusing on the protection of the environment and human health. As part of this policy, effective January 2018, China would no longer take in approximately 45 percent of the world's plastic waste, as it had been doing. This meant that 106 million metric tons of plastic waste needed to find a new home quickly. It is expected that, by 2030, almost 111 million metric tons of plastic waste will be displaced because of this policy. Currently, it is estimated that only about 9 percent of the world's plastic is recycled annually, with more than 80 percent ending up in landfills or in the natural environment. Between four and 12 million metric tons find their way into the oceans each year (*2*).

[1] Recycled Material Web Map. http://rmwm.caps.ua.edu/.

Photo: Pixabay

A plentiful supply of discarded plastic bottles are available to be recycled and mixed with asphalt, offering responsible recycling—and increased durability and affordability—to the world's roadway network.

Since 2018, U.S. cities and counties have responded by banning plastic straws, restaurants have replaced plastic utensils with compostable forks, and people outside of the asphalt pavement industry are now looking to asphalt to help resolve the plastic problem. In 2018, the Plastics Industry Association's New End Market Opportunities for Film working group published *Literature Review: Using Recycled Plastics for Compounding and Additives* (*3*), which—based on previous research—identified the use of plastic film waste in asphalt as a new potential end market opportunity.

It was not long before videos were going viral on social media, and traditional forms of media were reporting that plastic-modified asphalt could increase the life of a pavement by 10 times compared with standard neat asphalt. This solution would solve two of America's greatest issues: the plastic crisis and aging infrastructure.

Then, on November 28, 2018, at a hearing titled "Addressing America's Surface Transportation Infrastructure Needs," the chair of the U.S. Senate Committee on Environment and Public Works asked Robert Lanham, then vice president of the Associated General Contractors of America, about the use of recycled materials—specifically plastics—in roads to build longer lasting, more resilient infrastructure. The topic surfaced in early drafts of legislation. A bill was drafted in the California State Senate that would require the California Department of Transportation to evaluate the use of plastic in asphalt. And in the Fiscal Year 2021 House Transportation Housing and Urban Development Funding Bill, a study on plastics in asphalt was specifically mentioned.

Early media reports made claims about the use of plastic-modified asphalt without providing much data. People were asking "why are we not recycling?" instead of "is it responsible to recycle?" The asphalt industry and state agencies have faced this dilemma before in a long history of using recycled materials and can learn from it moving forward.

The Big Three

The asphalt industry has a 60-year history of recycling postconsumer products, with varying levels of success. In fact, asphalt is one of the most recycled materials in the world (*4*). Terrel et al. (*5*) identified rubber tires, glass, shingles, petroleum-contaminated soils, incinerator residue, slags, and polymers as the most common waste—or postconsumer—materials added to asphalt

mixes. Other materials—such as printer toner and sulfur—have even been incorporated in some asphalt mixtures. But three materials provide the most relevant lessons and blueprints on how to successfully implement recycled materials into asphalt mixtures: recycled tire rubber (RTR), recycled asphalt shingles (RAS), and reclaimed asphalt pavement (RAP).

RECYCLED TIRE RUBBER

RTR—often used as smaller particles and referred to as ground tire rubber—is typically mixed with either asphalt binder or an asphalt mixture to improve the asphalt binder properties and make it more resistant to rutting or cracking. The first modern use of this recycled material in asphalt mixtures was a product called asphalt rubber. It was introduced in the 1960s in Arizona as a field-blended product (*6*). In the late 1980s, other states began to evaluate the use of rubber-modified asphalts. For example, state Senate Bill 1192 urged Florida to begin a research program that showed that the rubber modification did indeed improve the overall performance of the mix (*7*).

In 1991, Section 1038(d) of the Intermodal Surface Transportation Efficiency Act shifted the use of RTR from a voluntary action to a federal mandate when it required states to use a minimum amount of RTR each year beginning in 1994. Although the mandate increased RTR usage, it also prematurely moved a material from the research phase to implementation. Because of pushback, the mandate was removed in 1995 under Section 205(b) of the National Highway System Designation Act. RTR usage continued in some states, but most states discontinued RTR programs and did not reconsider its use again until 2008, when the price of polymers increased, and states needed another option for modification. In 2019, a survey conducted by asphalt mixture producers showed the use of RTR in only 10 states (*4*).

RECYCLED ASPHALT SHINGLES

RAS was first thought to be a potential replacement for asphalt binder in new asphalt mixtures in the early 1980s. However, it was not until the cost of asphalt binder rose significantly in the mid-2000s that asphalt mixture producers and road owners really began to explore its use. Between 2009 and 2012, the amount of RAS used in asphalt mixtures rose from 0.702 million to 1.863 million tons. In 2014, RAS usage hit an all-time high of 1.964 million tons. But, then, usage began to drop, and in 2019 it was estimated that only 0.921 million tons of RAS were used in asphalt mixtures (*8*).

When RAS was introduced, states would commonly allow up to 5 percent RAS in new mixtures, with some states going as high as 7 percent. For example, the Texas Department of Transportation (DOT) did a preliminary study that suggested that RAS could be used in asphalt mixtures, allowing up to 5 percent in surface mixtures and up to 10 percent in base mixtures. The department then developed an implementation plan (*9*). RAS usage in Texas has decreased over the past few years, because the agency began to see poor performance of mixtures with RAS. Other states and contractors have reduced RAS usage intentionally, for similar reasons.

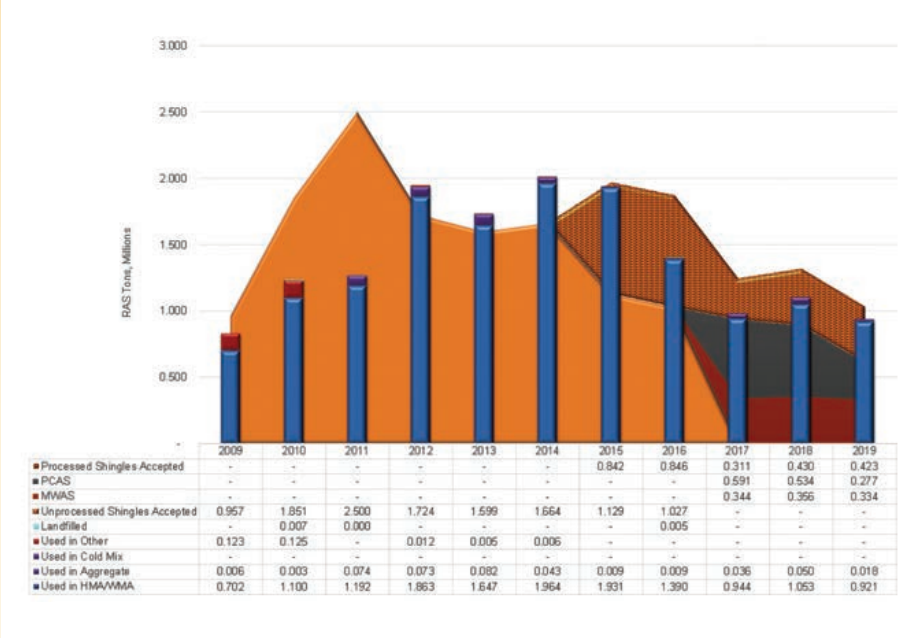
Numerous studies and organizations have found that RAS can be used effectively. However, these mixtures must be engineered to ensure performance. Such engineering includes using well-characterized RAS and ensuring that mixtures contain enough virgin asphalt binder. Construction and production of these mixtures are also critical (*8*). As Figure 1

Photo: Pixabay

Old tires brought new hope to the asphalt pavement industry in the 1960s, when Arizona introduced recycled tire rubber (RTR)—also known as ground tire rubber—as a field-blended product to resist rutting and cracking. Although it showed some improvement in performance, premature implementation via federal mandates resulted in reduced usage over the years. By 2019, only 10 states still used RTR.

Photo: Missouri Department of Transportation

Used as an asphalt binder, recycled asphalt shingles—or RAS—took off around 2009. In 2014, it reached its peak usage at 1.964 million tons. But it was all downhill from there. By 2019, only 0.921 million tons was in use as an asphalt mixture.



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Processed Shingles Accepted	-	-	-	-	-	-	0.842	0.846	0.311	0.430	0.423
PCAS	-	-	-	-	-	-	-	-	0.591	0.534	0.277
MWAS	-	-	-	-	-	-	-	-	0.344	0.356	0.334
Unprocessed Shingles Accepted	0.957	1.851	2.500	1.724	1.599	1.664	1.129	1.027	-	-	-
Landfilled	-	0.007	0.000	-	-	-	-	0.005	-	-	-
Used in Other	0.123	0.125	-	0.012	0.005	0.006	-	-	-	-	-
Used in Cold Mix	-	-	-	-	-	-	-	-	-	-	-
Used in Aggregate	0.006	0.003	0.074	0.073	0.082	0.043	0.009	0.009	0.036	0.050	0.018
Used in HMA/WMA	0.702	1.100	1.192	1.863	1.647	1.964	1.931	1.390	0.944	1.053	0.921

FIGURE 1 **Comparison of tons of RAS accepted and tons of RAS used or landfilled (million tons), 2009–2019. Processed RAS acceptance first tracked in 2015 (*8*).**

shows, the freefall on RAS usage plateaued and seemed to stabilize over the past three years, but more confidence in the product is needed for increased usage.

RECLAIMED ASPHALT PAVEMENT

RAP became a valuable material in the 1970s. The Arab oil embargo was driving up the price of crude oil, and the Federal Highway Administration (FHWA) responded by partially funding Demonstration Project 39 to include and document the use of RAP in pavements. Over the next 20 years, NCHRP and FHWA published guidelines and recommendations for the effective use of RAP in asphalt pavements (*10*).

From the late 1990s through the early 2010s, NCHRP and state departments of transportation funded research to help engineers understand how to use RAP effectively in mixtures (*10*). In 2013, research was completed on how contractors and agencies could move to high-RAP mixtures (*11*). Despite some countries using high-RAP mixtures effectively (*12*), the average RAP content in the United States in 2019 was about 21 percent but has steadily increased since 2009 (*4*), as shown in Figure 2. Although this calculation is about a 5 percent increase from the 2009 value, more recent research shows contractors and agencies whether and how to use recycling agents to increase recycled material content (*13*, *14*).

To move the industry and private road owners to a national average of 21 percent RAP usage, it has taken more than 40 years and millions of research dollars. It has also required road owners, the asphalt pavement industry, and academia to ask questions and find solutions to ensure that RAP is used responsibly. FHWA's policy on recycled materials states the following:

1. Recycling and reuse can offer engineering, economic, and environmental benefits.
2. Recycled materials should get first consideration in materials selection.
3. Determination of the use of recycled materials should include an initial review of engineering and environmental sustainability.
4. An assessment of economic benefits should follow in the selection process.
5. Restrictions that prohibit the use of recycled materials without technical basis should be removed from specifications. (*15*).

This policy shows that it takes research, collaboration, and time to ensure responsible recycling. When recycling is done responsibly, it is encouraged and even applauded. Data and analysis are needed to develop the technical merit, and only time can prove field performance.

Is Plastic in Asphalt the Answer?

When asphalt pavement industry technologists are asked how they feel about using plastics in asphalt, they commonly respond that they are "cautiously optimistic."

Road owners, researchers, and others

(*continued on page 26*)

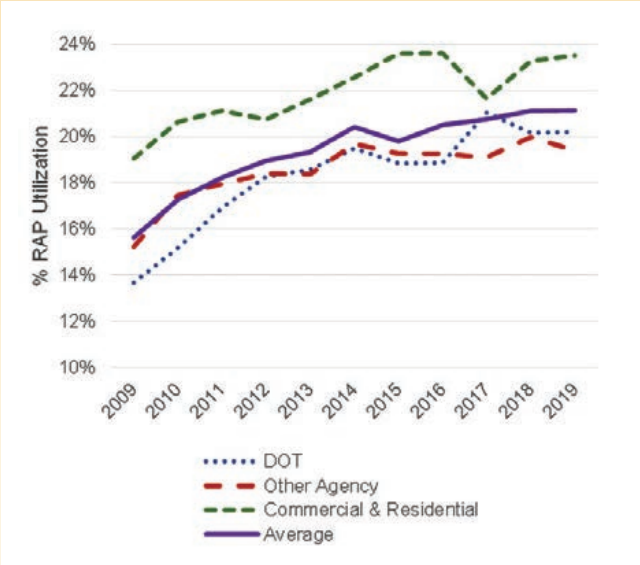


FIGURE 2 **Average percent RAP used by sector (*4*).**

When Funding and Sustainability Collide

J. RICHARD WILLIS AND ISAAC L. HOWARD

Informally, "green" is everywhere in the sustainability conversation: economics have a financial green, the environment often has a very different green, and social well-being is optimized when these two shades of green harmoniously interact. But, unfortunately, they often do not align. In Figure 1, asphalt binder—represented by PG 67-22 grade (or equivalent)—was generally $100 to $200 per ton from 1980 through 2005 (an average of $138). Just after Hurricane Katrina in 2006, prices spiked and have never achieved previous levels (values shown are actual prices and are not adjusted for inflation). The average price from 2006 through mid-2020 was $461 per ton, and polymer for modifying the material to PG 76-22 would have increased this price to roughly $600 per ton.

The other important value to consider in Figure 1 is the fuel tax. Although many states have recently passed legislation that has raised money for local roads, the federal fuel tax has not increased since 1993. As state agencies are doing more with less (adjusted for inflation), recycling becomes more enticing because it can sometimes lead to a cost reduction. For example, the cost of milling and processing reclaimed asphalt pavement typically is less than the cost of extracting and processing new aggregate sources or of refining crude oil into asphalt binder.

Not all recycled materials have a positive economic impact. There are times when recycling may be a break-even replacement or, because of processing, it may even cost more than nonrecycled alternatives. In the low-bid system wherein most pavements are constructed, the additional cost of some materials might dissuade use of recycled materials—unless there is an economic incentive to recycle.

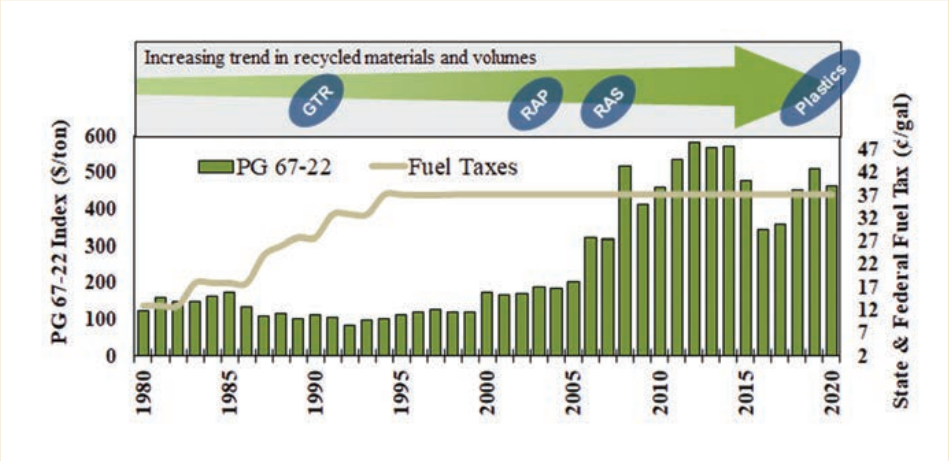


FIGURE 1 Paving market summary.

Photo: Caltrans

In July 2020, the California Department of Transportation (Caltrans) made highway history for the state when the department repaved Highway 162 between the Feather River and Christian Avenue in Oroville. Using recycled asphalt pavement and liquid plastic made from single-use plastic bottles, Caltrans marked the first time the department had paved a road with 100 percent recycled materials. The project illustrated responsible recycling at its best: a one-mile segment of pavement recycled approximately 150,000 plastic bottles.

(*continued from page 24*)

in the industry should consider the following factors when the subject is broached:

1. Not all plastic is the same. Some plastics will not melt at typical asphalt plant temperatures. And some plastics release toxic gases when heated. Research needs to evaluate how—or even if—each plastic type might best be leveraged in an asphalt mix.
2. This is not the first time the industry has tried to use plastic products in asphalt mixtures. In the 1990s, low-density polyethylene was used in asphalt mixtures with varying success. Lessons learned about plastics in asphalt have been synthesized to help technologists understand what the industry knows with regard to performance (*16*).
3. The industry needs to ask and researchers need to answer the following questions:
   a. How should a standard be written to ensure plastic quality?
   b. Does running plastic through an asphalt plant affect permitting because it changes the fumes released?
   c. Do microplastics leach into the environment over time as traffic moves over the pavement?
   d. If microplastics are released into the air during milling activities, do they pose health and safety risks for workers?
   e. Does incorporating plastic in the asphalt mixture prevent it from being recycled again? If so, is the industry exchanging a giant pile of plastic for a larger pile of asphalt? In 2019, 89.2 million tons of asphalt mixture were recycled into new pavements (*4*).
   f. Does the industry need to modify any current testing methods to characterize mixtures with plastic?
   g. If the plastics are added at the wrong point in a plant, could they ignite and set the plant on fire? Additionally, if the fine plastic particles are not totally captured by the binder and aggregate, then they may escape into the plant's baghouse filters and reduce functionality.

What Can We Do?

There is no quick and seemingly magical solution, but whether plastic in asphalt can be the next great recycling story boils down to patience, partnership, and open communication.

Right now, patience is most important. Research takes time, and rushing the use of plastic in asphalt for political reasons—as with RTR—or for economic reasons—as with RAS—is not optimal. The new NCHRP Project 09-66 focuses on plastics used in asphalt. FHWA is sponsoring research on the chemistry of plastic binder compatibility. Texas DOT is conducting research on the subject. And states and private road owners are starting demonstration projects to help answer questions.

After the science bears out, the asphalt industry, the plastic industry, academia, and road owners need to work in partnership to responsibly deliver safe, durable, and sustainable pavements to the driving public.

Good communication will ensure that the public understands the industry's current recycling efforts, as shown in the Mississippi State University video

Construction Matters 2: Recycling.[2] The TRB Standing Committee on Production and Use of Asphalt has focused efforts to assemble and communicate information on recycling plastic in asphalt to the industry and related agencies. One notable product is a pending TRB E-Circular that will tell part of the story of plastic in asphalt. It will present a historical overview, discuss binder compatibility, and provide two case studies of projects that have used plastic in asphalt.

Although plastic was incorporated in the past and worked well in varying degrees, the market has since changed considerably. Today's market factors may or may not be suitable for plastic. India uses plastic waste in a dry process, and France uses plastic in its high-modulus asphalt mixtures. However, coming full circle, patience is needed for partner-driven research to evaluate plastic waste's worthiness in conventional asphalt mixtures. Asphalt industry technologists should avoid the mindset of "this isn't going to work" or "the amount of plastic waste that the asphalt industry could reduce is just a blip on the radar." They also should avoid thinking that "just because we *can* recycle asphalt doesn't mean that we *should*." Any of these phrases may or may not be true. Time is the best storyteller, and the industry should let time tell the story of plastic in asphalt while it works toward as much responsible recycling as possible.

[2] *Construction Matters 2: Recycling*. https://www.youtube.com/watch?v=ho8eKKwsnqM.

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CENTENNIAL QUOTE

"My vision for the Transportation Research Board and the transport industry 100 years from now is that we will have transitioned to better, more efficient, and accessible modes of transportation that also take into consideration the complex utility needs of its users. The more technologically advanced society becomes, the greater the desire for community and human connection. I hope we, as transport-industry professionals, reimagine and build a transportation system that better accommodates all of us for a truly cohesive sense of community and oneness as a human race—if aliens aren't a thing by then.

—WINNIE OKELLO
Senior Civil Engineer,
Pennsylvania Department of Transportation, Harrisburg

RECYCLED MATERIAL WEB MAP

WHERE THE MATERIALS ARE AND HOW TO ACCESS THEM

Photo: Pixabay

DAVID WILSON, ANDREW J. GRAETTINGER, ED WALLINGFORD, ANGELA PAKES, AND RANDY K. SMITH

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Above: To the average person, what looks like common demolition debris—steel cable and chunks of concrete—is a rich source of reuse for a variety of transportation construction applications. Recycled steel reinforces concrete road surfaces. And reclaimed concrete converted to aggregate is used in constructing highway embankments.

Each year, the United States produces more than half a billion tons of recyclable materials, including construction and demolition debris, foundry sands, coal combustion products, and slags. Such materials—in addition to similar nonhazardous waste products generated from manufacturing, industry, and electric utilities—have the potential to be reused for a variety of transportation construction applications. Since its inception, the Transportation Research Board (TRB) Standing Committee on Resource Conservation and Recovery has maintained a focus on research that supports the environmentally responsible reuse and recycling of such materials in the transportation industry. The science and engineering testing of these materials often points to performance comparable to—if not superior to—virgin materials. However, numerous discussions within the committee reveal that widespread use of potentially recyclable materials—by engineers who develop construction specifications and construction contractors who might utilize these materials—is deterred by their lack of access to information that includes the following:

- An understanding of the beneficial use of a material,
- An understanding of the specifications and regulations that apply to allow beneficial reuse of various materials,
- An ability to locate an available source of recyclable material, and
- Case studies of where these recycled materials have been used in other projects.

Many committee members also noted that extensive research has been conducted on the engineering uses and applications of recycled material and that numerous material exchange websites provide opportunities for facilities and companies to post available and wanted material types, quantities, cost, and material characteristics. Nevertheless, there is a gap in available technology that 1) connects producers to consumers of

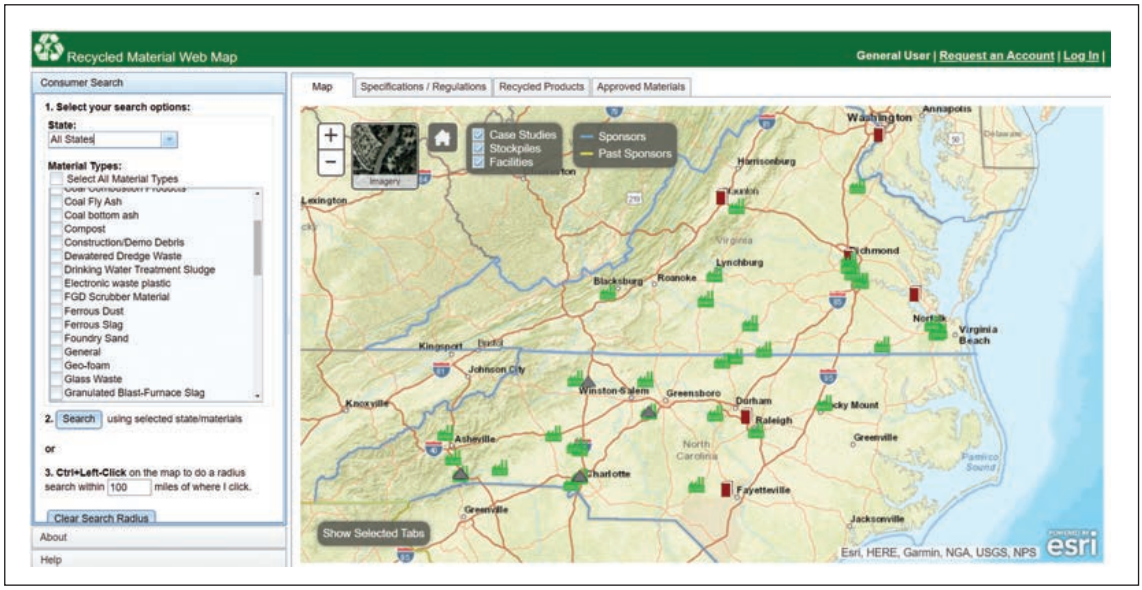


FIGURE 1 The home screen shows the interactive map and the Consumer Search option to the left. Users can click to search for one or several materials at a time.

recycled materials on a location basis and 2) connects consumers to additional information to facilitate increased use of recycled materials. In response, several committee members—in collaboration with the Recycled Materials Resource Center (RMRC) at the University of Wisconsin–Madison and the University of Alabama—contributed to the development of a Recycled Material Web Map (Figure 1).[1]

The primary objectives of the Recycled Material Web Map are to promote the reuse of nonhazardous recyclable material and to close the technology gap by creating an online GIS-based tool that includes 1) location and availability of recycled material sources to connect producers and their stockpile to consumers, 2) case studies of past projects that successfully used recycled material, 3) recycled products for the transportation market, and 4) approved materials and specifications and regulations that pertain to the use of recycled material in construction projects.

Spatial Component of the Site

The Recycled Material Web Map includes an interactive online tool and a supporting website developed by The University of Alabama and pool-funded at RMRC. Three user levels are associated with the map: general users, producers and suppliers of recycled material, and advanced users. General users can search for local recycled materials, specifications, and case studies that used recycled material in construction projects. Producers and suppliers can promote material by entering, updating, and maintaining material source information. Additionally, advanced users—such as researchers and transportation agencies—can add state department of transportation (DOT) specifications, environmental regulations, and case studies. The map application provides specific functionality for each of these user levels.

The website evolves as new producers, stockpiles, and case studies are added. The default map view of the website is underlain by an Esri base map that toggles between street view and aerial imagery. The map features a user-friendly interface and is accessible on mobile devices. Facilities are depicted with green factory symbols, stockpiles are shown as gray triangles, and case studies are represented as red rectangles.

Users can zoom in and out of the map using the plus or minus buttons located on the top left corner of the map view or by selecting a state from the dropdown menu on the search panel. When a state is selected, the map zooms in to the state level, and users can zoom in further to view a project site by using the plus button or the roller wheel of the mouse. Across the top of the default screen are tabs that include 1) Map, which is the default view; 2) Specifications/Regulations, which displays state and federal information; 3) Recycled Products, which lists transportation products with at least 50 percent recycled content; and 4) Approved Materials, which lists state DOT–approved recycled materials. All of this information can be filtered for a specific state.

The sidebar to the left of the map screen includes several panels: Consumer Search, About, and Help. The Consumer Search panel allows users to specify a state and search for specific materials of interest. The About and Help panels include a user guide and several video tutorials of the website's major components.

Users with producer or advanced user credentials will have additional sidebar panels to add and update materials, case studies, and specifications and regulations. A result grid at the bottom of the default map screen can be displayed by selecting Show Selected Tabs. This grid will display producers, stockpiles, and case studies that are selected based on the search criteria applied in the Consumer Search panel.

General Users, Producers, and Stockpiles

The general user access level is open access, allowing anyone to view and search the website for recycled material stockpiles, specifications and regulations, recycled products, approved materials, and past case studies. The user can search the Recycled Material Web Map in several ways. The Consumer Search allows the user to select a specific state and material type(s) to filter the stockpiles. For example, a contractor working on a shoulder project in Virginia wants to look for recycled asphalt and compost. He could zoom into Virginia on the map by clicking on the state or by using the computer's mouse

[1] The Recycled Material Web Map is available at https://rmrc.wisc.edu/.

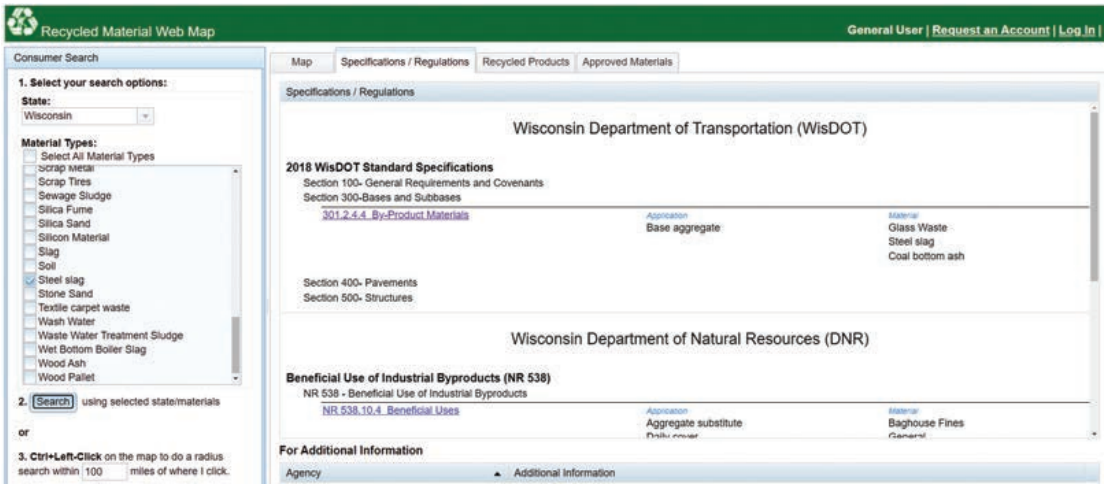


FIGURE 2 This view of the Specifications and Regulations tab demonstrates the results of toggling for information on steel slag in Wisconsin. Specifications and regulations website links are automatically checked each week to keep links current.

roller wheel. He also could simply go to the left side and select Virginia from the list of states in the dropdown menu.

Next, to drill down on the material of interest, the contractor would select reclaimed asphaltic material and compost from the material types list. If another material might work for his application, he could also add that material from the list. Finally, he can click Search on the sidebar and all the stockpile results will appear on the map and in a data grid at the bottom of the map. To see the results in the data grid, the contractor would click on the gray Show Selected Tabs button and producers, stockpiles, and case studies that match the search criteria would be displayed in the grid. The Selected Producer tab has information needed for him to contact the producer, and the Selected Stockpiles tab shows material type and quantities, if available.

The producer user level has all of the capabilities of the general user level, plus several additional mapping privileges. For example, a producer can locate her facility and stockpiles. If a producer at a foundry south of Cincinnati wants to post used foundry sand, she would first request a producer login from the login page on the Recycled Material Web Map. Next, she would login, select the Producers and Stockpiles tab from the left-hand sidebar, click on the Add a New Producer button, and zoom to the location of her facility.

Switching the base map from Street view to Imagery view allows the facility owner to place the new producer symbol directly on her building. Next, she can place stockpiles representing each pile of foundry sand. In the comments section, the producer can list any material characteristics and provide quantity information and cost, although these fields are not required. The new facility and any stockpile locations and information will be available to all site users, but only the facility owner can edit her information.

Specifications and Regulations

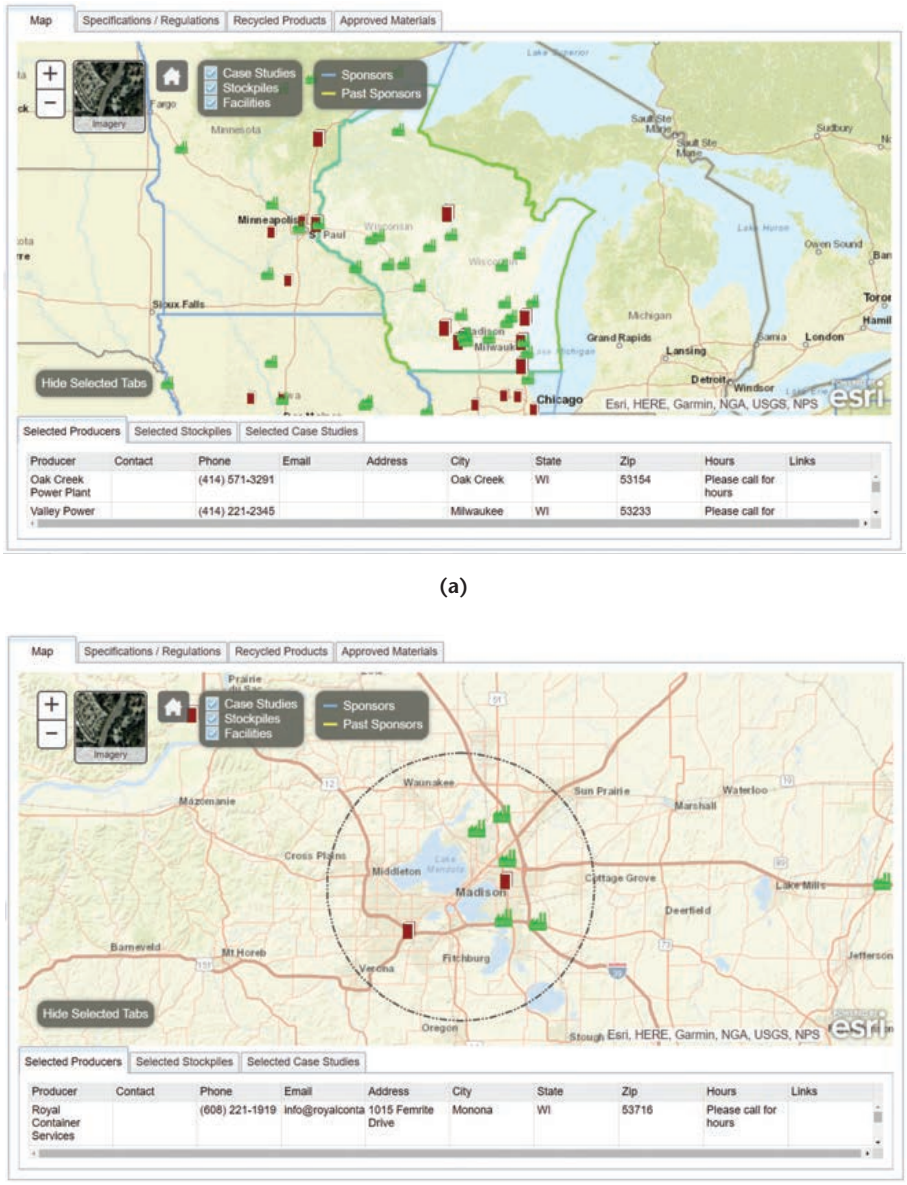
In addition to searching for available stockpiles and viewing producer contact information, general users can also search federal and state DOT specifications and environmental regulations that apply to the beneficial use of recyclable material. The majority of state DOTs maintain construction specifications for the use of recycled material in roadway construction projects, and the state environmental agency typically regulates the use of recycled material. Any recycled material that is used in construction projects must meet both sets of requirements. The recycled material specifications and regulations were collected for national and state entities and incorporated into the tool to provide focused information for users. Specifications and regulations from federal agencies including the American Association of State Highway and Transportation Officials, the Federal Highway Administration, and the U.S. Environmental Protection Agency were identified and included in the database. Specifications from state agencies (i.e., departments of natural resources, waste management, and ecology) included permissible use and guidance for reuse. Also, specifications and regulations for states in the RMRC pooled fund were included.

To search the specifications and regulations, users can filter by state or material on the aforementioned consumer search panel or simply click on a state on the map. For example, if an engineer wants to find specifications and regulations that pertain to steel slag in Wisconsin, he can follow the same steps as the contractor to select Wisconsin in the dropdown menu. Next, he can select Steel Slag from the Material Types list and click the search button. The engineer will need to switch to the Specifications/Regulations (Figures 2, 3, and 4) at the top of the page, which in this example will display WisDOT [Wisconsin DOT] Standard Specifications 301.2.4.4 By-Product Materials and Wisconsin Department of Natural Resources Regulations NR 538.10.4 Beneficial Uses of Industrial Byproducts. Both titles are hyperlinked to the agency web pages that display the specification and regulation.

Transportation agencies can receive advanced user login credentials, which will provide them with additional information on agency construction and materials specifications and regulations, as well as case studies.

Case Studies

The case study layer presents transportation projects that successfully utilized recycled materials. Case studies are uploaded to the site through a data entry form that



FIGURES 3–4 **Database results show a statewide search for Wisconsin (*a*), as well as a narrower 10-mile-radius search around the city of Madison, Wisconsin (*b*). Engineers and contractors commonly use the latter to locate materials within a specific distance from the job site.**

requires a location for the project, as well as the recycled material used in the project. Additional information about the case study can include a synopsis of the project, pictures, and any other project documentation, such as final reports or presentations. Currently, 40 case studies—primarily associated with pooled-fund states—are uploaded to the site.

If, for example, an engineer wanted to review case study projects in Illinois (Figure 5) that are uploaded to the Recycled Material Web Map, she would select Illinois from the map or sidebar and click on the Show Selected Tabs at the bottom of the map. Switching to the Selected Case Studies tab shows information about each project. The engineer can refine her search to a specific material, such as scrap tires, and only the projects using scrap tires will be displayed. She also can click on the red notebook icon on the map to bring up a pop-up that contains project information and hyperlinks, if they are available.

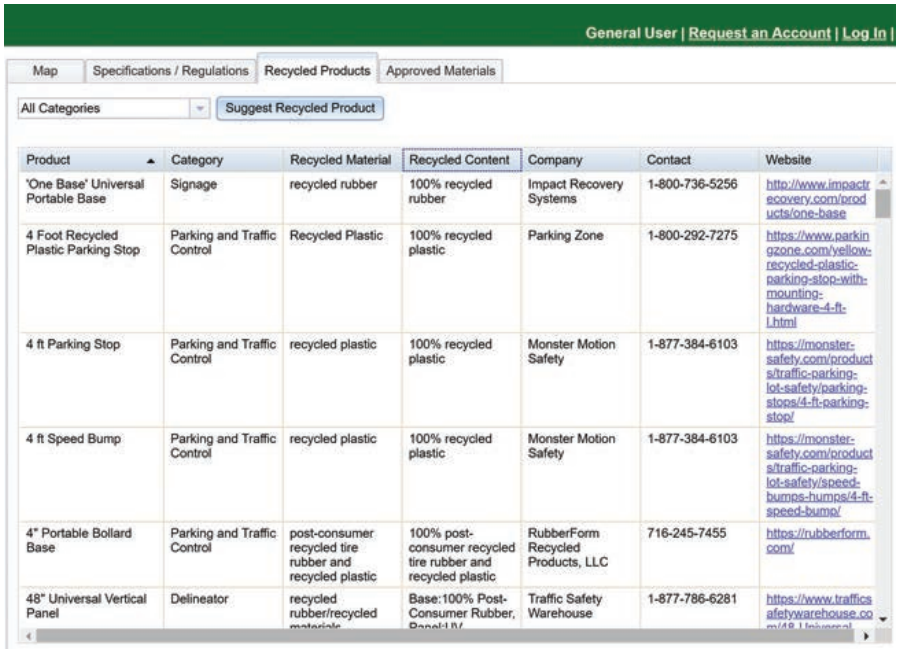
Transportation Products with Recycled Content

The Recycled Products information tab (Figure 6) includes transportation products made with a minimum of 50 percent recycled content. On the site, products are described and assigned a product category. The recycled material is used in a product, and the percentage of recycled content is listed, along with the company name, phone number, and website. Product categories include Parking and Traffic Control Devices, Signs, Delineators, Construction Products, Cones, Barricades, Channelizers, and Sound Barriers. New products are added to the site by the site administrator, but the Recycled Products tab includes a feature for users to recommend new products.

Approved Materials

The Approved Materials tab lists materials that have been approved by a state DOT. Each material and producer can be associated with one or multiple states. The materials are described with the material name, producer, source, address, application, and key information that allows engineers and contractors to better understand a recycled material. The approved material layer contains more than 350 recycled materials that have been approved by state DOTs for use in transportation applications. This tab allows engineers and contractors working in one state to have quick and easy access to approved materials and to also provide information that may be beneficial from neighboring states. It is interesting to note that allowable recycled material content levels in specific material–application combinations vary state by state. Observing recycled material and allowances in neighboring states provides information that may increase the use of recycled material in transportation projects.

FIGURE 5 This case study highlights recycled crumb rubber modifier in hot-mix asphalt from a paving project in Illinois.



Product	Category	Recycled Material	Recycled Content	Company	Contact	Website
'One Base' Universal Portable Base	Signage	recycled rubber	100% recycled rubber	Impact Recovery Systems	1-800-736-5256	http://www.impactrecovery.com/products/one-base
4 Foot Recycled Plastic Parking Stop	Parking and Traffic Control	Recycled Plastic	100% recycled plastic	Parking Zone	1-800-292-7275	https://www.parkingzone.com/yellow-recycled-plastic-parking-stop-with-mounting-hardware-4-ft-l.html
4 ft Parking Stop	Parking and Traffic Control	recycled plastic	100% recycled plastic	Monster Motion Safety	1-877-384-6103	https://monster-safety.com/products/traffic-parking-lot-safety/parking-stops/4-ft-parking-stop/
4 ft Speed Bump	Parking and Traffic Control	recycled plastic	100% recycled plastic	Monster Motion Safety	1-877-384-6103	https://monster-safety.com/products/traffic-parking-lot-safety/speed-bumps-humps/4-ft-speed-bump/
4" Portable Bollard Base	Parking and Traffic Control	post-consumer recycled tire rubber and recycled plastic	100% post-consumer recycled tire rubber and recycled plastic	RubberForm Recycled Products, LLC	716-245-7455	https://rubberform.com/
48" Universal Vertical Panel	Delineator	recycled rubber/recycled	Base:100% Post-Consumer Rubber,	Traffic Safety Warehouse	1-877-786-6281	https://www.trafficsafetywarehouse.com/

FIGURE 6 The Recycled Product tab lists details for common transportation-related products that are manufactured from recycled material, as well as manufacturers' website links and contact information.

Link Checker to Keep the Site Current

The Recycled Material Web Map provides web links in the regulations, specifications, case study, and recycled products layers. To avoid broken links over time, an automated process routinely checks for changes in the associated page for each link and notifies the site administrator for further review.

Conclusion

The Recycled Material Web Map is flexible and user-defined, allowing—but not requiring—producers the ability to provide information such as quantity, cost, or composite of material constituents. This flexibility overcomes proprietary issues associated with participation in similar recycled material exchange websites in the past. Also, the specification, regulation, case study, recycled products, and allowable materials layers are integrated into the website to provide pertinent information to users, thereby increasing traffic to the site and expanding the user base.

The map can be leveraged by producers and consumers to increase regional sustainability through the use of recycled material. Instead of landfilling recyclable material, producers can offer material and provide key information such as location, company contact, and type of material. By providing consumers a user-friendly map-based interface to find appropriate sources of recycled material closest to a project site, the map promotes the use of recycled material and sustainability. Material stockpiles from state DOTs participating in the transportation pooled fund are being collected and added to the map as part of this project, but any producer can request credentials and add their contact information and stockpile data.

Acknowledgments

The authors acknowledge Brittany Shake, a 2016 University of Alabama civil engineering graduate, who was instrumental in designing the functionality of the site as part of her master's of science thesis, and Steve Burdette and Spencer Livingston of The University of Alabama Center for Advanced Public Safety, who developed the site.

NCHRP RESEARCH REPORT 916

The Road to Sustainable Highway Construction Practices

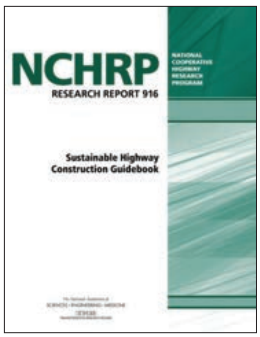
Photo: Washington State DOT

STEVE MUENCH

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

Above: Design–build projects allow a contractor to select aesthetic wall treatments, like the artist-commissioned retaining wall design along the I-5 corridor in Tacoma, Washington. Aesthetic wall treatments are some of the sustainable construction practices (SCPs) outlined in *NCHRP Research Report 916: Sustainable Highway Construction Guidebook*.

In 2016, researchers from the University of Washington, Michigan Technological University, and Greenroads International undertook National Cooperative Highway Research Program (NCHRP) Project 10-91A to produce a sustainable highway construction guidebook. A guidebook is a common request for NCHRP, but the path that led to the end result—*NCHRP Research Report 916: Sustainable Highway Construction Guidebook*—offers some insight into the current status of sustainability in the highway construction industry.



What follows is the story of how *NCHRP Research Report 916* came to be and what we, the research team, learned along the way.

Starting Point

The road to sustainability can be long and complex, but we believe it starts by fully leveraging our existing body of knowledge to produce a more sustainable outcome. Therefore, the best starting point for this guidebook was to ask the construction industry what it already knew. This means that the ideas in *NCHRP Research Report 916* come directly from the owners, contractors, inspectors, testers, consultants, and stakeholders of the highway construction business.

Members of the highway construction industry told us what works, what does not work, what is missing, and what needs to change. This approach produced an open disclosure of information and seems to have avoided any issues with trade secrets. As it turns out, sustainability really is not a trade secret.

Because sustainability is such an all-inclusive subject, a research project on sustainability can devolve into a giant tome about everything. The researchers were

well aware of the time constraints already placed on the construction industry, and we fully believed that a short, practical guide would work best. We were so confident in this idea that, in our proposal, we actually wrote that we would deliver something that was "decidedly not a dusty academic tome." Added pressure for sure.

These basic thoughts led us to base the guidebook on two principles:

1. **Provide ideas, but do not tell industry members how to construct highways.** Highway construction is best understood by the industry members that do it every day for a living. The guidebook would be a dud if it was an instruction manual on construction, but it would have real value as an idea book helping project owners and workers consider the breadth of sustainable possibilities when planning construction—much like a big Pinterest page on sustainable highway construction.

2. **Provide concise, useful information to practitioners.** Be direct, because nobody has time to read a long report—especially the construction industry. Also, give practical advice and not theoretical musings. One can contemplate the existential meaning of sustainability somewhere else.

Guidebook Summary

The approach to the guidebook was to 1) define a few common terms so that we can all speak the same sustainability language and 2) ask industry what they already knew, even if it was not common knowledge. Then, we could distill this down into a few fundamental sustainability ideas and a list of currently feasible sustainable practices.

Most importantly, we wrote minimally about each practice but made sure to point out the resources that contain the real expertise. For instance, accelerated bridge construction is listed as a sustainable construction practice, but we did not write much about its details. Rather, we pointed the reader to the great work the Federal Highway Administration (FHWA), state departments of transportation (DOTs), and others have already done in this area.

Our goal was to draw your attention to an idea, describe why it can be considered a sustainable construction practice, and then direct you to the expert works that best describe it. We also included a way to evaluate any construction practice for its contribution to sustainability. Finally, we added the collective wisdom of the industry concerning the procurement and execution of sustainability on the job.

Photo: Arizona DOT

From the deserts of Arizona to the wetlands of Florida, different transportation agencies have different needs. The guidebook would best function as an idea book for project owners and workers, presenting a range of sustainable approaches to construction.

Getting the Terms Right

There are many different takes on what sustainability means, so it was important to start off by giving everyone the same parameters for contemplating sustainable highway construction. We came up with a pretty standard—but bland—definition: construction practices that can assist in 1) building highways; 2) preserving and restoring surrounding ecosystems; 3) meeting basic human needs such as equity, employment, health, safety, and happiness; and 4) managing resources wisely—including but not limited to money.

We realized this was too long and not at all memorable, so we came up with a shorter version of this definition for our project:

> Sustainable construction practices (SCPs) are those that 1) go above and beyond standard practice, required national regulatory minimums, or both or that 2) show innovation in meeting these standards and minimums in support of people and the environment.

Probably still too long. Here is the shortest version: **Above and beyond for people and the environment.**

Asking the Industry

The researchers spent most of their time on the project asking industry members what they knew about sustainability. We did this using a literature review, a survey (with more than 350 responses), interviews (26 of them), and a two-day workshop in Irvine, California.

I will bypass the compiling, reporting, and categorizing that went along with all of this and cut to the findings. To start with, here are some interesting things industry had to say about sustainability:

- **Most organizations value sustainability.** About 70 percent of survey respondents either agreed or strongly agreed with this statement: "Sustainability is a core value of my company/organization." That was a pleasant but expected finding. Sustainability does nice things for people and the environment. Very

Photo: Steve Muench

Workers with contracting company Kiewit reuse a bridge pier from the demolished SR-99 waterfront viaduct in Seattle for a new pedestrian walkway to the adjacent ferry terminal. In the right situation, such as this, repurposing existing structures can save time, money, and materials and can reduce environmental impacts.

few oppose that on principle. What they typically oppose, if anything, is the perceived cost. In that sense, sustainability is a lot like safety.

- **Sustainability is strongly associated with durability and long life.** When asked to define sustainability in their own words, about one-third of respondents referred directly to endurance and durability of the infrastructure itself.
- **Sustainability efforts are often driven by cost.** Asked to rank motivation for sustainability among several choices, "optimize life-cycle cost of highway infrastructure" was ranked highest.
- **There is no leading entity in highway sustainability.** Unlike the building industry (for example, LEED or the Living Building Institute), there is no consensus leader in the highway industry that defines sustainable practices and their impacts.

Beyond these observations, several key concepts became clear regarding the industry's use of sustainable construction practices:

- There is little guidance on procuring sustainability in highway construction. Contractual requirements for sustainability often are not present; when they are, they can be sparse, imprecisely worded, or unverifiable.
- **Materials recycling is the most-identified sustainable construction practice.** About one-third of responses identified this practice on the survey, and it was the practice most frequently cited in answer to open-ended questions about sustainability.
- **In a competitive bid environment, contractors are likely to implement sustainable construction practices that directly reduce their costs or make them money; other practices must be compensated for by the owner.** It is unreasonable to ask a contractor to do something sustainable that costs them money if they are not compensated for it.
- **The competitive advantage from implementing a sustainable construction practice is short-lived.** Several contractors pointed out that competitors are quick to imitate successful practices. Although this may be good for sustainability as a whole, it can be a deterrent to early adoption if contractors cannot find a way to recoup their investment before the competition catches up.
- **Sustainable practices tend to work.** Only 16 percent of survey respondents identified failed attempts at a sustainable practice. This may be because the highway industry is quite conservative in its approach to adoption of alternative practices.
- **Alternative materials and methods must perform as good as or better than current standard practice.** Even though an alternative practice may have added benefits, many industry members feel that it must still match the current practice on traditional metrics. In other words, there is little appetite for trading off worse performance in one area for better performance in another.

Making the Guidebook

First, as researchers often do, we made some categories. After the literature review, survey, interviews, workshop, and panel input (of course), we had a list of 79 sustainable construction practices, but it was really important to display them in a straightforward way and to make them easily searchable by category.

Although an online presentation would have been ideal, we had to work with the standard delivery formats: PDF and paper. We organized the sustainable construction practices into categories similar to what you see in a typical state highway agency standard specification. Also, we organized the idea of sustainability into the standard

Photo: Steve Muench

Contractors routinely use reclaimed asphalt pavement (RAP) in new asphalt pavement mixtures. In the right situations, this kind of recycling reduces virgin-materials use (and the environmental impacts of extraction and production) eliminates potential waste, and saves money. RAP use is part of the Recycle Highway Materials SCP presented in *NCHRP Research Report 916*.

three dimensions (human, environment, and economy), but with subcategories that the workshop participants had told us would be most understandable to readers like themselves (the original categories we had used were pretty bad).

Finally, we related these two sets of categories to show which types of construction practices were most likely to address which sustainability categories (Table 1).

Second, we condensed each sustainable construction practice into three components (Figure 1):

- **A short summary of the practice.** This is similar to an executive summary that highlights why the practice can be considered sustainable.
- **A list of the top several references on the topic.** These are the documents, websites, or videos to go to if you really want to learn about something. Many of these are NCHRP reports, FHWA work, or state DOT–sponsored research.
- **A numerical score for that practice.** Yes, we scored each practice. Honestly, we thought this would be controversial, but in every sustainability effort we have been a part of there has been a strong urge to quantify practices—even when it is not really possible. So, we took a shot at it and used our research team, the NCHRP panel, and workshop participants as an expert review crew to score each sustainable practice. Each was subjectively scored on a 0–5 point scale for effort (based on the associated time and expense to do the sustainable practice—the cost, so to speak), and then benefits to human welfare, the environment, and cost savings. Then we divided the last three benefits by the effort to come up with a single number that represents the impact-to-effort ratio.

This Is Going to Get Old Real Fast, Isn't It?

As you might suspect, a list of sustainable best practices for 2017–2019 (when the research was done) may not withstand the test of time very well. Some will be superseded by better ideas, others will become standard practice, and new

TABLE 1 Construction and Sustainability Framework Mapping

Highway Construction Framework		Sustainability Framework									
		Human Wellbeing			Environment Wellbeing				Economic Wellbeing		
Level	Category	Workers	Neighbors and Stakeholders	Users	Pollution	Local Ecosystem and Habitat	Consumption	Climate	Project Budget	Maintenance and Operations	Economic Development / Employment
Project Delivery	Project Delivery Method								■	■	
	Financing								■	■	
	Procurement	■	■	■	■	■	■	■	■	■	■
	Contracting	■	■	■	■	■	■	■	■	■	■
Project	Scheduling	■	■	■					■		
	Estimating								■		
	Project Controls & Administration	■							■		
	Earthwork						■	■	■		
	Drainage/Sewer/Water		■		■	■			■	■	
	Aesthetics		■	■					■		
	Walls		■	■		■	■	■	■	■	
	Bridges					■	■		■		
	Pavement			■			■	■	■	■	
	Work Zone Traffic Control	■	■	■			■	■	■		
	Materials				■	■	■	■	■	■	
	Safety	■		■					■		
	Employment	■							■		■
	Training	■			■	■			■		
	Community Outreach		■	■	■				■		■
	Noise	■	■	■	■	■			■		
	Light	■	■	■	■	■			■		
	Constructability/Deconstruction	■	■				■		■		
	Quality	■		■			■	■	■	■	
	Equipment				■		■	■	■		
	Utilities		■						■	■	
	Landscaping		■	■		■			■		

Key: ■ If a Highway Construction Category addresses a Sustainability Category, the corresponding cell is colored green

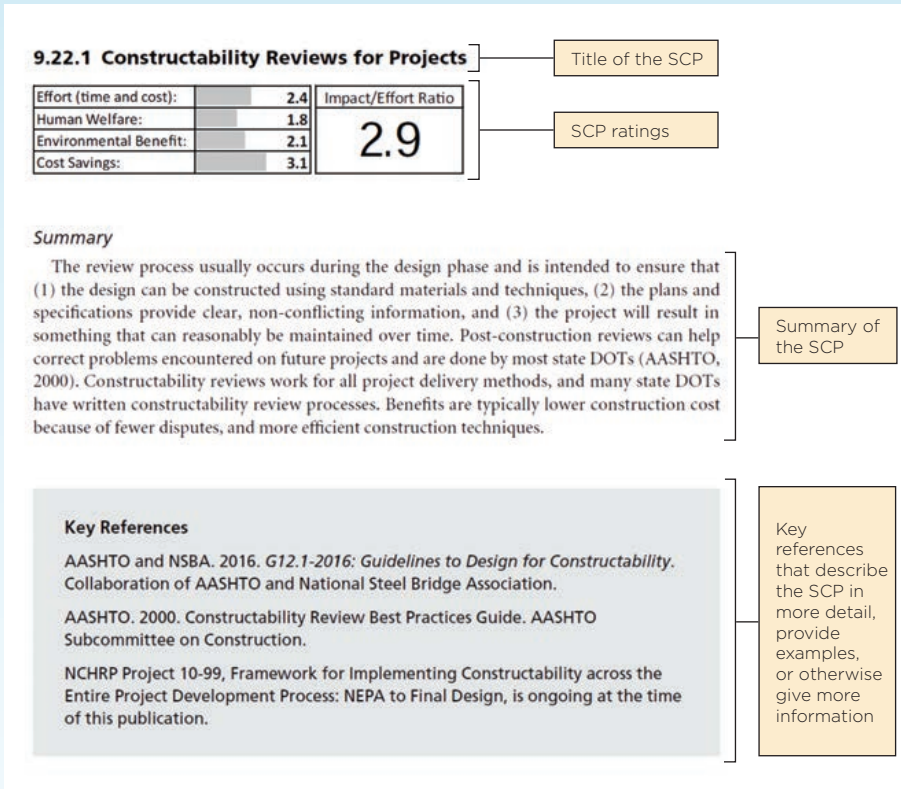


FIGURE 1 A typical sustainable construction practice listing. (Note: SCP = sustainable construction practices.)

ideas certainly will emerge. Therefore, it was important to include a simple, documentable way of evaluating any construction practice for sustainability. You can read *NCHRP Research Report 916* if you want the details on this, but it is a simple enough process that you can do it without a calculator.

What Else Besides a List of Ideas?

Remember that industry members said there really were not any standards for procuring or contracting sustainable highway construction. We took what they identified as good efforts in these areas and bundled them into sections on procuring and contracting for sustainability. Honestly, this could be another research project in and of itself: a project that could take us from hand-waving about these ideas to something as detailed as guide specifications.

For instance, there is room to include sustainability as an evaluation criterion in best-value procurement (it has been done to some extent already), in alternative technical concepts (for example, a contractor could propose a more sustainable alternative), and even in standard procurement (for example, using environmental product declarations as a regular part of materials procurement).

Finally, we learned that sustainability often loses out when pitted against budget or schedule. That is tough to overcome, but a starting point could be a standard sustainability management plan that asks projects to track progress toward sustainability goals and adjust when progress goals are not met—much like what we do for budget and schedule already.

Now What?

Well, that is how *NCHRP Research Report 916* came to be. Does it matter? That depends upon what happens from here. We think this guidebook defines sustainability and its key features, describes a list of current sustainable construction practices, and describes how better to integrate sustainability with construction procurement and delivery. We think this can help the industry in the following ways:

Photo: Steve Muench

On Multnomah County's Sellwood Bridge project in the Portland, Oregon, area, contractor Slayden/Sundt JV used a lateral slide technique in reverse to minimize traffic disruptions and associated delays, fuel use, and environmental impacts. This technique, in which the old 1,100-foot truss bridge was slid to an alternate temporary alignment so the new bridge could be constructed in the original alignment of the old bridge, also saved money compared with traditional in-place replacement.

- By providing a way to translate broad project owner sustainability goals into project construction actions.
- By assisting owners in describing their sustainability goals and objectives more precisely in project procurement and contracting.
- By helping owners and contractors understand which construction actions can address specific owner sustainability goals (Table 1). For instance, if reduced climate impacts is a sustainability goal, as it often is, then construction action in the following categories can address this: procurement, contracting, earthwork, walls, pavement, work zone traffic control, materials, quality, and equipment.
- By offering a source of SCP ideas. The categories that address climate impacts contain 39 different SCP ideas. There may be more, but this is a great start.
- By providing a simple framework to evaluate any construction practice for sustainability. We know that contractors and owners will have lots of great ideas beyond what we list. This framework helps see these ideas within the sustainability context.
- By presenting ideas for procuring and contracting sustainability.

Will the guidebook do all this? That is hard to say. When research projects are proposed, they tend to include a strong component of action: we need to investigate X because we want to do Y. By their nature, however, research projects stop short of implementation. Research is research and implementation is implementation, and the bridge between the two can be a big one to cross. NCHRP offers some help with its Implementation Support Program, and other organizations, like AASHTO and FHWA, can provide implementation support. But, ultimately, it is up to individual sponsoring agencies and their people as to whether or not work like this gets implemented in a meaningful way.

What is the potential? Think about this: as the United States and the world emerge from these trying times in 2020, there is likely to be a big push to build—and fix—infrastructure as part of a national and global economic recovery.

This thinking already exists in political platforms, potential funding bills, and the design and construction community itself. This could present the largest opportunity in a generation to build sustainability into the fabric of our infrastructure. We just need the collective willpower to do it. If we do, hopefully, something like this guidebook can help.

Transportation Network Companies

Impacts to Airport Revenues and Operations

Photo: Jonathan Cutrer, Flickr

CRAIG LEINER AND THOMAS ADLER

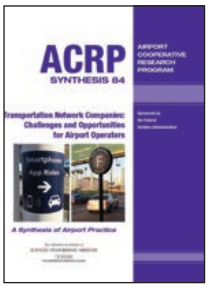
Leiner is Director, Ricondo Association, Alexandria, Virginia, and Adler is President, RSG, Inc., White River Junction, Vermont.

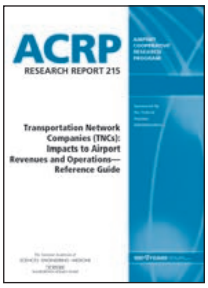
Above: Passengers wait for their rideshare pick-ups at Louis Armstrong New Orleans International Airport in Louisiana. Explosive growth in transportation network companies since 2014 has posed a challenge to airports, both in revenue extraction and management.

In most U.S. metropolitan areas, transportation network companies (TNCs)—for example, Uber and Lyft—provide on-demand transportation services. These companies emerged rapidly and now operate in ground transportation markets at all major domestic commercial airports. Although customers appreciate the convenience offered by these access options, the continued use of TNCs presents multiple challenges to states, regional transit authorities, municipalities, and airport operators.

In 2017, the Airport Cooperative Research Program (ACRP) published *ACRP Synthesis 84: Transportation Network Companies—Challenges and Opportunities for Airport Operators*, which identified the opportunities and challenges from ride apps that airport operators need to confront and manage (*1*). Some of the early impacts, identified from additional analysis of changing receipt volumes from parking and rental car transactions, indicated that the nonaeronautical revenue landscape and traditional space needs for cars and parking were changing quickly and dramatically.

As researchers collected and summarized this information, it became clear that more research was needed to help airports develop strategies to better adapt to TNC operations. Additional research addressing these issues was published in early 2020. *ACRP Research Report 215: Transportation Network Companies (TNCs)—Impacts to Airport Revenues and Operations* is a reference guide for airport operators to identify strategies for adapting airport land-side access programs to reflect the evolution of ground transportation modes and their impacts on airport revenue and operations (*2*).





ACRP Research Report 215 documents how airport operators

- Develop permitting procedures and enforce regulations,
- Assign passenger drop-off and pick-up areas within the overall context of ground access operations,
- Manage vehicle staging and holding areas,
- Establish trip fees charged to TNCs and collect and confirm payment of such fees,
- Monitor and respond to revenue impacts and the effects on airport finances, and
- Update capital plans to support evolving ground transportation operations.

ACRP Research Report 215 presents best practices that have proven to be effective tools for airport operators to manage TNC operations and in developing sustainable revenue models. It examines TNCs from multiple perspectives: regulatory, financial, operational, and managerial. The research included a survey of large-, medium-, and small-hub airports, interviews with landside managers, a disaggregate mode choice model, and a comprehensive review of the revenue and business impacts of TNCs.

Data Collection: Airport Survey and Ground Transportation Revenue

Both *ACRP Synthesis 84* and *ACRP Research Report 215* drew from a survey of the 100 largest U.S. airports that examined TNC experience and practices. The survey data contained detailed information about the TNC operations at each of these airports, the resulting access mode shares, and the revenues received from TNC fees. Reported and calculated TNC access mode shares ranged from 2 percent to 30 percent across the airports surveyed, with an average share of 13 percent. The data show significant increases in TNC use by air passengers over the period 2014 to 2017 (the most recent year of data provided in the survey).[1]

The survey responses indicate that airports have adapted to increases in TNC use in many ways, including improved wayfinding, managing pick-up and drop-off areas, providing holding lots, and imposing pick-up and drop-off fees that average between $2.50 and $3.

Corresponding to the increase in TNC use and fees, revenues from the TNC fees collected by airports have grown over this period—and most noticeably between 2015 and 2017, with a five- to tenfold increase in revenues. Over this same two-year period, taxi fee revenues declined by approximately 20 percent.

An important research task was to examine how TNCs have affected airport revenue and rental car transactions and the possible long-term consequences for overall airport financial performance. Airports have continued to realize sufficient revenues to support ongoing operations and to provide sufficient debt service coverage on outstanding airport bonds.

The team assembled data from three key sources: the Federal Aviation Administration Certification Activity Tracking System data, publicly available data from 37 airports, and proprietary data from several large-hub airports. Key findings include the following points.

GROUND TRANSPORTATION REVENUE

Ground transportation revenue per passenger has remained relatively flat, calculated using either total enplaned passengers or origin and destination enplaned passengers.

A recurring topic for airport operators is what constitutes a level playing field for commercial ground transportation operators. Of all the commercial ground transportation operators at airports, who should pay what fees? Airports have longstanding fiscal policies and business practices underlying these fees. At some airports, social equity considerations and living-wage goals now complicate the development of fee structures.

FINANCING

There has been no significant negative impact on near-term ability to finance airport facilities. Airports have generated replacement ground transportation revenue sources, and airport operators generally have been successful at developing the revenue necessary to support capital programs.

Model Development, Application, and Results

DEVELOPMENT

Using the data from the airport survey, the research team developed integrated supply and demand models to estimate the effects of TNC growth and TNC-related pricing policies on airport access mode shares and revenues. These models describe the ways and how many people choose to travel to and from airports. The models were developed using previously collected passenger survey data for two case study airports: San Francisco International Airport (SFO) and Reagan National Airport (DCA). Those two models were used as the core demand component of the integrated supply and demand models and then were combined with data describing current ground access mode shares, fees, and revenues.

Photo: Karl Schultz, Flickr

Rideshare drivers and users are directed to designated pick-up and drop-off spots at San Francisco International Airport in California, one of the airports examined in ACRP research on TNCs at airports.

[1] More detail on the survey data is available online at https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4415.

APPLICATION

Application of these models resulted in some interesting findings. Although TNCs drew most of their initial market share from taxis and parking, they also drew from other modes and now appear to draw market share from all of the major modal alternatives. The extent to which they draw market share from other modes depends on the competitive mix at each airport.

The price elasticities of demand for parking and rental cars are near –1.0 at one or both of the airports studied. This means that the reliable past practices of simply raising airport parking prices to increase revenues may now result in the reverse effect: further reductions in revenue.

Similarly, simply increasing TNC fees may result in shifts to lower-revenue access alternatives such as private vehicle drop-off, and thus these will not result in net increases to airport revenues.

The ground access–related revenue and fee structures used by airports result in complex interactions as a result of demand effects and significant differences in the amount of revenue derived from each mode's air passenger trips. The net result of fee changes can be very different if either or both of these effects are not appropriately accounted for.

Photo: Cory Doctorow, Flickr

ACRP Research Report 215 offers tools for airport operators to maintain efficient and effective TNC operations on terminal roadways, curbs, and staging areas.

The case studies of SFO and DCA demonstrate the value to airports of developing a tool that can estimate the effects of changing commercial ground transportation fee structures. The work required to build and apply an integrated disaggregate supply and demand model that can be used to properly calculate all of these effects is relatively straightforward. And, since the effort required to build a model that can be used both for ground access planning and for revenue analysis is relatively small, airports may want to consider developing and applying their own versions.

Pulling it All Together

An important theme in *ACRP Research Report 215* is that airport operators need tools not only to manage current operations but also to seek insight into the consequences of changes to their operations, regulations, and revenue models. The result of this research comprises specific tools, guidelines, and policy levers that airport operators can use to support decision making in a rapidly evolving environment.

The report presents practices that encompass the issues airport operators frequently encounter in the management of TNCs. The report details 24 practices, organized into four categories:

- **Policy development and permits** focuses on broad initiatives and regulatory tools.
- **TNC–ground access management, operations, and analysis** covers land-side management tools available to airport operators for maintaining efficient and effective TNC operations on terminal roadways, curbs, and staging areas.

Photo: Tony Webster, Flickr

Passengers at Honolulu International Airport in Oahu, Hawaii, are greeted not only with "aloha" but also an advertisement for ridesharing. ACRP research examined the effect of TNCs on modal market share.

- **Financial and business development, revenue analysis, and capital programming** includes methods for monitoring revenue impacts, including a model that can estimate the broad impacts of trip fee changes on mode share and revenue based on supply and demand.
- **Technology** covers current and emerging practices that use automated vehicle identification, PIN matching, and other technology-based tools and concepts.

These practices are packaged to inform a variety of audiences that have direct involvement in TNC operations at airports. Executive-level managers, planners, and legal staff are provided tools to assist with ground access policy development and managing their airport's TNC regulatory framework. Land-side supervisors will benefit from information to assist with their day-to-day responsibility for ensuring the safe and efficient operation of ground transportation operations and facilities. Also offered is information for transportation engineers and planners responsible for analyzing curb operations and developing capital improvements.

Finance and business development analysts can find the relative contributions and trends of commercial ground transportation revenue as well as impacts on airport finances and capital programs. Historical commercial ground transportation data and activities are included to assist information technology staff responsible for implementing, tracking, and identifying trends.

Summary

The rapid introduction and expansion of TNC activity generated immediate regulatory and revenue management responses from airport operators to ensure safe vehicle operations, vetting of TNC drivers, adequate insurance coverages, and trip fees sufficient to support land-side management and fiscal objectives. Airports progressed from initially reacting to TNCs to the current situation in which they are actively managing and controlling TNC operations in keeping with broad strategic goals.

As airport operators gain experience working with TNCs, they adjust operations, fee structures, capital programs, and technology to more effectively incorporate ride apps into their commercial ground access programs. Accordingly, the *Reference Guide* describes strategic approaches and practical tools that can serve as a resource to support ground access programs that are consistent with an airport's overall policy goals.

Additional work to assist airport operators in the changing landscape from ride apps can be found in ACRP Project 03-47, "Rethinking Airport Parking Facilities to Protect and Enhance Non-Aeronautical Revenue."[2]

[2] For more information on ACRP Project 03-47, see https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4426.

Related TRB Titles

- *Special Report 319: Between Public and Private Mobility—Examining the Rise of Technology-Enabled Transportation Services*
- *ACRP Report 146: Commercial Ground Transportation at Airports*
- *TCRP Research Report 195: Broadening Understanding of the Interplay Among Public Transit, Shared Mobility, and Personal Automobiles*
- *ACRP Project 03-47: Rethinking Airport Parking Facilities to Protect and Enhance Non-Aeronautical Revenue*

Acknowledgments

The contractor team thanks the members of the research panel for their support, insights, and advice throughout the duration of the project. Theresia Schatz, Senior Program Officer, guided the research team through its various tasks and panel meetings. The team is grateful for the data, perspectives, and materials shared by airport operators—particularly the airport staff who participated in telephone or onsite interviews.

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1. *ACRP Synthesis 84: Transportation Network Companies—Challenges and Opportunities for Airport Operators.* Transportation Research Board, Washington, D.C., 2017. https://dx.doi.org/10.17226/24867.
2. *ACRP Research Report 215: Transportation Network Companies (TNCs)—Impacts to Airport Revenues and Operations, Reference Guide.* Transportation Research Board, Washington, D.C., 2020. https://dx.doi.org/10.17226/25759.

Jane Jie Lin

University of Illinois at Chicago

Recognized internationally as a leading researcher in transportation and air quality—in particular, integrating transportation planning with mobile source emissions, air quality, and health exposure modeling—**Jane Jie Lin** applies state-of-the-art mathematical modeling and data mining techniques to discover new transportation knowledge with important policy implications and practical values.

"My research has been firmly established and internationally recognized in three major areas," she notes. "These are: sustainable transportation systems analysis with a focus on emissions, air quality, and health exposure modeling; green urban logistics and freight transportation; and emerging mobility service enabled by information technology."

Exploring sustainable transportation systems, Lin and her research team developed a holistic and integrated modeling approach to understanding the underlying relationship between travel demand, vehicular emissions, air pollution, and health exposure. The modeling tool involves agent-based modeling of finely resolved individuals' daily activity patterns (location and duration), which are then used to estimate transportation network congestion levels; vehicle emissions; pollution; and, ultimately, population exposure to vehicular pollutants. "Our work was among the early and leading research efforts in the research area," she observes.

Lin notes that an integrated modeling framework for sustainable transportation systems demonstrates both the importance of capturing the dynamics of population activities—as opposed to using only static population distribution, as is typically done—and the discrepancies between pollutant concentrations and exposure. "In practice and policy making, pollutant concentration is often used as a surrogate," Lin comments. "However, it may lead to misinformed policies."

Lin's research also focuses on minimizing operating costs, energy consumption, carbon footprint, and local pollution in first–last mile urban logistics problems. "Two driving forces are changing the landscape of city logistics, in particular urban delivery," she notes. "One is the rise of e-commerce; the other is the rapid advances in wireless communication and ubiquitous mobile computing that are enabling more efficient use of the otherwise unutilized or underutilized vehicle capacities in delivery services."

"I'm more determined than ever to make sustainability and resilience front and center of transportation research."

Lin investigates green urban delivery strategies in the context of new mobility forms, such as real-time cargo-sharing, crowdsourced, and new vehicle technology (e.g., electric commercial vehicles). Recent studies have explored the cost and environmental performance (energy and emissions) of urban delivery consolidation strategies, as well as an award-winning new urban last-mile delivery paradigm using crowdsourced couriers, or crowd-shippers.

"Advanced information and vehicle technology are changing the way people and goods move around and the way mobility services are provided to people and goods," Lin affirms. "As transportation service and mobility are increasingly transformed by advanced information and vehicle technology, I see this area of research as the future of transportation studies."

In this area, she focuses on matching among spatiotemporal resources and resource seekers, facilitating shared-use transportation (e.g., parking slots, electric vehicle charging stations, ride- and bike-sharing opportunities, and consolidated package deliveries). She observes that the underlying methodology and technology of this research can apply to a broad range of Smart City–type applications that involve spatial and temporal search and acquisition of resources.

"I firmly believe transportation is a real-world cross-disciplinary laboratory, in which academic researchers of various disciplines and academic backgrounds apply theories and principles of their own disciplines to solving transportation-related problems," Lin notes. This interdisciplinary collaboration is even more crucial as information technology—ubiquitous computing, sensing, crowd-sourcing, robotics, and social networking—becomes an increasing part of transportation research. It requires a shift from traditional, hypothesis-based knowledge discovery to a more data-driven process, she adds.

Lin became active on Transportation Research Board (TRB) committees in 2011, as chair of the Transportation and Air Quality Committee (now the Air Quality and Greenhouse Gas Mitigation Committee). Upon the TRB Technical Activities Division committee realignment in April, Lin became chair of the Sustainability and Resilience Group and a member of the Technical Activities Council. She recently served as vice chair of the Energy and Environment Section.

"The newly established Sustainability and Resilience Group is the first truly interdisciplinary group with TRB," Lin comments. "My mission is to grow the group and promote the critical importance of transportation sustainability and resilience by forging collaboration within and beyond it. With the global climate change crisis becoming more eminent and the COVID-19 pandemic unveiling the threats to economic, societal, ecological, and environmental sustainability, I'm more determined than ever to make sustainability and resilience front and center of transportation research."

Joel L. Ticatch

Kapsch TrafficCom USA, Inc.

A nationally recognized expert in operations planning, intelligent transportation systems (ITS), transportation safety, multimodalism, and commercial vehicle operations, **Joel L. Ticatch** is Director of Consulting at Kapsch TrafficCom USA, Inc. Over the course of a career delivering innovative, strategic approaches to implementing transportation systems management and operations (TSMO) initiatives, Ticatch has managed dozens of TSMO-related projects, particularly at the state level. He has led the development of multiple statewide systems operations program plans and integrated corridor management planning projects. Increasingly, these efforts have included connected and automated vehicle planning activities, as well.

Ticatch sees a few major throughlines in the work he has done. "I've looked at most of my projects as stories dying to be told," he muses. "With this as a backdrop, much of my work has involved unlocking those stories—seeing where they will take us, learning from the past, and making way for the future."

In recent years, Ticatch has focused on the use of innovative technologies and techniques to manage and mitigate congestion and improve safety. He assists practitioners in seeing transportation elements in an integrated, multimodal, symbiotic context, whereby events and responses on one part of the system reverberate across the other elements.

"Technologies have opened up new avenues and vistas for practitioners to move away from their stovepipes and to increasingly engage in corridor- and regionwide dialogue; real-time information exchange; and structured, multimodal decision making," Ticatch comments. Framework tools, such as capability maturity modeling, can help practitioners prepare their organizations for the emerging technologies paradigm, he adds.

For example, as a consultant program manager for the Virginia Regional Multi-Modal Mobility Program (RM3P), Ticatch leads a collaborative, integrated, and cohesive approach to improving safety, accessibility, and mobility by mitigating congestion for the traveling public. A public–private partnership cosponsored by the Northern Virginia Transportation Authority, the Virginia Department of Transportation (DOT), and the Department of Rail and Public Transportation, RM3P is deploying multiple technologies across Northern Virginia. These technologies include a data-exchange platform, an artificial intelligence–based decision support system, a commuter parking information system, a multimodal analytical planner, and dynamic incentivization for demand management.

"One similarity among the projects I have worked on in my career has been my desire to bring structured problem-solving to all of the work," Ticatch observes. "To organize often-complicated issues into bite-size chunks and work one's way through the material, one mouthful at a time. To endeavor—before jumping into a new basket of work—to always lay out a strategic plan of attack."

"One similarity among the projects I have worked on in my career has been my desire to bring structured problem-solving to all of the work."

One such project was development of an integrated prototype of cooperative automation capabilities. In the Federal Highway Administration's Cooperative Automation Research Mobility Applications (CARMA) program, which encourages collaboration in improving transportation efficiency and safety, Ticatch led the technical planning team that explored the relationship between TSMO strategies and cooperative automated driving systems (C-ADS).

"The effort focused on four sets of use-cases—work zone management, traffic incident management, road weather management, and basic travel—and developed a framework for the interactions between TSMO and C-ADS," Ticatch notes. After a series of workshops, the use cases were expanded into detailed concepts of operations and later used to build testable scenarios for integration into the CARMA platform.

Ticatch also has led many studies in commercial vehicle safety for various state DOTs and U.S. DOT modal agencies. These have included a field study on the crash rates of longer combination vehicles; a pilot review and validation of national revisions to commercial driver license, or CDL, testing modules; and a demonstration system to gauge truck parking space availability at public rest areas for the I-95 Corridor Coalition.

"Another similarity across most of my work has been the good fortune over these many years to be surrounded by deeply talented colleagues and clients who, invariably, have made me look good," Ticatch affirms.

An active Transportation Research Board (TRB) volunteer for almost 30 years, Ticatch was instrumental in forming the Truck and Bus Safety Committee. Starting in 2000, he served on the task force that investigated and documented the need for a permanent committee devoted specifically to the topic of truck and bus safety. He then served as the second chair of the committee from 2006 to 2012.

"During this period, the committee developed a sophisticated subcommittee infrastructure, better organized itself technically and administratively, and undertook the development and upkeep of research needs statements," he recalls. Ticatch also served on the Executive Committee of the TRB Safety and Systems Users Group from 2013 to 2019.

INFLUENCER

Chieh (Ross) Wang

Chieh (Ross) Wang is a member of the Research and Development staff in the Vehicle Connectivity and Autonomy Research Group at Oak Ridge National Laboratory in Oak Ridge, Tennessee. He is a member, communications coordinator, and paper review coordinator for the Traffic Control Devices Committee; a member of the Freight Transportation Data Committee; and a handling editor for the Transportation Research Record Editorial Board.

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

I first heard about TRB when I was in graduate school in Taiwan. And I attended my first Transportation Research Board (TRB) Annual Meeting in 2011, when I was in the PhD program at the Georgia Institute of Technology. Soon after, I became friends of and a paper reviewer for a few committees and—in 2015—was fortunate to be selected as the communications coordinator for the former Signing and Marking Materials Committee. In 2017, I was nominated as the cochair of the Young Members Subcommittee of the Maintenance and Preservation Section and the cochair of the Operations and Preservation Group Young Members Council (OPGYMC). Being involved in activities at the Section and Group levels helped me develop much appreciation for what TRB does for the transportation community.

How has TRB influenced your career so far?

Both of the positions I've held over the last 10 years have been possible because of connections I made at TRB. After I completed my PhD, a TRB committee chair—who I worked closely with—offered me my first job. After I applied for my current position, I learned that the senior staff person who opened the position was someone I had connected with every year at the TRB Annual Meeting. As a result, the interview process went as smoothly as anyone could ask for.

What was one of your most memorable TRB Annual Meeting moments?

During the 2019 and 2020 TRB Annual Meetings, the OPGYMC I cochaired hosted the Three-Minute Thesis workshop, a competition in which participants present their research to a general audience within three minutes, using only one slide. My most memorable TRB Annual Meeting moment was to see how participants who competed both years drastically improved their presentation and communication skills. The OPGYMC won the 2020 Blue Ribbon Committees Award partly because of this workshop.

Transportation Influencer highlights the journey of young professionals active in TRB. Have someone to nominate? Send an e-mail to TRNews@nas.edu.

CENTENNIAL QUOTE

"My "aha" moment happened early in my career when I became aware of the Transportation Research Board Annual Meeting. I learned about the magnitude, networking, and coordinated effort related to that special January meeting in Washington, D.C. As I attended my first annual meeting, I was in awe of the entire process. How could there be so many topics and so many people involved in transportation research? From there, I knew I had to dig deeper. It became a boundless learning interest, and that is how I became more involved in research for the betterment of transportation.

—CAROL ALDRICH
Engineer of Research,
Michigan Department of Transportation, Lansing

Bringing Young Minds to the Table

The Transportation Research Board (TRB) continues to engage a diverse array of transportation professionals and has targeted a number of multimedia efforts at younger transportation professionals. On TRB's @NASEMTRB social media accounts (e.g., Twitter, Facebook, and LinkedIn), Communications staff have sought to connect with these younger professionals through, for example, questions about their courses and thoughts on the careers they are considering.

Through its podcast series, TRB's Transportation Explorers (launching in January 2021), TRB will showcase interviews with a diverse array of movers and shakers in the transportation profession. Paul Mackie, TRB's Communications director, believes this format will appeal to a younger audience and increase awareness of a range of career paths.

Your Future in Transportation, a video produced with Texas A&M Transportation Institute as part of TRB's Centennial celebrations and available on YouTube, highlights emerging transportation fields and the multidisciplinary skills needed for entering the transportation industry today.

On TRB's Centennial website (https://trbcentennial.nationalacademies.org/), the Tell Us "Our" Story section has—since August 2019—allowed people at all stages in their transportation careers to post thoughtful responses in video and text to monthly questions such as, "How has TRB supported your professional development and career growth?" and "What drew you to the transportation community and what keeps you here?" Recognizing that the website is the entryway to TRB involvement for most young professionals and those new to TRB, Communications staff worked with IT staff to simplify the process for signing up online to become a friend of a committee. Multiple landing pages are now available for people to sign up to become a committee friend in just a few clicks or by going to https://trb.org/friend.

MEMBERS *ON THE MOVE*

Rhonda Hamm-Niebruegge has been elected chair of the Airport Cooperative Research Program Oversight Committee. She is Executive Director of St. Louis Lambert International Airport.

Tracy Hadden Loh has joined the Brookings Institution in Washington, D.C., as a fellow with the Anne T. and Robert M. Bass Center for Transformative Placemaking. She was a Senior Data Scientist at the Center for Real Estate and Urban Analysis at George Washington University.

Amanda Pietz has become Director of the Climate Office at the Oregon Department of Transportation (DOT). She was formerly Oregon DOT's Program Implementation Manager.

John Eagerton is retiring as Chief of the Aeronautics Bureau at Alabama DOT at the end of the year.

Clayton Stambaugh has become Deputy Director of Aeronautics at Illinois DOT.

Timothy McDowell has retired from Wyoming DOT, where he was a civil engineer.

Chad A. Allen has retired as Director of the Asset Management Bureau at the Vermont Agency of Transportation.

NCHRP Synthesis 540

Leveraging Private Capital for Infrastructure Renewal

BRYANT JENKINS

The author is Principal, Sperry Capital, Inc., Sausalito, California.

National Cooperative Highway Research Program (NCHRP) Synthesis 540: Leveraging Private Capital for Infrastructure Renewal documents the role of private equity in highway public–private partnerships (P3s) in the United States. The project team—infrastructure advisory consultants Sperry Capital and Stanford University's Global Project Center—explored current practices at U.S. transportation agencies, the potential benefits of private-sector discipline and innovation on project cost and schedule, risk mitigation, delivery certainty, and the advantages and disadvantages of certain partnership structures.

Highway and bridge P3s in the United States are still relatively rare. When the synthesis was being developed, only 12 states and one territory had reached financial close on a highway P3—that is, when the public-sector authority and the private developer have agreed on terms and conditions for the P3 contract and all required financing has taken place, usually before construction begins. For the synthesis, the authors contacted all U.S. state and local public sponsors of P3s, and the authors interviewed 60 percent of the public sponsors who have pursued highway P3s. These included the relevant P3 offices for Texas, Virginia, and Colorado, which have completed the majority of P3 deals for highways nationwide.

The team also compiled a data set of 28 highway and bridge P3 projects from 1989 to 2017. The synthesis reviewed this existing project data and P3 agreements from closed U.S. highway projects and performed a comprehensive review of reports on P3s, relevant FHWA publications, and state authorizing legislation for P3s.

NCHRP Synthesis 540 provides detail on the public-sponsor perspective and P3 policies, as well as on how state DOT P3 offices are organized. The report compares differences among state DOT P3 offices for the financial analyses required to procure a highway P3 project. This analysis differs for different sponsoring agencies in terms of methodology, as well as the transparency of the reports during the P3 process. None of the state DOTs interviewed for the

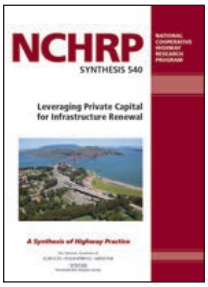


Photo: Flickr

The Presidio Parkway project, a joint effort of the California Department of Transportation and the San Francisco County Transportation Authority, was conducted in two phases: the first using a traditional design–bid–build approach and the second via P3.

report evaluate procurement results based on forecast private-sector equity returns of proposers. Rather, they generally focus on which proposal provides the best value for the transportation agency and, thus, for the public.

The report also highlights a leading concern of the public: that the private developer may generate outsized economic returns from its equity investment in P3 projects at the expense of the taxpayer. Public sponsors recognize this perception and their crucial role in mitigating this risk; *NCHRP Synthesis 540* summarizes certain mechanisms employed by state DOTs in their P3 agreements to accomplish this mitigation: refinancing gainsharing and timing restrictions on dividends and sales of the project.

The key finding in the synthesis report is that incentives do change when the private sector has increased financial risk to ensure successful outcomes of highway P3 projects. P3 projects that involve private equity have an additional stakeholder at the table, with equity capital at risk. This private-sector incentive and discipline provide a further level of schedule and cost certainty compared with projects that do not include private equity.

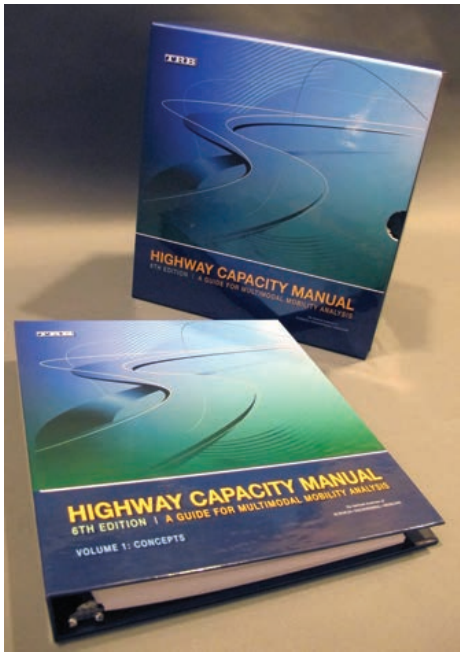
Further, public sponsors must understand the public perception that private-sector equity returns come at the expense of the taxpayer. This remains a critical issue, and it is helpful to the public for transportation agencies to communicate how this risk is mitigated through excess revenue–return sharing mechanisms. For example, a P3 can offer private developers the opportunity to accept additional risks (such as higher penalties for schedule delays) in exchange for longer P3 contracts or higher allowed financial returns.

A transparent process likely will help facilitate more highway and bridge P3 projects. *NCHRP Synthesis 540* also noted several areas for additional research, such as how P3 offices can be better managed, implications of transaction costs in P3 procurement, obtaining more information on the operations of U.S. highway P3s, and the use of excess return sharing mechanisms over a project's life cycle.

TRB History Highlights

As the Transportation Research Board (TRB) celebrates 100 years of information exchange, research, and advice in all modes of transportation, it is illuminating to look back at some of the defining events in TRB's history.

- ***Highway Capacity Manual.*** In 1945, Bureau of Public Roads engineers and researchers from state and local transportation agencies gathered to integrate the growing number of studies on capacity. When *Highway Capacity Manual: Practical Applications from Research* (HCM) was published in 1950, the Government Printing Office sold it for 65 cents. HCM went on to sell more than 26,000 copies and was translated into nine languages. Now in its sixth edition, HCM continues to play a foundational role in highway planning, design, and operations—and it even has its own Wikipedia page.



The sixth edition of the *Highway Capacity Manual*, released in 2016, incorporates the latest research on highway capacity, quality of service, active traffic and demand management, and travel time reliability.

- **AASHO Road Test.** Construction of the six test loops used in the American Association of State Highway Officials (AASHO, now the American Association of State Highway and Transportation Officials) began in August 1956, and test driving commenced in October 1958. At the project's peak, 170 researchers, technicians, mechanics, maintenance personnel, and clerical workers were employed in the field, and 400 military personnel lived in the onsite barracks. To reach the goal of at least 1 million axle loads, drivers circled the test loops at 35 miles per hour for nearly 19 hours per day, six days per week. Special studies continued into 1961 and the field office closed in January 1962.
- **Annual Meeting Poster Sessions.** In the early 2000s, TRB began experimenting with posters at the Annual Meeting, as too many quality research papers were being left out because of a lack of time in lectern sessions. First billed as "meet the author" events, the poster format took a few years to catch on—but by 2006, nearly half of Annual Meeting papers were presented at poster sessions.

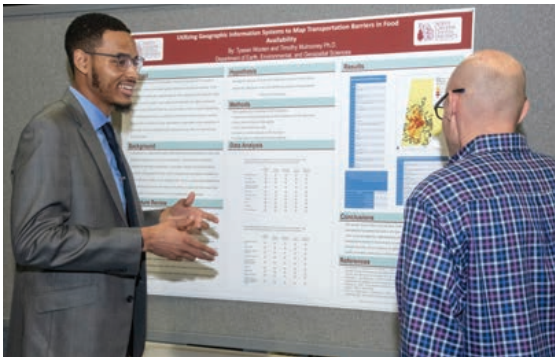


Photo: Risdon Photography

Tysean Wooten presents research on using geographic information systems to map transportation barriers to food availability at the 2020 TRB Annual Meeting.

These highlights are excerpted from The Transportation Research Board, 1920–2020: Everyone Interested Is Invited *by Sarah Jo Peterson, Copyright 2019. To view more History Highlights, visit https://trbcentennial.nationalacademies.org/trb-history-highlights.*

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TRB's Transportation Explorers

Have you heard? The Transportation Research Board (TRB) is launching a podcast! Listen to *TRB's Transportation Explorers* to hear transportation experts dig into current transportation innovations. The show, launching in January 2021, will feature the latest transportation advancements and research, with our hosts asking probing questions of experts in all modes of transportation. Tune into this brand-new programming during the 100th TRB Annual Meeting!

To listen to the TRB's Transportation Explorers podcast, visit https://dev.nap.edu/trb/podcasts.

CENTENNIAL QUOTE

"Early in my graduate studies, a professor described transportation as the means by which people get to the things they love in life. He hit the nail on the head, but I might extend his words to include "transportation is also the means by which the things people love in life get to them." Transportation is quite relatable; everyone interacts with it, even if their circumstances make it difficult for them to use—or preclude them from using—transportation services. That's probably what drew me to it as an engineer. It's a system to which individuals the world over interact and contribute a significant portion of their time and income. What keeps me here is the community I've found along the way. As a young researcher in urban freight, I felt like an outsider. It wasn't until I found other outsiders at the Transportation Research Board Annual Meeting that I knew I had found my place, one to which I wanted to dedicate a significant portion of my time and energy.

—TEDDY FORSCHER
PhD Candidate and Lead Researcher,
Transportation Sustainability Research Center,
University of California, Berkeley, Oakland

Improved Truck Driver Training and Testing May Hinge on Simulators

Simulators have gained acceptance and regular use in medical and military environments, so why not in the trucking industry—specifically, for commercial driver license (CDL) training and testing during the COVID-19 pandemic? Experts addressed this and other questions during a November 6, 2020, webinar hosted by the Transportation Research Board.

Traditional CDL training and testing require the trainer to sit next to the driver, thwarting social distancing protocols. And at the state government level, the pandemic has restricted credentialing operations to the extent that some states' capacity to issue licenses has been reduced to 60–70 percent. Certain elements of simulators—ranging from the variety of driving environments and situations that may not exist near a training facility to the ease of keeping them clean—make them a viable option for improving the rate of training and testing.

To view the webinar PowerPoint, see http://onlinepubs.trb.org/onlinepubs/webinars/201106.pdf.

Photo: Virage Simulation

Drivers at the Road Transport Training Centre in Mirabel, Québec, Canada, get a 180-degree view of the road in a truck simulator developed by Virage Simulation. "With simulators, we have an untapped source of a new method for improving driver training and testing," says webinar guest Pierro Hirsch, director of Road Safety Research at Virage Simulation. "We think there are applications even after COVID."

Photo: iStock

Texting while crossing the street can be a dangerous distraction, but—according to the National Safety Council—more than half of distracted walking injuries occur in the home. The lesson is simple: put down the phone and focus on your surroundings!

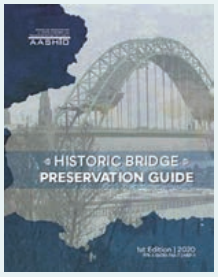
Eyes Up! Phones Down!

Research conducted at Canada's University of Calgary reveals even more evidence that texting pedestrians in traffic environments put themselves at risk of accidents.

Researchers looked at data compiled from 14 smaller experiments involving 872 pedestrians who used smartphones while walking. Results show that those who text are more prone to accidents than those who listen to music or talk on the phone. Pedestrians who text tend to look left and right less often before crossing a street. They also are at higher odds of bumping into other people, walking into objects in their path, or being involved in near-miss collisions.

The smaller experiments included simulations that mimicked what pedestrians would likely experience when walking down a sidewalk or crossing the street. Participants were instructed to perform a variety of street-crossing tasks while using their smartphone in different ways. Texting and browsing the Internet also were related to a slight increase in the time it took to start crossing the street.

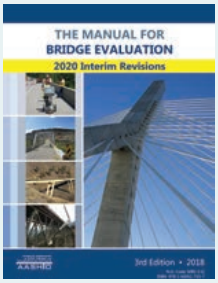
For more information, go to https://injuryprevention.bmj.com/content/26/2/170.



Historic Bridge Preservation Guide, 1st Edition

This guide is a reference for the preservation and rehabilitation of both fixed and movable historic highway bridges. It aims to familiarize engineers with the unique and diverse skills needed for successful historic bridge preservation and rehabilitation projects. Presented is a structural analysis and evaluation for historic bridges, masonry repair, balancing historic design with modern safety, consulting with state and tribal historic preservation officials, and more.

American Association of State Highway and Transportation Officials (AASHTO). 2020; AASHTO members, $115; nonmembers, $155. To purchase a copy, customers should visit the AASHTO Store online at store.transportation.org and search item code HBP-1.



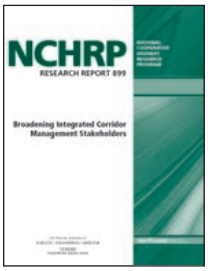
Manual for Bridge Evaluation, 3rd Edition Interim Revisions

The interim revisions to this volume add an alternate method to determine the nominal shear resistance of a stiffened web end panel in Section 6 and reflect updated current research regarding partial tension-field action in stiffened web panels. The increased shear resistance of stiffened end panels in steel girders will help prevent unnecessary retrofit work. To get closer correlation between the examples in the Appendix A and bridge analysis software, the examples have been updated.

AASHTO. 2020; AASHTO members, $70; nonmembers, $95. To purchase a copy, customers should visit the AASHTO Store online at store.transportation.org and search item code MBE-3-I1.

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

TRB PUBLICATIONS



Broadening Integrated Corridor Management Stakeholders
NCHRP Research Report 899

This report addresses a broad range of operational and efficiency issues that are critical to bringing nontraditional stakeholders (freight, transit, incident response, and nonmotorized vehicles) into the integrated corridor management process.

2020; 230 pp.; TRB affiliates, $73.50; nonaffiliates, $98. Subscriber categories: motor carriers, operations and traffic management, passenger transportation.

Update of Security 101: A Physical Security and Cybersecurity Primer for Transportation Agencies
NCHRP Research Report 930

This report offers valuable information about current and accepted practices associated with both physical security and cybersecurity and their applicability to surface transportation.

2020; 212 pp.; TRB affiliates, $71.25; nonaffiliates, $95. Subscriber categories: data and information technology, public transportation, security and emergencies.

A Guide to Emergency Management at State Transportation Agencies
NCHRP Research Report 931

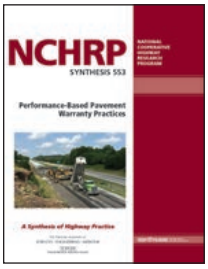
This volume is an update to a 2010 guide to all-hazards emergency management and emergency-response planning. Significant advances in emergency management, changing operational roles at transportation organizations, and federal guidance issued since 2010 have resulted in a need to reexamine requirements for state transportation agency emergency-management functions, roles, and responsibilities.

2020; 400 pp.; TRB affiliates, $84.75; nonaffiliates, $113. Subscriber categories: education and training, public transportation, security and emergencies.

Evaluating Mechanical Properties of Earth Material During Intelligent Compaction
NCHRP Research Report 933

This report details the development of procedures to estimate the mechanical properties of geomaterials using intelligent compaction technology in a robust manner so that departments of transportation (DOTs) can incorporate it into their specifications.

2020; 146 pp.; TRB affiliates, $65.25; nonaffiliates, $87. Subscriber categories: construction, geotechnology, materials.



Performance-Based Pavement Warranty Practices
NCHRP Synthesis 553

This synthesis documents highway agency practices associated with the use of performance-based pavement warranties, focusing on

asphalt, concrete, and composite pavement projects with warranty periods of at least one year.

2020; 128 pp.; TRB affiliates, $61.50; nonaffiliates, $82. Subscriber categories: highways, construction, maintenance and preservation, pavements.

Advances in Unstable Slope Instrumentation and Monitoring
NCHRP Synthesis 554

This synthesis documents and synthesizes the state of practice for implementation and use of advancements in unstable slope instrumentation and monitoring by state DOTs over the past decade.

2020; 102 pp.; TRB affiliates, $54.75; nonaffiliates, $73. Subscriber categories: geotechnology, highways.

Airports and Unmanned Aircraft Systems: Managing and Engaging Stakeholders on UAS in the Vicinity of Airports
ACRP Research Report 212, Volume 1

The first volume of this report provides guidance for airport operators and managers to interact with unmanned aircraft systems (UAS) operations in the vicinity of airports. The demand for commercial UAS may increase significantly once advanced UAS operations are allowed via broader regulatory frameworks.

2020; 96 pp.; TRB affiliates, $78.75; nonaffiliates, $105. Subscriber categories: aviation, operations and traffic management, vehicles and equipment.

Airports and Unmanned Aircraft Systems: Incorporating UAS into Airport Infrastructure—Planning Guidebook
ACRP Research Report 212, Volume 2

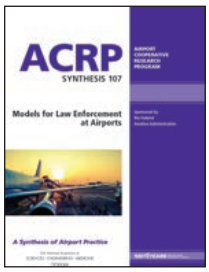
The second volume of this report provides suggested planning, operational, and infrastructure guidance to safely integrate existing and anticipated UAS operations into an airport environment. This guidebook is particularly applicable to smaller airports (non-hub and general aviation) that do not have capacity issues and could help these airports prepare for and attract UAS operations for additional revenue in the near term.

2020; 132 pp.; TRB affiliates, $61.50; nonaffiliates, $82. Subscriber categories: aviation, operations and traffic management, vehicles and equipment.

Airports and Unmanned Aircraft Systems: Potential Use of UAS by Airport Operators
ACRP Research Report 212, Volume 3

The third volume of this report offers resources for airports to appropriately integrate UAS missions as part of their standard operations. The use of UAS by airports can result in efficiency gains if implemented effectively, but improper implementation can cause safety risks and damage effective airport operations.

2020; 50 pp.; TRB affiliates, $44.25; nonaffiliates, $59. Subscriber categories: aviation, operations and traffic management, vehicles and equipment.



Models for Law Enforcement at Airports
ACRP Synthesis 107

Presented in this synthesis is a concise body of knowledge to airport management, operators, researchers, and users, detailing the varying types of law enforcement models available to them. The types of airport law enforcement models include airport police, city police, county sheriffs, departments of public safety, and state police. Many airports operate by using layers of law enforcement responses.

2020; 84 pp.; TRB affiliates, $52.50; nonaffiliates, $70. Subscriber categories: aviation, administration and management, law.

To search for articles in the *Transportation Research Record: Journal of the Transportation Research Board* (TRR), visit http://journals.sagepub.com/home/trr. To subscribe to the TRR, visit https://us.sagepub.com/en-us/nam/transportation-research-record/journal203503#subscribe.

Escalator Falls
ACRP Synthesis 109

This synthesis identifies and describes methods to mitigate risks associated with escalator usage. Risk management professionals from airport and transit environments have expressed interest in developing common reporting schemes and more robust data analysis to identify common causes of escalator falls.

2020; 86 pp.; TRB affiliates, $54.75; nonaffiliates, $73. Subscriber categories: aviation, safety and human factors.

Guidebook for Detecting and Mitigating Low-Level DC Leakage and Fault Currents in Transit Systems
TCRP Research Report 211

This report provides specifications for sensors being tested in the field and outlines their capabilities and appropriate operating conditions.

2020; 54 pp.; TRB affiliates, $44.25; nonaffiliates, $59. Subscriber categories: energy, public transportation, safety and human factors.

Transportation Research Record 2674
Issue 6

Authors present research on such topics as signal plans under incidents with real-time traffic prediction, a laboratory method to assess efficacy of dust suppressants for dirt and

gravel roads, and a deep learning approach for predictive analytics to support diversion during freeway incidents.

2020; 492 pp. For more information, visit http://journals.sagepub.com/home/trr.

Transportation Research Record 2674 Issue 7

A reliability-based design for passing maneuvers based on observational data, a city-to-city and temporal assessment of peer city scooter policy, and induced vehicle travel in the environmental review process are among the topics explored in this volume.

2020; 620 pp. For more information, visit http://journals.sagepub.com/home/trr.

Transportation Research Record 2674 Issue 8

The papers in this volume examine topics including why drivers cross the line at activated railway crossings, a temporal analysis of predictors of pedestrian crashes, emergency response times for fatal motor vehicle crashes between 1975 and 2017, and more.

2020; 951 pp. For more information, visit http://journals.sagepub.com/home/trr.

Transportation Research Record 2674 Issue 9

Addressed in this issue are topics including the effect of speed bumps on pavement condition; fleet sizing for pooled, automated vehicle fleets; and the safety effects of horizontal curve reliability index.

2020; 1,156 pp. For more information, visit http://journals.sagepub.com/home/trr.

Transportation Research Record 2674 Issue 10

A hybrid machine learning approach for freeway traffic speed estimation, an innovative nonparametric method for data outlier filtering, and an examination of the typology of bikeshare users combining bikeshare and transit are among the research topics presented in this volume.

2020; 1,002 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.

CENTENNIAL QUOTE

"I made my first presentation as a PhD student at the 2012 Transportation Research Board (TRB) Annual Meeting. I was nervous but prepared; I had polished the presentation for weeks. On the big day, I stepped up to the podium to realize that the only tool I had in front of me was a slide clicker. There was no display! The large screen was located at the corner of the hall, but I couldn't make out the text—even when squinting. My palms got sweaty and my mouth went dry as a desert. I heard senseless combinations of words coming out of my mouth. In my mind's eye, I already saw my advisor telling me to drop out of the PhD program. After returning home, I thought about the embarrassment again. If I was unable to read my slides, how was the audience supposed to do it? Most were much farther from the screen than I was. This was my "aha" moment! I realized that there is more to presenting than cramming as much information on the slides as possible. Fast forward eight years, and I am finishing a book on communication for academics. My TRB experience marked the starting point of a journey leading to the book.

—MARTINS ZAUMANIS
Scientist, Empa Concrete and Asphalt Laboratory,
Swiss Federal Laboratories for Materials Science and Technology, Dübendorf

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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ADDRESS SERVICE REQUESTED

2021 TRB ANNUAL MEETING
Transportation Research Board

100TH Annual Meeting
A Virtual Event
January 2021

The TRB 100th Annual Meeting will cover all transportation modes, addressing topics of interest to policy makers, administrators, practitioners, researchers, and representatives of government, industry, and academic institutions. A number of sessions will focus on the spotlight theme for the 2021 meeting: *Launching a New Century of Mobility and Quality of Life.*

COVID-19 program: The meeting also will feature dozens of sessions on how the coronavirus disease, COVID-19, has impacted transportation, and how transportation professionals and researchers are responding.

2021 Event Dates: Committee meetings will be January 5–8 and 11–15; sessions and exhibits will be January 21–22 and 25–29.

Plan now to attend. For more information, visit **www.trb.org/AnnualMeeting**.

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