TR NEWS
March–April 2021 NUMBER 332

2021 VIRTUAL EVENT

TRB'S 100TH ANNUAL MEETING

PLUS

The State of TRB

TRB and the Bureau of Transportation Statistics

Near-Road Air Quality

The National Academies of
SCIENCES · ENGINEERING · MEDICINE
TRB
TRANSPORTATION RESEARCH BOARD

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

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

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

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

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

Learn more about the National Academies of Sciences, Engineering, and Medicine at **www.nationalacademies.org**.

The **Transportation Research Board** is one of seven major programs of the National Academies of Sciences, Engineering, and Medicine. The mission of the Transportation Research Board is to provide leadership in transportation improvements and innovation through trusted, timely, impartial, and evidence-based information exchange, research, and advice regarding all modes of transportation. The Board's varied activities annually engage about 8,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state departments of transportation, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

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

TRB

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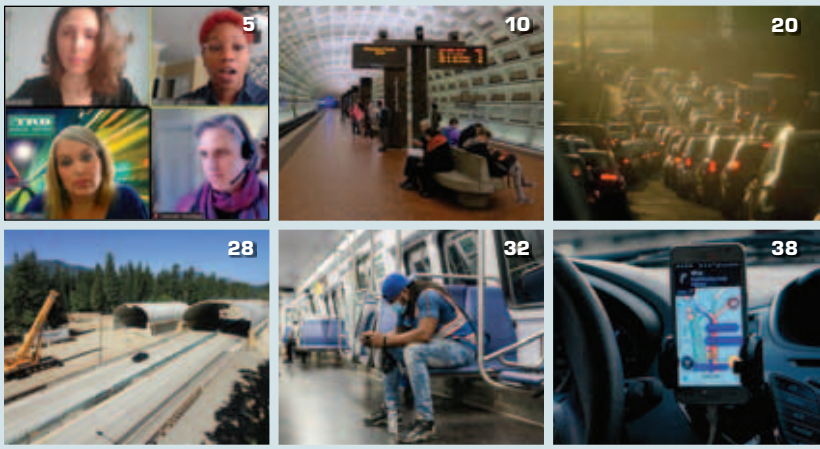

COVER TRB's 100th Annual Meeting in January 2021 was a virtual event, with a record-breaking 20,000 participants logging in from across the globe.

TRB COVID-19 Resources

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

Coming Next Issue

The theme of the May–June 2021 issue of *TR News* is diversity, equity, and inclusion (DE&I) in transportation and its critical role in a just, fair, and equitable society. Authors highlight TRB's initiatives addressing DE&I, along with programs within the larger transportation community, from the federal government to states to universities.

Adonis Rucker visits a job site as part of Michigan Department of Transportation's Transportation Diversity and Recruitment Program, a partnership with the University of Michigan and the Atlanta University Center Consortium, a group of historically Black colleges and universities, or HBCUs, in Atlanta, Georgia.

Photo: Michigan DOT

Also in This Issue

TR NEWS

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

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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.

Notice: The opinions expressed in articles appearing in *TR News* are those of the authors and do not necessarily reflect the views of the Transportation Research Board. The Transportation Research Board and *TR News* do not endorse products or manufacturers. Trade and manufacturers' names appear in an article only because they are considered essential.

Printed in the United States of America.

THE STATE OF TRB

Meeting the Challenges of the Future

NEIL J. PEDERSEN

The author is the executive director of the Transportation Research Board at the National Academies of Sciences, Engineering, and Medicine, Washington, D.C.

I hope that all of you found the 100th TRB Annual Meeting to be a rewarding and enriching experience. I would like to thank the thousands of volunteers, as well as all my colleagues on the TRB staff who worked so hard to adapt to our new virtual format this year and made this milestone Annual Meeting such a success. I want to thank our sponsors, our annual meeting patrons and exhibitors, and our global affiliates, without whose financial support this meeting would not have been possible. And I would be remiss if I did not thank the TRB Executive Committee, under the leadership of Chair Carlos Braceras and Vice Chair Susan Shaheen, who provided guidance and support to TRB programs and to the dedicated TRB staff throughout the year.

This annual meeting brought a close to TRB's year-long Centennial celebration. The Centennial gave us the opportunity to reflect on the storied history that led to TRB being what it is today, as well as to appreciate many of the people who made TRB the influential and valued organization that it has become. November 11, 2020—Veterans Day—marked the actual 100th anniversary of TRB. It also served as the pivot point for the Centennial celebration to change its focus from celebrating TRB's past to thinking about its future.

I would like to offer a few personal thoughts as we look to TRB's future. Major changes are occurring in transportation and the forces that influence it, and not just because of the pandemic. Advances in technology, demographic shifts, climate change, an aging transportation infrastructure, changes in travel behavior and consumer demand, and changes in manufacturing locations and processes are some of the forces that will have far-reaching and long-term implications for transportation.

We also continue to face challenges that have not been solved during TRB's first 100 years; challenges that require our best thinking to resolve. These issues include the unacceptably high rate of fatalities and injuries in our highway transportation system, a fragmented institutional framework for decision-making

and governance, financial resources that repeatedly fall short of investment needs, workforce challenges, a growing share of greenhouse gas emissions coming from the transportation sector, and inequitable access and mobility for all our citizens. Looking to the future, we have no shortage of issues for TRB to address through its convening, research, advising, and dissemination activities.

I have identified seven principles that I believe have been critical to TRB's success that should guide us as we look to the future:

1. Taking full advantage of being part of the National Academies of Sciences, Engineering, and Medicine and the expertise available to TRB throughout the Academies;
2. Bringing together researchers and practitioners to interact with and learn from each other;
3. Capitalizing on the multidisciplinary and multimodal expertise of TRB's participants and the multidisciplinary and multimodal scope of its portfolio;
4. Taking advantage of the expertise and commitment of TRB's volunteers as its "heart and soul";
5. Producing useful products and services that meet the needs of TRB's sponsors and stakeholders;
6. Offering professional development and growth opportunities for transportation professionals at all stages of their careers; and, most importantly,
7. Ensuring adherence to the National Academies' and TRB's high standards for objectivity, independence, nonpartisanship, integrity, and excellence, as well as an evidence basis for all that we do.

Guided by these principles and by direction from National Academies' leadership in forging its new strategic plan, TRB will be developing its own strategic plan that will focus on the following:

1. Anticipating and preparing the transportation professional community and society for future challenges and opportunities;
2. Leveraging advances in technology to facilitate communications, collaboration, data collection and analysis, and information exchange and knowledge transfer;
3. Diversifying those who participate in TRB in terms of professional disciplines, gender, racial and ethnic minorities, and participants from outside the United States;
4. Expanding TRB's impact and influence through the work it does and through effective communications about its work, its products, and resources that it makes available; and
5. Assuring TRB's continued creativity, resilience, and sustainability in an ever-changing world.

I would like to challenge all of us to make TRB even more impactful and influential in its next 100 years than it was in its first 100 years.

- I would like to challenge the unprecedented number of young people who attended this year's Annual Meeting to continue to press for new ways for transportation to enable a prosperous and equitable society and to protect and improve our environment;
- I would like to challenge TRB veterans to help mentor and develop the talent of younger colleagues, who are the future of TRB; and
- I would like to challenge every one of us to work to continue to make TRB a welcoming environment where the value of different ideas and viewpoints are respected and encouraged, because the only way to address the diversity of challenges we will face in the next 100 years is by bringing as many perspectives to the table as possible.

We are all TRB, and we are all in this together! TRB's success depends on all of us collectively meeting the challenges of the future! I look forward to working with all of you as we launch TRB's next century!

Looking to the future, we have no shortage of issues for TRB to address through its convening, research, advising, and dissemination activities.

A Virtual Event
TRB's 100th Annual Meeting

Although the world changed a great deal in 2020, transportation research remained essential. For its 100th Annual Meeting, TRB hosted an entirely virtual event—keeping the health and safety of TRB employees, contractors, and meeting attendees paramount—that took place over the month of January 2021.

The world's largest transportation research conference had even greater reach this year—approximately 20,000 people logged on from across the globe to view more than 400 sessions and workshops, participate in committee meetings, and browse exhibits. Many of the sessions explored the meeting's spotlight theme—Launching a New Century of Mobility and Quality of Life—as well as the crucial topics of the COVID-19 pandemic and of racial justice and equity in transportation.

At the Chair's Plenary Session, Marcia McNutt, President of the National Academy of Sciences, addressed future transportation-related issues in science. Chicago Transit Authority President Dorval R. Carter, Jr., delivered the 2021 Thomas B. Deen Distinguished Lecture, titled *Our Work Is Never Done: Examining Equity Impacts in Public Transportation*.

Details and highlights appear on the following pages.

All screenshots taken by TRB staff members.

1 Contemporary artist Jim Hodges designed the sculpture of colorful glass fragments that greets travelers passing through New York City's Grand Central–42nd Street subway station. The public art installation, titled *I dreamed a world and called it Love*, was one of the works addressed in the session *Transit Interactions Reimagined: Art, COVID and Equity*, which explored how transit agencies have responded to COVID-19 with art and inclusivity, collaborating with communities to make transit stations and environments safer and more inviting for everyone.

2 (*Clockwise from upper left*) Moderator **Charles Brown**, Alan M. Voorhees Transportation Center, and panelists **Celeste Chavis**, Morgan State University; **Keshia Pollack Porter**, Johns Hopkins University; **Lincoln Edwards**, University of Arizona; and **Richard Ezike** (*center*), The Urban Institute, shared knowledge on the ways in which Black, indigenous, and people of color experience restrictions, risks, indignities, and inequities while navigating pedestrian, bicycle, transit, and other transportation systems at a session titled *Arrested Mobility*.

3 The 25 students who received Minority Student Fellowships to present at the 2021 TRB Annual Meeting had a very different experience than previous attendees, but an "engagement challenge" checklist helped them get the most out of the meeting.

4 In her keynote address, National Academy of Sciences President **Marcia McNutt** examined TRB's crucial role in the mission of the National Academies of Sciences, Engineering, and Medicine.

Committees

1 **Hyun-A Park**, Spy Pond Partners, guides a meeting of the Technical Activities Council (TAC) on the first day of the Annual Meeting. TAC supervises and facilitates the work of TRB's more than 160 standing committees.

2 **Oriana Aguas**, University of Waterloo, delivers a presentation on modeling impacts of the Trans-Pacific Partnership on Canada's trade infrastructure at a meeting of the International Trade and Transportation Committee.

3 **Tracee Strum-Gilliam**, PRR, Inc., cochairs a meeting of the Equity in Transportation Committee, along with **Gloria Jeffs**, Minnesota Department of Transportation (*not pictured*). The committee surveyed current research in transportation equity, planned upcoming events, and heard updates on Federal Highway Administration (FHWA) activities, as well as on the U.S. Department of Transportation Rural Opportunities to Use Transportation for Economic Success program.

4 At a meeting of the Geospatial Data Acquisition Technologies Committee, **David Unkefer**, FHWA, participates in one of the group's many discussions on topics from geospatial control to data acquisition using small unmanned aerial systems.


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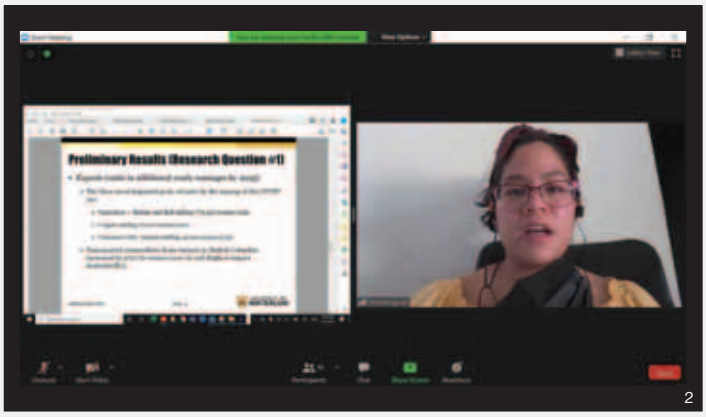

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Executive Committee

5 **Ashby Johnson**, executive director of Texas's Capital Area Metropolitan Planning Organization, takes part in TRB Executive Committee deliberations. The Executive Committee devoted its policy session to examining the impacts of the COVID-19 pandemic on mobility and equity.

Executive Committee Leaders Take Helm

The 2021 TRB Executive Committee Chair is **Susan Shaheen**, Civil and Environmental Engineering professor at the University of California (UC), Berkeley, and codirector of the Transportation Sustainability Research Center, Institute of Transportation Studies, Berkeley. An expert and pioneer in future mobility strategies, Shaheen was among the first to observe, research, and write about changing dynamics in shared mobility and the rise of automated vehicles.

Shaheen

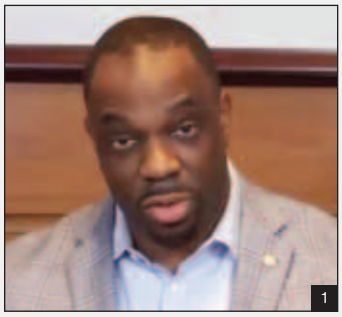
The first Honda Distinguished Scholar in Transportation at the Institute of Transportation Studies at UC Davis, Shaheen also served as the Policy and Behavioral Research Program Leader at California Partners for Advanced Transit and Highways and as a special assistant to the Director's Office of the California Department of Transportation from 2001 to 2004.

Nathaniel P. Ford, Sr., CEO of the Jacksonville Transportation Authority in Florida, is 2021 Executive Committee Vice Chair. Over his four-decade career, Ford has championed multimodal transportation, walkable neighborhoods, public–private partnerships, and transit-oriented development.

Randell Iwasaki, Amazon Web Services, is a new member of the Executive Committee.

Sessions & Workshops

1 **Toks Omishakin**, California Department of Transportation, leads an opening panel discussion about perspectives on public health and transportation.



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2 **Trenna Terrill**, University of Wyoming, conducts a workshop segment on a road safety toolkit for Indian tribes, one of seven presentations during the *New Developments in Safety on Low-Volume Roads* workshop.

2

3 **KeAndra Cylear Dodds** (*top, right*), Los Angeles County Metropolitan Transportation Authority, presents a research paper on equity programs at Los Angeles Metro, part of the *Advancing Transportation Equity* lectern session. Other participants include (*clockwise from lower right*) **Hannah Twaddell**, ICF; **Valerie Lefler**, Feonix Mobility Rising; and **Ipek Sener**, Texas A&M Transportation Institute.

4 **Dan Lamers** (*top, center*), North Central Texas Council of Governments, presents his research paper, "Managed Lanes: The First 50 Years," during the *Managed Lanes: Adapting, Enduring, Anticipating* lectern session. Other participants include (*clockwise from upper right*) **Robert Poole**, Reason Foundation; **Suzanne Murtha**, AECOM; **Timothy Haile**, Contra Costa Transportation Authority; **Darren Henderson**, WSP; and **Charles Fuhs**, Chuck Fuhs, LLC.

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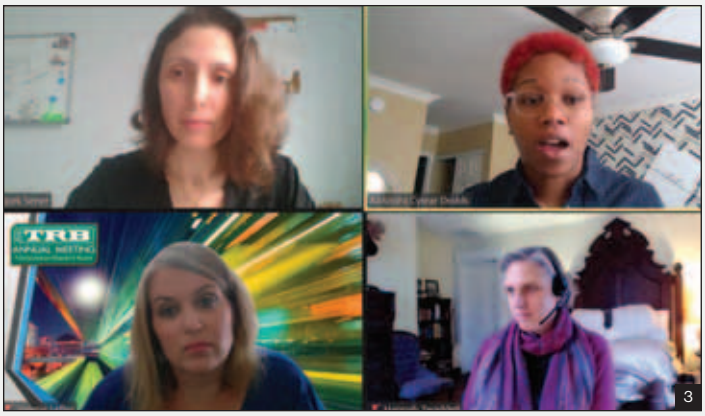

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Sessions & Workshops

(*continued*)

5 TRB Annual Meeting participants toured virtual exhibit spaces—such as the Cooperative Research Programs (CRP) booth, with CRP Director **Chris Hedges** at the entrance—to experience a bit of whimsy, a lot of creativity, and a hefty load of transportation research and information on airports, behavioral traffic safety, highways, and transit. (Design: Community Brand)

6 During the *Air Carrier Business Models for Recovery and Post COVID-19* lectern session, **John Heimlich** (*bottom*), Airlines for America, presents his research paper, "Airlines for America Perspective." Other participants include (*clockwise from upper left*) **Katherine Harback**, Institute of Health Economics; **Kenneth Strickland**, Raleigh–Durham Airport Authority; **Torque Zubeck**, Alaska Airlines; and **David Clark**, JetBlue Airways.

7 Presiding over the *Transit Interactions Reimagined: Art, COVID, and Equity* lectern session, **Zipporah Lax Yamamoto**, Los Angeles County Transportation Authority, provides background on her Zoom backdrop. The hand-painted mural, *Hecho a Mano* by Sonia Romero (installed in Mariachi Plaza Metro Station in the East Los Angeles neighborhood of Boyle Heights), highlights the neighborhood's Latinx, Jewish, and Japanese influences, presenting legacies of community struggle and resilience through objects of significance. (Backdrop photo: Elon Schoenholz, courtesy of Sonia Romero)

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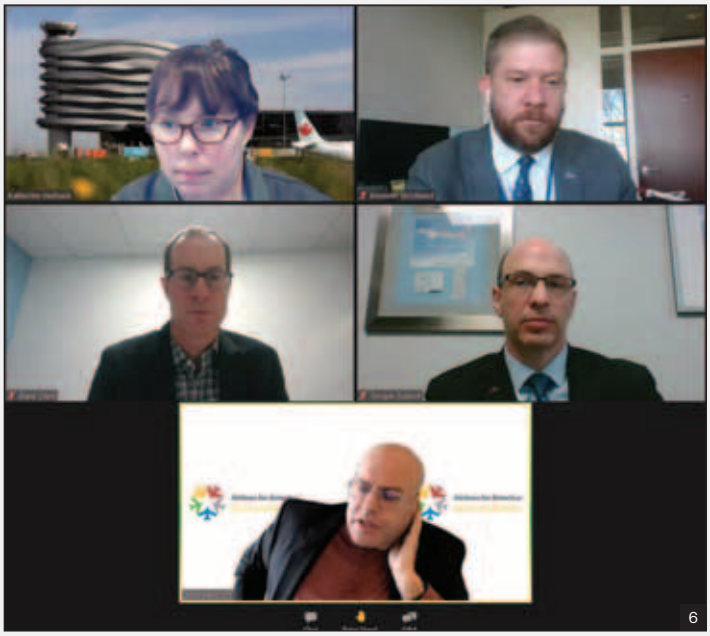
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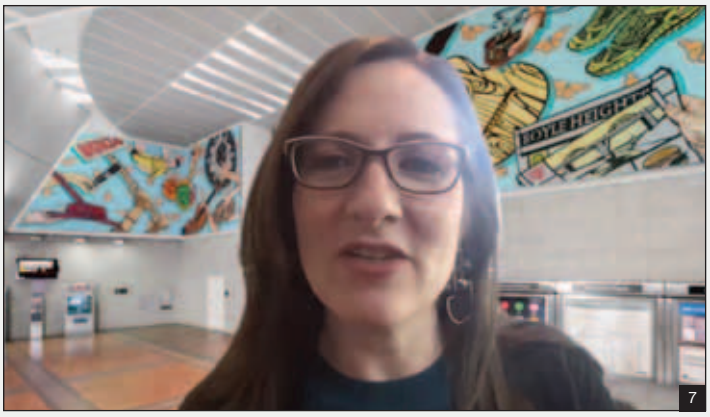

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8 **Noelle Trent**, National Civil Rights Museum, shares an image of the Lorraine Motel in Memphis, Tennessee, where Martin Luther King, Jr., was assassinated on April 4, 1968. The site of the historic tragedy is now home to the museum. Trent participated in the lectern session titled *The Influence of Discrimination and Civil Rights Laws on Shaping Our Transportation Systems*. The panel discussed how discrimination impacts transportation and how the legal system, interstate commerce, and civil rights laws have been and are being used to minimize adverse effects and, ultimately, ensure access and equity within transportation systems.

Major Awards

1 President of the Chicago Transit Authority **Dorval R. Carter, Jr.**, is the 2021 recipient of the Thomas B. Deen Distinguished Lectureship. Named in honor of TRB's eighth executive director, who served from 1980 to 1994, the lectureship recognizes the career contributions and achievements of an individual in one of the areas covered by TRB's Technical Activities Division. Carter is recognized for his leadership in the transit industry and legal community and for spearheading significant advances in public transportation.

2 Trustee chair, Pegasus Professor, and chair of the Department of Civil, Environmental, and Construction Engineering at the University of Central Florida **Mohamed Abdel-Aty** is the 2021 recipient of the Roy W. Crum Distinguished Service Award. Named for TRB's former director, who served from 1928 until his death in 1951, the award recognizes outstanding leadership in transportation research or research administration. Abdel-Aty is recognized for his achievements in developing immediate practical applications for his fundamental and developmental research results, as well as for his broad contributions to transportation safety.

3 **Martha Grabowski**, McDevitt Distinguished Chair in Information Systems; professor and director of the Information Systems Program at Le Moyne College in Syracuse, New York; and senior research scientist in the Department of Industrial and Systems Engineering at Rensselaer Polytechnic Institute in Troy, New York, is the recipient of the 2020 W.N. Carey, Jr., Distinguished Service Award. Named for TRB's Executive Director from 1967 to 1980, the award recognizes individuals who have given leadership and distinguished service to TRB. Since 1991, Grabowski has provided continuous volunteer service to TRB, the Marine Board, and the National Research Council of the National Academies of Sciences, Engineering, and Medicine.

4 **Rodney E. Slater** is the 2021 recipient of the Frank Turner Medal for Lifetime Achievement in Transportation. Secretary Slater is a partner at Squire Patton Boggs LLP in Washington, D.C., the former U.S. Secretary of Transportation, and the former administrator of the FHWA. Named for its initial recipient, the award recognizes a distinguished career in transportation; professional prominence; and a distinctive, widely acknowledged contribution to transportation policy, administration, or research. Slater is honored for his influential career in the areas of aviation, surface transportation, and infrastructure, as well as for his commitment to the role of transportation in safety, mobility and access, economic development and trade, and the environment and national security.


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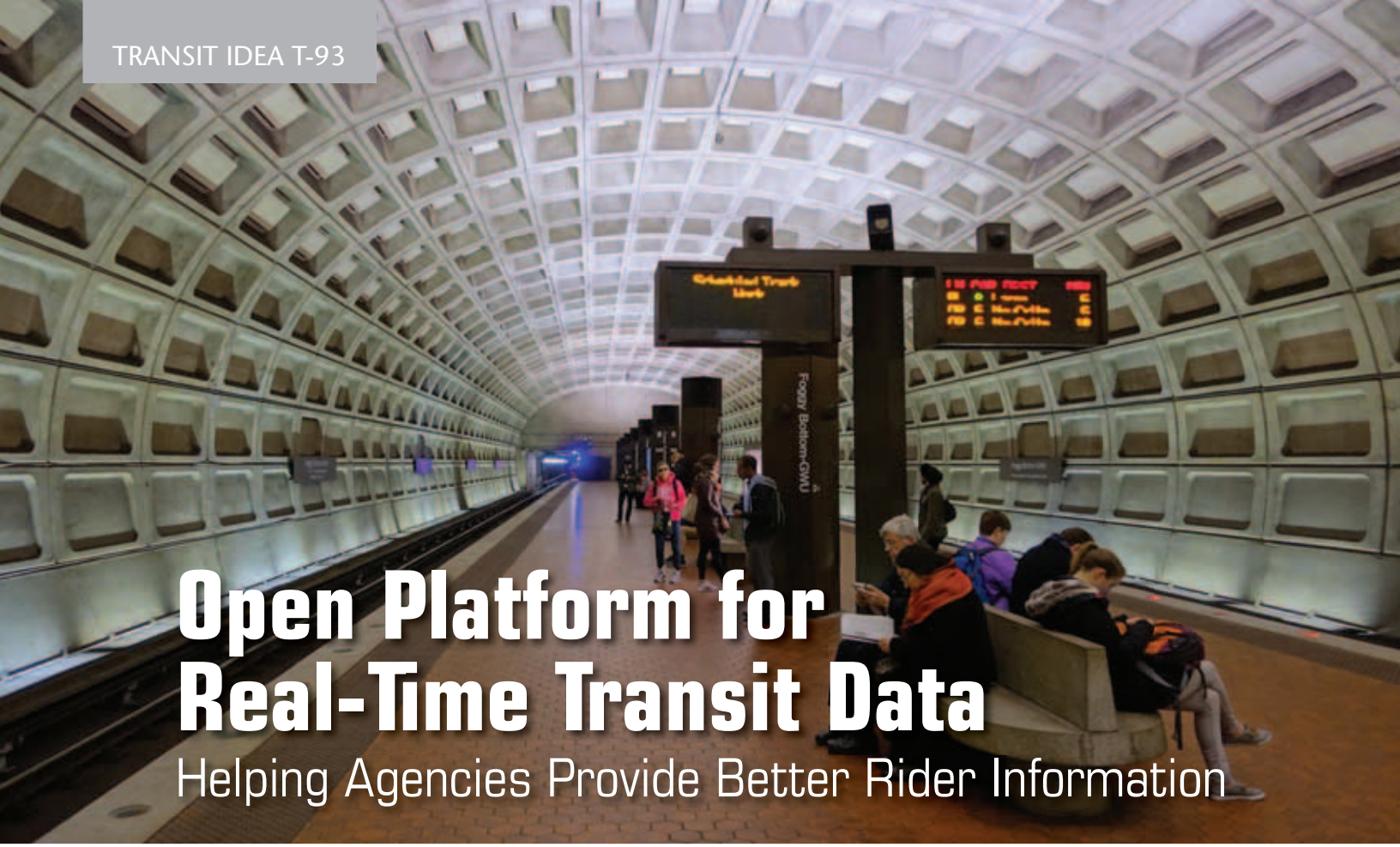

Open Platform for Real-Time Transit Data

Helping Agencies Provide Better Rider Information

Photo: Daderot, Wikimedia Commons

DREW DARA-ABRAMS

The author is a principal at Interline Technologies in San Francisco, California.

Above: Passengers wait for their train to arrive at the Foggy Bottom–GWU (George Washington University) Metro Station in Washington, D.C. In cities all over, transit riders get real-time transit information via smartphone apps that—among other benefits—helps them manage their travel time. But such an advantage can be thwarted when information is incorrect or when transit agencies fail to monitor their data.

Pull out a smartphone, open an app, and see when the next bus is estimated to arrive. What was once available in only a handful of cities has now become commonplace, if not expected. Real-time transit information has brought measurable benefits to riders and agencies but also has introduced new complexities for agencies and their staffs. Researcher Ian Rees at Interline Technologies in San Francisco, California—along with Sean Barbeau at the Center for Urban Transportation Research (CUTR) at the University of South Florida—collaborated as part of a team that recently completed a TRB Transit IDEA (Innovations Deserving Exploratory Analysis) project to develop an open web-based platform that validates the quality of real-time transit data and helps agency staff to understand issues.[1]

[1] For the full project report, see http://www.trb.org/Main/Blurbs/181415.aspx.

Real-Time Transit Data: Benefits and Challenges

Researchers have found that when transit agencies provide real-time transit information to their riders, there are measurable gains, including:

1. Shorter perceived and actual wait times. Wait times are *actually* shorter because riders are able to consult real-time information in advance, decide when to arrive at a stop or station, or decide to go to an alternative stop or station. Wait times are *perceived* to be shorter because riders have more information once they have arrived at a stop or station (*1*).
2. A more welcoming experience for new riders (*2*).
3. An increased feeling of safety (e.g., at night). Riders may be able to choose to wait at an alternative location before going to a stop or station, or they may have more confidence in their safety

Photo: Piqsels

When passengers have access to reliable real-time information, transit agencies receive a direct benefit: an equally reliable increase in ridership.

once they have arrived at a stop or station (*3–4*).

4. Increased ridership as a direct result of the previously listed effects and as the benefits compound (*5–6*).

An additional plus for transportation agencies is that real-time transit data is—compared with many other potential operational or capital improvements to bus or rail service—an affordable and efficient means of increasing ridership.[2]

However, there are two key challenges to realizing the benefits of real-time information:

1. Providing real-time transit data can backfire if that information is not up to date and accurate. Incorrect real-time transit data have been found to have a negative effect on ridership, the rider's opinion of an agency, and the rider's satisfaction with mobile transit apps (*4*).
2. A limited number of transit agencies monitor the reliability and accuracy of their traveler information systems. Lacking this capability, many agencies provide real-time information of unknown quality. Because of this uncertainty, some agencies instead try to limit distribution of real-time data (*7–8*).

How can agency staff actually measure the quality of their real-time transit data? This is a simple question to ask but a more complex one to answer. GTFS (general transit feed specification) and GTFS Realtime are closely related data specifications that agencies use to disseminate transit information. The technical architectures used to create and distribute GTFS and GTFS Realtime data feeds are often complex, with different agency departments or vendors responsible for different components (Figure 1).

Solution: An Open Platform for GTFS Realtime Validation

The research team's goal for the Transit IDEA T-93 project was to build and test a web-based platform that transit agency staff could use to assess their GTFS Realtime feeds. They began this project with two open-source components already in hand:

1. **Transitland**—an open-data platform that aggregates GTFS data from thousands of transit providers. Transitland provides a directory of

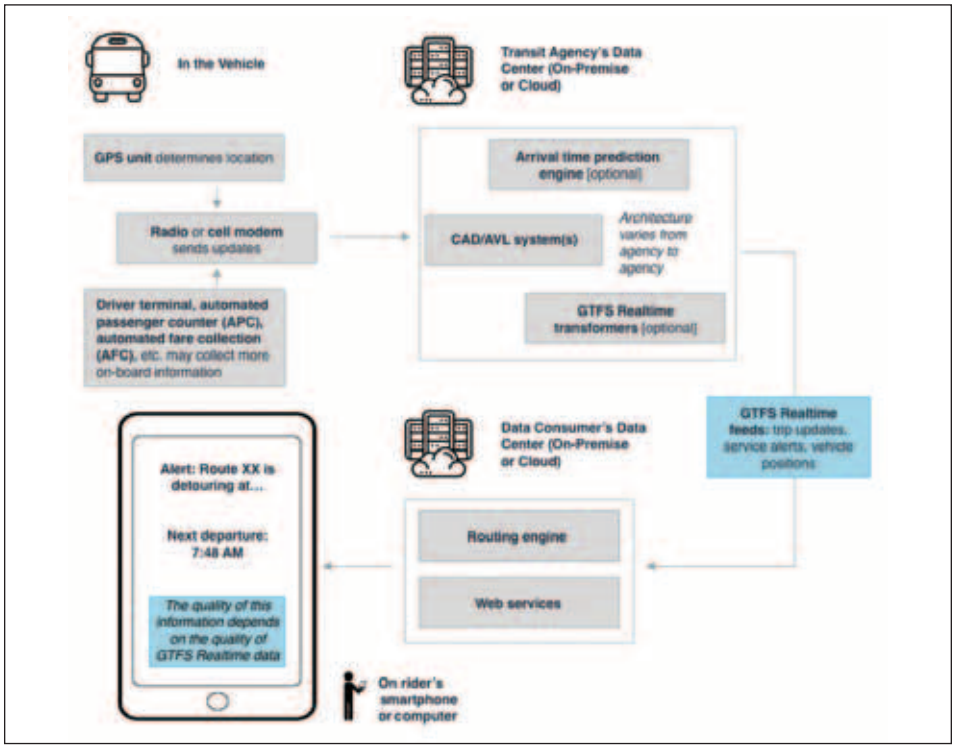

FIGURE 1 GTFS Realtime feeds are typically produced and consumed in an overall technical system architecture. (Note: CAD/AVL = computer-aided dispatch/automatic vehicle location.)

[2] The *APTA 2017 Fact Book* notes: "The growth of automatic vehicle location systems, which improves the operation of bus fleets, as well as the availability of information on bus arrival times, has made public transit systems more efficient and data more accessible."

these feeds and a set of application programming interfaces for querying the feeds and their contents.[3]

2. **The GTFS Realtime Validator**—a prototype created by CUTR that can be run in a variety of contexts to evaluate a given GTFS Realtime feed and produce a report on the feed's data quality.

The researchers' goal was to combine the breadth and ease of use of Transitland—accessed using any web browser—with the depth and power of the GTFS Realtime Validator, which requires some expertise to run and tune.

The team's combined platform collects GTFS Realtime data from each feed, runs the validation process, and produces a report on any detected errors. Each report shows the counts of data entities, the percentage with errors, and a brief text description of any errors (Figure 2). Links take users to additional documentation about each error type. Some errors also provide further contextual information in maps and tables to assist users as they try to determine root causes (Figure 3).

User Research and Platform Testing

The project team tested the platform by preparing validation reports for seven public transit agencies and reviewing the results in the platform user interface with agency staff members. In these user-testing sessions, the team collected information from agency staff about how GTFS and GTFS Realtime data are currently created at each agency, all known issues, and any open goals. After being given a tour through the platform and its interface, agency staff reviewed the reports for their own GTFS Realtime feeds. Using a standardized question list, agency staff were asked to provide input on both the specific quality checks and the overall presentation and approach used by the platform.

Key findings included the following:

1. GTFS and GTFS Realtime are often the responsibility of separate groups or departments within an agency. For agencies that operate both bus

[3] See https://www.transit.land.

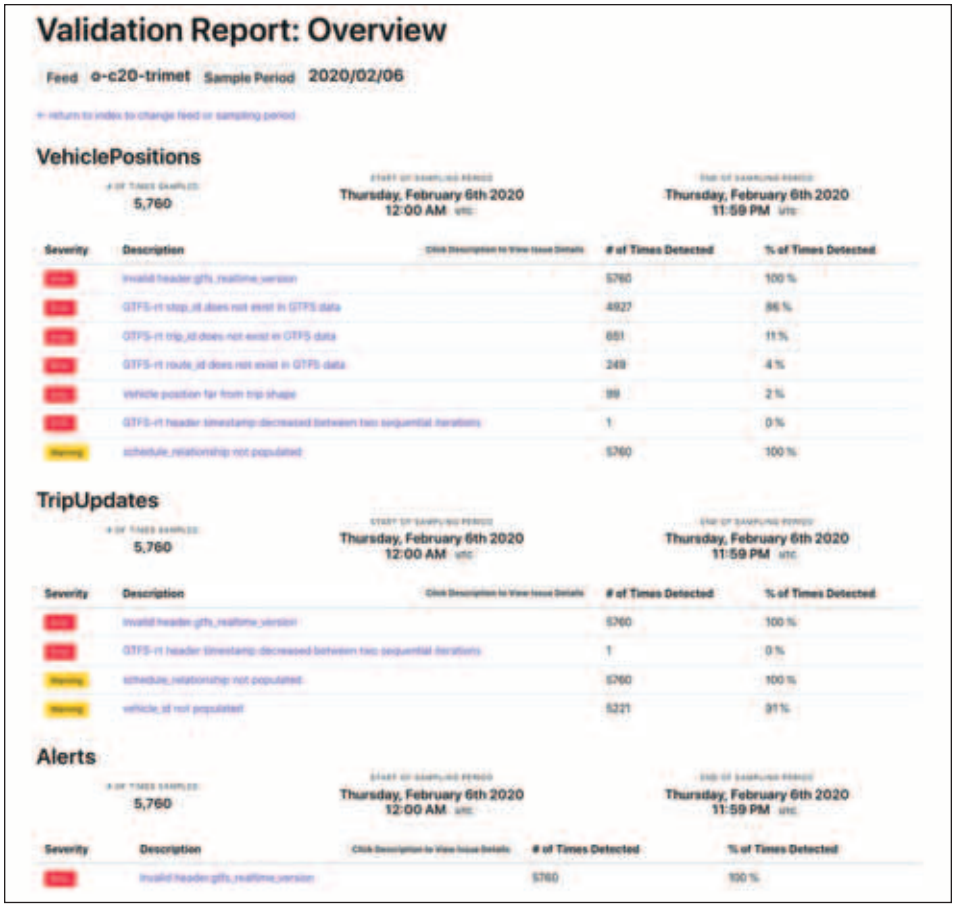

FIGURE 2 The validator library run against a day's worth of GTFS Realtime data displays the new user interface in a web browser.

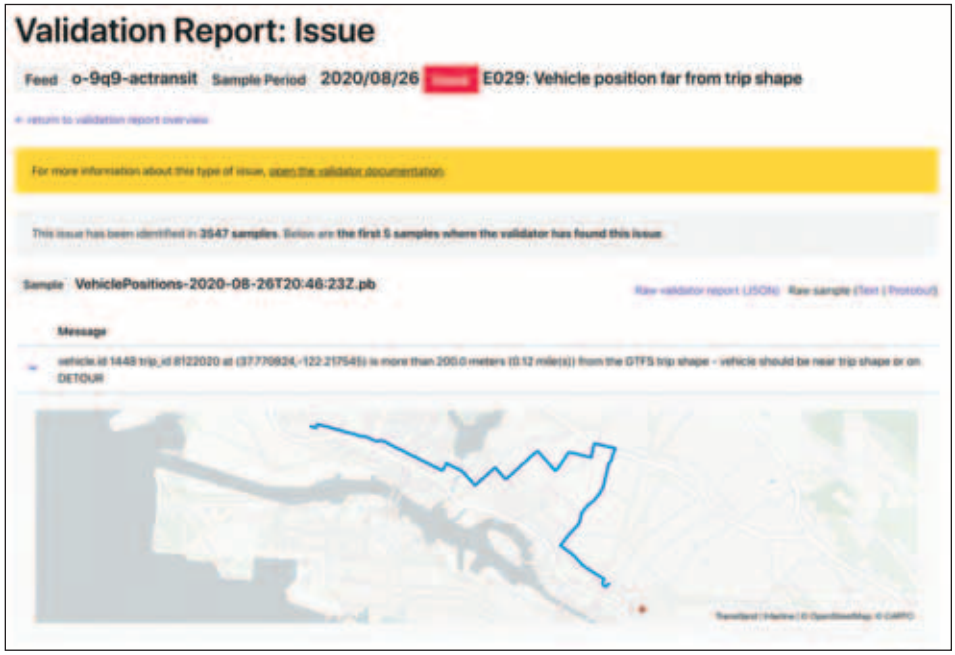

FIGURE 3 A screenshot of the validator platform shows contextual information from both a GTFS Realtime feed and its associated static GTFS feed. The E029 error indicates that a vehicle position is too far from its associated trip shape. The map shows the bus position as a red dot and its scheduled route shape–alignment in blue.

and rail service, separate groups or departments often are responsible for the data systems associated with each mode. A few agencies have formed working groups with cross-cutting responsibilities for static and real-time data across bus and rail.

2. Most agencies validate their static GTFS feeds, but most have not validated the contents of their GTFS Realtime feeds.
3. Vendor systems are "black boxes" with "no visibility into data generation." Agency staff are aware of what types of information are sent to the vendor systems and what data are output, but they are not provided with access to see what processing and transformation happens within the systems. Without this understanding, agency staff may not be able to identify the source of data quality issues.
4. Improvements to GTFS Realtime feed generation often must happen at the same time as new computer-aided dispatch/automatic vehicle location hardware is procured, so overall requests for proposals may be complex to write and evaluate.
5. Several agencies voiced the opinion that vendors rather than agency staff may be more responsive to fixing errors flagged by the validator, as the validator would be seen as an objective tool.

All agencies found the experience of exploring the warnings and errors useful, to the point that most of the sessions ran long. Video calls turned into miniature consulting sessions, with the conversation between agency staff and the research team often ranging from specific GTFS Realtime data fields to system-level architecture concerns. On the one hand, this shows the power of the platform as a way to surface useful information for such wide-ranging investigations. Agency staff reported that some of this information was available through other sources but not aggregated in one place, while other information was previously unknown. On the other hand, these consultations showed how unique each GTFS Realtime system is and how wide a range of information and functionality is necessary for the platform to serve all agencies' potential needs.

Next Steps

The research team welcomes transit agencies with existing GTFS, GTFS Realtime feeds, or both to add them to Transitland's open directory or to provide more information.[4] Registering feeds will make them available to a wider range of users (Figure 4).[5] Registered feeds also will be available through the validation platform when it is rolled out for self-serve use by agency staff. Based on the initial round of user testing, the research team has identified ways to simplify the validation reports so that they will be easy for self-serve use.

Finally, based on the user-testing feedback and the findings from validating a representative sample of real-time data feeds, the team has started to sketch a certification process for GTFS Realtime data feeds. This certification process would provide a common set of minimum expectations, recommended best practices for achieving those expectations, and the hosted web-based platform for assessing feeds.

The researchers are currently pursuing sponsorship for this next round of work, and they welcome feedback and collaboration.

[4] E-mail hello@transit.land for more information.
[5] The map is available at https://www.transit.land/map.

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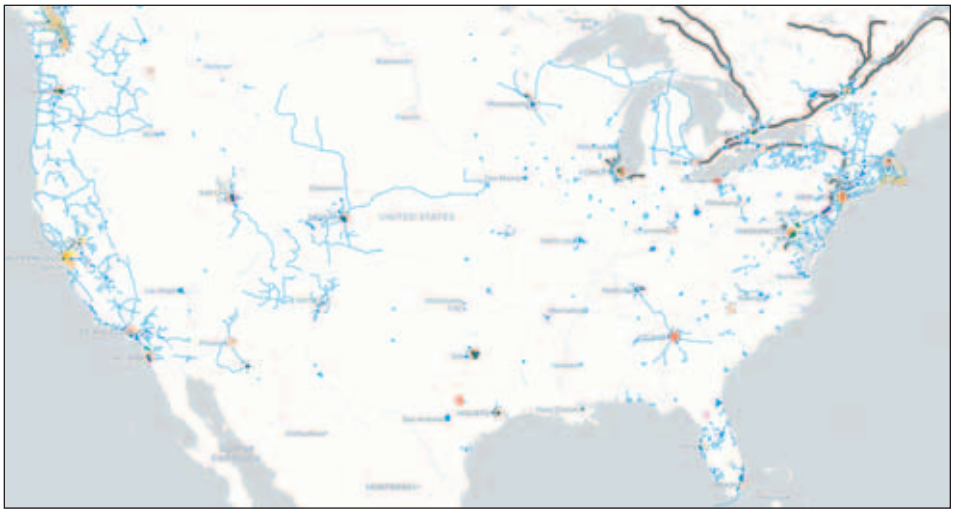
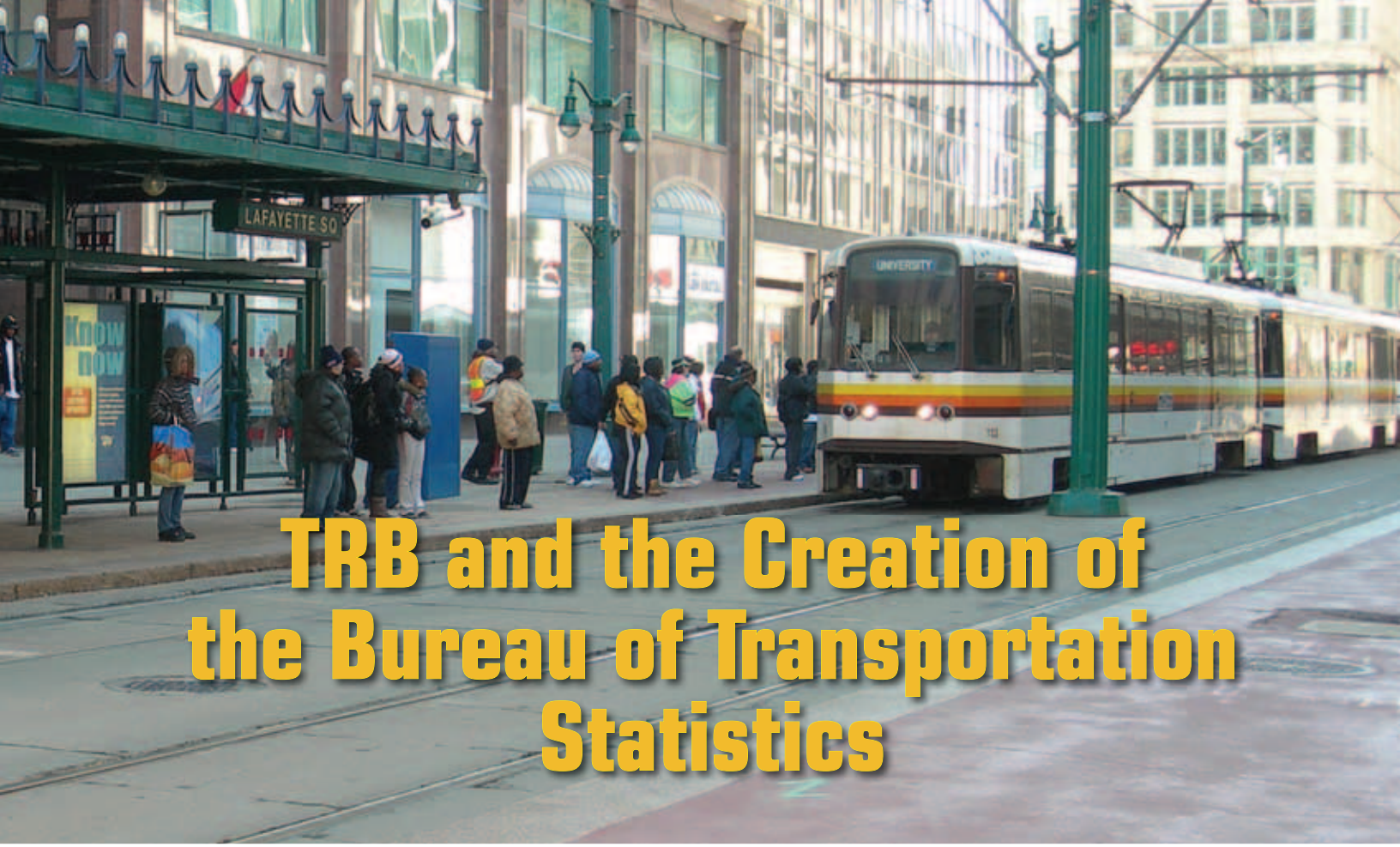


FIGURE 4 Transitland's global transit map shows its coverage of the continental United States. All routes are covered in static GTFS feeds, and some are covered in GTFS Realtime feeds.[4] Users may click on routes to learn more about available data sources. Agencies have the option to specify route colors, and many agencies that operate rail service have provided color codes.



TRB and the Creation of the Bureau of Transportation Statistics

Photo: Jason Paris, Flickr

ROLF R. SCHMITT

The author is the deputy director of the Bureau of Transportation Statistics, U.S. Department of Transportation in Washington, D.C., and a Member Emeritus of the Freight Transportation Data Committee and the former Transportation History Committee.

The views expressed are those of the author and not necessarily those of the U.S. Department of Transportation.

Above: Passengers board the train at Lafayette Square Metro Station, a stop in the Buffalo, New York, Metro Rail system. The Bureau of Transportation Statistics compiles passenger-related data in *Passenger Travel Facts and Figures*, a quick look at personal travel characteristics and trends in the United States; the passenger travel network; and the economic, safety, and environmental aspects of passenger travel.

The Bureau of Transportation Statistics (BTS) of the U.S. Department of Transportation (U.S. DOT) owes its origin and early directions in large part to the Transportation Research Board (TRB). The concept for BTS was first proposed publicly in a TRB workshop. Subsequently, the concept was refined in TRB's *Special Report 234: Data for Decisions—Requirements for National Transportation Policy Making*, published in 1992. Soon after, a TRB panel member's testimony to a Senate subcommittee inspired the legislation that established BTS. Finally, members of the TRB data community became key leaders and advisors for the new bureau. The relationship between BTS and TRB has remained strong throughout the bureau's nearly 30-year history.

The history of TRB and BTS has its roots in the Committee on Origin and Destination of the Highway Research Board (HRB), which eventually evolved into the 19 current TRB committees related to transportation data and information technology. Although several HRB and TRB committees discussed data among their many topics, the Committee on Origin and Destination and its successors concentrated exclusively on data issues. That focus was primarily on urban transportation data from the 1960s through the 1980s. TRB hosted a series of major conferences in which the transportation community worked closely with the U.S. Census Bureau to create the wealth of commuting statistics from the decennial census and, more recently, from the American Community Survey. Beyond the conferences, members of the TRB Committee on Transportation Data and Information Systems formed an ad hoc group that developed the Census Transportation Planning Program. The 50-year history of TRB involvement in census data for transportation planning is documented in *Transportation Research Circular E-C233: Applying Census Data for Transportation—50 Years of Transportation Planning Data Progress*.

In the 1980s, the TRB focus on urban transportation data expanded to freight data. Nationwide commuting data were

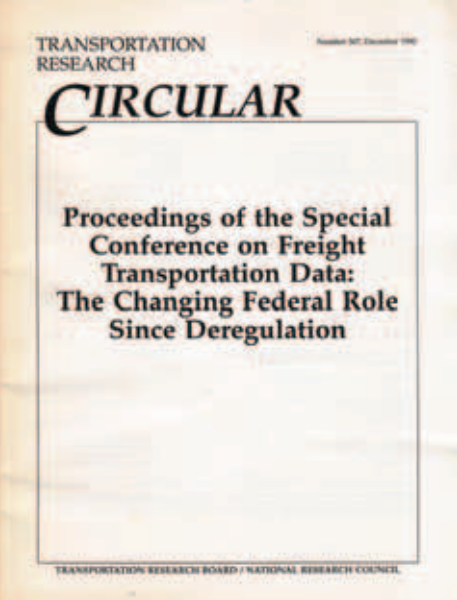
thriving, but national data on freight transportation were declining. Deregulation significantly reduced the data collection programs of the Interstate Commerce Commission. In addition, the Commodity Transportation Survey—conducted by the U.S. Census Bureau to measure freight movement—required expensive fixes for methodological problems that exceeded available funding, a constraint that ultimately led to its collapse. National data programs were not helped by the hiatus of national transportation policy studies after 1979. U.S. DOT's national transportation studies in 1972 and 1974, U.S. DOT's *Trends and Choices* report in 1977, and the 1979 report of the National Transportation Policy Study Commission featured statistics on all modes of transportation, reinforcing the value of national data programs.

The road to BTS through TRB started with the revival of U.S. DOT national transportation policy studies in 1989. U.S. Transportation Secretary Samuel Skinner recruited Thomas D. Larson to oversee a national transportation policy effort and to become Federal Highway Administrator. As a professor at Pennsylvania State University and as Pennsylvania Secretary of Transportation, Larson was a long-time participant in TRB initiatives. While U.S. DOT's National Transportation Policy team was being organized in the spring of 1989, Larson met with TRB Executive Director Thomas B. Deen to discuss possible roles that TRB could play. Soon afterwards, TRB asked John Fuller of the University of Iowa to prepare a scoping paper for a study on national data needs.

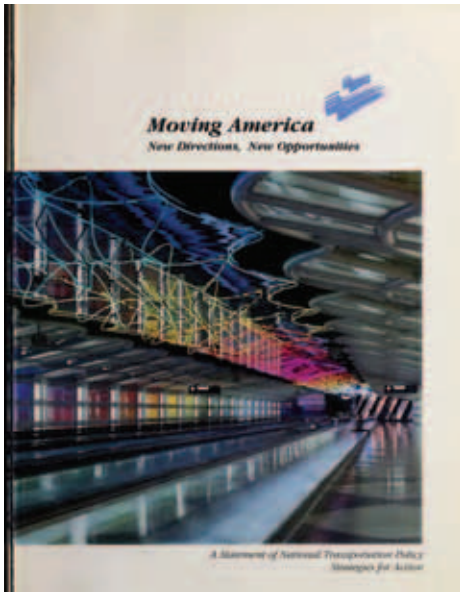
Throughout the summer and fall of 1989, TRB held outreach sessions on data needs and issues at the 14th Summer Conference on Ports, Intermodal Shipping, and Freight; the 6th International Workshop on the Future of Aviation Activity; the midyear meeting of the TRB Committee on Transportation Data and Information Systems; and the Scenic Byways Conference. TRB also held invitational meetings on safety and accident data.

Continuing its efforts, TRB cosponsored a conference with the Washington, D.C., chapter of the Transportation Research Forum on Freight Transportation Data: The Changing Federal Role Since Deregulation. Held November 14–15, 1989, at the National Academy of Sciences Building, this conference was notable for two presentations: first, the keynote speech by Charles A. Waite, associate director for Economic Fields at the U.S. Census Bureau, introduced the idea of creating a Center for Transportation Statistics similar to the federal statistical agencies in education and health; and second, the dinner speech by Robert A. Knisely, U.S. DOT's Deputy Assistant Secretary for Budget. He would go on to become the first deputy director of BTS. *Transportation Research Circular 367: Proceedings of the Special Conference on Freight Transportation Data—The Changing Federal Role Since Deregulation* documents the conference.

A session at the January 1990 TRB Annual Meeting summarized these many outreach activities. All nine of the papers published in the *Transportation Research Record No. 1253* document the session and summarize other highlights of the outreach activities. Nine of the 15 papers published in the *Transportation Research Record No. 1271* provide additional detail on the midyear meeting of the TRB Committee on Transportation Data and Information Systems.



A piece of transportation history, *Transportation Research Circular 367* documents the November 1989 conference in which Charles A. Waite, associate director for Economic Fields at the U.S. Census Bureau, delivered a speech that introduced the idea of what would become the Bureau of Transportation Statistics. (Source: Rolf R. Schmitt)



In support of the transportation industry, the White House released *Moving America: New Directions, New Opportunities* in February 1990. The policy statement committed the U.S. DOT to develop a comprehensive assessment of transportation data needs and priorities and to determine ways to integrate and disseminate such data. (Source: Rolf R. Schmitt)

The White House approved and released *Moving America: New Directions, New Opportunities* in February 1990. The policy statement identified many transportation data gaps and charged U.S. DOT to "develop a comprehensive assessment of data needs and priorities of the department and the transportation community [and] develop more effective and permanent institutional mechanisms within the department to ensure that transportation-related data collected by different agencies can be effectively linked to collect data on multimodal passenger and freight transportation flows and to integrate and disseminate transportation-related data collected by [U.S.] DOT and other public agencies."

By June 1990, U.S. DOT tasked TRB to produce a study of strategic transportation data needs. The committee appointed to

Photo: Belle Aungst, Pixy

With each flight, U.S. commercial airlines contribute information that BTS collects monthly and quarterly. Such data include passenger travel, air cargo, on-time performance, and even aviation finance and employment. The bureau's employment statistics were used to allocate billions of dollars in COVID-19 payroll protection payments to the airlines.

oversee the study met for the first time October 17–18, 1990, with Lillian Liburdi (now Lillian Borrone) of the Port Authority of New York and New Jersey as chair.

The committee was unusual for its number of participants. Beyond the 14 members and seven official liaisons, eight data program managers from U.S. DOT and the head of the Transportation Data Program at Statistics Canada served as special representatives. The large number of liaisons and special representatives assured wide engagement in the committee's work and acceptance of the committee's recommendations.

On February 7, 1991, two weeks after the committee's second meeting, committee member William (Bill) Johnston and committee consultant Alan E. Pisarski testified on Demographic Trends and Transportation Demand in a hearing convened by the Subcommittee on Water Resources, Transportation, and Infrastructure of the Senate Committee on Environment and Public Works, chaired by Sen. Daniel Patrick Moynihan of New York. Fresh from a long discussion of data issues with the TRB committee, Johnston said in his opening statement: "The one thing we lack today is data about the performance of the system. . . . Mr. Chairman, you have been one of the users and developers of data in areas relating to poverty, relating to health care, relating to the labor force, but data is the poor relation in transportation, where we make these multibillion-dollar developments and investments without really understanding how they are going to affect the performance of the system. . . . So if there is one plea I could make to the committee in the reauthorization of the bill, it is that we need the underpinnings of information, that we not be coming back to a periodic hearing where a bit of data is assembled but that there is an ongoing data collection process, performance data driving investment decision making for the system."

In addition to leading the Senate effort on surface transportation legislation, Moynihan was trying to elevate the Environmental Protection Agency into a Cabinet-level Department of the Environment with a Bureau of Environmental Statistics. Whether Johnston's testimony planted the

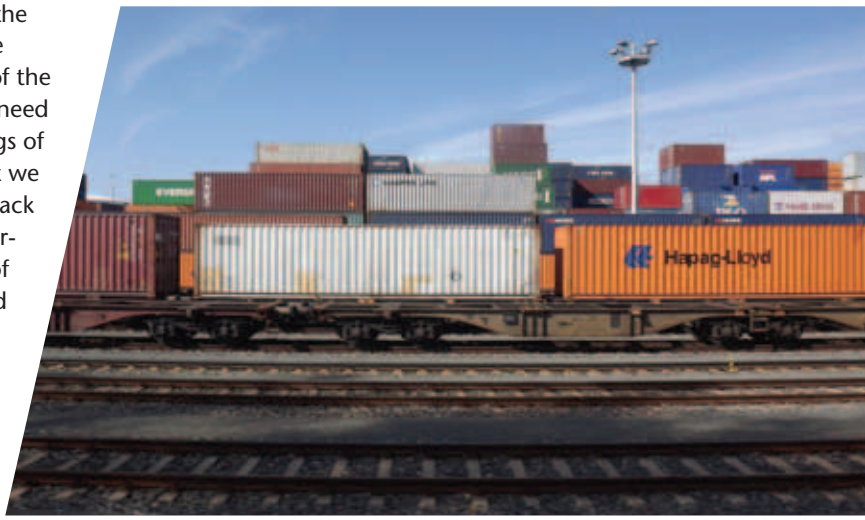
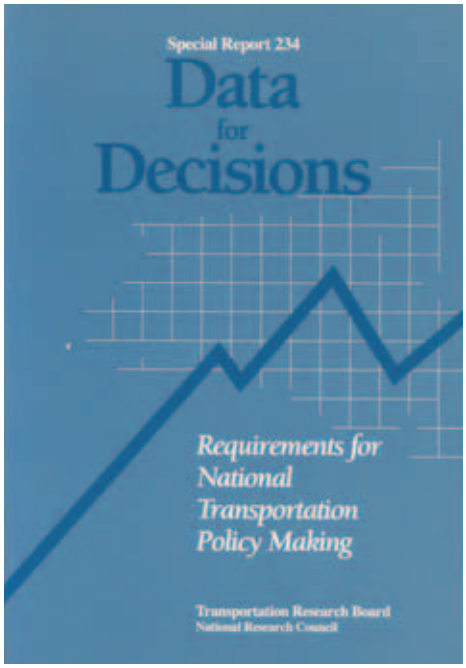


Photo: Unsplash

Data on all modes of U.S. freight transportation are compiled through a variety of BTS sources, including the Freight Analysis Framework (FAF). The FAF integrates data to create a complete picture of how all modes of freight—including goods shipped by train—move among the states and metropolitan areas.



Finalized with great speed, the recommendations in TRB's *Special Report 234*—organization plans and programs that would shape BTS's early years—became law within hours after they were presented to the Senate. (Source: Rolf R. Schmitt)

seed or nourished a seed already planted, Chuck Waite's proposal for a Center for Transportation Statistics was about to become a bureau.

On April 25, 1991, Moynihan introduced the Surface Transportation Efficiency Act of 1991. Section 115 of the Act would establish a Bureau of Transportation Statistics to deal with the "absence of adequate, accurate, and complete data on the performance of transportation systems in the United States." The committee report (Senate Report 102-71) reflected Johnston's testimony: "No one seems to know just why productivity in transportation is so low. For one thing there is a stunning absence of data–facts. Transportation economics is clearly held back by the paucity of reliable information. (It is for this reason that the Act proposes to establish a Bureau of Transportation Statistics in the Department of Transportation.)"

The TRB Committee for the Study of Strategic Transportation Data Needs held its third meeting two weeks before the release of Moynihan's bill, and the committee met for its last meeting on July 16, 1991. While the committee referred to BTS as the Transportation Data Center, its findings and recommendations on monitoring national transportation performance were anticipated by Johnston in his February testimony and reflected in Moynihan's bill. TRB initiated the final review process for *Special Report 234: Data for Decisions—Requirements for National Transportation Policy Making* after the committee's last meeting.

At about the same time as the committee's last meeting, the House of Representatives released its version of the bill. The House included a proposal for an Office of Intermodalism charged with creating an intermodal transportation database—among other responsibilities—but had no provision for BTS.

On November 13, 1991, the National Research Council approved *Special Report 234*. Before its publication and as TRB's principal liaison to the TRB study, the author gave a one-page summary of the report to Federal Highway Administrator Larson's special assistant, highlighting that the report was approved. That sheet was sent immediately to Moynihan, who was starting negotiations in the congressional conference committee to resolve differences between House and Senate versions of the research title. Moynihan was reported to have waived the summary in the conference committee meeting and said that the National Academy of Sciences thought that BTS was a good idea.

U.S. DOT's legislative status sheet for November 15, 1991, indicated that the BTS provision was accepted. U.S. DOT did not object to the provision, reaffirming the value of engaging so many of its data program directors in the TRB study.

President George H. W. Bush signed the Intermodal Surface Transportation Efficiency Act (ISTEA) on December 18, 1991, including the original mandate for BTS in Section 6006. On October 19, 1992, Bob Knisely (the dinner speaker at the 1989 TRB freight data conference) authored the U.S. DOT press release announcing that BTS had started operations. A U.S. DOT management order formally established BTS as an operating administration on December 16, 1992.

That same week, a contractor explained to Knisely that compact discs (CDs) could be used for data and not just music. In a time when data were stored primarily on punch cards and big reels of nine-track tapes, the idea of storing enormous amounts of data on a small disc was radical. Creating CD-ROMs was not easy in those days, requiring special equipment

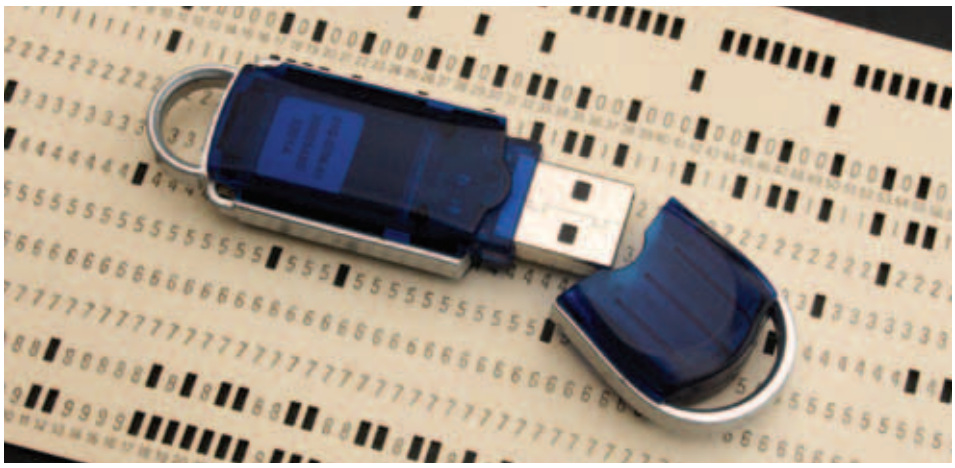


Photo: Ian, Flickr

Data storage has come a long way since the punch card (shown here with a flash memory stick), BTS's primary form of storage when it was established in 1992. A programmer transferred written data into a computer output device that punched coordinating holes into the card. The card could then be translated by running it through a punch card reader. A data set typically required a large stack of cards. BTS soon moved to CD-ROMs. Today, the bureau stores massive amounts of data in commonly available forms: servers and the Cloud.

to compile the data into glass masters that were used to press the disks. Recognizing that the fast-approaching 1993 TRB Annual Meeting would be an ideal place to roll out the bureau's first product, BTS produced the *Transportation Data Sampler Number 1* and within 26 days had prepared CD-ROMs that they handed out to Annual Meeting participants. BTS has used TRB Annual Meetings as a major venue for launching data products ever since.

ISTEA required BTS to establish an Advisory Council on Transportation Statistics to guide the bureau's development. Lillian Borrone served as the first chair of the council, continuing her positive influence on BTS that started with her leadership of the TRB Committee for the Study of Strategic Transportation Data Needs. The last chair of the Advisory Council was C. Michael Walton, a long-time TRB leader who also served as former chair of the TRB Executive Committee. Many other TRB members have advised BTS formally and informally throughout the bureau's history.

TRB recommendations are rarely implemented with the speed and completeness of the recommendations of *Special Report 234*; the organization proposed in *Special Report 234* was placed into law within hours of the report's approval. The programs proposed in *Special Report 234* became the roadmap for BTS throughout its early years, and many of the report's findings and recommendations still guide BTS today. As TRB concludes its Centennial and BTS approaches its 30th anniversary, the bureau still depends on TRB and its members to help BTS serve the transportation community.

Following her leadership role on TRB's Committee for the Study of Strategic Transportation Data Needs, Lillian Borrone of the Port Authority of New York and New Jersey served as the first chair of the Advisory Council on Transportation Statistics, established to guide BTS's development. (Source: TRB)

VOLUNTEER VOICES

"Although my parents steered me in the direction of math, science, and, ultimately, civil engineering, it was my professor who sold me on transportation engineering. As an undergraduate student at Vanderbilt University, I had the opportunity to take three transportation engineering courses, all taught by Doc Bob. His zeal and the novelty of the subject matter pulled me in. Transportation engineering presented itself as an area of engineering that had a technical aspect but incorporated a variety of other areas, including environment, health, economics, policy, politics, equity and justice, and art. It wasn't just number crunching and formulas; transportation engineering was about saving lives, reducing environmental pollution, improving quality of life, and connecting communities. That sense of purpose is what keeps me in the transportation community.

—DENISE SMITH,
Vice President of Business Development
Hummingbird Firm, Atlanta, Georgia

Remembering TRB

STEPHEN E. BLAKE

The author is a Language Arts teacher at Fred Flynn Middle School in Woodbridge, Virginia, and a former senior program officer at the Transportation Research Board of the National Academies of Sciences, Engineering, and Medicine in Washington, D.C.

I was a naïve 22-year-old and fresh out of college when I was hired as the first African-American senior program officer on the Technical Activities Division staff. I had the pleasure of working with William (Bill) Carey, Roy Edgerton, K. B. Johns, Ken Cook, James Scott, Campbell Graeub, and many others at the Transportation Research Board (TRB).

My first day on the job was the opening Sunday of the 1974 TRB Annual Meeting. Group 1 (Technical Activities) was headquartered at The Shoreham Hotel, where staff was also housed. I had no idea what I was in for. Committee meetings started at 6 a.m. and lasted well past midnight, often with post-meeting discussions in the lounge for several more hours. I marveled at the ability of the staff and participants to conduct business, attend presentations, and still have time for those wee-hour discussions. It was a tribute to the dedication that the staff and attendees had to the field of transportation research that allowed them to engage at this level. And, at 22, I was part of it.

I remember being exhausted at the end of that week and excited about my future. For 14 years, I worked at TRB. Ken Cook, James Scott, and Campbell Graeub were my teachers, my mentors, and my friends. They taught me the things I needed to know to be a successful professional at TRB and to be successful in life.

Being the first African-American *did* present some challenges. Field visits to the state departments of transportation were a major part of the job. I remember Roy Edgerton calling me to his office and asking how I felt about visiting Alabama, Mississippi, Georgia, and Louisiana. He wanted to know whether I was ready to face the racism that I might encounter. I always appreciated his thoughtfulness and concern for my well-being. I think that those states were the last ones he assigned to me, in my 10th year.

I could write a book about my experiences at TRB. I could tell you about my first trip report, which Bill Carey covered in red ink and stuck on the bulletin board. It did not have my name on it. But I saw that it was mine, and I corrected all the mistakes I had made without ever having to sit down and discuss it with him. That made me a better writer.

A year into his job as a senior program officer, and Stephen Blake is hard at work—and in a much better office. "I was on the 5th floor of the old National Academies offices on 21st and Pennsylvania Avenue, NW," he notes. "However, my first office was a former storage closet." (Source: Stephen E. Blake)

I could tell you about James Scott, whom I would join during his long lunchtime walks. He always encouraged me to chase my dreams. He saw talent in me that I did not realize I had. Campbell Graeub taught me about finances and managing money. All the things that a young man needed to start life and to become a professional, they taught me.

In 1987, I left TRB to pursue other opportunities, returning for a one-year stint in 1996. I created the Center for Transportation Training, Education, and Research (CTTER), where I ran an internship program for the U.S. Department of Transportation. Tom Larson, whom I had met at TRB, was Federal Highway Administrator and funded that first internship program. Without TRB, I would never have met Tom, Milton Pikarsky, Buzz Passwell, Bill Garrison, and so many more of the luminaries in the transportation field. I would not have been able to create, manage, and run CTTER or the National Transportation Safety and Health Institute without the training I received at TRB.

In the late 1970s, Technical Activities Division team members included (*from left*) Kenneth (K.B.) Johns, Ken Cook, Elaine King, Campbell Graeub, Ed Ward, Adrian Clary, James Scott, G. Patrick Ring, Blake, William (Bill) Gunderman, David Witheford, and Jim Williams. (Source: Stephen E. Blake)

Looking back at that time, I feel some pride in having been the first African-American on the Technical Activities staff. I would like to think that I paved the way for other minorities at TRB.

I retired from transportation in 2015 after serving as director of the Transportation Academy at the University of the District of Columbia Community College. I currently teach middle school Language Arts. All of the perseverance, focus, dedication, and hard work that I learned at TRB, I bring to my job every day.

After more than 40 years in the transportation industry, Stephen Blake retired and followed his love of communications into the classroom, where he helps middle school students improve their reading, writing, and communication skills. (Source: Stephen E. Blake)

Near-Road Air Quality

Insights from a U.S. DOT Five-Year Transportation Pooled Fund Study

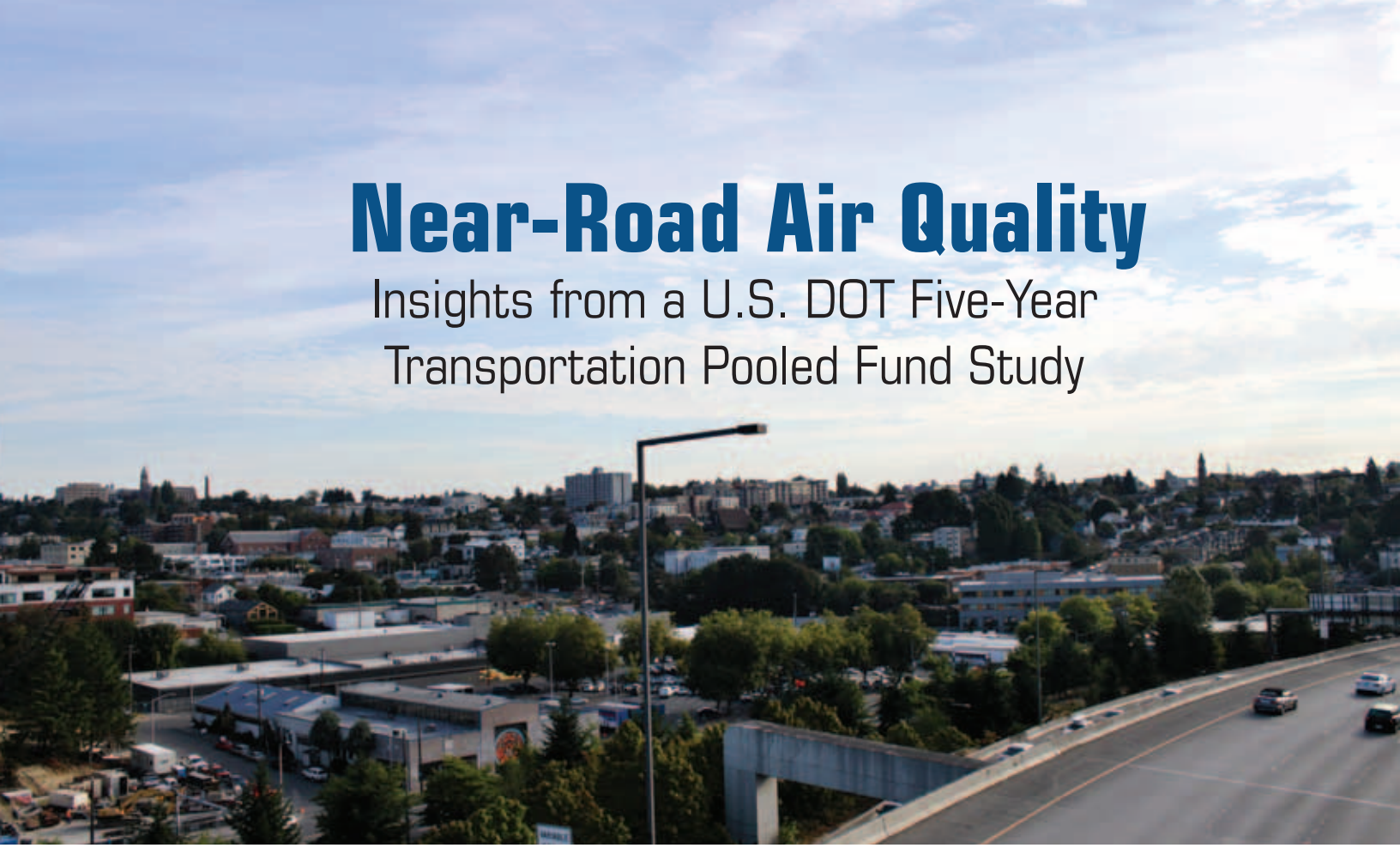


Photo: SounderBruce, Flickr

DOUGLAS EISINGER, KENNETH CRAIG, KARIN LANDSBERG, ANONDO MUKHERJEE, JENNIFER DEWINTER, MICHAEL MCCARTHY, AND STEVEN BROWN

Eisinger, Craig, Mukherjee, DeWinter, McCarthy, and Brown are with Sonoma Technology, Inc., in Petaluma, California. Landsberg is with the Washington State Department of Transportation's Environmental Services Office in Olympia.

Above: The Atlantic neighborhood of Seattle, Washington, can be seen from the José Rizal Bridge. This and surrounding neighborhoods were subject to redlining—a discriminatory practice occurring throughout the 20th century that rated communities of color and lower-income neighborhoods as "high risk" for investment. Among redlining's many consequences is poor air quality in neighborhoods that often were (and still are) chosen as locations for high-traffic freeways.

Air pollution in urban areas has been closely connected with vehicle use for more than half a century. Emissions from cars, trucks, and other vehicles are harmful on their own, and they combine in the atmosphere with air pollutants from other sources to form regional-scale pollution that includes a mix of particulate matter (PM), ground-level ozone (O_3), nitrogen dioxide (NO_2), and other substances. Pollutants directly emitted by vehicles—from exhaust, wear from brake pads and tires, or dust from disturbing the road surface—are of special concern in areas adjacent to heavily traveled roads.

Research shows that substantial traffic—especially diesel-powered trucks and buses—can create pollution hot spots within a few hundred meters of major roads. Example hot spot pollutants of concern are the soot emitted from diesel vehicle exhaust, often referred to as diesel PM, oxides of nitrogen [both nitric oxide (NO) and NO_2], carbon monoxide (CO), and toxics such as benzene.

Near-road hot spots are of particular concern, given the growing awareness of the need to address environmental justice and community-based air quality. Communities near heavily traveled roads often are more economically disadvantaged and have a higher proportion of minority residents than communities in other settings.

> Near-road air quality is an environmental justice concern.

Many factors govern the formation of near-road pollution hot spots. For example, traffic volumes and speeds, the number and ages of cars and trucks on the road, roadway design, topography, and local meteorology all play a role in determining whether near-road air pollution is worse than in surrounding neighborhoods. Since near-road pollution is a health concern and the conditions

Photo: National Association of City Transportation Officials

To mitigate the health impacts of near-road pollution, the U.S. Environmental Protection Agency mandates air quality impact evaluations of proposed highway projects.

Photo: joiseyshowaa, Flickr

Exhaust fumes cloud the scene of a traffic jam along the New Jersey Turnpike. Even though fleet turnover—when older, higher-polluting vehicles are replaced with newer, lower-polluting vehicles—plays a big role in decreasing near-road air pollution, the particulate matter found in vehicle exhaust is still hazardous to human health.

under which hot spots form vary, the U.S. Environmental Protection Agency (EPA) mandates evaluation of proposed highway project impacts and measurement of near-road pollution levels.

In recognition of the importance of addressing near-road air pollution, eight state and federal agencies pooled their research efforts on the topic, obtaining and evaluating an unprecedented amount of near-road air quality data. From 2014 through 2019, the agencies formed the Near-Road Air Quality Transportation Pooled Fund (TPF), sponsored by the U.S. Department of Transportation (DOT), and selected Sonoma Technology, Inc., to provide planning and research support.

The 2014 launch of the EPA national requirement for near-road air quality monitoring sparked the formation of the TPF. The EPA mandate helped create the first-ever widespread U.S. air measurement network to assess near-road conditions. TPF work took place from 2014 to 2019, directly overlapping the network's launch, and took advantage of the availability of this unique data set.

The Near-Road Air Quality TPF research program included participants from the U.S. Federal Highway Administration (FHWA), as well as from Arizona, California, Colorado, Ohio, Texas, Virginia, and Washington State DOTs. STI researchers carried out the technical work program, while Washington State DOT served as lead agency and managed overall research.

Even though TPF state DOT partners represented just seven of the 50 states, their work evaluated data from the entire national network of EPA-mandated near-road air quality measurement sites located next to major highways across the United States. As of late 2019, this network included nearly 60 U.S. metropolitan areas. Researchers also completed in-depth case studies of various metropolitan areas, based on air quality, traffic, and site characteristics, independent of whether the sites were in TPF sponsor states. This article highlights the TPF research findings.

Near-Road Pollutant Concentration Findings

The research confirmed some well-understood insights, produced some surprise "good news" findings, and found long-term trends headed in a positive direction. TPF research showed unequivocally that CO is no longer a near-road problem. For every mile a new vehicle is driven today, it emits a tiny fraction of the CO emitted by similar vehicles built decades ago.

As older vehicles are retired from the fleet, the turnover to cleaner vehicles continuously reduces CO and other tailpipe pollutants. The result is a remarkable pollution-control success story: CO hot spots have disappeared adjacent to major U.S. roads. Though expected, the research partners found it important to document this good news because CO remains a hot spot assessment requirement for highway projects.

Somewhat surprisingly—and also good news—the research showed that virtually all near-road NO_2 concentrations fell below existing health-based air quality standards. When TPF work began, near-road NO_2 had not yet been measured extensively, and, EPA had recently adopted new National Ambient Air Quality Standards (NAAQS) for NO_2 with a focus on near-road settings, under authority of the U.S. Clean Air Act. NAAQS are EPA's health-based air quality standards, or concentration values at or below which public health is protected. Until the near-road monitoring network was established, it was unclear whether many areas had NO_2 concentrations of concern.

With those findings in mind, researchers focused on assessing the concentration of very small particles: particulate matter less than 2.5 microns in diameter, or $PM_{2.5}$ (for comparison, a human hair is about 70 microns in diameter). $PM_{2.5}$ is one of the most important air pollutants from a health perspective—its small size means it can penetrate deeply into the respiratory system, and $PM_{2.5}$ exposure can increase respiratory problems, cancer incidence, and risk of death.

The work of the TPF characterized near-road $PM_{2.5}$ conditions across the United States, identified areas with concentrations above health-based benchmarks, identified

relationships between concentrations and roadway characteristics, observed and forecasted trends, and compared both modeled and measured concentrations. The research findings offer a positive outcome: Most areas have $PM_{2.5}$ concentrations below NAAQS, and emission trends suggest that future conditions will continue to improve.

The material that follows illustrates findings using data from 2016 as an example. Generally, findings illustrated here were consistent across analysis years covered by TPF assessments. For research purposes, researchers compared measured data to NAAQS levels. Each NAAQS includes an averaging period, the number of hours that the value represents. For example, for CO there are two standards: 1-hour and 8-hour. The 8-hour standard is the average value over eight consecutive hours. In their analysis, researchers focused on key averaging periods of interest for each pollutant: 8-hour for CO, 1-hour for NO_2, and 24-hour for $PM_{2.5}$. They also evaluated concentrations across annual and multiyear time windows.

These comparisons are for context only and are not meant to assess whether an area officially meets NAAQS; EPA makes those official determinations. Table 1 highlights these findings.

CARBON MONOXIDE

TPF findings reinforce that CO emissions control is a U.S. success story and that CO concentrations are well below levels of concern. The 2016 8-hour CO concentrations at near-road sites ranged up to a maximum of 3.5 parts per million (ppm). For comparison, the 8-hour NAAQS is 9 ppm.

NITROGEN DIOXIDE

TPF findings illustrate that near-road NO_2 concentrations are not a concern according to NAAQS. In 2016, only four 1-hour NO_2 values exceeded the EPA standard of 100 parts per billion (ppb). There were no values above the NAAQS at the 98th percentile for the data; EPA uses a three-year average of 98th percentile data when determining whether an area violates air standards.

$PM_{2.5}$

TPF findings showed that although there were exceedances of the $PM_{2.5}$ standard, they were rare and limited to a few locations. In 2016, $PM_{2.5}$ was monitored at 42 sites, six of which had two monitors. There were 29 monitors that measured $PM_{2.5}$ hourly; the remaining 19 sampled $PM_{2.5}$ on a 24-hour basis at various frequencies (daily, or one out of every three or six days). EPA uses the 98th percentile value of daily data to assess whether an area violates the standard; this is roughly equivalent to ignoring the seven days of the year with the highest concentrations.

In 2016, 24-hour $PM_{2.5}$ concentrations exceeded the NAAQS value (35 μg/m³) in 19 instances. Only Ontario, California, had a 98th-percentile concentration that exceeded 35 μg/m³, however.

Background Concentration Assessments

One TPF objective was to better understand air pollution differences between near-road and surrounding areas. In simple terms, the roadway pollution contribution, or increment, is calculated by subtracting a background concentration from a measured near-road concentration.

Numerous practical challenges make background concentration estimation difficult. Most urban areas have more than one background monitor and identifying the "true" background concentration at the near-road site is difficult. More monitors in an area can provide confirmation of the background concentration if they agree, or they can provide differing values. Discerning which background concentration to use is a critical step in a hot spot analysis.

A key issue the TPF research examined was to understand how big an error might be introduced in hot spot analyses by inadvertently assigning an incorrect background concentration value at a particular transportation project site. One way this issue was dealt with was to assess how background values varied across 45 core-based statistical areas (CBSAs). Since $PM_{2.5}$ hot spot analyses use three years of data, TPF analyses used data from 2015 to 2017 to identify the range of concentrations within each CBSA.

For about half of the CBSAs, there was not a large difference in background concentrations from one monitor to another. However, in the other half of the CBSAs, the range of background values varied substantially: The highest measured background was anywhere from 14 to 106 percent above the lowest background concentration, depending on monitor choice.

Figure 1 shows the range of background values by CBSA. As shown in Figure 1, some areas have many more background monitors than others. More monitors generally mean better differentiation of background pollution differences across a given metropolitan area. If a CBSA has big concentration differences among its monitors, however, there is a higher risk of error estimating background concentration if an analyst incorrectly chooses which monitor or monitors to use.

The TPF findings help bound uncertainty for each of the CBSAs assessed. Bounding is important because the larger the range of potential background values, the greater the need to carefully assess which monitors to use when estimating a representative background concentration.

TABLE 1 Amount of 2016 Pollutant Data at or Below EPA Air Quality Standards

Pollutant and NAAQS Averaging Period	Total Number of 2016 Measurements	Number Above NAAQS	Values ≤ NAAQS (%)	NAAQS
CO (8-hour values)	387,310	0	100%	9 ppm
NO_2 (1-hour values)	547,398	4	99.9993%	100 ppb
$PM_{2.5}$ (24-hour values)	11,459	19	99.83%	35 μg/m³

NOTE: NAAQS = National Ambient Air Quality Standards; CO = carbon monoxide; NO_2 = nitrogen dioxide; $PM_{2.5}$ = atmospheric particulate matter with diameter less than 2.5 micrometers; ppm = parts per million; ppb = parts per billion; μg/m³ = micrograms per cubic meter air.

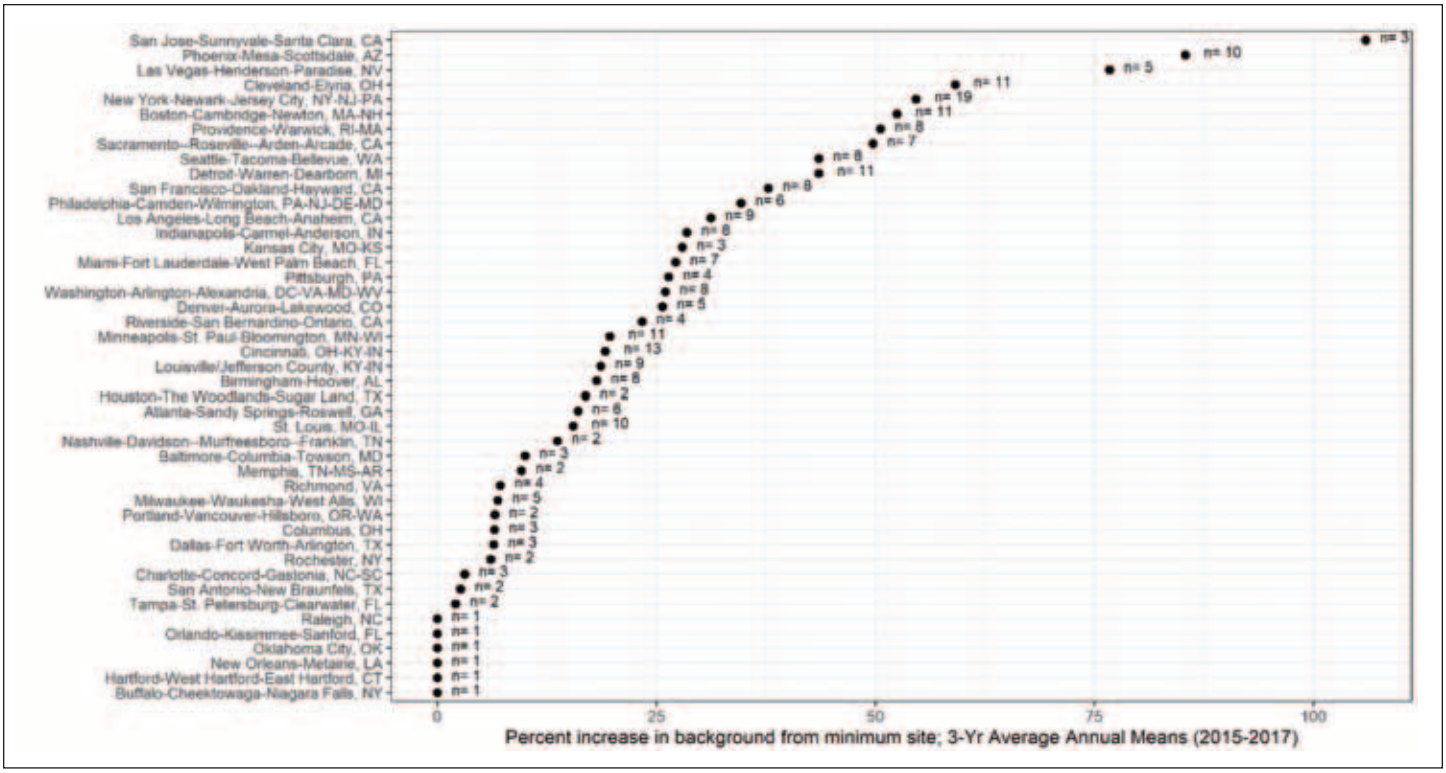


FIGURE 1 Percent increase in $PM_{2.5}$ background concentrations that might be estimated in a metropolitan area, based on monitor choice. (Note: n = number of monitors in each core-based statistical area, excluding the near-road monitor.)

$PM_{2.5}$ Increment Findings

The following $PM_{2.5}$ increment findings use 2017 data from 20 sites with nearby background monitors and minimal confounding factors such as other major nearby pollution sources. The upper bound of $PM_{2.5}$ increments at the 20 sites was 2.0 µg/m³ (Figure 2). Values shown in Figure 2 were computed using two methods to select and weight monitors measuring background concentrations: an inverse distance weighting approach that used multiple monitors but weighted the closest sites more heavily and a nearest monitor calculation using one site.

Three sites had an increment greater than 1.4 µg/m³; monitors at these sites were less than 10 meters from the road. The findings show that the maximum incremental $PM_{2.5}$ impact from a major road is approximately 1-2 µg/m³ for the major roadways researchers assessed in their data set.

They also assessed how much pollutant concentrations decrease the further one gets from the road and evaluated the relationship of increments to other factors such as fleet mix, which is the fraction of vehicles that are cars and other light-duty vehicles, versus diesel-powered trucks and buses.

When evaluating NO_2 and $PM_{2.5}$, a key consideration is the fraction of diesel trucks and buses in the fleet, since diesel vehicles contribute disproportionately to those emissions. For analyses involving NO and NO_2 (together referred to as NO_x) or $PM_{2.5}$, EPA and others often consider a

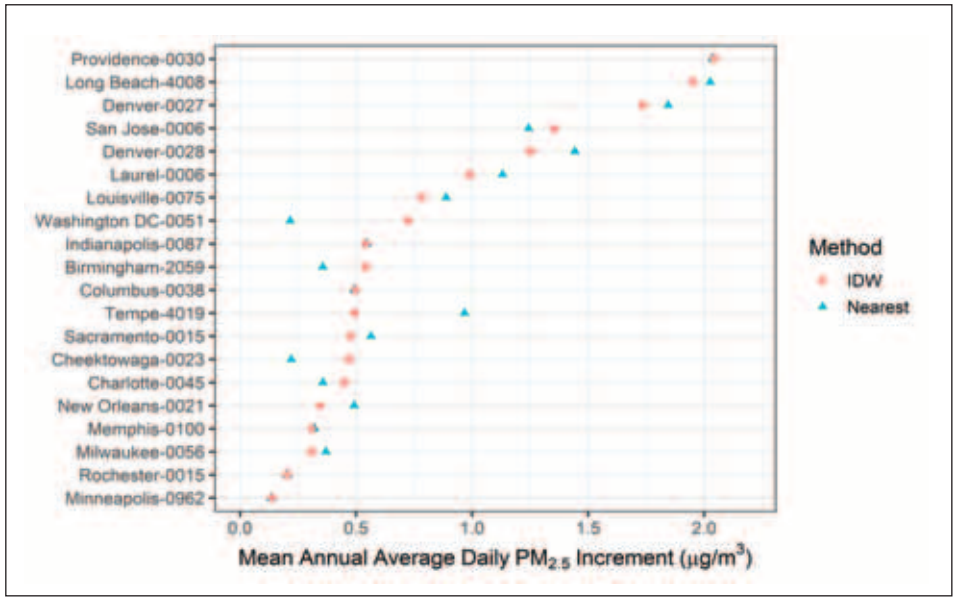


FIGURE 2 Distributions of annual average $PM_{2.5}$ increments. (Note: IDW = inverse distance weighting method; Nearest = nearest monitor calculation.)

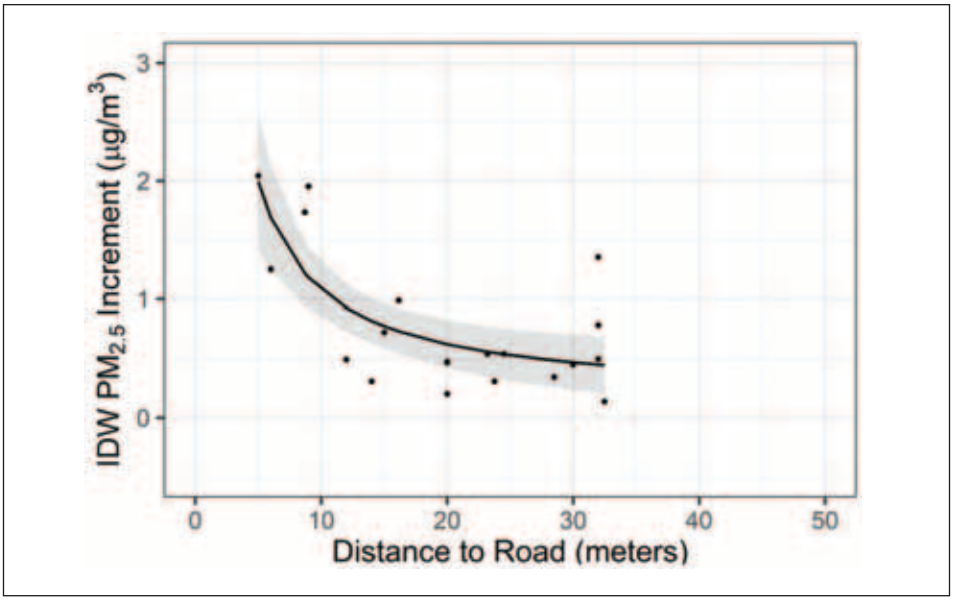


FIGURE 3 Relationship between $PM_{2.5}$ increment (roadway contribution) and distance to road. Regression lines are shown in black, with the range of the standard error of the regression line shown in dark gray. (Source: Mukherjee et al., 2020.)

single heavy-duty diesel vehicle (HDDV) equivalent to about 10 light-duty vehicles (LDVs) in terms of emissions contribution. This allows analysts to convert annual average daily traffic (AADT) counts, which are a mix of cars and trucks, into one pollutant-weighted number, referred to as fleet-equivalent (FE) AADT.

The TPF used FE-AADT to assess relationships between $PM_{2.5}$ and traffic. The research showed, for example, that $PM_{2.5}$ increases by about 0.14 μg/m³ for every 100,000 increase in FE-AADT, and that $PM_{2.5}$ increments fell from about 2 μg/m³ at 5 meters from the road to 0.5 μg/m³ at 30 meters from the road (Figure 3).

Changes on these scales are important because research has shown that death risk from $PM_{2.5}$ exposure rises with increased concentration. Those ages 65 and older, for example, have been shown to experience a 7 percent increased risk of death with every 10 μg/m³ increase in annual average $PM_{2.5}$ concentrations.[1]

[1] See the 2019 report from the Health Effects Institute, "Assessing Adverse Health Effects of Long-Term Exposure to Low Levels of Ambient Air Pollution: Phase 1, Synopsis of Research Report 200," found at https://www.healtheffects.org/publication/assessing-adverse-health-effects-long-term-exposure-low-levels-ambient-air-pollution.

Fleet Turnover Projections

Fleet turnover occurs over time as older, higher-polluting vehicles are replaced with newer, lower-polluting vehicles. Table 2 shows projected changes in exhaust emissions for calendar years 2017 to 2040 using an EPA emissions model called MOVES. Data show percent emissions change relative to 2017 for HDDVs, LDVs, and the average vehicle in a fleet composed of 8 percent HDDVs and 92 percent LDVs.

Fleet turnover reduces exhaust emissions in all cases when traffic volumes, fleet mix, and speeds are held constant. For example, exhaust emissions decrease 80 percent from 2017 levels by 2040 for a fleet that is 8 percent HDDVs. Emissions changes for a given roadway will depend on the vehicle fleet and traffic activity over time.

The upper bound increment for near-road sites in 2017 can be combined with the projected change in exhaust emissions (Table 2)—and an assumed fraction of $PM_{2.5}$ that is due to exhaust—to forecast near-road $PM_{2.5}$ increments in the coming decades.

The implications of fleet turnover on $PM_{2.5}$ increments are substantial. In 2017, the upper bound increment from observed annual average $PM_{2.5}$ was 2.0 μg/m³, and 1.4 μg/m³ for sites 10 meters from the roadway or farther. Assume, as an example, that 40 percent of total roadway-related $PM_{2.5}$ emissions are related to exhaust and 60 percent to nonexhaust emissions such as brake wear, tire wear, and road dust. By 2040, exhaust emissions for an average vehicle in a fleet composed of HDDVs (8 percent) and LDVs (92 percent) are projected to be 20 percent of what they were in 2017 (Table 2).

This means that the $PM_{2.5}$ impact of a highway would fall from about 2.0 μg/m³ in 2017 to about 1.4 μg/m³ by 2040, assuming constant fleet mix and traffic volumes (FE-AADT) and constant travel speeds across time. For sites 10 meters from a roadway or farther—assuming MOVES national average estimates and constant FE-AADT and speeds—$PM_{2.5}$ roadway increments would fall from about 1.4 μg/m³ in 2017 to 1.0 μg/m³ by 2040.

Given these projections, the research team also evaluated $PM_{2.5}$ concentration trends using data from the near-road monitoring network. Their findings generally indicated declining concentrations; however, as

TABLE 2 Relative Change in $PM_{2.5}$ Vehicle Exhaust Emissions, 2017–2040

Year	MOVES HDDV	MOVES LDV	MOVES HDDV 8%
2017	100	100	100
2018	87	93	88
2019	75	87	79
2020	66	81	70
2025	34	62	42
2030	18	49	28
2035	13	42	21
2040	12	39	20

NOTE: HDDV = heavy-duty diesel vehicle; LDV = light-duty vehicle.

Photo: Quinn Dombrowski, Flickr

Road dust and other elements—brake and tire wear, for example—can comprise 60 percent of roadway-related $PM_{2.5}$ emissions.

of 2019, locations with multiyear data were limited. Measurement trends will become more apparent in the years ahead.

PM Hot Spot Impact Findings

Per EPA mandate, projects identified as projects of local air quality concern (POAQC) must be quantitatively assessed for their PM hot spot impacts. PM hot spot analyses are complex and TPF partners were interested in identifying highway project situations that could be reasonably excluded from such assessments. TPF research used an EPA-defined hypothetical example of a POAQC—set in calendar year 2006, when EPA created the POAQC example—and evaluated how impacts from that project changed over time with fleet turnover.

The EPA hypothetical 2006 project assumed 125,000 AADT and 8 percent diesel truck traffic. The 2006 project example is helpful since emissions from that calendar year and project scale (125,000 AADT at 8 percent diesel trucks) set an EPA-defined benchmark for projects of concern. From this starting point, the TPF estimated emissions for $PM_{2.5}$ and a larger form of PM, particles 10 microns in diameter or less (PM_{10}), for analysis years 2006 to 2035. The point of the work was to illustrate how fleet turnover (newer, cleaner vehicles replacing older, higher-polluting vehicles) affected emissions relative to the EPA benchmark example.

$PM_{2.5}$ emissions based on EPA's emissions model, MOVES, were reduced by 92 percent between 2006 and 2035. Modeling based on a California model, EMFAC, forecasted that $PM_{2.5}$ emissions fell about 70 percent between 2006 and 2035. As exhaust emissions fell, the relative importance of nonexhaust emissions increased (Figure 4).

Because of the emissions-reducing effects of fleet turnover, in later years higher traffic volumes are required to produce the emission levels equivalent to 125,000 AADT in 2006. To examine this effect, researchers held the truck percentage constant at 8 percent and calculated the AADT required in later years to yield emissions equivalent to the 2006 baseline. Using data from EPA's MOVES model, for example, by 2035 it will take more than 1.5 million AADT to produce $PM_{2.5}$ emissions equivalent to those generated by only 125,000 AADT in 2006 (Figure 5).

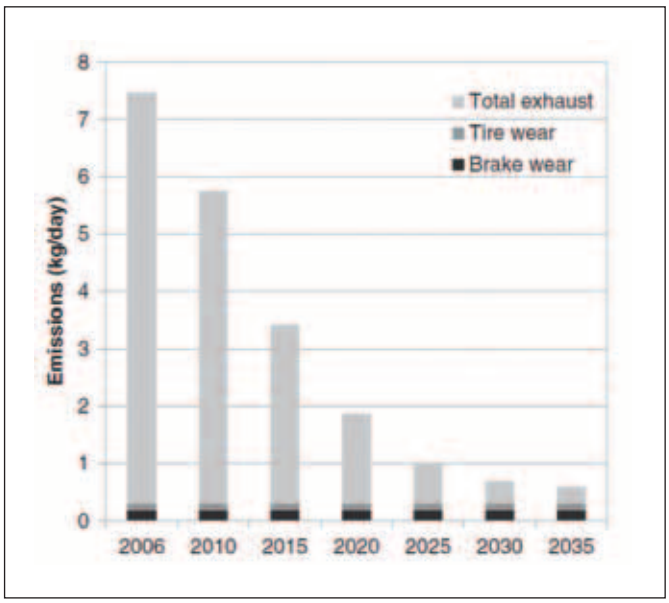


FIGURE 4 $PM_{2.5}$ emissions for a hypothetical freeway project with an AADT of 125,000 vehicles, 8 percent of which are diesel trucks, based on EPA MOVES model. (Source: Reid et al., 2016. Note: AADT = annual average daily traffic.)

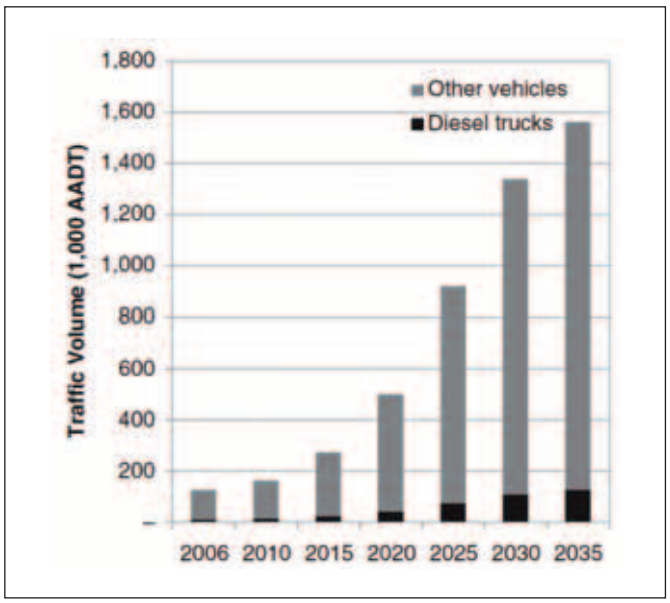


FIGURE 5 Projected traffic volumes needed to produce 2006-equivalent $PM_{2.5}$ emissions, based on EPA MOVES model. (Source: Reid et al., 2016.)

Because transportation projects that may require a hot spot analysis typically add capacity, understanding how capacity and AADT changes affect emissions in future years can help transportation agencies differentiate between projects that may or may not be of concern for air quality.

Comparing Modeled and Measured $PM_{2.5}$

With the 2014 launch of the national near-road air monitoring network, a unique opportunity emerged to compare measured air quality to modeled concentrations. This was of interest to the TPF for two reasons: First, EPA-mandated hot spot analyses rely on modeled outcomes; second, in recent years, EPA encouraged agencies to use an air quality model called AERMOD to assess near-road concentrations. AERMOD is an advanced tool, but compared with other models historically used by transportation agencies, it is complex to run. Therefore, TPF partners were interested in better understanding how AERMOD-modeled outcomes compared to real-world measurements, and how AERMOD results compared to results from simpler-to-run tools used historically.

The TPF evaluated $PM_{2.5}$ concentrations near major freeways in Indianapolis, Indiana, and Providence, Rhode Island, because of their site characteristics and availability of traffic and air quality data. The analyses were built upon bottom-up estimates of temporally and spatially resolved roadway $PM_{2.5}$ emissions based on detailed traffic monitoring data and emission factors specific to the local vehicle fleets. Researchers estimated the difference between $PM_{2.5}$ concentrations at the near-road monitor and at nearby background sites (the measured "increment"), and compared modeled and measured increments.

For Indianapolis, AERMOD was run for 152 analysis days in 2016. The average modeled $PM_{2.5}$ near-road increments for these days were compared to the monitored near-road $PM_{2.5}$ increments. The modeled increment (3.7 μg/m^3) was three to four times larger than the measured increments obtained from Federal Reference Method (FRM) or Federal Equivalent Method (FEM) monitoring instruments (1.2 μg/m^3 for FRM and 0.9 μg/m^3 for FEM). EPA allows the use of either FRM or FEM monitors; FRM measurements usually are more accurate.

AERMOD modeling results for Providence for 2015–2016 were compared with measured increments for 382 analysis days. The AERMOD-based analysis for Providence also significantly overpredicted the average measured near-road $PM_{2.5}$ increment. The average modeled $PM_{2.5}$ increment (8.8 μg/m^3) was more than six times, or 530 percent, greater than the average measured increment (1.4 μg/m^3).

Photo: Pictr73, Flickr

Researchers evaluated $PM_{2.5}$ concentrations near major freeways in Indianapolis, Indiana, and Providence, Rhode Island, because of their site characteristics and availability of traffic and air quality data.

Digest of Major Technical Findings

Highlights of major findings from the 5-year TPF program include the following:

1. Near-road concentrations of CO and NO_2 were not problematic when benchmarked against existing NAAQS.
2. Relative to the total number of near-road sites measuring $PM_{2.5}$, a small number of locations exceed the 24-hour or annual $PM_{2.5}$ NAAQS.
3. Near-road $PM_{2.5}$ concentrations are likely trending downward; however, these findings are based on a limited number of sites that operated over the analysis years covered by TPF work. More data are becoming available each year to help establish multiyear trends.
4. Based on 2017 data, for 20 sites across the United States, the upper bound of $PM_{2.5}$ increments was about 2.0 μg/m^3. Only three sites had an increment greater than about 1.4 μg/m^3; monitors at these three sites were less than 10 meters from the roadway.
5. The work provides a better understanding of the likely incremental increase in pollutant concentrations coming from the roadway. Over time, because of anticipated fleet turnover, the forecasted $PM_{2.5}$ increment will decrease for a given volume of traffic with constant speeds and fleet mix. TPF findings can help transportation agencies differentiate between projects that may or may not be of concern for air quality.
6. There can be substantial differences between measured and modeled near-road $PM_{2.5}$ concentrations. For the case studies presented here, modeled concentrations substantially overpredicted measured values.

Areas of Future Research

Future work could further examine the following topics:

1. The relative contribution of exhaust and non-exhaust $PM_{2.5}$ emissions.
2. Modeled and measured near-road concentrations across different geographic settings, roadway types and configurations, and at more sites over multiyear periods.
3. Modeling chain biases contributing to differences between measured and modeled concentrations.
4. Quantitative estimates of the effects of near-road barriers and roadway grade on near-road pollutant concentrations, to derive insights that will help mitigate concentrations considered problematic in some near-road settings.

Acknowledgments

The authors appreciate the invaluable support and assistance from the many partner agency participants who helped fund and guide the TPF's technical work: Beverly Chenausky and Dianne Kresich, Arizona DOT; Robert Buendia, Yoojoong Choi, Harold Hunt, and Marilee Mortenson, Caltrans; Cindy Copeland and Rose Waldman, Colorado DOT; Michael Claggett, Cecilia Ho, and Victoria Martinez, FHWA; Noel Alcala and Nino Brunello, Ohio DOT; Jackie Ploch and Tim Wood, Texas DOT; Jim Ponticello and Chris Voigt, Virginia DOT; and Jon Peterson and Scott Selby, Washington State DOT. Tim Sexton, formerly with Washington State DOT and now with Minnesota DOT, provided important early assistance to help launch the TPF.

The authors would also like to acknowledge the assistance of Nealson Watkins, David Heist, and Richard Baldauf, EPA. The authors acknowledge the support of staff from several state DOTs in making travel data available for this work: Jeffery Baird, Missouri DOT; Don Crownover, Oregon DOT; Philip d'Ercole, Rhode Island DOT; and Ralph Jones, Virginia DOT. Numerous current and former STI scientists contributed to the findings presented here, including Song Bai, Lynn Baringer, Shih-Ying Chang, Yuan Du, Garnet Erdakos, Ashley Graham, ShihMing Huang, Nathan Pavlovic, Bryan Penfold, Vikram Ravi, Stephen Reid, and Annie Seagram.

Also, appreciation goes to the STI Publications team: Jana Schwartz, Mary Jo Teplitz, and Bryant West. Findings included here are excerpted from prior TPF work.

The work presented here was completed as part of the Near-Road Air Quality Research Pooled Fund, Project TPF-5(284) under the U.S. Federal Highway Administration (FHWA) Transportation Pooled Fund Program. The lead agency for TPF-5(284) was Washington State DOT. Other participants included FHWA and the Arizona, California, Colorado, Ohio, Texas, and Virginia DOTs. STI provided technical support. The findings presented here are those of the authors and do not necessarily reflect the requirements or position of any governmental agency.

Further Reading

The following peer-reviewed articles document findings from the Near-Road Air Quality TPF:

Craig, K.J., L. M. Baringer, S.-Y. Chang, M. C. McCarthy, S. Bai et al. Modeled and Measured Near-Road $PM_{2.5}$ Concentrations: Indianapolis and Providence Cases. *Atmospheric Environment*, Vol. 240, Nov. 2020, p. 117775. doi.org/10.1016/j.atmosenv.2020.117775.

Mukherjee, A., M. C. McCarthy, S. G. Brown, S. Huang, K. Landsberg et al. Influence of Roadway Emissions on Near-Road $PM_{2.5}$: Monitoring Data Analysis and Implications. *Transportation Research Part D: Transport and Environment*, Vol. 86, Sept. 2020, p. 102442. doi.org/10.1016/j.trd.2020.102442.

Brown, S. G., B. M. Penfold, A. Mukherjee, K. Landsberg, and D. Eisinger. Conditions Leading to Elevated $PM_{2.5}$ at Near-Road Monitoring Sites: Case Studies in Denver and Indianapolis. *International Journal of Environmental Research and Public Health*, Vol. 16, No. 9, 2019, p. 1634. doi.org/10.3390/ijerph16091634.

Seagram, A. F., S. G. Brown, S. Huang, K. Landsberg, and D. S. Eisinger. National Assessment of Near-Road Air Quality in 2016: Multi-Year Pollutant Trends and Estimation of Near-Road $PM_{2.5}$ Increment. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2673, No. 2, 2019, pp. 161–171. doi.org/10.1177/0361198119825538.

DeWinter, J. L., S. G. Brown, A. F. Seagram, K. Landsberg, and D. S. Eisinger. A National-Scale Review of Air Pollutant Concentrations Measured in the U.S. Near-Road Monitoring Network During 2014 and 2015. *Atmospheric Environment*, Vol. 183, 2018, pp. 94–105. doi.org/10.1016/j.atmosenv.2018.04.003.

Reid, S., S. Bai, Y. Du, K. Craig, G. Erdakos et al. Emissions Modeling with MOVES and EMFAC to Assess the Potential for a Transportation Project to Create Particulate Matter Hot Spots. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2570, No. 1, 2016, pp. 12–20. doi.org/10.3141/2570-02.

SAFE CROSSINGS FOR WILDLIFE

Photos: Washington State DOT, Oregon DOT

PHILLIP BAIGAS AND KARI GUNSON

Baigas is a wildlife biologist with WSP USA, Inc., in Asheville, North Carolina. Gunson is the principal road ecologist at Eco-Kare International in Peterborough, Ontario, Canada.

Above: A bear in Washington State and a coyote in Oregon pause while using wildlife crossing structures. Two National Cooperative Highway Research Program (NCHRP) projects focused on wildlife connectivity solutions for mammals, amphibians, and reptiles.

In two recently completed research topics of the National Cooperative Highway Research Program (NCHRP) Project 25-25, researchers investigated ways to mitigate the effects of roadways on habitat connectivity and facilitate wildlife passage. The research examined current national practice to help transportation planners and practitioners lessen the effects of the roadway network on biodiversity and to improve roadway safety.

Safe Crossings for Small Animals

Fences and crossing structures are the most commonly installed wildlife mitigation measures. Fences keep animals off the road and guide them toward crossing structures—underpasses or overpasses that allow the animals to move safely across the road. Although transportation agencies have been integrating these practices into road construction projects more and more, the structures' details and effectiveness are not fully known. Historically, large animals have received the most attention, but the effectiveness of road mitigation for small animal species—amphibians, reptiles, and mammals smaller than a coyote—has largely been overlooked (see box, page 31).

Principal investigators Marcel Huijser, Western Transportation Institute, and Kari Gunson, Eco-Kare International, worked with WSP USA company Louis Berger on NCHRP Project 25-25, Task 113, "Road Passages and Barriers for Small Terrestrial Wildlife: Summary and Repository of Design Examples." Researchers synthesized the knowledge base of mitigation measures for small animals in North America by compiling a comprehensive database of technical reports, books, conference proceedings, and peer-reviewed publications and by conducting an expert-based survey.[1]

The literature and expert surveys showed that the most common method

[1] All summary documents, including a repository of technical drawings and relevant photos, are available at https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4337.

Photo: The Wetlands Institute

A diamondback terrapin considers whether to attempt to scale fencing installed along a roadside. Just tall enough so that the terrapin cannot climb over, exclusion fencing helps keep these small animals safe from vehicle strikes.

for providing safe passage for small animals was the installation of designated crossing structures during road upgrade projects. For amphibians and reptiles, these structures often were installed at grade with the road with slots on top to allow penetration of light, air, and moisture inside the tunnel. Box structures also are commonly used for small animal passage.

CULVERTS AND CROSSING STRUCTURES

Drainage culverts, suitably located and sized, offer enormous opportunities for small-animal passage. These can be adapted for terrestrial passage for land-dwelling creatures by incorporating a terrestrial bench, or elevated walkway alongside the structure. In three cases, overpasses were at least partially or completely designed for small animal species: in the Netherlands, amphibians; in Canada, snakes; and in Washington State, small animals.

Projects monitored the effectiveness of the structures at least 77 percent of the time. In almost half of the cases, however, the effectiveness in reducing the barrier effect of roadways—that is, how effective the structures were at providing connectivity—was unknown because most of the monitoring studies only evaluated the use of the structures by the target species. The studies did not collect information about the number of unique individuals that used the structures nor did they evaluate the proportions of males versus females or juveniles versus adults. This information is important to help evaluate whether small-animal populations indeed benefit from crossing structures. The authors suggest more-detailed monitoring that is aimed at evaluating effectiveness rather than just documenting wildlife use.

Other recommendations included structure maintenance for wildlife permeability, for example, annually clearing vegetation growth at entrances and removing trapped debris inside the structures. Crossing structures often are required to be sufficiently close to each other to accommodate shorter movement distances for smaller animals—otherwise these individuals may perish when moving alongside barriers.

FENCING AND BARRIERS

Exclusion fencing and barriers were evaluated 67 percent of the time, primarily by counting the number of living and road-killed animals within the enclosed section of road. Twenty-three studies reported an average roadkill reduction of 65 percent.[2] Fencing ineffectiveness was caused primarily by gaps in the fence; washouts or barrier deterioration; improper design of the barrier for target species, that is, animals could climb over or under them; or animals crossing at or beyond the fence ends.

Barriers only remained functional for an average of 2.2 years, typically after monitoring studies were completed. Barrier ineffectiveness was mostly due to wear and tear: small holes, gaps, vegetation growth, erosion, and partial fence collapse. In some cases, however, barriers

[2] Minimum 16 percent; maximum 100 percent; standard deviation 31 percent.

Photo: Washington State Department of Transportation

Contractor crews finish installing the sections of the eastbound portal of the wildlife overcrossing on I-90 east of Snoqualmie Pass in Washington State.

Photo: British Columbia Ministry of Transportation and Infrastructure

Before the British Columbia Ministry of Transportation and Infrastructure installed a protective culvert in 2014, the millions of migrating juvenile Western toads—a species of concern in Canada—had no safe way to traverse Highway 6 near Summit Lake. Species data such as age and sex are important to help determine the effectiveness of a crossing structure.

did not exclude target species effectively and, in many cases, were not adequately designed or installed to persist in the roadside environment—that is, to withstand snow removal and mowing activities.

Recommendations included providing robust materials such as concrete or metals and plastics, along with recommended installation guidelines that would not pose a safety hazard for motorists or animals. In addition, adaptive management is required to integrate recommendations from monitoring studies to improve overall barrier effectiveness.

Compensatory Mitigation Credits

For many wildlife species, the connectivity impacts of highways can be mitigated effectively by wildlife crossings and other connectivity enhancements. Mitigation crediting instruments and agreements could provide a novel approach that state departments of transportation (DOTs) could use to promote the construction of wildlife crossings and other enhancements.

In *NCHRP Web-Only Document 280: Valuing Wildlife Crossing and Enhancements for Mitigation Credits*, researchers Phillip Baigas and Edward Samanns, WSP USA, and Marcel Huijser and Robert Ament, Western Transportation Institute, sought to identify quantitative methods and approaches for establishing the mitigation values of wildlife overpasses, underpasses, bridges, and culverts for habitat connectivity and how that value is translated to mitigation credits.

The research found very few examples of quantitative valuation of wildlife connectivity mitigation from state DOTs. A survey of practitioners found that only a handful of states are starting to develop crediting and valuation systems for wildlife crossings and that only one project in California, the Laurel Curve Wildlife Habitat Connectivity Project, has a pilot credit agreement associated with a standalone wildlife crossing.[3]

CHALLENGES AND OPPORTUNITIES

According to survey respondents, a major impediment to developing a crediting approach was a lack of regulatory requirements and processes requiring compensatory mitigation. Respondents surmised, however, that credit programs would create financial incentives for state DOTs to fund connectivity enhancement actions; provide flexibility on the best mitigation location; contribute to the restoration of lost connectivity; and be useful for situations in which providing connectivity mitigation as a standalone project is cost-prohibitive.

[3] For more information, see https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=142107.

The survey respondents and literature review identified several categories of potential metrics to value wildlife connectivity mitigation, including the following:

1. **Condition-based connectivity metrics**, or types of measurements based on the physical, chemical, and biological attributes of a system, such as the highway footprint area within the highway-crossing zone used by focal species.
2. **Function-based connectivity metrics**, or types of measurements based on wildlife habitats and ecosystem processes, such as the number of individuals of focal species crossing the highway or the habitat quality of connected or fragmented habitat.
3. **Model-based connectivity metrics**, or types of measurements based on computer models that combine elements of function- and condition-based metrics to estimate wildlife connectivity, such as species distribution models, animal movement models, and habitat-based population viability models.
4. **Avoided-cost metrics**, or types of measurements based on the economic value of wildlife, human life, or property, such as reductions in insurance settlements from wildlife–vehicle collisions (WVCs).

Practitioners generally supported using function-based metrics to value mitigation credits for wildlife crossings and other connectivity enhancements. They acknowledged, however, that using function-based metrics to quantify pre- versus post-construction wildlife values would require extensive biological data, which are costly to obtain. In contrast, using condition-based metrics to value wildlife connectivity mitigation would be more straightforward but would not measure the ecological gain from the connectivity action.

Similarly, model-based metrics to value wildlife connectivity are not linked explicitly to the ecological gain that would result from a wildlife crossing structure or other connectivity enhancement, but these

Photo: Alderleaf Wilderness College

Safe road crossings for amphibians, reptiles, and smaller mammals, like the red fox, offer ample opportunity for study.

metrics can incorporate robust ecological data sets and results from prior modeling efforts to predict potential ecological gain for multiple species.

Lastly, many state DOT practitioners surveyed have used avoided-cost metrics (for example, reduced WVCs) in cost–benefit models to prioritize wildlife connectivity enhancement actions based on the predicted improvement in motorist safety and wildlife conservation. Several practitioners pointed to avoided-cost metrics as among the most practical metrics for monetarily valuing wildlife connectivity mitigation credits, because most state DOTs have roadkill data-collection protocols in place and maintain databases of WVCs.

CASE STUDIES

The research team conducted interviews with 13 practitioners from four state DOTs and wildlife agencies to discuss case studies of wildlife connectivity mitigation in California, Colorado, and Florida. These interviews offered insight into various approaches to value wildlife crossings and enhancements for mitigation credits. Practitioners in California described how the advance mitigation framework developed by Caltrans has provided the opportunity to invest in a standalone wildlife connectivity mitigation project via advance mitigation credit creation.

The Laurel Curve Credit Agreement was a proof-of-concept effort to demonstrate the framework for developing credit agreements for wildlife crossing structures. It showed how credits generated from a wildlife crossing could be applied as compensatory mitigation to satisfy future transportation project permit conditions. Although other function- or model-based metrics could have been used—at least in concept—a condition-based metric was straightforward, repeatable, and inexpensive to calculate.

A California Department of Fish and Wildlife program also facilitates mitigation credit agreements for wildlife connectivity enhancement actions through a voluntary, nonregulatory regional planning process. Respondents from the agency anticipated that future mitigation credit agreements would consider other factors to quantify ecological gain, such as improved access to breeding sites or improved gene flow. Whatever the metrics and methods used to calculate mitigation credits for wildlife connectivity enhancement actions, the practitioners interviewed generally agreed upon the importance of consistent quantification of the benefits to focal species from wildlife connectivity mitigation (credits) and the impacts of transportation projects requiring compensatory mitigation (debits).

Ideally, the metrics used to calculate wildlife connectivity mitigation credits would be easy to measure, based on the focal species' biology, and would result from collaboration and agreement among stakeholders.

Wildlife Crossing Literature

Peer-reviewed literature on wildlife crossings began appearing regularly in the 1970s. The number of published studies is increasing steadily; over the past 10 years, 68 studies for amphibians and reptiles and 25 studies for small animals have been conducted.

Practices shared by TRB and U.S. researchers have inspired further international research, such as the 2019 African Conference for Linear Infrastructure and Ecology in Kruger National Park, South Africa.

Photo: Christine Gerencher

Foraging for grass, a white rhinoceros blocks the roadway in Kruger National Park, South Africa, during a park tour of African Conference for Linear Infrastructure and Ecology attendees in 2019.

Declines in Transit Ridership

Analysis of Recent Trends

Photo: Cory Hancock, IMF

KARI EDISON WATKINS, CANDACE BRAKEWOOD, GREG ERHARDT, SIMON BERREBI, AND BRENDON HEMILY

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Above: A rider takes a Metro train through L'Enfant Plaza in Washington, D.C. Before the COVID-19 pandemic, trains traveling through this busy hub were almost always full of riders. Two Transit Cooperative Research Program studies examine the decline in U.S. transit ridership that, though exacerbated by the pandemic, had begun some years prior.

Even before the COVID-19 pandemic, in 2019 transit ridership in the United States had declined for the fifth consecutive year. Buses were the most affected, with the lowest transit ridership levels since the 1970s. Even rail travel has declined over the past few years, after having experienced an upward trend since 2009 (see Figure 1). As transit ridership declines, agencies lose fare revenue and often reduce service to meet budget constraints—resulting in further transit ridership losses.

Even though these trends are remarkably consistent across U.S. cities, in many other countries transit ridership has increased in the past several years. Canadian transit agencies have seen a steady rise in transit ridership that has closely followed increases in service since the mid-1990s. Among 39 countries tracked by the International Association for Public Transport, 24 "experienced an increase or at least maintained a stable rate of public transport use (journeys per capita) over the past 15 years." The United States is not alone in its transit ridership losses, but most countries with similar losses have poor economic conditions or have experienced substantial demographics changes.

Photo: Seattle DOT

A crowded bus makes its way through Seattle, Washington. Bus ridership is less affected by changes in population and density than that of other modes like rail.

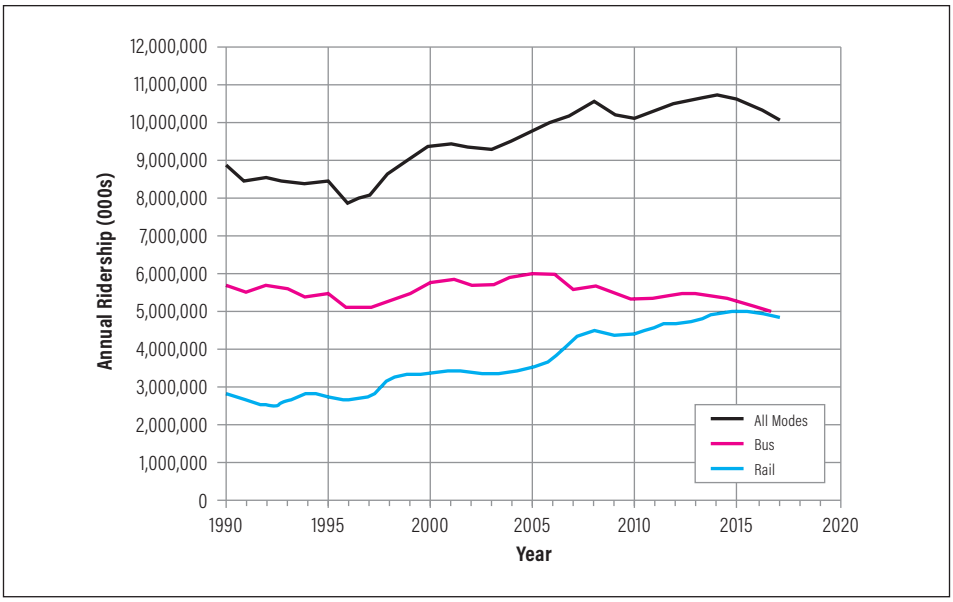


FIGURE 1 Transit ridership in the United States, 1990–2018.

The recent decline in transit ridership is particularly worrisome because traditional factors of transit ridership do not seem to be involved. Although U.S. transit agencies experienced drastic service cuts following the recession, overall vehicle revenue miles rebounded to their 2010 level by 2015 and have kept growing ever since. Meanwhile, urban population and employment rates, which are both typically associated with high transit ridership, have risen substantially in the same period.

The most comprehensive effort to understand transit ridership change within the industry has been the Transit Cooperative Research Program (TCRP) Project A-43, "Recent Decline in Public Transportation Ridership—Analysis, Causes, Responses," and the preceding TCRP Project J-11, Task 28, "Analysis of Recent Public Transit Ridership Trends," whose final report was published as *TCRP Research Report 209: Analysis of Recent Public Transit Ridership Trends*. A few of the most important findings in *TCRP Research Report 209* include the following:

- Although not uniformly true, in most regions, population has increased; therefore, transit ridership per capita has been falling at an even faster rate than total transit ridership. Population is a strong predictor for bus ridership historically, but **mixed traffic (generally bus) ridership change seems unaffected by the recent increases in population**. Population is a more moderate predictor for dedicated right-of-way (mostly rail) ridership historically, and population change also explains some of the recent rail ridership changes.
- The amount of transit service provided is an important lever available for transit agencies to affect transit ridership. **The relationship between transit ridership and transit service levels is strong.** Especially in mid-sized regions, transit service levels explain much of the variation in transit ridership. However, in looking at recent changes in transit service, **in larger metro areas, more bus service does not equal more bus ridership.** The change in transit ridership is much more closely associated with recent change in transit service levels for dedicated right-of-way than for mixed traffic modes.
- **Small- to mid-sized regions that didn't increase transit service levels between 2012 and 2016 saw, on average, an 8–10 percent loss in transit ridership.** In *TCRP Research Report 209*, the authors created a series of graphics showing transit ridership as it related to such factors as service provided. On a simplified version of the graphic (Figure 2), the *y*-axis intercept of the trend lines in the transit service change versus transit ridership change figure is the amount of ridership change that should be expected if transit service levels had not changed ($x = 0$). Although there is a definite relationship between the change in transit ridership

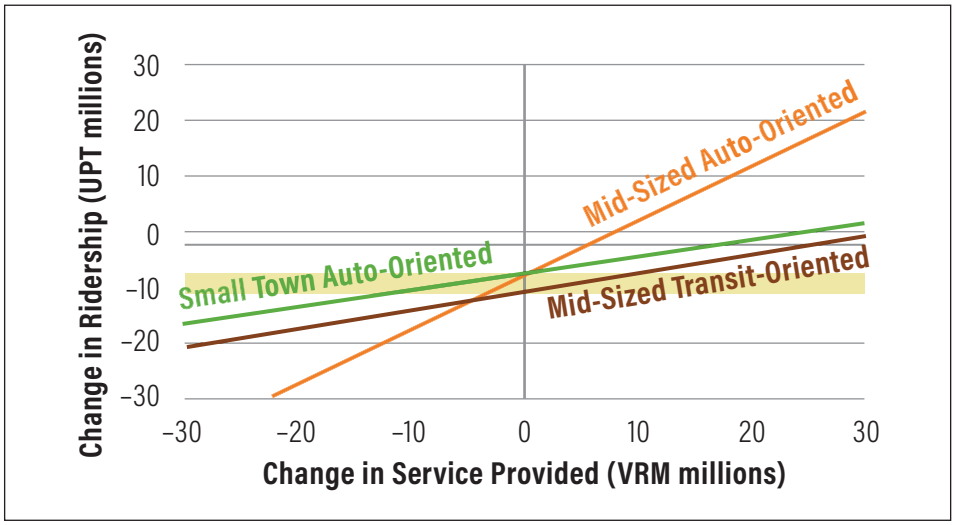


FIGURE 2 Change in service versus change in ridership, 2012–2016. (Note: UPT = unlinked passenger trips; VRM = vehicle revenue miles.)

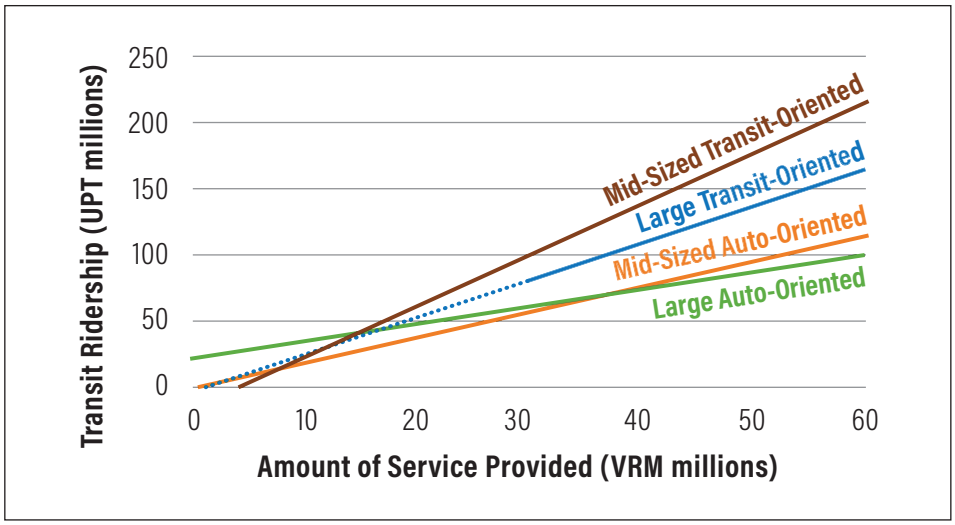


FIGURE 3 Transit ridership versus service provided.

and the change in transit service levels, there is some other effect at play that is driving transit ridership down. Only if transit service was substantially increased would transit ridership go up. If service levels remained the same, in most regions, transit ridership would have decreased.

- In mid-sized, transit-oriented regions, such as those in the "Rust Belt" (Baltimore, Pittsburgh, and Cleveland), each marginal vehicle revenue mile is associated with twice the transit ridership as in similar mid-sized, car-oriented regions in the "Sun Belt" (Kansas City, Charlotte, and Nashville). Similarly, the relationship between transit ridership and transit service levels is three times greater for transit-oriented metro areas (Boston, Philadelphia, Chicago, and Seattle) than for car-oriented metro areas (Atlanta, Houston, and Phoenix). In other words, **increasing transit service in denser transit-oriented regions, both in mid-sized and large metro areas, will increase transit ridership much more than in car-oriented regions**. This is demonstrated in the simplified graphic shown in Figure 3.

Explaining Transit Ridership Declines

The follow-on to *TCRP Research Report 209* is TCRP Project A-43, an ongoing project that employs a two-phase research approach to consider changes at the system, route, and stop levels, as shown in Figure 4.

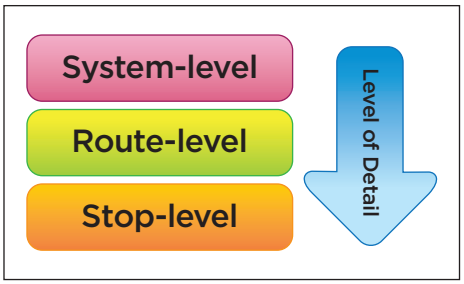


FIGURE 4 TCRP Project A-43 research approach.

TCRP PROJECT A-43

Phase 1 of TCRP Project A-43 included an extensive literature review and hypothesis development, as well as a system-level analysis. Researchers identified four categories of factors and strategies for transit ridership change. These were broken into traditional and emerging factors and internal and external factors, and their intersection is summarized in Table 1.

Traditional factors are those that have affected transit ridership for many decades, while emerging factors are newer to the transportation system and require more research. Internal factors are those that the transit agency can control (sometimes with

TABLE 1 Four Categories of Factors and Strategies Affecting Transit Ridership

	Internal	External
Traditional	• Service quantity • Fares • Speed and reliability • Service concentration • Access to transit • Security • Service quality	• Density • Population • Employment • Income • Gas prices • Commuting policies • Car ownership • Demographics
Emerging	• Restructuring transit networks • Demand response, flex route services, and microtransit pilots and partnerships • New fare media and fare integration • Real-time information • Maintenance issues • Dedicated transit right-of-way • School and employer partnerships • Fare discounts or elimination	• Gentrification • Aging population • Millennials • Telecommuters • Delivery services • Congestion and parking pricing • Shared mobility (ride-hailing, bikesharing, car-sharing, scooters)

help from local or regional governments), while external factors are those that affect transit agencies but over which they have little control.

Current literature on the topic successfully identifies the important factors and the likely direction of each, but a mix of factors contribute to recent trends, pushing transit ridership in competing directions. To separate the effect of each of these factors, researchers conducted statistical analyses that correlate each of these with changes in transit ridership. In a system-level, multicity analysis, they estimated longitudinal models of total bus and rail ridership for 215 metropolitan statistical areas (MSAs) in the United States between 2012 and 2018. This allowed the research team to establish the sensitivity of transit ridership to changes in the descriptive variables (service miles, fares, population, and so on).

The resulting models show elasticity, or the percent change in ridership that would result from a 1 percent change in each descriptive variable. Researchers grouped the results into three clusters of MSAs based on transit operating expenses: high (greater than $300 million), medium (between $30 and $300 million), and low (less than $30 million). New York was excluded from this main analysis because it is such a substantial and distinct portion of U.S. transit ridership. Major data sources include the National Transit Database, the U.S. Census Bureau American Community Survey, the Bureau of Labor Statistics, the U.S. Energy Information Administration, the Bureau of Transportation Statistics, and Uber.

FACTORS AFFECTING TRANSIT RIDERSHIP

Overall, two sets of factors pushed an increase in transit ridership from 2012 to 2018:

- **More service.** Across all clusters, transit operators are providing more bus and rail service. These service additions resulted in a net bus ridership increase ranging from 2.5 percent in high-operating-expense cities to 4.7 percent in mid-operating-expense cities. Rail service increases were associated with ridership gains of 10 percent in high-operating-expense cities to 18 percent in mid-operating-expense cities.
- **Land use.** Land use affects transit ridership in terms of total population and employment growth, as well as how centralized that growth is. By cluster, metro areas grew between 5.8 and 7.9 percent in population and employment, pushing up ridership. However, in most clusters, that growth became less centralized, pushing ridership down, so that the combined effect of land use changes is a less than 2 percent increase in ridership.

Photo: J. C. Burns, Flickr

Falling gas prices in the late 2010s made driving less expensive, reducing bus and rail ridership.

The net transit ridership decline between 2012 and 2018 was due to a combination of four main sources. Together, these sources more than offset the factors cited above that pushed ridership up over this period. They include:

- **Income and household characteristics changed.** Higher incomes, higher car ownership, and an increase in the percentage of people working at home contributed a net ridership decline of about 2 percent for bus and rail. This remained relatively consistent across clusters.
- **Bus and rail travel became more expensive.** Average bus fares went up in two of the three clusters. Average rail fares in all clusters increased, with that increase ranging from 7 to 13 percent. The result was net ridership declines of zero to 4 percent.
- **Driving became less expensive.** Average gas prices decreased by about 30 percent over this period, contributing to an approximately 4 percent reduction in bus and rail ridership.
- **New modes competed with bus and rail.** The model results suggest that ride-hailing was the biggest contributor to lower bus ridership between 2012 and 2018, resulting in net decreases of between 10 and 12 percent. The effect of ride-hailing on rail ridership in larger metro areas (with high operating expenses) was much smaller, but the effect in the mid-operating-expense group was similar to that for buses. Bikeshare and e-scooters had a much smaller impact: less than or about 1 percent.

Transit Agency Strategies and Ridership Factors

In Phase 2 of TCRP A-43, researchers tested specific strategies and factors and related transit ridership effects that are difficult to discern at the system level, by analyzing

Photo: MetroTransit

As transit in the United States enters a post-pandemic future, researchers continue to investigate lasting effects on mobility and public transit in particular.

the change in route- and stop-level transit ridership data for a handful of cities. In each city, the team also assembled several additional data sets, such as level-of-service metrics, spatially detailed population data, employment and demographic data, and spatial and temporal data on micromobility trips. They uncovered several key points:

- **Transit should be given priority.** Case studies from Minneapolis–St. Paul, Minnesota, and Cleveland, Ohio, showed that high-quality light rail and bus rapid transit can increase ridership substantially, even with limited service increases.
- **Agencies should get creative with fare policies and prices.** A case study in Topeka showed that strategic fare discounts can substantially increase transit ridership. Fare-free promotions for kids in the summertime, as well as for seniors and veterans, can increase transit use.
- **Micromobility has limited impacts on transit ridership.** A case study in Louisville showed that e-scooters had limited, if any, impact on local bus ridership and may even have led to slightly higher express bus ridership. Agencies can consider micromobility partnerships to address first mile–last mile connectivity issues.
- **Transit ridership was peaking.** Morning and evening peak ridership declined the least and nighttime ridership declined the most. The most productive service (measured in ridership per vehicle hour) occurred on weekdays. Researchers found, however, that nighttime ridership was the most sensitive to changes in frequency. The final report from TCRP Project A-43 will be published this summer.

Future Transit Ridership Impacts

Over the past year, the transit industry has been hit by what is likely its biggest challenge to date: a global pandemic that uniformly discouraged the close proximity between people on which transit depends to be the most spatially efficient mode. Across cities, rail ridership has significantly declined, as rail modes are most often used by workers who are more likely to have work-from-home options. Bus ridership has also declined, although much of the lower-income and critical workforce populations that buses often serve still ride transit out of necessity.

Moving forward, researchers are still trying to understand the longer-term impacts that the pandemic might have on mobility and public transit in particular. Using these findings as a basis, a few key ideas emerge:

- **Telecommuting impacts on transit will probably continue.** The impacts of telecommuting were already emerging before the pandemic. During the pandemic, these impacts were substantial and necessary. But as the pandemic subsides, many firms will retain some telecommuting practices, changing expectations for the "five days per week at the office" model and reducing the gap between peak hours and off-peak demand.

- **Population density may continue to decline.** Population densities were already starting to decrease before the pandemic, offsetting a rise in transit ridership that had resulted from previous population increases. It is hard to predict how the public will react in the longer term, but with more flexibility in job locations comes more flexibility in living locations and a need for greater space in the home.
- **Low gas prices hurt transit ridership.** During the pandemic, oil producers could not give their product away. As congestion has increased, so have gas prices, but are still generally very low. Sustained lower demand could continue to keep gas prices low, making driving a much cheaper option and adversely affecting transit ridership.
- **Potential for higher transit fares.** Similarly, driving can stay cheap compared with transit if agencies are forced to raise fares as they begin to recover their financial losses during the pandemic. The key to affordable transit is high ridership on a per vehicle hour basis. With low ridership per vehicle hour, transit must be subsidized to keep it affordable.
- **Impact on new modes is unknown.** Like transit, ride-hailing services also require that users share space. Although ride-hailing use grew rapidly before the pandemic, its future trajectory and resulting impact on transit remains to be seen.

These future impacts point even more toward the successful strategies that agencies have been pursuing before the pandemic. Prioritizing transit modes above lower-capacity modes, giving transit exclusive right-of-way, will make transit run faster and more reliably, thereby encouraging ridership. Integration with shared mobility and micromobility providers can help address some first mile–last mile issues via e-scooters and bicycles, but such partnerships should be approached carefully so that modes such as ride-hailing do not compete directly with transit in the most productive corridors, further reducing transit ridership. Regional agencies and municipalities should pursue densities and development that are supportive of transit to ensure that transit can stay competitive in the urban environment.

New strategies in response to the COVID-19 pandemic have emerged. Transit agencies must become more creative about fare media and pricing policies to ensure that commuters with many options are choosing transit as often as possible, even if it is not for every trip.

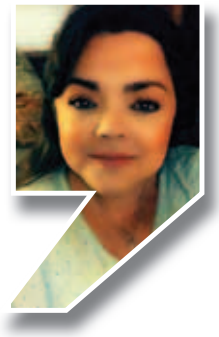
It is time for the transit industry as a whole to rethink its service standards, service delivery, and performance metrics to ensure that they are reflective of the twin missions of good public transit: to respectfully serve those who rely on transit on a day-to-day basis via greater emphasis on equity of accessibility and service, and to efficiently provide mobility in urban areas.

Acknowledgments

The authors thank the students who helped with this research, particularly Abubakr Ziedan, Wesley Darling, Jawad Hoque, and Vedant Goyal.

VOLUNTEER VOICES

"My father was in the transportation industry, and he gave me a nudge in this direction. I stay because of the diverse culture, the diversity of the people involved, and the ever-changing reality that is asset carrier transportation. As a woman in business, I find it is an exciting and constantly evolving career path with a lot of opportunity for advancement and entrepreneurship."



—KELLY MORRIS
Director of Transportation, Midwest Region
Phoenix Cargo, LLC, Grove City, Ohio

Capacity for Transformation

The Role of Transit, Shared Modes, and Public Policy in the New Mobility Landscape

Photo: Dan Gold, Unsplash

KATHERINE KORTUM

The author is a senior program officer at the Transportation Research Board, National Academies of Sciences, Engineering, and Medicine, Washington, D.C.

Above: By the time the COVID-19 pandemic arrived in early 2020, rideshare services—mostly car-sharing companies, bikeshare, and e-scooters—proliferated in nearly every U.S. city. COVID-19 slowed the growth of many of these services, but shared mobility is likely a permanent part of the transportation landscape.

This study on opportunities to use shared modes more effectively in coordination with public transit was largely completed before the novel coronavirus (COVID-19) pandemic began. By early 2020, the transportation systems of most metropolitan areas included shared modes such as Uber and Lyft, bikeshare, e-scooters, and more. Although these modes still accounted for a small share of total travel, they were growing in availability and popularity and showed potential to serve many societal goals of mobility, equity, and sustainability—especially if carefully combined with public transit and scaled up substantially.

The pandemic led to unprecedented drops in travel demand and deep uncertainty about when and how demand will rebound, however. At the time of this study's completion in late 2020, the pandemic and its immediate aftermath threatened to reshape both demand for and supply of transportation services in most locations, including public transit systems, which were in distress from months of lost patronage and revenues.

Photo: Alexander Popov, Unsplash

Real-time travel information, one-stop mobile payment systems, and cross-modal management can help agencies integrate public transit and shared mobility services like ridesharing.

If agencies are to realize the full, potentially transformative benefits of shared services and transit, they must 1) provide travelers with real- or near-real-time information on modal and multimodal travel options and their relative costs, duration, reliability, and impacts on concerns such as carbon emissions; 2) integrated e-tickets and payment apps that will greatly simplify the process of arranging and paying for the use of multiple modes for a single trip; and 3) effective management across modes and jurisdictions.

This report recommends steps to help facilitate the integration of shared mobility modes, starting in urban cores with historically robust transit service but with the aim of increasing the value and viability of transit and shared mobility services more broadly across regions.

Challenges to Service Integration

Currently, there are barriers to a fully integrated set of transportation services. Significantly, public agencies are unable to gather information systematically on the availability and real-time performance of all public and private shared-mode options—particularly from the ride-hailing companies that comprise the majority of private shared-mode trips. The many separate public agencies providing transit, operating roads, and overseeing shared mobility providers mean that, even if this information could be acquired, it would be challenging to put it to beneficial use.

Because of fragmented governance, regions lack common goals and shared strategies to facilitate multimodal trips that cross jurisdictional boundaries. The few organizations with a regional perspective—such as regional planning bodies—generally are weak institutions without strong influence on regional operations.

Other important barriers include the following:

- Local, regional, state, and federal laws and policies that underprice road use when accounting for the effects of congestion and emissions and that encourage driving alone over all other modes;
- A lack of integrated transit fares, routes, and schedules across the multiple transit providers at the regional scale, a reflection of funding often tied to local revenue sources and service intended only for local taxpayers; and
- A shared mobility landscape that is rapidly evolving, with services regularly arriving, leaving, and changing as private companies seek profitable markets.

A customer-centered multimodal system could improve efficiency, reduce emissions, and improve equity. Necessary major elements of a mobility management framework would include

- Easy-to-access, real-time information on all modes for customers;
- Convenient integrated options for arranging multimodal trips and simplified ways of paying for them;
- Multiple travel options for consumers;
- Quality transit service and seamless transfers across modes; and
- Transit-supportive land use development.

Exercising these elements can serve accessibility, efficiency, equity, safety, and sustainability goals. Many cities and transit agencies are addressing individual strategies included in this framework. The framework proposed in this report provides a more complete, holistic approach in which multiple strategies reinforce the impact of others. Within each of the mobility management categories, the report lays out a variety of implementation strategies to achieve these objectives. The findings that follow (abbreviated from those in the full report) summarize the strategies.

Findings and Observations

For travelers to have consistent information, **cities and regions must clarify the information needed from aggregators.** This likely would include all possible travel modes and combinations of modes, travel time, travel cost, and some measure of the negative externalities of trips by alternate modes.

Provision of information and integrated payment will require the **cooperation and coordination of a variety of entities** and raises the question of which regional entity would take the leading role. Information currently comes from transit agencies, roadway operators, traffic data analytics companies, micromobility providers, parking managers, and ride-hailing companies. All these entities would need to provide their data in standardized form to a back-end processing mechanism so that it can be aggregated and provided to travelers.

Payment processing would require the coordination of transit agencies, ride-hailing companies, shared-mobility providers, and toll and parking operators. For a seamless mobility management experience, the customer would pay once, with the distribution of that payment happening on the back end. This degree of cooperation generally does not occur within the United States, particularly given the lack of governance at the regional scale and variations in laws and policies across the country. Because of this, agencies and organizations that commit to a regional mobility management strategy are likely to seek unique solutions to the question of which organization should take the leading role.

Regions with metropolitan transportation authorities or regional transit agencies could task such organizations to take on the assignment of mobility manager. Those without either metropolitan transportation authorities or regional transit agencies could expand the roles and authorities of metropolitan planning organizations (MPOs), perhaps with an MPO acting as a convener and other agencies following their own missions but in a coordinated fashion.

The data required for consumers to have a complete array of travel options and methods of payment **should not require trip data** that could risk disclosure of personal information about individual consumers. However, aggregation by a single app covering all public and private options may require private companies to disclose information about the availability of shared-mode options that some companies may consider proprietary. If consumer-facing systems were to evolve into a series of private providers that control user access to

content and services, this concern would be resolved—but it would result in many individual systems that lack all the options consumers would want to use.

In principle, the disclosure of credit card transactions could reveal the trips of individuals; however, that risk also exists for trips made today, policies are in place to minimize this risk, and the public appears to have much less reticence about their personal information being available to private companies than to government agencies.

Photo: City of St. Petersburg

The City of St. Petersburg, Florida, gave the green light to e-scooters in late 2020—albeit with a handful of regulations guiding their use, such as speed limits and docking after rides.

THREE MODELS

A remaining open question is **how to create an efficient, cost-effective regional information and payment system** that is capable of keeping up with the rapid change in information and communications technologies. Current models for mobility as a service (MaaS) worldwide fall into three major categories: public only, private only, or mixed public and private. Public-only models, in which public agencies control both the data acquisition and analysis and the customer interface, may be the best at prioritizing the public good but may limit competition and innovation that drive down costs for consumers. Private-only models, in which each private company acquires its own sets of data on travel options and provides it to the customer, are likely to be more innovative and responsive to change than a public option but may result in models in which individual applications limit customers' choices.

In the mixed model, a public agency sets regulations, acquires the data, and allows any interested private companies to use those data to develop the customer interface. This model might work best in the U.S. context, given the proliferation of private companies willing and able to sell travel options to consumers and the public's wariness about private data in public hands. However, for MaaS models with a substantial private role, it is not known whether regional MaaS markets would have the enough competition to foster innovation and control costs.

Providing consumers with multiple options for making their trips can enhance mobility, efficiency, equity, and sustainability—if guided by public policy. A variety of strategies can be used. For example, a permitting/regulatory structure for micromobility gives cities a framework within which they can support the supply of micromobility while managing its adverse side effects. Strategies to encourage supply and competition include easing regulations on taxi entry and pricing; subsidies for micromobility, microtransit, and ride-hail riders and operators also can enhance consumer choices and mobility.

EQUITY CONSIDERATIONS

Expanded shared mode services to lower-income neighborhoods can be accomplished through the kinds of subsidies mentioned above, as well as through regulation. Ensuring wheelchair-accessible vehicle service has long been a challenge for cities and taxi authorities, but many promising strategies can be employed. New and expanded transit services will enhance the ability of multimodal options to compete with shared-occupancy vehicle (SOV) trips.

Bus network redesigns to better align routes and frequencies with concentrations of population and employment have become a popular strategy to grow transit ridership, although evidence is lacking to date on their effectiveness. Road and sidewalk space allocation for shared modes will expand supply and safety.

OTHER CONSIDERATIONS

Increased emissions from ride-hailing vehicles are among the adverse side effects that can be addressed by public policy. The safety and personal security of ride hailing compared with taxi use has been a source of controversy, one that has been difficult to resolve because of the asymmetries between the business models of ride-hailing and taxi companies and the regulations that apply to each. With the injury and travel data that should be available after eight years of ride-hailing trips, it should be possible to settle this debate empirically.

Automation of shared ride and taxi and transit services could transform travel options and consumer choices, but it remains highly uncertain when, whether, and how this would happen.

Quality multimodal services can enhance the ability of more sustainable modes to compete with private automobiles through a variety of strategies. Improved road network reliability will improve bus speeds and make buses more attractive to riders accustomed to the convenience of SOVs, and many options are available to improve traffic operations.

Convenient transit service, through enhanced service frequency and hours of operation, will increase ridership as well as operational costs. States and local jurisdictions would need to provide funding for this purpose. Seamless transfers across modes may make trips by shared mobility and transit more competitive with SOV trips. Making transfers convenient includes providing parking for micromobility vehicles near transit, providing mobility hubs to facilitate transfers, and managing curb space for access and egress to and from shared modes.

Integration of schedules, routes, and fares across transit agencies in regions with multiple providers would make

transit more appealing in those regions, but doing so is complicated by provisions restricting local use of funds that many transit agencies rely on. Transit agency partnerships with shared-mode providers are beginning to show the benefits of multimodal trips for a variety of purposes and in a variety of settings. Results of pilot test evaluations funded by the Federal Transit Administration are becoming available and will provide insight into the efficacy of these efforts.

Transit-supportive development and parking regulation can increase the ridership needed to ensure the cost-effectiveness of transit services. Transit-oriented development (TOD) increases population density around rail stations and reduces personal automotive trips and trip distances in the right settings. Parking management by cities, including setting maximum rather than minimum parking requirements in new and redeveloped properties, is an important and valuable strategy supporting TOD for reducing SOV trips in cities and encouraging shifts to transit and shared modes.

Innovative experimentation is needed to coordinate across the multiple entities responsible for various aspects of mobility management.

Photo: Eric Wheeler, Metro Transit

A METRO Green Line train pulls into Raymond Avenue Station in St. Paul, Minnesota. Transit-oriented development like that near Raymond Avenue is a necessary element of a mobility management framework.

Photo: Elvert Barnes Photography

Montgomery County, Maryland, integrated a bus rapid transit line into its busy Route 29 corridor in 2020. Flash Bus is intended to prioritize transit and alleviate traffic along the corridor.

Recommendations

Opportunities to overcome the barriers described here include collaboration among cities, transit agencies, and shared mobility providers based on the following recommendations:

- **Share information.** To provide consumers with information about real-time service availability across all modes, cities and states should change their shared-mode enabling regulations to require access to such information. With these data in hand, agencies and jurisdictions should collaborate to create publicly available platforms that integrate and share information from all sources about modal options and their cost, duration, and emissions.
- **Prioritize transit.** Cities, states, and other jurisdictions should prioritize transit in their transportation networks and evaluate the outcomes of prioritization measures to improve the reliability and quality of road-based transit services.
- **Price appropriately.** Cities and local jurisdictions should institute strategies—such as dynamic street and garage parking pricing, congestion pricing, and employee cash-out benefits of parking subsidies—to better charge for the externalities of all modes. Such policies may improve traffic flow and the performance of the networks that road-based transit systems depend on.
- **Promote equity.** The public sector should use its regulatory powers over shared mode providers to encourage equitable access to transit and shared services by all travelers within its jurisdiction.
- **Partner for paratransit services.** Transit agencies should take action under their own authorities to improve mobility options and choices for riders by partnering with ride-hailing companies, taxis, and other providers.
- **Test and analyze.** All entities involved in a partnership with transit or shared modes should pilot-test, evaluate, and share best practices. Public-sector research agencies could provide a valuable public service by supporting such pilot testing and evaluation as well as conducting research to address other important unanswered questions identified in the report.
- **Overcome fragmentation and expand geographically.** The previous recommendations can be adopted most readily by core cities and transit agencies because of the smaller number of involved jurisdictions and agencies across regions. Over time, adoption should expand beyond core cities to their metropolitan areas. Every region will have to work out its own governance solutions given great disparities across the country in how governments are organized and in the authorities they can exercise under prevailing laws and policies. Metropolitan planning organizations can facilitate this process by serving as coordinators and conveners.

To view the full report, visit https://www.nap.edu/catalog/26053/the-role-of-transit-shared-modes-and-public-policy-in-the-new-mobility-landscape.

James P. Hall

Associate Professor Emeritus, University of Illinois Springfield

Some might say that **James Hall** has had two careers: 25 years as an engineering and information systems manager at the Illinois Department of Transportation (DOT) and 21 years as a professor in the Department of Management Information Systems at the University of Illinois Springfield (UIS). However, Hall sees it as a natural progression. "Technology investigation and implementation have been a constant throughout my professional life," he says.

Hall first used computers in undergraduate civil engineering classes at the University of Illinois at Urbana–Champaign (UIUC). Concurrently, he worked with mainframe outputs in his part-time position in the Sears credit department. "I was fascinated by how data could be translated into useful information," he states.

Upon graduation, Hall joined Illinois DOT as a construction engineer and then resident engineer on a new 10-mile expressway project. As he progressed through managerial positions, he developed his mainframe software programming skills to generate early decision support outputs.

After earning a master's in business administration at UIS, Hall became the pavement technology engineer for Illinois DOT, where he led the development of a comprehensive pavement management (PM) system for the Interstate system to research pavement design and performance. He also implemented new automated pavement condition assessment methods, including video collection to minimize crew roadway exposure and expand information distribution.

As the planning services chief for the Office of Planning and Programming, Hall managed Illinois DOT's asset inventory databases, statewide traffic data collection, and cartographic products. He also led the implementation of the department's geographic information system (GIS).

In 2000, a year after earning his PhD in civil engineering from UIUC, Hall accepted a faculty position at UIS, where he has taught courses in technology management, decision support systems, and systems analysis and design. His research includes projects in data analysis and online training through Illinois DOT, the Federal Highway Administration, and the Illinois Center for Transportation.

"State and local DOTs have a great reputation of professionalism and a can-do attitude, especially in challenging times."

Hall has served as an instructor in a Transportation Research Board (TRB)–sponsored National Highway Institute advanced course on PM systems, with attendees from all 50 states. Over the past 30 years, he has regularly attended and presented at TRB Annual Meetings and held memberships on the Pavement Management, Statewide Data and Information Systems, and Information Systems and Technology committees. For six years, he chaired the Geographic Information Science and Applications Committee and currently chairs the Research Subcommittee for the Data and Data Science Section. Among his publications, he is especially proud of coauthoring *National Cooperative Highway Research Program* (*NCHRP*) *Research Report 800: Successful Practices in GIS-Based Asset Management*. "TRB participation is invigorating," he notes. "Committee and peer exchange activities provide opportunities to learn the latest advances in transportation technology applications and to talk with experts and practitioners from different fields."

Hall has been a member of the Illinois Traffic Records Coordinating Council for more than 20 years. He has been active in the Association of Information Systems, as well as in the Illinois Society of Professional Engineers, where he was president of the Capital Chapter and was named 1997 Engineer of the Year. He also was named Illinois DOT's 1984 Engineer of the Year, and at UIS, he was named the Hanson Professional Services Faculty Scholar.

Says Hall about his involvement with public transportation agencies: "State and local DOTs have a great reputation of professionalism and a can-do attitude, especially in challenging times such as weather-related emergencies. They often are on the forefront of emerging technologies."

Hall believes that future technology advances, such as new data analytics tools and the accessibility of data from a wider range of private and public sources, will lead to dramatic advances in decision support. "State DOTs should enhance their information systems' infrastructure and their workforce's technological capabilities," he adds. "Knowledge of agency business practices, active participation in professional committees, and interactions with other state DOTs are proven methods to advance technology implementation. Above all, executive management must develop a technology vision, allocate resources, and communicate the goals and value to the organization."

As he continues to teach and participate in assessments of state DOTs' data management practices, Hall sees the value of multidisciplinary knowledge and experience. His advice to young professionals? "Engage in your organization, and commit to lifelong learning. TRB is a great resource!"

Pamela Keidel-Adams

Vice President, Kimley-Horn and Associates, Inc.

Pamela Keidel-Adams' career in aviation planning started with an internship before she graduated in 1989 from Ohio's University of Cincinnati with a bachelor of science in urban administration, sparking her lifelong passion for aviation. Over the years, her experience has advanced to include managing airport master plans; conducting state, regional, and local airport planning studies; and leading the business development and marketing of a national aviation group. Today, as a vice president at Kimley-Horn, a major part of her role is serving as one of three members of the aviation leadership team. "We support our aviation staff across the country by developing strategies for pursuing new clients, serving as mentors and technical advisors on major projects, and promoting the firm's aviation practice through industry engagement," she comments.

Throughout her career, Keidel-Adams' technical work has mostly focused on aviation system analyses and general aviation. "My participation with the Transportation Research Board (TRB) has contributed to my knowledge of trends and issues that affect the aviation industry, which has been valuable to the analyses and studies I've worked on," she attests.

Research of methods to obtain data from airports and aviation stakeholders also has been an important component of Keidel-Adams' career: "I look at new ways to request and obtain information as communication styles and techniques change."

Keidel-Adams is the project manager for the Nevada Airport and Heliport System Plan and Airport Economic Impact Study and has worked on system planning projects that include the Arizona State Aviation System Plan, Colorado Aviation System Plan and Economic Impact Study, and Idaho Aviation System Plan and Economic Impact Study. She also is the principal for the Pennsylvania Aviation Economic Impact Study, the Arizona Aviation Economic Impact Study, and the Illinois Aviation System Plan and Economic Impact Analysis. In all, she has completed state system planning projects in 35 states.

She also served as project manager for airport master planning assignments, including Fresno Yosemite International Airport in California, Phoenix Goodyear Airport in Arizona, Bentonville Municipal Airport in Arkansas, Mena Intermountain Municipal Airport in Arkansas, Denton Enterprise Airport in Texas, Saline County Regional Airport in Arkansas, Fresno Chandler Executive Airport, Douglas Municipal Airport in Arizona, and Tombstone Airport in Arizona.

"TRB has given me a holistic view that many others who work in single industries don't have."

TRB has contributed to Keidel-Adams' career in several ways: "TRB has provided me the opportunity to better understand how aviation interacts with other transportation modes and needs, giving me a holistic view that many others who work in single industries don't have. It also has afforded me access to a wide range of professionals, who have enhanced my career as mentors, advisors, and teaming partners on projects throughout the United States."

For six years, Keidel-Adams served as chair for TRB's Aviation Administration and Policy Committee (formerly the Intergovernmental Relations in Aviation Committee) and is current chair of the Aviation Group. She also has contributed as a panel member for three Airport Cooperative Research Program projects. She has attended TRB Annual Meetings for more than 20 years, participating in activities of the committee she chaired, as well as the Aviation System Planning Committee. She also helped develop the committee's Triennial National Aviation System Planning Symposium.

In addition to her work with TRB, Keidel-Adams is a member of the Airports Consultants Council, where she twice served as the planning track host for the Airport Planning, Design, and Construction Symposium; officiated as chair of the 2020 symposium; and held various committee chair positions. She is a Business Partner with the National Association of State Aviation Officials and has presented at more than 30 industry conferences.

Highlights in Keidel-Adams' career include completing projects in all of the Federal Aviation Administration (FAA) regions and with FAA Airports headquarters, as well as developing an industry-leading methodology for analyzing aviation system performance, including performance measure tracking. She also has mentored aviation planners who now serve as project managers, FAA staff, and airport leaders.

Her mentoring efforts continue as she offers advice to new aviation planners. "I encourage them to participate in TRB as a way to meet aviation leaders and researchers and to learn about current issues and trends," she notes. "They should join committees and actively support research needs.

"My relationship with TRB has allowed me to learn about aviation issues I had not had access to before, from air quality to the FAA's modernization of the U.S. airspace system. These experiences have given me deeper insights into issues that affect the aviation system, and I've used the experience to expand my opportunities."

INFLUENCER

Eleftheria (Ria) Kontou

Eleftheria (Ria) Kontou is an assistant professor in the Department of Civil and Environmental Engineering at the University of Illinois Urbana–Champaign. She is the incoming chair of the Young Members Coordinating Council and a member of and the communications coordinator for the Standing Committee on Alternative Fuels and Technologies.

How did you first hear about and become involved with the Transportation Research Board (TRB)?
While pursuing my master's degree at Virginia Tech, my advisor, Dr. Pamela Murray-Tuite, encouraged me to submit my research paper to the TRB Annual Meeting because it is the premier conference in our transportation engineering field. Through TRB, I gradually expanded my research network, got involved with Young Members Coordinating Council work, and contributed to the Standing Committee on Alternative Fuels and Technologies activities.

How has TRB influenced your career so far?
TRB and its academic and professional community play a very important role in my career development. Through TRB and the TRB Annual Meeting, I have been given the opportunity to present my research and receive feedback from leaders in our field, create a network of peers and collaborators, and work with my committee to develop research need statements that influence future research direction in my alternative transportation fuel and energy research domain.

What was one of your most memorable TRB Annual Meeting moments?
During the 2019 TRB Annual Meeting, I gave a lectern presentation on how future travel demand prediction can be used to reduce empty vehicle miles traveled by ridesourcing services. The room was full, and the questions and discussions at the end of my talk were so intellectually stimulating that they resulted in new research ideas and a great collaboration related to modeling ridesourcing services electrification.

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

VOLUNTEER VOICES

"When debating (in my younger years) what I wanted to do in life, it occurred to me that I had always had a fascination with the various modes of travel: boats, planes, trains, cars, buses, bikes, legs. The list goes on and on! I'm very fortunate to be able to improve and maintain the transportation system as a transit planner. Every day, I see how the presence of a variety of transportation modes can enhance society in so many ways: from improving our health (both mental and physical) to increasing our opportunities and bettering our finances. I stay in the transportation industry because it's a passion of mine to help people get from Point A to Point B.

—MATT SLOTMAN
Senior Service Planner
NJ Transit, Camden, New Jersey

New Committee Name Bolsters TRB's Commitment to Equity

After the killing of George Floyd in May 2020, when the call for social justice erupted once again, members of the Transportation Research Board's (TRB's) Special Committee on Inclusion and Diversity met to consider the extent to which their mission reflected greater societal awareness of long-time inequities. In the summer of 2020, members recommended that "equity" be added to the committee's name and incorporated into its strategic plan to better respond to the calls for social justice reforms. Members discussed how different levels of input and resources are needed to get to equal outcomes. The committee wanted to emphasize that transportation professionals must attend to equity issues in their work in the transportation community. Furthermore, at TRB it is necessary to identify and eliminate barriers to full and active participation in the organization, especially among those from underrepresented groups.

The committee, therefore, proposed to change its name to the Special Committee on Diversity, Equity, and Inclusion. TRB's Subcommittee on Planning and Policy Review subsequently approved the name change and associated revisions to the strategic plan. In addition, the committee developed a working definition of equity:

> **"Equity is the process of ensuring that individuals, especially those from traditionally marginalized groups, have equal access to opportunities to advance, contribute, and develop in a group, organization, or function. Achieving equity involves dismantling the barriers that have prevented equality of access to opportunity, participation, and outcomes for members of disadvantaged groups."**

As the Special Committee on Diversity, Equity, and Inclusion moves forward, it will be furthering the work it already does to address equity, considering other work it can do to advance equity throughout TRB, and encouraging those on TRB committees and panels to consider equity as part of their work.

MEMBERS *ON THE MOVE*

Lynn Zanto has retired from the Montana Department of Transportation, where she was transportation planning administrator.

Gail R. Staba has retired from the Transportation Research Board, where she was a senior program officer in Cooperative Research Programs.

Jalonne White-Newsome has left the Kresge Foundation in Troy, Michigan, where she was a senior program officer, to form her own consultant firm. She is a member of the National Academies of Sciences, Engineering, and Medicine's Board on Environmental Change and Society and a panel member on NCHRP Project 25-64, "Considering Greenhouse Gas Emissions and Climate Change in Environmental Reviews—Resources for State DOTs."

Melinda McGrath, executive director of the Mississippi Department of Transportation and Executive Committee member, resigned at the end of March 2021.

CONSENSUS REPORT

Accelerating Decarbonization of the U.S. Energy System

CHRIS HENDRICKSON

The author is Hamerschlag University Professor Emeritus at Carnegie Mellon University in Pittsburgh, Pennsylvania. He is a member of the TRB Executive Committee.

The world faces a transformation of the energy system from one dominated by fossil-fuel combustion to one with vastly reduced emissions of carbon dioxide (CO_2), the primary greenhouse gas (GHG) causing climate change. To help policy makers, businesses, communities, and the public better understand what a transition to net-zero emissions would mean for the United States, the National Academies of Sciences, Engineering, and Medicine convened a group of experts to investigate how the country could best decarbonize its energy system.

Led by the Committee on Accelerating Decarbonization in the United States: Technological, Policy, and Societal Dimensions, the study addresses socioeconomic goals and recommends policies and changes to achieve net-zero GHG emissions by 2050. The committee assessed the technological, social, and behavioral dimensions of policies and research activities required over the next five to 20 years to put the United States on a path to net-zero emissions by midcentury.

The interim consensus study report, *Accelerating Decarbonization of the U.S. Energy System*, focuses on the electricity, transportation, industrial, and building sectors that comprise most of the energy system and produce the most GHG emissions. The committee offers a technical blueprint and policy manual for U.S. energy system transformation over the critical first 10 years of a 30-year effort to reach net-zero GHG emissions. The report focuses both on actions to achieve such a system's final technological mix and on actions that can facilitate as many viable paths to net-zero as possible.

Photo: Dennis Schroeder, National Renewable Energy Lab

Black-eyed Susans, a type of rudbeckia native to North America, greet the sunlight at a solar research site. Scientists from the National Renewable Energy Lab researched the economic and ecological impact of pollinator plants underneath the photovoltaic array.

Net-zero policy is about more than implementing nonemitting energy technologies because the manner in which the U.S. economy produces and consumes energy affects a host of other issues. The energy transition offers an opportunity to build a more competitive U.S. economy, increase the availability of high-quality jobs, build a socially just energy system, and allow currently marginalized individuals and businesses to share equitably in future benefits.

To maintain public support through a 30-year transition, the United States will need policies to ensure that the costs and benefits of the transition are distributed fairly. The committee's technological and socioeconomic recommendations for net-zero policy during the 2020s are as follows:

Technological Goals

- Invest in energy efficiency and productivity;
- Electrify energy services in transportation, buildings, and industry;
- Produce carbon-free electricity;
- Plan, permit, and build critical infrastructure; and
- Expand the innovation toolkit.

Socioeconomic Goals

- Strengthen the U.S. economy;
- Promote equity and inclusion;
- Support communities, businesses, and workers; and
- Maximize cost-effectiveness.

Of these recommendations, four explicitly mention transportation:

1. **Invest in energy efficiency and productivity**. Increase industrial energy productivity from 1 percent to 3 percent per year. Energy efficiency in transportation overlaps with electrification to reduce demand. For example, switching to electric heat pumps and motors also significantly increases the efficiency of heating and transportation relative to fossil-fueled boilers and internal combustion engines.
2. **Electrify energy services in transportation, buildings, and industry**. Achieve zero-emissions vehicles in approximately 50 percent of new vehicle sales across light, medium, and heavy classes by 2030.

3. **Plan, permit, and build critical infrastructure**. Accelerate the construction of the nation's electric vehicle recharging network. This infrastructure should be a mix of private and public ownership and operation, including fleet operators. Plan and initiate a national CO_2 transportation and storage network to ensure that CO_2 can be captured at point sources across the country, including in industry, power generation, and low-carbon fuels production.
4. **Triple federal investment** in clean energy research, development, and demonstration to provide new technological options and reduce the cost of existing options. Such innovations would include next-generation energy systems for transportation and low-cost, zero-carbon fuels. Progress is needed on net-zero options for aviation, marine transport, and the production of steel, cement, and bulk chemicals.

Moving Forward

The final report, due out in 2023, will assess a wider spectrum of technological, policy, social, and behavioral dimensions of deep decarbonization and their interactions. Questions will include those focused on sectoral interactions and systems impacts; technology research, development, and deployment at scale; social, institutional, and behavioral dimensions; and policy coordination and sequencing at local, state, and federal levels.

Acknowledgment

The author acknowledges the Committee on Accelerating Decarbonization in the United States: Technological, Policy, and Societal Dimensions, as well as committee chair Stephen W. Pacala.

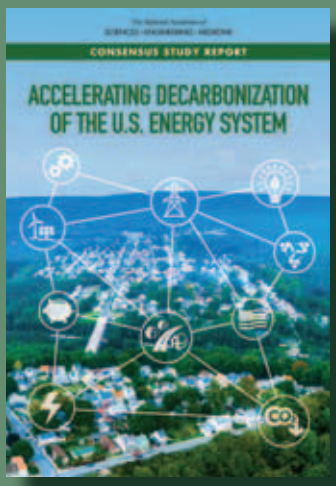
Photo: Ivan Radic, Flickr

Industrial electrification significantly increases energy efficiency—for example, electric car motors versus internal combustion engines.

Accelerating Decarbonization Study

This study was carried out within the National Academies' Board on Energy and Environmental Systems, part of the Division on Engineering and Physical Sciences. The authoring committee was chaired by Stephen W. Pacala of Princeton University.

To read the complete report, visit www.nap.edu/catalog/25932/accelerating-decarbonization-of-the-us-energy-system.



Portland, Oregon, Weighs Bike Emergency Transportation Routes

Natural disasters such as earthquakes can decimate a city. Damaged infrastructure and roadways blocked by debris leave fire trucks and ambulances challenged to get to where they are needed.

Since Hurricane Sandy almost a decade ago, bikes have shown their resiliency in navigating a disaster. Now, in an effort to update the regional emergency transportation route map for the five-county Portland–Vancouver metropolitan area, which includes Clackamas, Columbia, Multnomah, and Washington counties in Oregon and Clark County in Washington, the Joint Policy Advisory Committee on Transportation is recommending that bike emergency transportation routes be part of the update.

A draft of the *Regional Emergency Transportation Routes Update* mentions the need for roads to be cleared for bike use. In an emergency, many people do not have access to private or public transportation. Designated bike routes can enhance mobility while yielding the right-of-way to emergency responders on primary emergency routes. Bikes can more easily maneuver unimproved and spontaneous pathways. The report also proposes that bridges be included when planning bike and pedestrian routes.

Photo: Jonathan Maus, BikePortland

Tightening loads at a north Portland checkpoint, cargo cyclists compete in the Disaster Relief Trials. The event was founded in 2012 out of the potential threat of an earthquake along the Cascadia Subduction Zone. Cyclists, nonprofits, and emergency managers come together for a race across the city, carrying simulated supplies that may be needed in an actual disaster.

Learn more at https://bikeportland.org/2021/02/18/regional-disaster-response-effort-will-include-bike-emergency-transport-routes-326250/amp.

INTERNATIONAL

Kenyan Woman Invents Better-Than-Concrete Pavers

As she navigated Nairobi, Kenya, each day, Nzambi Matee could not close her eyes to the piles of plastic that littered its streets. In Nairobi alone, fewer than 5 million people generate some 500 metric tons of discarded plastic every day. So, the materials engineer decided to do something about it. After three years of experimenting with select plastic waste (and exhausting her personal savings), she created a durable, lightweight paver—fused with sand as a binder—that is five to seven times stronger than concrete materials used for construction. That success not only resulted in the establishment of her own paver production company in 2018, but she also was selected as one of the 2020 Young Champions of the Earth—an honor bestowed by the United Nations Environment Programme.

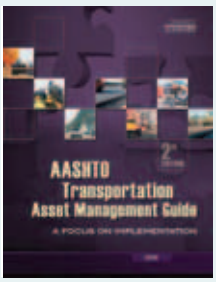
Matee's small company—Gjenge Makers—currently produces 1,500 pavers a day on three machines that mix, sift, and compress the heated plastic and sand. Plastic is collected by members of her team, as well as acquired free from large packaging companies. However, not all plastics will work. The pavers contain high-density polyethylene used for milk and shampoo bottles, low-density polyethylene used for sandwich bags, and polypropylene used for ropes and buckets. They do not contain polypropylene terephthalate, often found in water bottles.

Video: United Nations Environment Programme

Taking matters into her own hands, Kenyan entrepreneur Nzambi Matee decided not to wait for the government to do something about Nairobi's plastic waste problem. The result is a recycled plastic paver that is several times stronger than the traditional concrete equivalent.

The company's first product line, pavers—in a variety of colors—are used for streets, footpaths, and at schools. But Matee also sees enormous potential in using the sustainable composite material for manhole covers, tiles, and the products needed for housing. Their light weight and the low cost of the materials used make the pavers cheaper to transport than traditional construction materials, a benefit that affects the supply chain and keeps the pavers affordable.

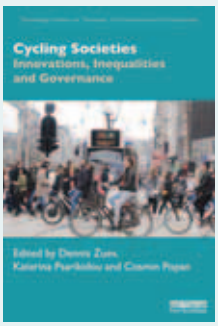
Meet Nzambi Matee and learn about her recycled plastic pavers in this video at https://worldarchitecture.org/article-links/egmeg/kenyan-startup-founder-nzambi-matee-recycles-plastic-to-make-bricks-that-are-stronger-than-concrete.html.



AASHTO Transportation Asset Management Guide: A Focus on Implementation, 2nd Edition

American Association of State Highway and Transportation Officials (AASHTO), 2020. AASHTO members, $120; nonmembers, $162. To download a copy, visit https://store.transportation.org and search for TAMGFI-2-UL.

This volume encourages transportation agencies to address strategic questions as they confront the task of managing the surface transportation system, helping decision makers at state, county, and municipal transportation agencies best use their financial resources to preserve highway assets and provide effective service.



Cycling Societies: Innovations, Inequalities, and Governance

Edited by Dennis Zuev, Katerina Psarikidou, and Cosmin Popan. Routledge, 2020, 296 pp., $46.95, 978-0-36733-661-5.

This book examines emerging debates and questions around cycling to critically analyze and challenge dominant framings and conventions. Via an examination of five case studies, *Cycling Societies* brings to light the plurality of voices and forms of cycling, revealing its diversity and complexity across different sociopolitical regimes, geographies, and cultures.

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

TRB PUBLICATIONS

New Cover for CRP Reports

Cooperative Research Programs publications are getting a new look. Leading with the new cover design is the inaugural report of the Behavioral Traffic Safety Cooperative Research Program (BTSCRP), *Using Electronic Devices While Driving: Legislation and Enforcement Implications*.

This report offers an examination of the current state and provincial legislation on electronic device use while driving, a complex and ever-increasing risk to public safety on roadways. Authors evaluate the benefits and impediments associated with enacting, enforcing, and adjudicating electronic device use and propose model legislation and educational materials that can be used by relevant stakeholders to enact a law and educate key individuals on its importance.

2021; 260 pp.; TRB affiliates, $77.25; nonaffiliates, $103. Subscriber categories: law, safety and human factors.

Design and Access Management Guidelines for Truck Routes: Planning and Design Guide
NCHRP Research Report 943

This report helps transportation agencies establish appropriate methods of choosing truck routes to ensure that the selected roads and streets are suitable for truck travel but do not decrease efficiency by taking trucks too far out of their way or increase crash risk by increasing travel distance too much.

2020; 102 pp.; TRB affiliates, $54.75; nonaffiliates, $73. Subscriber categories: design, motor carriers, and operations and traffic management.

Proposed AASHTO Guidelines for Performance-Based Seismic Bridge Design
NCHRP Research Report 949

This report presents a methodology to analyze and determine the seismic capacity requirements of bridge elements expressed in terms of service and damage levels of bridges under a seismic hazard.

2020; 86 pp.; TRB affiliates, $54.75; nonaffiliates, $73. Subscriber category: bridges and other structures.

Proposed AASHTO Guides for Bridge Preservation Actions
NCHRP Research Report 950

This report presents the development of two AASHTO guides for bridge preservation, including a general guide to preservation of highway bridges and a guide to preservation of highway bridge decks.

2020; 126 pp.; TRB affiliates, $61.50; nonaffiliates, $82. Subscriber category: bridges and other structures.

AASHTO Load Rating Provisions for Implements of Husbandry
NCHRP Research Report 951

State and local jurisdictions vary widely

in managing farm equipment, also known as implements of husbandry (IoH). The growth of IoH has far outpaced that of other legal highway vehicles, warranting bridge safety concerns.

This report proposes new IoH load-rating provisions for the *AASHTO Manual for Bridge Evaluation* in load factor rating and load and resistance factor rating and develops protocols to evaluate IoH with various configurations for load rating and overload permits.

2020; 152 pp.; TRB affiliates, $65.25; nonaffiliates, $87. Subscriber category: bridges and other structures.

Guidebook for Managing Data from Emerging Technologies for Transportation
NCHRP Research Report 952

This report offers guidance, tools, and a big data management framework and lays out a roadmap for transportation agencies on how they can begin to shift—technically, institutionally, and culturally—toward effectively managing data from emerging technologies.

2020; 134 pp.; TRB affiliates, $61.50; nonaffiliates, $82. Subscriber categories: administration and management, data and information technology, and highways.

Availability and Use of Pedestrian Infrastructure Data to Support Active Transportation Planning
NCHRP Synthesis 558

This synthesis documents how state departments of transportation are collecting, managing, sharing, and analyzing pedestrian infrastructure data. Documenting and summarizing current practices for defining, storing, collecting, and sharing pedestrian infrastructure data will help agencies tailor the data collection process to build data infrastructure that supports various uses.

2020; 110 pp.; TRB affiliates, $58.50; nonaffiliates, $78. Subscriber categories: data and information technology, pedestrians and bicyclists, and planning and forecasting.

Performance Measures for State Aviation Agencies
ACRP Research Report 223

Across the country, state transportation agencies of various modes have been required to incorporate performance measures into their core business functions. This report develops performance measures for the National Association of State Aviation Officials membership and their respective state aviation agencies.

2020; 148 pp.; TRB affiliates, $65.25; nonaffiliates, $87. Subscriber categories: aviation, economics, and terminals and facilities.

Advanced Ground Vehicle Technologies for Airside Operations
ACRP Research Report 219

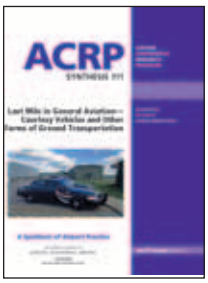
This report identifies potential advanced ground vehicle technologies for application on the airside. Recent advancements in automated and advanced driving technologies have demonstrated improvements in safety, ease and accessibility, and efficiency in road transportation.

2020; 168 pp.; TRB affiliates, $65.25; nonaffiliates, $87. Subscriber category: aviation.

Collecting and Sharing of Operations and Safety Data
ACRP Research Report 222

This report identifies data sources, best practices, and the challenges associated with collecting and sharing information with other stakeholders. It provides a potential roadmap to a future safety and operations national database. The collection and sharing of data are essential in an airport's risk management process.

2020; 90 pp.; TRB affiliates, $54.75; nonaffiliates, $73. Subscriber categories: aviation and safety and human factors.



Last Mile in General Aviation: Courtesy Vehicles and Other Forms of Ground Transportation
ACRP Synthesis 111

This synthesis compiles options, practices, and tools for airports to develop a sustainable last-mile strategy connecting airport users to communities. Providing connectivity to the local community or region served by a general aviation airport is essential for providing a complete service to airport users and capturing economic benefit, whether large or small.

2020; 122 pp.; TRB affiliates, $58.50; nonaffiliates, $78. Subscriber category: aviation.

Minutes Matter: A Bus Transit Service Reliability Guidebook
TCRP Research Report 215

This report details eight steps that a transit agency can undertake to develop and maintain a reliability improvement program.

2020; 126 pp.; TRB affiliates, $61.50; nonaffiliates, $82. Subscriber category: public transportation.

SAGE is the publisher of the *Transportation Research Record: Journal of the Transportation Research Board* (TRR) series. To search for TRR articles, 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.

Improving the Safety, Health, and Productivity of Transit Operators Through Adequate Restroom Access
TCRP Research Report 216

This report presents a catalog of good practices, tools, and resources that provide a foundation for implementable strategies to improve restroom access, primarily for transit vehicle operators.

2020; 228 pp.; TRB affiliates, $73.50; nonaffiliates, $98. Subscriber categories: public transportation, administration and management, and safety and human factors.

Improving the Health and Safety of Transit Workers with Corresponding Impacts on the Bottom Line
TCRP Research Report 217

Transit workers experience more health and safety problems than the general workforce, primarily as a result of a combination of physical demands, environmental factors, and job-related stress. This report focuses on the prevalence of these conditions, associated costs, and statistical analysis of data on participation in and the results of health and wellness promotion programs.

2020; 150 pp.; TRB affiliates, $65.25; nonaffiliates, $87. Subscriber categories: public transportation, administration and management, and policy.

Third Rail Insulator Failures: Current State of the Practice
TCRP Synthesis 150

This synthesis documents the present practices and lessons learned, challenges, and gaps in information related to the use of third rail insulator systems in the United States.

2020; 80 pp.; TRB affiliates, $52.50; nonaffiliates, $70. Subscriber categories: maintenance and preservation, public transportation, and vehicles and equipment.

Transportation Research Record 2675
Issue 1

Featured in this volume is the 2021 Thomas B. Deen Distinguished Lecture by Dorval R. Carter, Jr., titled Our Work Is Never Done: Examining Equity Impacts in Public Transportation. Also examined are traffic and welfare impacts of credit-based congestion pricing applications, the effect of moisture content on the shakedown limits of base course materials, and association between driveway land use and safety performance on rural highways.

2021; 364 pp. For more information, visit http://journals.sagepub.com/home/trr.

Transportation Research Record 2675
Issue 2

Authors present research on such topics as severity analysis of wildlife–vehicle crashes using generalized structural equation modeling, and winter maintenance of permeable interlocking concrete pavement.

2021; 242 pp. For more information, visit http://journals.sagepub.com/home/trr.

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VOLUNTEER VOICES

"A love of cars, trucks, and motorcycles since I was a young girl drew me into the transportation community. The ever-changing technology and development of safety features in vehicles keep me interested and involved.

—ROBIN TALLON
Project Manager
The Transtec Group, Austin, Texas

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June

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2–3 **Environmental Issues in Aviation Committee Midyear Meeting**
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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 as 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 Nancy Whiting at 202-334-2956 or nwhiting@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).

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- **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.

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