NUMBER 314

MARCH–APRIL 2018

TR NEWS

Test Track for New Tech

Plus:

3-D Printing in Construction

Successful Strategic Program Delivery

Different Type of Conference

TRB 97th Annual Meeting Photo Highlights

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. C. D. Mote, Jr., 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 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.national-academies.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 innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied committees, task forces, and panels annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation. **www.TRB.org**

TRB

TR NEWS

NUMBER 314 MARCH–APRIL 2018

3 HIGHLIGHTS FROM THE TRB ANNUAL MEETING 2018
Transportation: Moving the Economy of the Future
Photo highlights of the 97th Annual Meeting of the Transportation Research Board. More than 13,000 participants gathered in Washington, D.C., in January at approximately 800 sessions and workshops; more than 500 committee meetings; and the vast exhibit hall, as well as at award presentations, networking events, and more.

15 A Look Inside a New Mode of Transportation: Virgin Hyperloop One
Diana Zhou
In 2014, Virgin Hyperloop One was a sketch of an idea; today, it is a full-scale prototype. The author examines the conceptual foundation and the organizational and staff support underpinning the design, construction, and testing of the hyperloop prototype, as well as lessons learned along the way. Also discussed are the early feasibility and technology implementation efforts for hyperloop routes by state departments of transportation.

20 3-D Printing in Transportation: Already in Action
Mohammad S. Khan
In transportation infrastructure construction, is 3-D printing a buzzword or a revolutionary technology that can change the design, construction, and maintenance of transportation systems? The construction industry already has used 3-D printing technology for quite some time—only the name is new. The author explores the history of 3-D printing in construction as well as ways in which 3-D printing can transform the industry, together with dynamic information and computer technology.

27 Fellowships for Interdisciplinary Gulf Coast Research
Karen Febey
The Gulf Research Program's early-career and science policy fellowships support young scientists researching the issues that can advance science and practice at the intersections of human health, environmental resources, and offshore energy safety. This article profiles the career and research backgrounds of three GRP fellows whose research and other work overlap with transportation: Ali Mostafavi, Texas A&M University; YeongAe Heo, Case Western Reserve University; and Laura Mansfield, U.S. Department of the Interior's Bureau of Ocean Energy Management. Among the specialties of these fellows are community and infrastructure resilience after extreme weather events and disasters and the safety of offshore oil and gas systems.

32 TRB SPECIAL REPORT
In-Service Performance Evaluation of Guardrail End Treatments
Highway agencies install many different types of guardrail end treatments, all intended to absorb energy in a crash and to redirect the vehicle into a safe trajectory. A study committee, formed by the Transportation Research Board and cosponsored by the National Cooperative Highway Research Program (NCHRP), helped highway agencies supplement crash testing with evaluations of the safety performance of these devices on roads. The resulting report offers a research design and data requirements for assessing the in-service performance of roadside safety devices like guardrail end treatments.

35 NCHRP SYNTHESIS 504
Strategic Program Delivery Methods
Dan Tran, Chris Harper, and Edward Minchin
A recently released NCHRP synthesis report documents the state of the practice in strategic program delivery. Through a literature review, state survey, content analyses, and case studies, researchers discovered that to advance success in program delivery, transportation agencies must establish sound policies and procedures regarding organizational approaches, staff, alternative contracting methods, and program management. Also documented in this article are practices that have been proven effective at other agencies.

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COVER: Virgin Hyperloop One's test track—as well as rapid prototyping—allowed the company to speed its development of a hyperloop vehicle. (Photo: Virgin Hyperloop One)

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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38 Collaborative Convening at TransportationCamp
Karen Febey
TransportationCamp bills itself as an "unconference" convening researchers and practitioners interested in urban transportation and technology, with onsite development of session topics based on interest from attendees, informal gatherings, and social media–based collaboration. The January 2018 TransportationCamp, which immediately preceded the TRB Annual Meeting in Washington, D.C., tackled such topics as accessibility, shared mobility, autonomous vehicles, and safety.

42 Research Pays Off
Wyoming Intercity Bus Service Study: Finding and Filling the Gaps in Rural Areas
David Kack

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46 Profiles
Tribal transportation expert and attorney Raquelle Myers; geotechnical engineer and professor Erol Tutumluer

48 TRB Highlights

49 News Briefs
Airport wildlife management K-9, effects of deicing materials on environment, and wildlife deterrents on Japan's railroads

50 Bookshelf

COMING NEXT ISSUE

The year 2018 marks the 40th anniversary of the passage of the Airline Deregulation Act of 1978. Although it was not the first congressional action to reduce federal economic regulation of transportation, the landmark act is widely regarded as the turning point in the more than 90-year history of the federal government intervening in the structure and operation of the country's transportation industries. Soon after deregulating the airlines, Congress deregulated the freight railroad, trucking, intercity bus, and maritime industries and would begin the process of dissolving the Interstate Commerce Commission and other longstanding federal agencies responsible for regulating transportation rate and service offerings. Forty years later, the era of deregulation remains familiar to most transportation practitioners, even if the specifics of how it came about may not be. In the May–June 2018 issue of *TR News*, experts from the federal government and private industry will examine how deregulation came to the policy forefront and what it has meant for the deregulated industries after four decades.

Photo: U.S. National Archives and Records Administration

President Jimmy Carter signs the Airline Deregulation Act on October 24, 1978.

Transportation: Moving the Economy of the Future

More than 13,000 transportation research practitioners, academics, policy makers, and representatives from private industry convened at the 97th Transportation Research Board Annual Meeting, January 7–11, 2018, in Washington, D.C. Approximately 800 sessions and workshops explored the role of transportation in the global economy; also featured were exhibits, award sessions, committee meetings, and networking events.

Nearly 200 sessions addressed the critical topics of transformational technology, health and transportation, sustainability and resilience, and equity; 45 sessions addressed the meeting's theme, "Transportation: Moving the Economy of the Future." New in 2018 was the Careers in Motion networking fair, which offered the opportunity for transportation professionals to meet with prospective employers from a wide range of sectors and modes.

Patricia L. Mokhtarian, Susan G. and Christopher D. Pappas Professor of Civil and Environmental Engineering at the Georgia Institute of Technology, delivered the 2018 Thomas B. Deen Distinguished Lecture, "The Times They Are A-Changin': What Do the Expanding Uses of Travel Time Portend for Policy, Planning, and Life?" James Ray, Senior Advisor for Infrastructure, U.S. Department of Transportation, delivered the Chairman's Luncheon address.

Details and highlights appear on the following pages.

Annual Meeting photographs by Risdon Photography.

1 Sessions and workshops at the 2018 TRB Annual Meeting, many drawing standing-room-only crowds, covered all modes of transportation.

2 James Ray, Senior Advisor for Infrastructure, U.S. Department of Transportation (DOT), delivered the keynote address at the Chairman's Luncheon.

3 The Chairman's Luncheon honors transportation leaders and preeminent TRB volunteers.

INTERSECTIONS

1 Andy Palanisamy, Leidos; Katherine Kortum, Transportation Research Board (TRB); and Danielle Elkins, Advance Atlanta, lead a quick-fire talk at a Careers in Motion event.

2 With approximately 5,000 presentations in more than 800 sessions and workshops, the Annual Meeting draws transportation professionals from around the United States and from more than 70 countries.

3 The Technical Activities Council administers the activities of TRB's more than 200 standing committees.

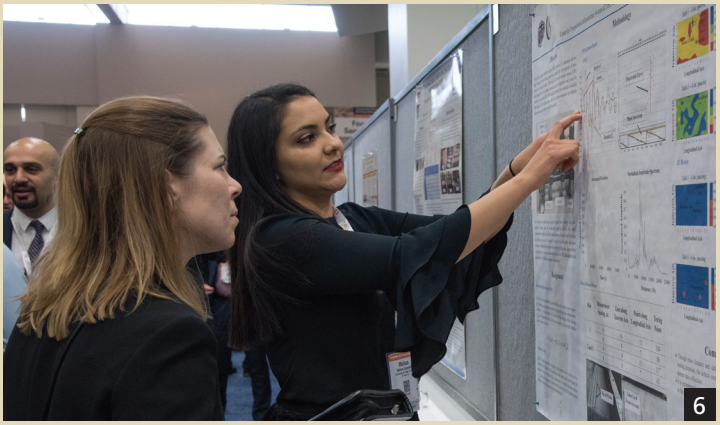
4 Derek Kan, Undersecretary of Transportation for Policy, U.S. DOT, delivered a short address at the International Participants Reception.

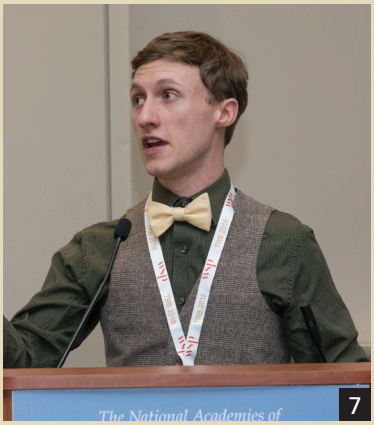
5 Along with their faculty mentors, 21 students from 14 schools attended the Annual Meeting as part of the Minority Student Fellows program.

6 The exhibit hall hosted displays of a variety of transportation-related products.

7 Many exhibits offered hands-on experiences with new technology and transportation systems.

3 2018–2019 TRB Technical Activities Council (*front row, left to right*): Ram Pendyala, Anne Goodchild, Hyun-A Park, Joseph Schofer, Eric Shen, (*back row, left to right*) Ann Brach, William Varnedoe, Nikola Ivanov, Dennis Hinebaugh, C. James Kruse, Avery Grimes, David Ballard, Coco Briseno, David Harkey, Elizabeth Rushley, and Stephen Lane.





SESSIONS & WORKSHOPS

1 Annual Meeting workshops encourage active participation, brainstorming, strategy, and teamwork.

2 Deborah A. P. Hersman, National Safety Council, addresses attendees at the Human Factors Luncheon.

3 Jonathan Dees, North Carolina DOT, presides over a workshop on the American Recovery and Reinvestment Act's impact on high speed rail.

4 Mollie Pellon, National Association of City Transportation Officials, participates in a panel on automated driving.

5 Dave Johnson, Asphalt Institute, presents key factors that influence the in-place density of asphalt pavement.

6 Melissa Escalante *(right)*, University of Texas at El Paso, shares her research on the assessment of reproducibility and defect detectability of high-frequency seismic methods with Karen Febey, TRB.

7 Zach Barlow, Oregon State University, presents research on highway worker safety strategies.

8 The Welcome and Attendee Orientation Session gives participants the opportunity to network, gain familiarity with the schedule, and plan their week.

9 Kirk Steudle, Michigan DOT, highlights the successes of SHRP 2 implementation in his state and explores next steps for adopting SHRP 2 products.

SESSIONS & WORKSHOPS

(continued)

1 (*Left to right:*) Brian Calvert, ICF; Marianne Hatzopoulou, University of Toronto; Julia Salinas, Los Angeles County Metropolitan Transportation Authority (LACMTA); Stephen Paul, AECOM; and Stephanie Blanco, LACMTA, participate in a discussion on technology in evaluating the environmental impact of future transportation infrastructure.

2 Karayan Cole, Jackson State University, presents her poster, Advanced Immersing Bio-Inspired Treatment to Stabilize Sandy Soil.

3 Gabe Klein, Fontinalis Partners (*left*), and David Zipper, German Marshall Fund and 1776, judge transportation innovations at the 6-Minute Pitch session.

4 Public transit in minority and low-income areas was the research focus for Jermaine Potts, Texas Southern University (*left*).

5 Andrea D'Amato, Massachusetts DOT, asks a question to the panel at a session on real-time decision making.

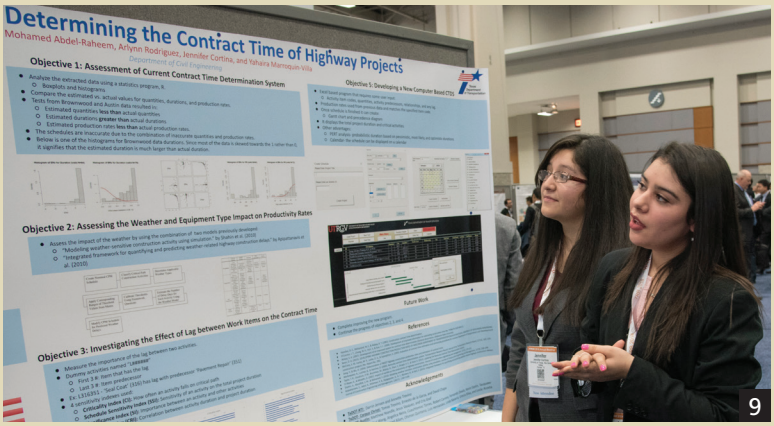
6 Haena Kim, University of Washington, presents her research on freight systems and marine transportation in progress.

7 Eulois Cleckley, City and County of Denver, guides a session on the effect of e-commerce on city truck trips.

8 Diana Cabrera, University of Texas at El Paso, discusses the rate of erosion of backfill materials for mechanically stabilized walls.

9 W. Jeff Lillycrop, Coastal and Hydrolics Laboratory, offers perspective on inland waterway resiliency.

10 Mary Brooks, Dalhousie University, examines the future of marine transportation infrastructure.



9 Jennifer Cortina (*left*) and Arlynn Rodriguez, University of Texas, Rio Grande Valley, present their research on methods for determining highway project contracts.

SESSIONS & WORKSHOPS

(continued)

1 Raju Thapa, Iowa State University, explains his evaluation of truck and agriculture vehicle behavior at reduced-conflict intersections.

2 (*Left to right:*) Carlos Braceras, Utah DOT; Thilo Tecklenburg, Meridiam Infrastructure; and Grover Burthey, Office of the Secretary of Transportation, U.S. DOT, lead discussion on investing in infrastructure.

3 Eric Schmidley, AECOM, showcases Pennsylvania's waste minimization design during construction of I-95.

4 Mohammad Najafi, University of Texas at Arlington (*left*), and Natasia de Gama, Ministry of Transportation, Netherlands, share insights on automated freight transportation systems.

5 Acting Federal Highway Administrator Brandye Hendrickson opens sessions on Tuesday with an update on FHWA.

6 The State CEO Roundtable featured DOT leaders, including Pennsylvania Secretary of Transportation Leslie Richards.

7 Frederick Douglas, Sr., Cosmos Technologies, participates in a panel discussion on achieving regional reciprocity in state Disadvantaged Business Enterprise certification programs.

8 Anne Strauss-Wieder, North Jersey Transportation Planning Authority, addresses supply chain and business continuity in a session on disaster relief and intermodal freight.

SESSIONS & WORKSHOPS

(continued)

1 Kenneth Ned Mitchell, U.S. Army Corps of Engineers, discusses automatic identification system tools used in transportation.

2 K. Jane Williams, Federal Transit Administration, presides over a panel discussion on innovations in the public transportation life cycle.

3 Heidi King, National Highway Traffic Safety Administration, leads conversation on the current pace of innovation, industry convergence, and technological change.

4 Julie Lorenz, Burns and McDonnell Engineering Company, heads a spotlight session on real-time decision making.

5 Scott Kuznicki, Transpo Group, shares aerial footage of traffic congestion in Oregon during the 2017 total solar eclipse.

6 Tony Seba, RethinkX, offers starting points for connected and automated vehicle planning.

7 The TRB Planning and Environment Group created the Communicating with John and Jane Public Competition in 2007 to highlight the value and importance of involving the public.

8 Adam Hand, University of Nevada, Reno, presents a case study of a contractor's best practices in a session focused on quality assurance.

9 Darcel Collins, FHWA, examines the status of tribal safety data.

10 Somayeh Nassiri, Washington State University, examines enhancing mechanical properties of pervious concrete using carbon fiber composite reinforcement.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7 Communicating with John and Jane Public Competition winners (*left to right*): Josh Pearson, Minnesota DOT; Ted Ritter, North Jersey Transportation Planning Authority; Miriam Salerno, Rutgers University; Lugene Keys, McCormick Taylor, Inc.; Natalie Stiffler, City of Boulder; and Jessica Clark, Pennsylvania DOT.


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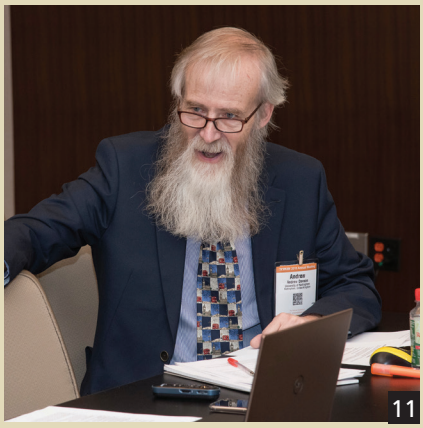


COMMITTEE MEETINGS

1 Concrete Materials and Placement Techniques Committee chair Mark Felag (*left*) and Concrete Materials Section chair Mohammad Khan deliver section updates.

2 Elizabeth Rushley, Transportation System Policy, Planning, and Process Section chair, participates in a networking session for committee leaders.

3 Nancy McGuckin, Travel Behavior Associates, offers comments in a committee meeting.

4 Jacek Pawlak, Imperial College London, engages with committee members on technologies in travel.

5 Yu Zhang, University of South Florida, chairs the Airfield and Airspace Capacity and Delay Committee.

6 Georgene Geary, Georgia Institute of Technology, guides discussion in the Design and Rehabilitation of Concrete Pavements Committee.

7 Fred Wagner, Venable LLP, presides over a meeting of the Legal Resources Group Executive Board.

8 Judy Rochat, Transportation-Related Noise and Vibration Committee, solicits webinar ideas.

9 Robert Hazlett guides the agenda of the Metropolitan Policy, Planning, and Processes Committee.

10 Scott Babcock, TRB, delivers an update on Board activities at a meeting of the Urban Freight Transportation Committee.

11 Andrew Dawson chairs the Aggregates committee.

COMMITTEE MEETINGS

(continued)

1 Stuart Anderson (*second from left*) receives emeritus membership for his contributions to the Construction Management Committee. Presented by (*left to right*) group chair Tom Kazmierowski, committee chair Paul Goodrum, and Nelson Gibson, TRB.

2 Christine Carrigan presides over the Roadside Safety Data Needs and Applications Committee meeting.

3 Sougata Roy leads the discussion on research needs statements for the Fabrication and Inspection of Metal Structures Committee.

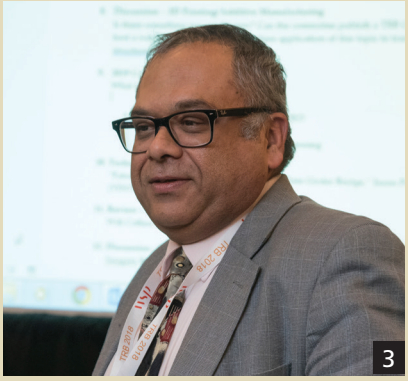
4 Ashley Wiand delivers a presentation on ASTM at a meeting of the Basic Research and Emerging Technologies Related to Concrete Committee.

5 Domenic Coletti receives the TRB Blue Ribbon Award for his committee's work generating research needs statements for and disseminating the results of high-quality research projects.

Volunteer Leaders Recognized with Emeritus Status

The following individuals received emeritus membership in TRB at the 2018 Annual Meeting for their long-term contributions and exceptional service to TRB's standing committees:

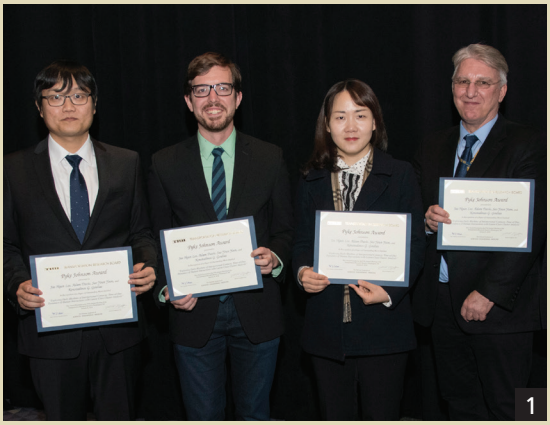
- Stuart Anderson, Construction Management Committee;
- Joseph Bryan, Urban Freight Transportation Committee;
- Curtis Clabaugh, Geospatial Data Acquisition Technologies Committee;
- James Crites, Airfield and Airspace Capacity and Delay Committee;
- Alan Danaher, Transit Capacity and Quality of Service Committee;
- Joseph Demko, Roadside Maintenance Committee;
- Mohamed Elfino, Subsurface Drainage Committee;
- Karl Frank, Steel Bridges Committee;
- Brendon Hemily, Public Transportation Planning and Development Committee;
- Edward Kussy, Legal Resources Group;
- D. Stephen Lane, Aggregates Committee;
- Anne Morris, Environmental Justice in Transportation Committee;
- Robert Peskin, Transit Management and Performance Committee;
- Donald Streeter, Concrete Materials and Placement Techniques Committee;
- Paul Thompson, Bridge Management Committee;
- Samuel Tignor, User Information Systems Committee; and
- Ronald Van Houten, Pedestrians Committee.



Committee Leadership Awards

The Technical Activities Council presented Blue Ribbon Awards, recognizing committees for exemplary best practices and volunteer efforts:

- Community Building and Mentoring: Logistics of Disaster Response and Business Continuity Committee, chaired by Anne Strauss-Wieder; Traffic Control Devices Committee, chaired by Paul Carlson.
- Advancing Research: Steel Bridges Committee, chaired by Domenic Coletti.
- Contributing to TRB and the Transportation Community: Intermodal Freight Transportation Committee, chaired by Richard Easley; International Cooperation Committee (honorable mention), chaired by O. A. Elrahman and George Giannopoulos.
- Communications: Roadside Maintenance Operations Committee, chaired by John Rowen; Technology Transfer Committee, chaired by Patrick Casey.



PAPER AWARDS

1 Pyke Johnson Award for planning and environment (*left to right*): Jay Hyun Lee and Adam Davis, University of California (UC), Santa Barbara; Seo You-Yoon, Korea Research Institute for Human Settlements; and Konstadinos Goulias, UC Santa Barbara.

2 K. B. Woods Award for design and construction (*left to right*): Thomas Enrico Fletcher, AECOM; Theuns Henning, University of Auckland, New Zealand; Petrus Gerhardus van Blerk, New Zealand Transport Agency; and Seosamh Costello, University of Auckland.

3 D. Grant Mickle Award for operations and preservation (*left to right*): Anthony J. DePrator, Owen Hitchcock, and Vikash V. Gayah, Penn State University.

4 William W. Millar Award for public transportation: James Pritchard, University of Southampton (*left*), and Millar, past president of APTA.

5-8 The Fred Burggraf Award is given to researchers age 35 or younger.

5 For operations and preservation (*left to right*): Kan Wu, S. Ilgin Guler, and Vikash V. Gaya, Penn State University.

6 For public transportation (*left to right*): Rachel Beer, Jennifer Viscardi, Subrina Rahman, and Candace Brakewood, City College of New York.

7 For freight systems: Chris Bachmann, University of Waterloo, Ontario.

8 For planning and environment: Calvin Thigpen (*left*) and Kevin Fang, UC Davis.

9 John C. Vance Award for legal resources: Dorothy Glancy, Santa Clara University Law School.

10 Charley V. Wootan Award: William T. Scherer (*left*) and Michael C. Smith, University of Virginia.

MAJOR AWARDS

1 The Sharon D. Banks Award for Humanitarian Leadership in Transportation was presented to William W. Millar (*second from left*) by TRB Executive Director Neil Pedersen (*left*), 2017 Executive Committee Vice Chair Katie Turnbull, and 2017 Executive Committee Chair Malcolm Dougherty.

2 The W. N. Carey, Jr., Distinguished Service Award was presented to Michael Trentacoste (*second from left*).

3 For her career contributions and achievements, Patricia Mokhtarian, Georgia Institute of Technology, received the Thomas B. Deen Distinguished Lecture Award.

4 Susan A. Shaheen (*center*) received the Roy W. Crum Distinguished Service Award from (*left to right*) Neil Pedersen, Daniel Sperling, Malcolm Dougherty, and Katie Turnbull.

5 The premier event of the Annual Meeting, the Chairman's Luncheon is a longstanding TRB tradition.

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5 James Ray, U.S. DOT, offers insights on transportation and infrastructure policy at the Chairman's Luncheon.

EXECUTIVE COMMITTEE

The TRB Executive Committee policy session focused on public transportation, with a panel of experts including (*left to right:*)

6 Steven Polzin, Center for Urban Transportation Research, University of South Florida;

7 Susan Shaheen; and

8 Randy Clarke, American Public Transportation Association.

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New Leaders Guide Executive Committee

Katherine F. Turnbull, Executive Associate Director, Texas A&M Transportation Institute (TTI), is 2018 Chair of the TRB Executive Committee. At TTI, Turnbull manages the Environment and Planning Research Group and directs many research initiatives. She is recognized nationally for her work in performance measurement and assessment of high-occupancy vehicle and toll facilities, intelligent transportation systems technologies, and innovative transit service in national parks and public lands.

A tireless TRB volunteer for nearly 30 years, Turnbull has served as member and chair of more than two dozen councils, groups, sections, committees, panels, and task forces. As chair of the Technical Activities Council from 2011 to 2013, she helped launch the Young Members Council and the Blue Ribbon Committee awards program, and implemented a research agenda focus for TRB's standing committees. In 2015, she received the W. N. Carey, Jr., Distinguished Service Award from TRB.

Turnbull is a native of Minnesota and holds bachelor's degrees in political science and history from the University of Minnesota, Duluth; a master's degree in urban studies from the University of Wisconsin, Milwaukee; and a Ph.D. from Texas A&M University.

Victoria A. Arroyo, Executive Director, Georgetown Climate Center (GCC), and Professor and Assistant Dean of Centers and Institutes, Georgetown Law, is 2018 Executive Committee Vice Chair. Arroyo supervises GCC's work in climate and energy policy and on climate migration and adaptation. She also teaches environmental law and has taught courses on environmental policy and climate change at Catholic University, George Mason University, and Tulane Law School. Arroyo has served on several federal panels related to climate change legislation and adaptation.

Arroyo received a bachelor's degree in biology and philosophy from Emory University, a Master of Public Administration degree from Harvard, and a J.D. from Georgetown Law.

Newly appointed members include Ginger S. Evans, Chicago Department of Aviation, and Leslie S. Richards, Pennsylvania Department of Transportation (DOT). Reappointed to the Executive Committee are Chris T. Hendrickson, Carnegie Mellon University; Roger B. Huff, HGLC, LLC; Geraldine Knatz, University of Southern California; James P. Redeker, Connecticut DOT; Mark L. Rosenberg, The Task Force for Global Health, Inc.; and Daniel Sperling, University of California, Davis, Institute of Transportation Studies.

EXECUTIVE COMMITTEE

(continued)

New and reappointed Executive Committee members include (*left to right:*)

1 Ginger Evans, Chicago Department of Aviation;

2 Roger Huff, HGLC, LLC;

3 Geraldine Knatz, University of Southern California; and

4 Chris Hendrickson, Carnegie Mellon University.

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EXECUTIVE COMMITTEE

(continued)

1 Katie Turnbull, 2017 Executive Committee Vice Chair, addresses TRB initiatives.

2 Victoria Arroyo participates in Executive Committee discussions. She holds the post of Vice Chair for 2018.

3 Malcolm Dougherty, 2017 Executive Committee Chair, presents information on research focus areas for TRB.

4 As Division Committee Chair, Susan Hanson guides TRB's report review and committee and panel appointments.

Also participating in Executive Committee deliberations were

5 Pat Thomas, United Parcel Service;

6 Audrey Farley, Office of the Assistant Secretary for Research and Technology;

7 Mark Buzby, Maritime Administration;

8 Karl Simon, U.S. Environmental Protection Agency;

9 Bevan Kirley, University of North Carolina Highway Safety Research Center;

10 Nathaniel Ford, Jacksonville Transportation Authority;

11 Charles Zelle, Minnesota DOT;

12 Brandye Hendrickson, FHWA;

13 Jack Hu, University of Michigan, Ann Arbor; and

14 Michael Berube, U.S. Department of Energy.


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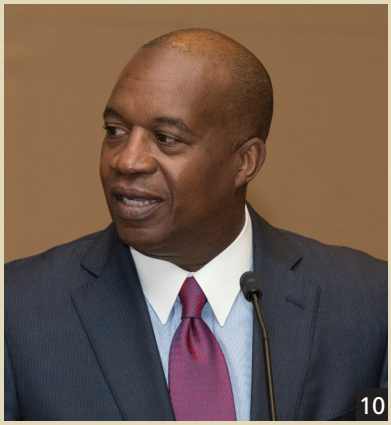
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Photo: Virgin Hyperloop One

A Look Inside a New Mode

Virgin Hyperloop One

DIANA ZHOU

The author is Market Strategy Manager, Hyperloop One, Los Angeles, California.

DevLoop site in Nevada, a 500-m complete system test track.

Irfan Usman, Virgin Hyperloop One Senior Levitation Design Engineer, bent over the test rig, adjusting the cables and checking the sensors before turning on the system. A giant machine whirred to life, lifting a heavy piece of metal up to its counterpart component under the force of an unseen power. The piece of metal slid back down again gently and a room full of engineers cheered—it was the birth of the highest-performance transportation magnetic levitation system in history. It did not happen in a well-funded national research lab or in the research department of a major Fortune 500 company, but in an old industrial ice factory repurposed into the offices of a start-up in the Arts District of Los Angeles.

In 2014, the hyperloop was an idea, a series of obscure equations sketched on a whiteboard in a garage, unintelligible to all except for rocket scientists. Elon Musk had recently published "Hyperloop Alpha," a white paper in which he outlined the technical components of a new mode of transportation that was faster, greener, and more energy-efficient than any existing mode—the hyperloop.[1] This idea captured the imagination of many futurists, technologists, and transport officials; shortly after Musk published his paper, Virgin Hyperloop One—then called Hyperloop Technologies—was founded. Three years later, Virgin

[1] www.spacex.com/sites/spacex/files/hyperloop_alpha-20130812.pdf.

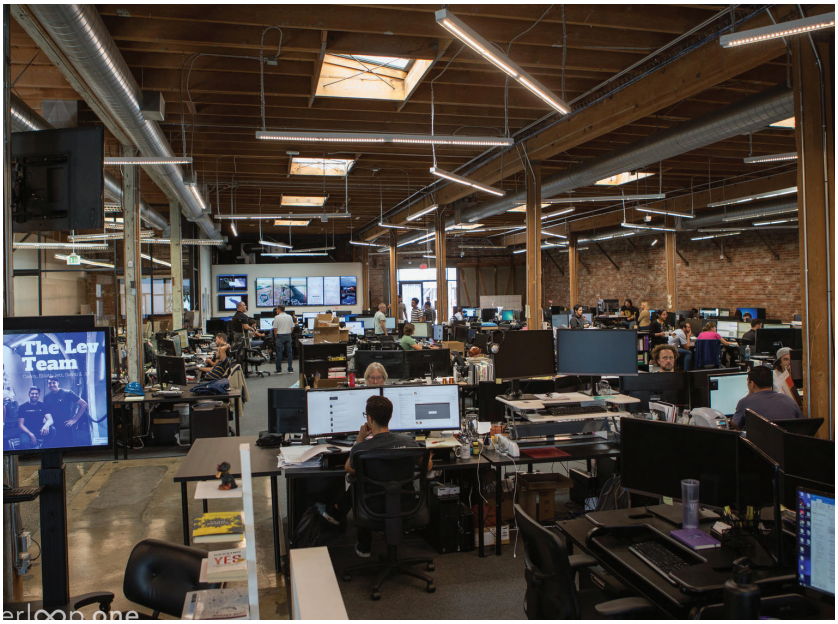


Photo: Virgin Hyperloop One

Design engineers at Virgin Hyperloop One's headquarters.

Hyperloop One built the world's first full-scale, full-system hyperloop test track.

How did it happen in such a short time? Rapid prototyping—the development and testing of components early in the design process to understand how materials work in practice—is a key design principle at the company, ingrained in each engineer when they join and emphasized in the spatial layout of the office. The Test and Development Center is located next to the offices of the company's design engineers, separated only by a coffee bar.

Once the design engineers designed the components and confirmed that they worked in theory, experienced welders and technicians built to the design specifications, making sure that the components worked as the math had predicted. This joint effort is driven by the recognition that builders and tradespeople are just as important as the designers. The principle of rapid designing, building, testing, and redesign was key to the ability to develop parts rapidly and to learn from early mistakes.

Early rendering of the hyperloop pod, with the air bearings and compressor in front.

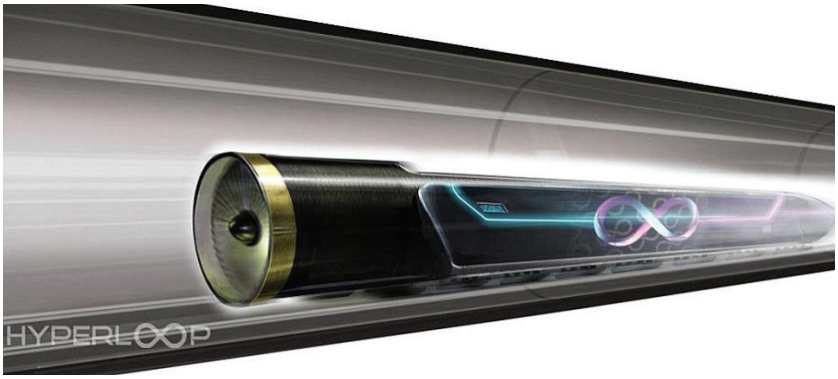


Photo: Virgin Hyperloop One

One critical component of the technology proposed in the "Hyperloop Alpha" white paper was the usage of air bearings to levitate the pod. According to Musk, "air bearings, which use the same basic principle as an air hockey table, have been demonstrated to work at speeds of Mach 1.1 with very low friction." Air bearings are known to be energy efficient and to have high performance.

Testing in a Vacuum

In June 2015, Hyperloop Technologies ordered an autoclave, a piece of equipment similar to a giant pressure cooker. Autoclaves commonly are used for a multitude of industrial purposes, including curing aerospace parts and other types of composites. In this case, however, the purpose of the autoclave was to create a near-vacuum environment to test levitation. A small team of engineers carefully built and installed a levitation rig—a device used to simulate levitation in a vacuum—within the autoclave. The specifications outlined in Musk's white paper were carefully measured out, built, and tested.

The results were depressing. It quickly became apparent that an enormous amount of power was needed to compress air in a partial vacuum to fuel the air bearings. Contrary to what was proposed in the white paper, this design was neither energy-efficient nor cost-effective. The air gap between the tube-shaped track structure and the bottom of the pod was extremely small; therefore, the dimensional tolerances required of the entire system were extremely high. This meant that the track needed to be nearly perfectly aligned, making it difficult to account for expansions or contractions due to temperature or other factors. For example, a hot day might cause the track to fall out of alignment. Heavy maintenance would be required, and the costs of installing and maintaining a track with such high-tolerance requirements would be massive.

Switching Tracks

The vacuum test quickly led to the decision to move from air bearings to magnetic levitation. This was a fundamental shift in the design of the modern Virgin Hyperloop One system. The air compressor—the fan seen at the front of the pod in many early renderings of the hyperloop system—also was discarded. Without air bearings, the need to reduce the air at the front of the pod and improve aerodynamic drag in a near-vacuum environment was minimal.

Magnetic levitation is a well-known and tested technology that has been on the market for more than 30 years. The Levitation, Power Electronics, and Test and Development teams at Virgin Hyperloop One spent months designing the ultimate mag-

netic levitation system. The team experimented with different types of track, composed of materials ranging from the commonplace—steel and aluminum—to the sophisticated, such as superconductors.

Researchers experimented with different electrical currents and various rig configurations. The specifications were clear: the system needed to have similar levitation properties as air bearings, but with a higher ride height and a design to tolerate larger variances in gap. The team at Virgin Hyperloop One understood how the technology worked, but needed to make it better—that is, cheaper and easier to implement.

Rapid prototyping allowed the team to pivot quickly from a theoretically correct but impractical design for a key component of the system to one that performed better in practice. For a new start-up with vast ambitions, it was important to focus the design process. The more focused the process was, the less money was wasted and the less time was spent on designs that ultimately would be scrapped.

Full-Scale Testing

In May 2017, Hyperloop One ran its first full-system test on its DevLoop system, a 500-m test track in the Nevada desert approximately 40 mi outside of Las Vegas. DevLoop is short for "Development Loop," the first functioning hyperloop system in the world, complete with power electronics, an autonomous pod, motor control and braking systems, levitation track, guidance systems, and more than 1,100 tons of steel and concrete. The vacuum pumps reduced the air in the tube to 100 pascals, or approximately 1/1,000 standard atmospheric pressure.

On July 29, 2017, Phase 2 testing was complete. XP-1, the only vehicle in the world that can achieve autonomous high-speed propulsion and levitation in a vacuum environment, accelerated from zero to 192 mph and back to zero mph again over a distance of less than 500 m. Acceleration g-forces hit nearly 1.48—the equivalent of going from zero to 60 mph in 1.85 s. This marked a momentous occasion in the company's history and was a testament to the team that put it all together in just three years.

Less than five months later, XP-1 achieved even faster speeds. The company also tested a new airlock system to transition test pods between atmospheric and vacuum conditions. On December 15, 2017, Virgin Hyperloop One set a test-speed record during its Phase 3 testing at DevLoop: nearly 240 mph.

Yet despite its achievements, critiques of DevLoop included the following: "It doesn't go as fast as they said it would," "it's not as big as they said it would be," and "it can't carry passengers." DevLoop was never meant to carry passengers or test pods at 700 mph, the hyperloop design speed, however. The DevLoop design was purposeful and meaningful: to test as much as it could as cheaply and as quickly as possible, and to stress test the integration of the system without overengineering the entire system.

For example, the tube track was built smaller than the size required for production—3.3 m rather than 4–5 m—but the smaller size meant that the tube was big enough to stress-test the welds between tube segments and the system's structural stability without spending more than necessary on steel or supporting columns. Although the tube was not long enough to allow the pod to reach its full speed of 700 mph, DevLoop ensured that all the components functioned together as theoretically designed—and that ultimately achieving 700-mph speeds would be only a matter of distance.

As these technology milestones were reached,

Photo: Virgin Hyperloop One

Test and development area at the Virgin Hyperloop One headquarters.

Photo: Virgin Hyperloop One

The XP-1 pod at the Nevada site.

Photo: Thomas Hawk, Flickr

Elon Musk has open-sourced his hyperloop concept for others to design and develop.

Virgin Hyperloop One moved toward commercialization, focusing on developing markets.

Global Challenge

During the unveiling of the hyperloop's propulsion system in May 2016, Virgin Hyperloop One launched the Hyperloop One Global Challenge to gather feedback from customers and stakeholders as to where the first routes should be built.

The results of the Global Challenge far exceeded expectations. Proposals were received from 25 countries. Of these, the company selected 35 semifinalists—including 20 that had strong governmental support—and announced the ten winning routes in September 2017. The company also launched global events in Delhi, India; Amsterdam, Netherlands; and Washington, D.C., bringing together major government stakeholders and private-sector representatives to discuss the future of transportation. The Global Challenge results demonstrated how quickly public and private sectors could come together to make hyperloop systems a reality around the world.

The ten winning routes were judged based on a few factors: ease of construction, a compelling business case, a favorable regulatory environment, and strong political support. Considered were the following questions:

- Would there be any technically challenging hurdles in the construction of a hyperloop along this corridor?
- Is there sufficient ridership and demand to justify the construction and operations of a new transportation corridor?
- Is there strong and sufficient political support?
- Is this an organization that can move quickly in bringing both private and public stakeholders together?

RoadX in Colorado

One of the most impressive applications, spearheaded by then-Executive Director Shailen Bhatt, was submitted by the Colorado Department of Transportation (DOT). In April, Bhatt and his team traveled to Washington, D.C., for the Hyperloop One Vision for America event. The Rocky Mountain Hyperloop team included a diverse group of stakeholders in addition to Colorado DOT: RoadX, a relatively new agency within the DOT that evaluates and implements such new technologies as autonomous cars and truck platooning; the High-Performance Transportation Enterprise, which develops innovative means to finance new technologies; Denver International Airport, which saw in the hyperloop project the potential for development of an aerotropolis; and the global engineering firm AECOM. The team saw a clear vision in what hyperloop could bring to the state of Colorado: a remedy to congestion stemming from a system built nearly 70 years ago.

"Colorado's transportation network was planned in the 1950s and built in the 1960s for the population of the 1980s," Bhatt observes.

Photo: Hobble Caldwell, Flickr

Colorado Department of Transportation's (DOT's) RoadX, an agency focused on new technologies, submitted a hyperloop proposal to the Hyperloop One Global Challenge. Among the goals of a hyperloop system in Colorado would be to decrease rural highway fatalities.

By 1990, Colorado's population had reached 3 million; today, the state's population is 5.3 million and is expected to grow to 8 million over the next 20 years as new residents are drawn to the state for its jobs and famed outdoor lifestyle. "I can't build my way out of the current congestion, let alone the congestion that will come," Bhatt commented in a recent article in *Wired* magazine.[2]

"Hyperloop technology directly aligns with our goals of reducing the cost of transporting goods, of turning rural state highways into zero-death roads, and of decreasing congestion within Colorado's critical corridors," notes Bhatt.[3]

In October, under the umbrella of the RoadX program, Hyperloop One embarked on a nine-month-long feasibility study with Colorado DOT, AECOM, and several other transportation agencies in the state to assess potential routes from both a technical feasibility perspective and a commercial perspective. Working together, the organizations provided a framework to evaluate, implement, and finance new technologies like the hyperloop.

Road to Tomorrow in Missouri

Missouri DOT was named one of the finalist teams in the Hyperloop One Global Challenge. In October 2017, Missouri DOT, the St. Louis Regional Chamber, the Kansas City Tech Council, the University of Missouri System, and the Missouri Innovation Center in Columbia, formed a public–private partnership called the Missouri Hyperloop Coalition to advance a hyperloop project connecting St. Louis and Kansas City via Columbia along the I-70 corridor.

The proposal envisioned using the I-70 corridor to facilitate travel between the two largest cities in the state in less than half an hour, effectively creating an economic superregion. On January 30, the Missouri Hyperloop Coalition announced an agreement to move forward on a seven- to nine-month feasibility study with the global engineering firm Black & Veatch and Virgin Hyperloop One.

Similar to Colorado DOT's RoadX program, Missouri DOT's Road to Tomorrow program assesses new business opportunities in innovative technologies for Missouri. Tom Blair, who leads the program in St. Louis, pulled together a team of members from St. Louis and Kansas City to work collaboratively to deliver Missouri DOT's proposal to the Global Challenge.

[2] www.wired.com/2017/04/cities-crave-hyperloop-shiny-talk-cheap.

[3] www.codot.gov/news/2017-news/january/cdot-announces-colorado-selected-as-hyperloop-one-global-challenge-semifinalist.

PHOTO: CAMERA_OBSCURA, FLICKR

According to the Rocky Mountain Hyperloop team, the technology could ease congestion on Colorado's highways.

Route Forward

These feasibility studies—along with several more to be announced in coming months—are the beginning of a journey to make the hyperloop a reality in the United States. As with any transportation or infrastructure project, careful and deliberate analysis of the route economics, environmental impacts, and other factors are required before the project can progress to subsequent phases.

If the outcome of these studies is favorable, the project then will move to a longer and more involved environmental impact study or assessment, in which the corridor and impacts on neighboring communities will be examined in greater detail. These studies provide the information required to allow a project sponsor to move forward with a project, to secure sufficient funding from private or public sources, and obtain approvals to begin construction. Compared with the permitting, approvals, and regulatory process, developing the technology to create the first new mode of transportation in more than 100 years almost looks easy.

Public agencies and private companies collaborated on a proposal to build a hyperloop project along the I-70 corridor in Missouri.

PHOTO: DOUG KERR, FLICKR

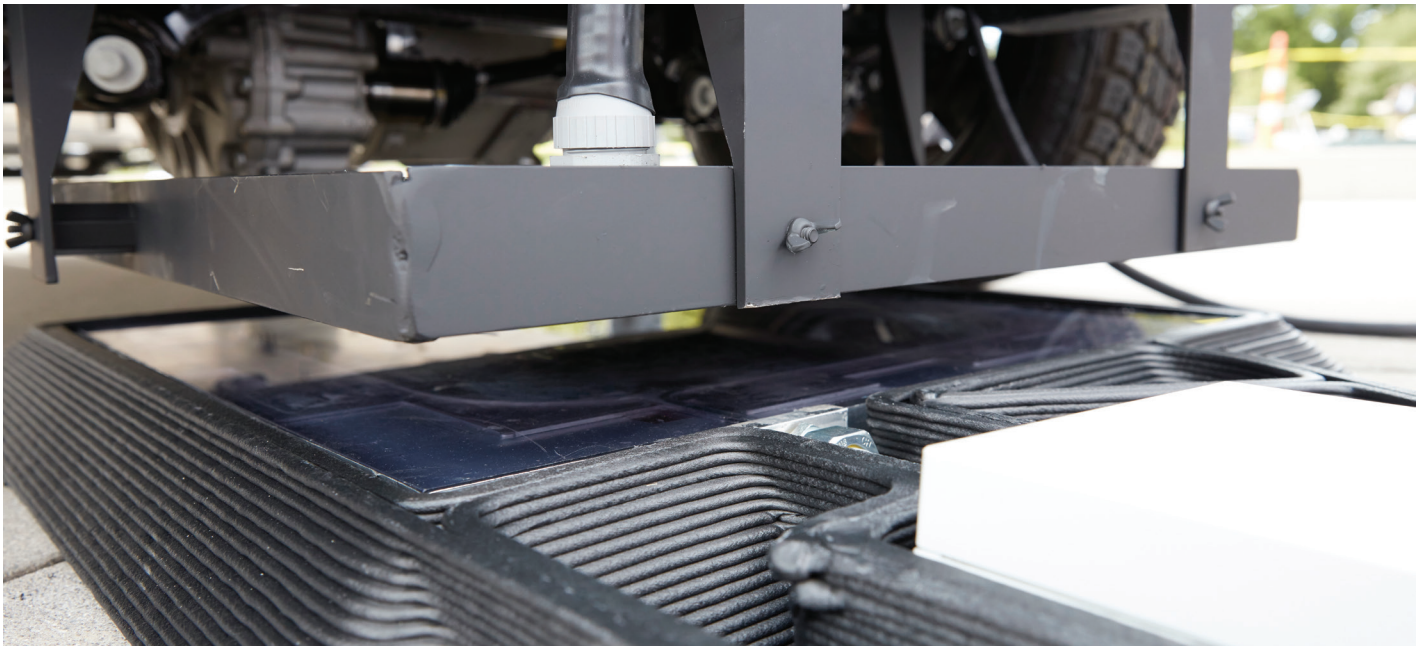


Photo: Oak Ridge National Laboratory

3-D Printing in Transportation

Already in Action

MOHAMMAD S. KHAN

The author is Executive Vice President, High Performance Technologies, Inc., Bethesda, Maryland, and chair of the TRB Concrete Materials Section.

In essence, 3-D printing—or additive manufacturing—is layer-by-layer creation. Several construction methods already in use deploy additive manufacturing techniques.

With its origins in automated and robotic construction, 3-D printing is not new to the construction industry. The 3-D printer consists of a mobile or stationary system with several robotic subsystems or components; construction materials such as concrete, mortar, and asphalt serve as the "ink." On a desktop printer, a digital image is sent through a computer to be printed on a piece of paper; in construction, a digital model is sent to the printer to create an object at, above, or below the surface of the ground. For the purposes of this article, 3-D printing is defined as follows: "Transforming an imagination of a facility, in whole or in part, depicted through a computer model, into a real facility—bridges, highways, buildings, and more—with as little human involvement and as much conservation of natural resources as possible."

Interdisciplinary and Multidisciplinary

3-D printing in construction is highly interdisciplinary and multidisciplinary. It starts in the imagination of an architect, traverses the inquisitive mind of a designer, challenges the ingenuity and innovation of materials scientists, and forces often-traditional construction practitioners to think and act differently—all with the support of electrical, electronics, and computer engineers and scientists in hardware and software (Figure 1, above). Expertise can come from academia; research institutions; engineering, design, and construction organizations, both public and private; and professional and scientific associations and societies.

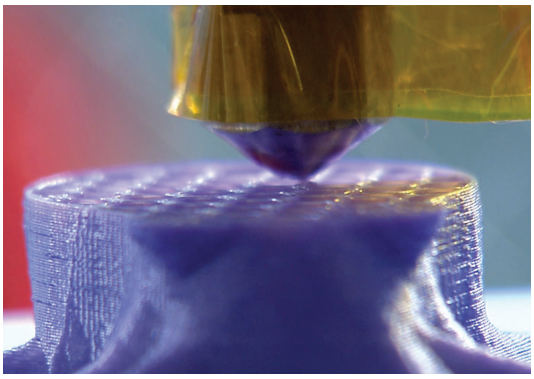


FIGURE 1 Illustrative 3-D printing. (Source: National Science Foundation.)

A unique feature of 3-D printing in construction compared with traditional construction is that different disciplines and varieties of expertise come

into play much earlier in the process—primarily during the manufacturing of the 3-D printer and formulation of the ink. Once the printer is built and the ink is prepared, the automated process can easily be conducted by regular operators.

3-D Techniques in Use

Of the many synonyms for 3-D printing in construction, the most commonly used is "additive manufacturing," which is derived from the aerospace, automobile, biomedical, energy, consumer goods, and other industries. In general, 3-D printing is an automated process of addition, or layer-by-layer creation—similar to rock formation—as opposed to progressively removing materials from a large mass to create a smaller mass of desired size and shape, as in sculpture and the creation of most industrial products. Other synonyms include "layered manufacturing," "free-form fabrication," and "digital manufacturing" (*1*).

Unlike in other industries, the construction of buildings, bridges, highways, airport runways, marine structures, and other facilities traditionally has involved an additive, or layered, manufacturing process—one that traditionally has been manual and labor-intensive. Because construction and manufacturing have operated as separate industries, however, the existence of additive processes in construction has not been widely recognized by other industries.

Slip-Form Construction

Even in the case of automation of additive and layered construction processes, the concept is not new. For example, the use of slip-forming techniques in construction began in the early twentieth century; since then, these processes have been used to construct concrete towers, tanks, high-rise buildings, Interstate highways, runways, and other facilities in which traditional construction techniques would have been too difficult or time-consuming.

In slip-form construction, the formwork is mechanized to move automatically in a vertical or horizontal direction as the material is deposited continuously in layers. Slip-form construction also can be used cost-effectively and safely to construct tall bridge pier columns and abutments.

A recent example of slip-form construction is the 2016 expansion of an airport runway using 3-D automated machine guidance via a digital model, equipment sensors, and GPS. Located at the Fort Lauderdale–Hollywood International Airport in Broward County, Florida, the runway is 16.5 in. thick and 2,700 ft long, and the construction technique easily could have been labeled 3-D printing.

Photo: ITB495, Flickr

In Indiana, slipform technology is used to construct a concrete wall barrier on a newly widened highway.

Photo: DSM

3-D printing is multidisciplinary and draws upon the creativity and expertise of architects, designers, material scientists, and engineers.

Photo: MTA Capital Construction Mega Project, Flickr

Workers use shotcreting techniques to cover steel ribs in a tunnel under construction in New York City.

titious composites have been developed for such applications (*3*), and robotic machines to help automate the shotcreting process have been available for quite some time.

Shotcreting

Shotcreting is another example of additive manufacturing in construction; like slip-form construction, it is a century-old technique. In shotcreting, the concrete is conveyed through a hose to a nozzle, then applied under pneumatic pressure to a surface, layer by layer. In dry shotcreting, water is added to the dry concrete mix at the nozzle of the hose, and the mixing and compaction of the concrete takes place at the applied surface. In wet shotcreting, the fluid concrete mixture—including water and any other admixtures—is pumped through the hose to the nozzle and applied pneumatically to the surface.

Shotcreting is used both in new construction and in the repair or rehabilitation of existing facilities, including extensively in tunnels (*2*). Specialty concrete mixes and fibers called engineered cementitious composites have been developed for such applications (*3*), and robotic machines to help automate the shotcreting process have been available for quite some time.

Other Techniques

Other examples of additive manufacturing in construction—with varying levels of automation—include robotic bricklaying and the prefabrication of concrete elements at plants and assembly at construction sites. The construction of bridges using these prefabricated units can be completed in a few days; the process is known popularly as accelerated bridge construction (ABC) (*4*).

The next steps for 3-D printing in construction involve automation; that is, the process is not automated to the level to which other industries have advanced. The sheer magnitude and size of construction projects, in conjunction with stringent safety requirements, contributes to the slow pace of automation. Furthermore, every construction project and resulting facility is unique; a cookie-cutter approach generally is not applicable.

Evolution of the Technology

The automation of construction advanced slowly during the Industrial Revolution but gained momentum in the 1950s. Any new piece of construction equipment or its improvement was a contribution to the automation process. Also in this period, modern-day robotics gained momentum and the concept permeated all the industries—including construction. These efforts in automation were facilitated by advances in computer and information technology in the final quarter of the twentieth century and continue today. Automation of construction technologies

Photo: Aaron Vorkening, Flickr

Shotcreting was used to repair a bridge over the Donges Bay Gorge in Wisconsin.

like shotcreting and slip-form construction improved and matured during this time.

In mid-1980s, 3-D printing gained popularity in such industries as biomedical and industrial manufacturing. Commercial 3-D printers became available, allowing people to transform digital images into a solid 3-D object via a computer. Initially, these 3-D printers were limited to producing small objects but research and development efforts later led to the production of objects as large as an automobile. People also likely started thinking about construction along the lines of 3-D printing in other industries—essentially imagining the transformation of a model or digital image into a constructed facility with the push of a "print" button.

The mid-1990s brought about contour crafting technology, which could be termed modern-day additive manufacturing in construction. This technology was patented in 2010 (*5*). Contour crafting technology initially started as a ceramic paste extrusion method (*6*), but later was expanded to cementitious materials to create large-scale structural elements—even an entire facility, or "printed building." One of the main differences between contour crafting and shotcreting is that in contour crafting, the concrete from the nozzle is not applied to the receiving surface at a high pneumatic pressure; rather, the material is extruded with a piston-pump type of mechanism similar to a syringe.

During the same time period, another additive manufacturing technique was introduced. Selective aggregation involved laying down a matrix of sand, or silica, followed by selective deposition of cement on the sand matrix and activation of the cement binder using steam. The process resulted in a strong, dense material and could be automated with computer-aided drafting and analytical modeling tools (*7*).

In the first decade of the twenty-first century, freeform construction, or concrete printing, came to attention. The process is similar to contour crafting, with some differences in the design of the extrusion nozzle; it focused on upscaling additive manufacturing in terms of large-scale structural elements. The technology also added functionality to such structural components as acoustic, thermal, and ventilation (*8*, *9*).

Photo: C Watts, Flickr

A car constructed with 3-D printing technology by the Jefferson Lab in Newport News, Virginia.

Impacts of 3-D Printing in Transportation

Construction is one component of transportation; however, the transportation industry is multifaceted and multimodal, affecting individuals; businesses; and local, regional, national, and global economies. Transportation keeps people, goods, and services connected and moving—therefore, other industries rely heavily upon a safe, efficient, economical, and well-connected transportation system.

3-D printing in industries like manufacturing will have much more widespread and far-reaching impacts on the transportation industry than 3-D printing in construction alone.

In simple terms, 3-D printing means more machine involvement and less human involvement, as well as the capability to create products in any configuration and at any time and place. This would transform the balance of the movement and consumption of ingredient materials versus finished products.

The impacts of general 3-D printing or additive manufacturing in transportation could include the following:

- Freight movement
- Air transport
- Marine transport
- Rail transport
- Space explorations
- Energy efficiency and sufficiency
- Safety and security
- Sustainability
- Education and workforce development
- Training and retraining
- Policies, regulations, and deregulations

Photo: MX3DD

A steel pedestrian bridge is constructed over a canal in Amsterdam using 3-D printing, robotics, and welding.

Since 2010, additive manufacturing has extended beyond cementitious materials to include large volumes of engineered wax, created using automated processes to make reusable molds or forms (*10*). Integrated robotic and welding technologies also are being used in the manufacture of steel structures, as is demonstrated in the 3-D printing construction of a pedestrian steel bridge over a canal in Amsterdam, Netherlands.

Present Status

Approximately 25 years into the development of modern-day 3-D printing in construction, some advances have been made; however, the media hype is greater than actual accomplishments. Credit is due to those inspired by 3-D printing in the manufacturing industry for their efforts in bringing the concept to the construction industry, but the process is still at the beginning of a long journey.

In order to understand 3-D printing in construction, it is important to differentiate between the process and the equipment of 3-D printing. Although there are many different types of 3-D printing equipment, only two types of 3-D printing processes involving cementitious materials are under development: extrusion-based 3-D printing and 3-D printing based on selective aggregation, or binder jetting.

These processes take time, however. The technological readiness level has not reached the point at which the push of a button can build a whole house, but it is possible to deploy 3-D printing to create the components of these houses in a factory and then to assemble them onsite, as in ABC technology. Prefabricated bridge element systems are transported to a site and assembled and connected in a matter of days (*11*). The self-propelled modular transporter, also in commercial use for many years, can move large bridge elements in or out of a construction site in mere hours with minimal disruption to traffic (*12*).

A demonstration project by the Oak Ridge National Laboratory (ORNL) best depicts the current state of the art of 3-D printing in construction: a small house has been created using panels of polymeric materials printed in the laboratory. The house is connected remotely to a vehicle—also printed in the laboratory—and both the house and the vehicle power each other (Figure 2, below). Researchers at ORNL also show a timeline for progress in big-area additive manufacturing using free-form construction, from a prototype system with a build volume of 7 × 7 × 5 ft in January 2013 to a build volume of 7 × 13 × 8 ft in March 2017; the deposition rate increased from 10 lb/hr to 100 lb/hr during this time (*13*). ORNL has collaborated with private and public organizations, including the U.S. Army Corps of Engineers Construction Engineering Research Laboratory, in these development efforts.

Challenges

One of the major challenges related to any emerging technology, including 3-D printing in construction, is

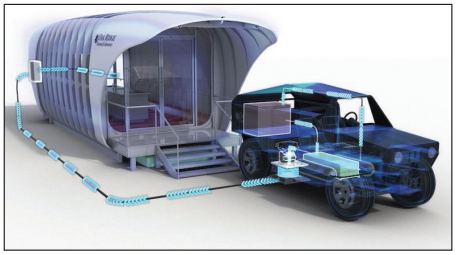
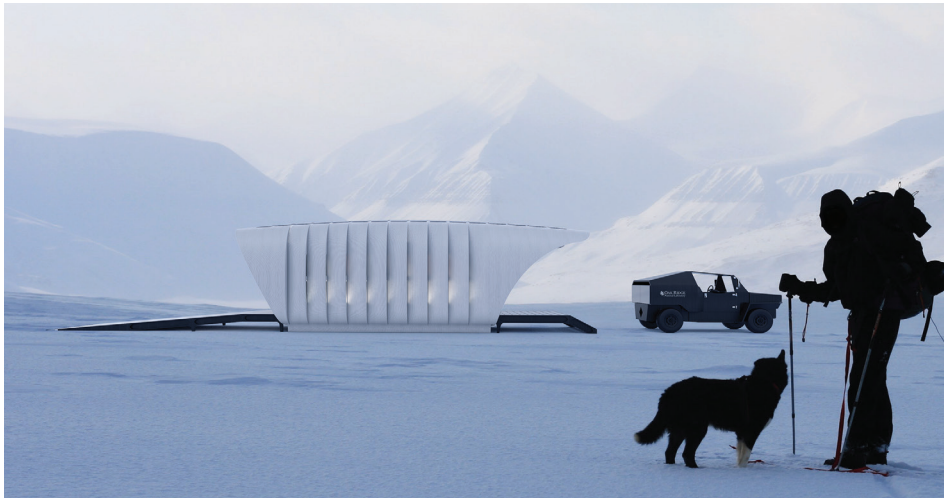


FIGURE 2 Demonstration 3-D printed house and 3-D printed vehicle. (Source: Oak Ridge National Laboratory.)



that previous contributions and related technologies often are discounted or even ignored, limiting collaborative efforts and confining innovators and entrepreneurs to development silos. Lack of coordination also leads to unnecessary complexity in the heavily regulated construction industry, with a negative effect on industry safety and quality assurance–quality control standards. To successfully advance 3-D printing in construction, it is important to build upon previous experiences and to take advantage of such technologies as shotcreting and slip-form construction.

Whether they are high-rise buildings or elevated bridges in difficult terrain, the sheer size of constructed facilities is an example of how the industry must build upon established knowledge of 3-D printing techniques. Small-scale advances have been made in laboratory or factory settings, but large printers capable of 3-D printing in situ are the next frontier. Cranes—an invention from the sixth century BC—are critical to the automation of construction processes and will continue to play a key role in the development of large 3-D construction printers.

Another major challenge for 3-D printers is ink formulation—that is, the optimization of concrete mixtures. Concrete mixture optimization studies have been conducted for more than 100 years, and whenever new cementitious materials (e.g., fly ash, silica fume, or slag) or new chemical admixtures (e.g., superplasticizer, accelerator, or retarder) are introduced in traditional construction practices, a flurry of new studies are conducted. Now, concrete materials scientists will need to develop, test, and study a completely new generation of concrete mixtures for 3-D printing applications.

Incorporating reinforcing steel into 3-D printed structures also is a challenge, particularly in the case of in situ printing. This technology will have serious limitations if reinforcing steel cannot be easily incorporated into the 3-D printing process or if the structural and load-bearing capacity of the constructed facility is not comparable to that of traditionally constructed structures. The current code of practice is based on a composite concrete–steel

Photo: Misanthropic One, Flickr

Among the challenges facing 3-D printing applications is the optimization of concrete mixes—the "ink" of the printing process.

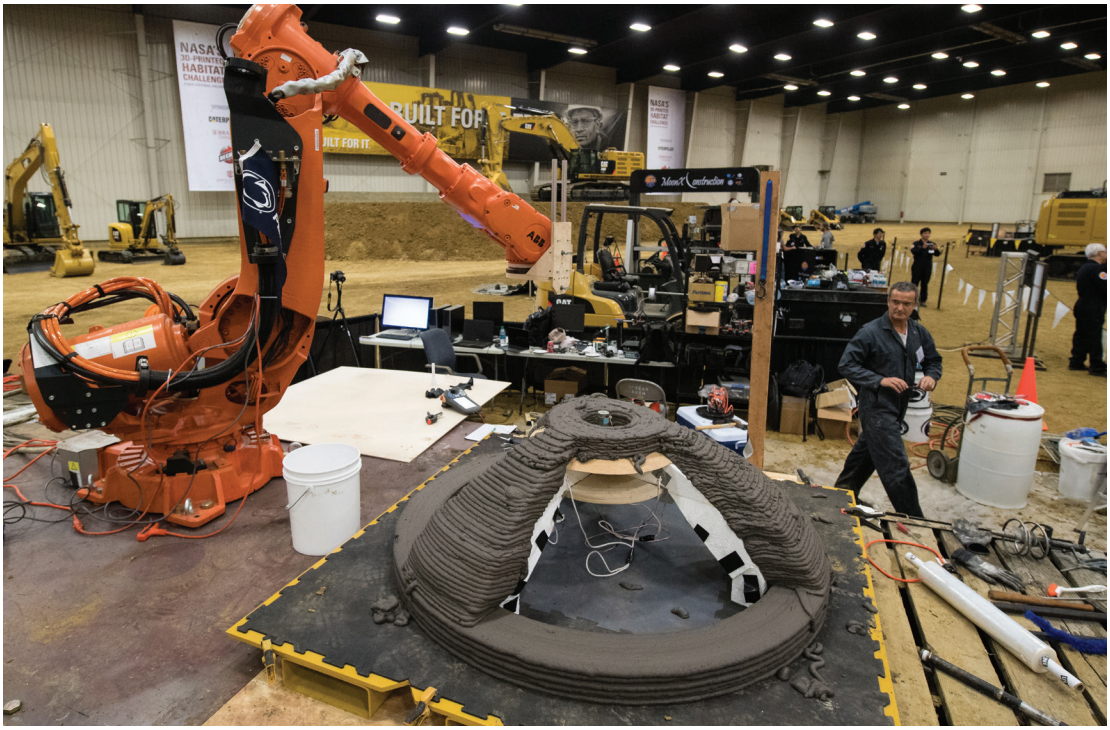


Photo: NASA/Joel Kowsky

The National Aeronautics and Space Administration and other government agencies are engaging with 3-D printing technologies, hosting design challenges and conducting research into the technology.

Transformational Transportation Technologies

Along with 3-D printing, other transformational technologies in transportation are being addressed by committees, sections, and groups of TRB. These include, but are not limited to, the following:

- Vehicle and highway automation
- Big data
- Internet of things
- Nanotechnology
- Geospatial data acquisition
- Advanced computer modeling
- Carbon sequestration technologies
- Greenhouse gas emission control technologies
- Noise and vibration mitigation technologies
- Next-generation air traffic navigation technologies
- Alternative fuel technologies
- Critical infrastructure protection technologies
- Advanced environmental remediation technologies for ground contamination
- Unmanned aerial vehicle technology
- Remote construction quality control–quality assurance technologies
- Integrated asset management technologies
- Advanced highway safety technologies (e.g., enforced speed control)
- Advanced airport safety technologies
- Advanced underwater inspection and monitoring technologies
- Safe hazardous materials transport technologies

system and will remain so until a new material can offer the same attributes of compressive strength and tensile strength.

Path Forward for 3-D Printing in Construction

With the involvement and engagement of all disciplines and collaboration among concerned public and private institutions—including academia and research—the challenges for 3-D printing for construction can be overcome. The participation of government organizations is particularly important; the National Science Foundation (NSF) is a leading agency in 3-D printing for construction, as are the National Institute of Standards and Technology, the National Aeronautics and Space Administration, the U.S. Army, and ORNL. Government institutions look beyond individual, group, or entity interests to the near- and long-term benefits of a technology to national interests.

In 2013, NSF organized "Frontiers of Additive Manufacturing: Research and Education," a workshop that marked the beginning of a broad conversation on 3-D printing (*1*). This was followed by a workshop in 2014 that addressed the environmental and health impacts of 3-D printing and a 2016 workshop that focused on 3-D printing in biomedical industry. In July 2017, the NSF workshop series focused on 3-D printing in construction. The event, "Additive Manufacturing for Civil Infrastructure Design and Construction," attracted a wide cross-section of participants from around the world. The leadership and participation of the departments of transportation, both at federal and state level, will be crucial in advancing this technology.

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Photo: Georgia Department of Natural Resources

Fellowships for Interdisciplinary Gulf Coast Research

KAREN FEBEY

The author is Senior Report Review Officer, Transportation Research Board, Washington, D.C.

Founded as part of a settlement from the Deepwater Horizon oil spill in 2010, the Gulf Research Program (GRP) supports research and programs to protect human health and the environment and to enhance offshore energy system safety.

The Gulf Research Program (GRP) of the National Academies of Sciences, Engineering, and Medicine is an independent, science-based program founded in 2013 as part of legal settlements with the companies involved in the 2010 Deepwater Horizon oil spill. The mission of GRP is to enhance offshore energy system safety and protect human health and the environment by catalyzing advances in science, practice, and capacity to generate long-term benefits for the Gulf of Mexico region as well as the nation. With $500 million in funding to use over 30 years, the program supports grants, fellowships, and other activities in the areas of research and development, education and training, and monitoring and synthesis.

Through the Early-Career Research and Science Policy fellowships programs, GRP assists early-career scientists to hone their skills and leadership experience as they conduct research on issues relevant

Photo: NOAA

to the GRP's focus on advancing science, practice, and capacity at the intersections of human health, environmental resources, and offshore energy safety. Fellows come from a variety of academic backgrounds—social and behavioral sciences, health sciences and medicine, engineering and physical sciences, earth and life sciences, and other interdisciplinary scientific fields.

The Early-Career Research Fellowship Program provides two-year fellowships to emerging scientific leaders who are tenure-track faculty members focusing on offshore energy system safety or the well-being of coastal communities and ecosystems. These fellows remain at their institutions, receiving mentoring and pursuing innovative research that allows them to become leaders and specialists in GRP's focus areas.

In the Science Policy Fellowship Program, scientists early in their careers receive one-year fellowships to work as staff at federal or state environmental, natural resource, energy, or public health agencies. Their work takes place in one of five states in the Gulf of Mexico region and is designed to help them gain first-hand policymaking experience.

The research, specialties, and policymaking expertise of these fellows is wide-ranging and intersects with the transportation field—for example, community and infrastructure resilience after extreme weather events and natural and manmade disasters, or the safety of offshore oil and gas systems.

Profiled below are three fellows whose research and other work intersect with transportation: Early-Career Research Fellows Ali Mostafavi, an assistant professor at Texas A&M University, and YeongAe Heo, an assistant professor at Case Western Reserve University, and Science Policy Fellow Laura Mansfield, a social science and risk specialist at the U.S. Department of the Interior's Bureau of Ocean Energy Management in New Orleans.

Ali Mostafavi

Texas A&M University

As assistant professor in the Zachry Department of Civil Engineering at Texas A&M University, Ali Mostafavi researches the impacts of coastal stressors, the decisions that residents make, and physical characteristics of land and infrastructure to find ways for communities to adapt to both commonplace and major coastal events, from nuisance floods to hurricanes.

"In these studies, I realized that my interdisciplinary approach can be extended to integrated engineering, science, and policy aspects of resilience in coastal communities," he observes. A graduate of the K.N. Toosi University of Technology in Tehran, Iran; the University of Tehran; and Purdue University, Mostafavi applied to the Gulf Research Fellowship Program to extend the interdisciplinary depth and broaden the impact of his work at the intersection of engineering, complex systems, social systems, and health sciences. The flexibility in the use of the

Photo: Gui Carvalho, Flickr

According to Mostafavi's research, nuisance flooding events—like those that occur often in Miami, Florida—are costlier than hurricanes over time.

Photo: United Nations Development Programme

About his research on the infrastructure effects of the 2015 Nepal earthquake, Mostafavi comments that studying different disasters can help protect communities in the future.

Early-Career Research Fellowship funds allows him to examine high-impact research problems.

Mostafavi's work will explore the complex behaviors and relationships at the interface of human and infrastructure systems that shape coastal community resilience. "Through the lens of a complex adaptive systems approach, my research will create simulation models that integrate the impacts of coastal stressors, adaptive decision-making processes, and physical attributes and interdependencies of infrastructure into exploratory scenario analysis, specifying resilience mechanisms and identifying robust adaptation pathways," he adds.

Mostafavi hopes that his research findings can help infrastructure agencies develop robust adaptation plans to enhance the resilience of their systems. He cites a recent study he conducted with a doctoral student that used data from the City of Miami Beach road network to show that nuisance flooding that is due to sea-level rise can increase the life-cycle cost of road networks in coastal cities more than five times over the next 50 years.

"In other words, the chronic impacts of nuisance flooding on roads would be greater than a major hurricane," Mostafavi comments. "We also showed that investments in adaptation measures can have a return of investment of greater than 300 percent."

In the aftermath of Hurricane Harvey, Mostafavi received two awards from the National Science Foundation (NSF) to conduct Rapid Response Research studies, which include interdisciplinary collaborations among researchers from civil engineering, computer science, urban planning, and public policy. He is investigating complex network relationships among organizations, plans, policies, and physical infrastructure that affect the resilience of communities to flooding and extreme weather events.

He also was the recipient of an NSF award to study infrastructure resilience in the aftermath of the 2015 earthquake in Nepal. "Our work on infrastructure resilience from different disasters and different socioeconomic contexts help us learn how to better protect communities in the future," Mostafavi notes.

YeongAe Heo

Case Western Reserve University

Early-Career Research Fellow YeongAe Heo is investigating ways for coastal communities to mitigate the risk of coastal hazards by improving oil and gas system safety. Her expertise in probabilistic modeling and simulation of complex systems performance has led Heo to address unexplored engineering hazard risk problems for resilient infrastructure and communities. "As a Gulf Research Fellow, I am investigating the long-term physical safety of the existing oil and gas systems across the United States and the global socioeconomic impact of a local system failure that is due to any potential hazards," she comments.

"The ultimate goal of my research is to improve the resilience of our community by promoting the safety of structural and infrastructural systems exposed to potential failures because of their aging and complexity as well as exacerbated weather

An oil platform, damaged by Hurricane Ike, is towed into Galveston, Texas. Heo's research focus includes energy infrastructure resiliency in severe weather.

Photo: Dean Terry, Flickr

conditions," Heo notes. "As our modern society has become more complex, critical lifeline systems including transportation as well as energy and water supply systems have been highly interdependent."

Heo received a Ph.D. from the Department of Civil and Environmental Engineering at the University of California, Davis, in 2009. After joining the Offshore Technology R&D Center of Samsung Heavy Industries in 2010, she examined diverse multihazard problems for offshore oil and gas process systems that were exposed to severe weather and operation conditions. She has identified critical issues in probabilistic vapor cloud explosion risk assessment. She also holds three patents for offshore structural systems.

In 2014, Heo joined the Department of Civil Engineering at Case Western Reserve University as Assistant Professor. Through many professional activities and such efforts as technical meetings, conferences, and service on technical committees, she works to eliminate barriers between different engineering disciplines and to consolidate hazard and risk-mitigation studies.

In Heo's previous career in offshore engineering, she observed that global engineering markets have grappled with a serious shortage of experts in risk-informed decision making. The need for risk-assessment personnel has increased drastically in both academia and industry, but very few engineering students are prepared for careers in this field.

"Since I moved to academia with a mission to produce well-prepared risk engineers, I have been developing a strategic multilevel workforce training program, which aims to cultivate essential skill sets and leadership required in the multidisciplinary hazard and risk engineering field," Heo observes.

Despite increasing interest in risk-based approaches because of misunderstandings or different perspectives, it still is challenging for risk practitioners to help communities understand the benefits of investing in risk-management resources, Heo notes. Conflicts of interest among different sectors also act as a barrier to the application of risk measures to practice. In collaboration with other GRP research fellows, Heo has been investigating how such discrepancies in communities' perception of risk affect infrastructure risk-management plans.

Laura Mansfield

Bureau of Ocean Energy Management, U.S. Department of the Interior

Laura Mansfield is a Science Policy Fellow working at the regional New Orleans office of the Bureau of Ocean Energy Management (BOEM), which manages the exploration and development of the nation's offshore resources and seeks to balance the aspects of economic development, energy security, and environmental sustainability. BOEM upholds its mission to manage U.S. outer continental shelf resources in an environmentally and economically responsible way by conducting oil, gas, and renewable energy lease sales as well as congressionally mandated environmental reviews and associated studies.

In the Office of Environment's Social Science Unit, Mansfield works primarily on socioeconomic

issues associated with the oil and gas industry—for example, the economic value of oil platforms to commercial and recreational fishing and diving—and helps the unit prepare for an upcoming environmental impact statement. Mansfield also works with the BOEM Risk Management Operations Group on an implementation strategy for financial assurance activities and will attend an executive training on Extractive Industries and Sustainable Development at Columbia University in June.

As an undergraduate at Hampshire College and graduate student at Tufts University, Mansfield studied the social implications of oil and gas; she applied this knowledge to the Gulf of Mexico region, which faces positive and negative impacts of oil and gas activities. As a research consultant for the Natural Resource Governance Institute on their Resource Governance Index, she compiled primary research and evaluated the management of hydrocarbon resources in the Gulf of Mexico, focusing on the federal government's responsibility to manage offshore oil and gas effectively. Through this research, she became familiar with the work she now conducts at BOEM. "I sought out the Science Policy Fellowship opportunity because of an interest in public service and to utilize my knowledge and skills to help improve the management of natural resources," Mansfield comments.

Before joining BOEM, Mansfield worked for the U.S. Department of Energy's (DOE's) Office of Environmental Management, on a mission to address the nation's Cold War–era environmental legacy—five decades of nuclear weapons production and government-sponsored nuclear energy research. The office conducts an ongoing effort to clean up radioactive sites, many near national laboratories.

Through Mansfield's work on tribal relations within the Office of Intergovernmental and Stakeholder Engagement (OISE), she noticed a common issue of concern with many tribal nations: the transportation of nuclear waste on roads through their lands. As part of cleanup, it is necessary for some waste to be transported to another location for proper disposal or storage; if it passes through tribal lands, DOE notifies tribes in accordance with government-to-government policy. To address concerns, DOE has worked with tribes to establish Transportation Emergency Response programs, enhancing the capability of tribes to be first responders for potential incidents on reservations and nearby areas. OISE corresponds with tribes to better understand their concerns and to incorporate their knowledge into DOE decision making.

"Transportation is consistently an important consideration in my work," Mansfield notes, adding that the Deepwater Horizon oil spill that affected Gulf Coast communities was, ultimately, a transportation issue. "You take a risk getting oil from point A to point B, but if you can't transport oil to where it is needed, you can't gain any of the benefits associated with energy access, which is proven to improve health and well-being and to increase income. Transportation is the key factor to energy access."

Mansfield sees similarities between the oil and gas sector and the issues she was exposed to while working with DOE on nuclear-related issues. Transportation is a crucial element of nuclear cleanup efforts, she comments: "The research of our nation's national labs, which supports leading nuclear energy research and serves the national security strategy, depends on transportation of hazardous waste to processing and disposal sites. There are benefits and costs, and it is the government's duty to evaluate what risks are worth taking."

Mansfield hopes that her work will contribute to effective natural resource decisions that maximize benefits for the public good.

Photo: U.S. Department of Energy

Workers secure waste for transport away from a nuclear production complex undergoing cleanup. Mansfield works with agencies on the safe transportation of energy.

Photo: NOAA

Emergency response and cleanup of the Deepwater Horizon disaster in 2010.

Guardrails, end treatments, signs, and other roadside safety devices were the subject of *TRB Special Report 323: In-Service Performance Evaluation of Guardrail End Treatments.*

Photo: Jeff Garris, Flickr

In-Service Performance Evaluation of Guardrail End Treatments

The end of a length of guardrail must be designed so that it is not a hazard to the occupants of a vehicle that strikes it. Highway agencies install end treatments in a variety of forms, all intended to absorb energy in a crash and to redirect the vehicle into a safe trajectory. The Transportation Research Board (TRB) formed a committee (see box, page 34), cosponsored by the National Cooperative Highway Research Program (NCHRP), to help highway agencies supplement crash testing with evaluations of the safety performance of these devices on roads.

TRB Special Report 323, In-Service Performance Evaluation of Guardrail End Treatments, presents a research design for assessing the in-service performance of roadside safety devices like guardrail end treatments and identifies the data required to do so. The report offers guidance for highway agencies to

- Develop a research design for evaluating the in-service performance of guardrail end treatments,
- Determine the data required for the analysis,
- Examine state data systems to confirm whether the required data would be available, and
- Identify next steps for carrying out evaluations.

Most commonly, laboratory crash tests are used to evaluate the performance of guardrail end treatments and other roadside safety devices—guardrails, barriers, and sign supports. The guidance document that highway agencies follow for roadside safety device crash tests advises that in-service evaluations are conducted to monitor field performance. The 2015 report of a joint federal–state task force that examined crashes involving guardrail end treat-

Real-life evaluation of safety performance of guardrails is needed to supplement laboratory crash testing.

Photo: Michael (aka moik) Mc, Flickr

Photo: Utah DOT

Utah police examine guardrail damage.

ments suggested a program of national- and state-level in-service evaluations.

Despite these and other recommendations, however, these evaluations rarely are completed. The committee's findings noted that, for several reasons—including the limitations of data systems, a lack of funding and staff, and a lack of perceived benefit—highway agencies are not prepared to commit resources to systematic in-service evaluations. Agencies are unlikely to invest in assessment capabilities without evidence that the results can be useful for supporting decisions on selection, maintenance, and replacement of devices.

Necessary Data

The study committee concluded that in-service evaluation can help ensure that roadside safety devices effectively reduce the risk of injuries and fatalities. Crash testing cannot reproduce the variety of characteristics of the dynamics, sites, and installations that affect crash outcomes, so in-service data are necessary to determine the frequencies of these characteristics that then can help determine the conditions that should be included in crash tests.

In-service evaluation also is necessary to verify that devices perform in the same ways as they do in testing. Data collection for evaluation is more likely to be cost-effective if it addresses multiple device categories rather than just end treatments.

Trials to demonstrate in-service evaluation methods and applications are a necessary first step toward establishing capabilities. More information is needed about the benefits and practicality of routine in-service evaluation before new data collection and analysis programs can be launched. Results of modest, initial studies would indicate whether the potential benefits justify further investment.

Recommended Actions

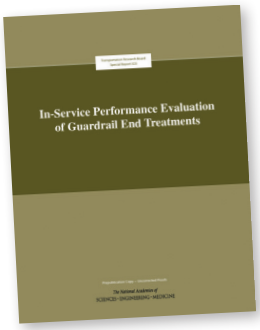
The study committee recommends that the U.S. Department of Transportation (DOT), state DOTs, or both take the following actions to examine the in-service performance of roadside safety devices such as guardrail end treatments:

Photo: Arizona DOT

In-service evaluation and simulation modeling can assist federal and state agencies in evaluating guardrail end treatments.

Photo: Washington State DOT

Highway guardrail repair. A statistical modeling approach to measuring the effects of various factors on guardrail performance could provide a basis for the direction and scale of future research



TRB Special Report 323, In-Service Performance Evaluation of Guardrail End Treatments, is available from National Academies Press at www.nap.edu/catalog/24799/in-service-performance-evaluation-of-guardrail-end-treatments; to view the book online, visit www.trb.org/Publications/Blurbs/176085.aspx.

◆ **Validation of crash test procedures**. In the committee's view, U.S. DOT and state DOTs should cooperate in a research program to validate and refine crash testing of guardrail end treatments and other roadside safety devices through in-service evaluation and simulation modeling. The analysis for validating crash test procedures should have two components: (1) a comparison between actual crash circumstances and test circumstances and (2) a comparison of the outcomes of actual crashes that match test circumstances with test outcomes. A validation research program should include an assessment of the usefulness of simulation models as well as crash testing to certify new device designs.

◆ **Demonstration of evaluation methods for routine highway agency use**. According to the committee, state DOTs—or the U.S. DOT and state agencies acting cooperatively—should conduct a demonstration of methods suitable for highway agencies to use to routinely check roadside devices; such a demonstration could determine whether evaluation would improve the safety and cost-effectiveness of highway programs.

◆ **Evaluating effects of design, installation, and maintenance practices on performance**. The study committee notes that U.S. DOT and state DOTs should begin exploring the data to develop a statistical modeling approach to measuring the effects of device design, installation, maintenance, and site characteristics on the performance of guardrail end treatments. This analysis should begin with the data collected in the crash test validation study and would provide a basis for the appropriate scale and direction of future research on development and application of crash severity models.

◆ **Organization of a nationally coordinated evaluation research program**. According to the committee, two alternative organizational forms for planning and oversight of a nationally coordinated evaluation research program could be (1) an extension of the charge and term of the American Association of State Highway and Transportation Officials' (AASHTO's) and Federal Highway Administration's Task Force on Guardrail Terminal Crash Analysis or (2) an AASHTO-led effort conducted through NCHRP.

The entity overseeing the evaluation program first should develop a plan that defines the objectives, scope, funding needs, and schedule of the evaluations. This entity would be responsible for obtaining cooperation of the federal, state, and local agencies that would be involved and for monitoring the conduct of evaluations and applications of results.

For more information, contact Joseph R. Morris, Senior Program Officer, Consensus and Advisory Studies, Transportation Research Board, at 202-334-3109 or at jmorris@nas.edu.

Committee for the Study of In-Service Performance of W-Beam Guardrail End Treatments, Phase 1

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Washington State DOT

Strategic Program Delivery Methods

DAN TRAN, CHRIS HARPER, AND EDWARD MINCHIN

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A common goal of all state departments of transportation (DOTs) and transportation agencies across the United States is seeking solutions to improve managerial, operational, and organizational effectiveness in the delivery of necessary transportation projects. In recent years, several state DOTs have delivered transportation programs—groups of projects that help achieve an organizational goal—via a more holistic approach, rather than delivering projects individually, to maximize the benefits of time and cost savings. These approaches include combining winning strategies, taking an all-inclusive approach to project delivery, implementing a project management culture, improving project delivery processes, and enhancing communication across an organization. In this study, the word "program" is used to mean a collection of projects; bundled projects; or a budgeted transportation construction program in a state, region, or district.

Daniel Ohnes, Flickr

The Alaskan Way Viaduct replacement (*above*) involved many related projects, requiring Washington State DOT to work closely with residents, businesses, and local transportation agencies.

The key challenges of program delivery include the following:

- Selecting a delivery method that provides the best outcomes and cost savings for the program and agencies;
- Maximizing the efficiency and effectiveness of agency resources;
- Meeting customer expectations;
- Minimizing the negative impacts to customers and stakeholders;
- Adhering to project scope, schedule, and budget; and
- Managing needed changes in projects and programs (*1*).

To overcome these challenges, state DOTs increasingly use a variety of alternative contracting methods (ACMs) and strategic programming approaches to deliver their transportation programs. The ACMs—design–build (D-B), construction manager–general contractor (CM-GC), public–private partnerships, and other innovative techniques—require greater coopera-

Photo: Washington State DOT

Construction on the bridge over the Columbia River in Washington State was part of a $7.1 billion program.

tion, partnering, and risk sharing among agency owners, designers, contractors, and other parties.

Effective Practices

The main goal of *National Cooperative Highway Research Program (NCHRP) Synthesis 504: Strategic Program Delivery Methods* is to document the state of the practice in strategic program delivery. The research methodology consisted of four main steps:

1. A rigorous literature review;
2. A survey of 50 state DOTs;
3. Content analyses of documents, guidelines, and manuals relevant to program delivery from 13 state DOTs that have extensive experience in strategic program delivery; and
4. Seven case studies to verify and validate the findings (2).

NCHRP Synthesis 504 indicates that the success of program delivery depends on the establishment of sound policies and procedures that address organizational approaches, staff requirements and outsourcing, alternative contracting methods, and program management throughout the delivery process.

Specifically, *NCHRP Synthesis 504* documents many effective practices for strategic transportation program delivery, as follows:

◆ **A case-by-case approach to program delivery**. A holistic, or programmatic, approach to program delivery is relatively new to most state DOTs. Ninety percent of the agencies studied in *NCHRP Synthesis 504* select project delivery methods on a project-by-project basis for programs.

◆ **A corridor approach to program delivery**. Some state DOTs have used a corridor approach, or "bundling approach," in which agencies combine several capital or maintenance projects into a single project to maximize the benefits of delivering a program. Of the transportation agencies studied in this synthesis, 27 percent choose project delivery methods for their programs.

Photo: Bruce Fingerhood, Flickr

By bundling the repair of the Whilamut Passage Bridge with other bridge reconstruction projects, Oregon DOT was able to work with a variety of state and local contractors.

◆ **Use of ACMs for program delivery**. Many state DOTs increasingly are using ACMs in an attempt to improve cost and time performance and to enhance the innovation and effectiveness of program delivery. *NCHRP Synthesis 504* found that accelerated scheduling, streamlined processes, and innovation are the top motivational factors for implementing program delivery methods.

◆ **Risk management and program delivery selection**. A growing trend in state DOTs is to conduct a project risk assessment and analysis when choosing project delivery methods. *NCHRP Synthesis 504* found that program and enterprise risk management (e.g., the formal effort to control uncertainty and variability of an organization's strategic objectives) are effective ways to select program delivery methods.

◆ **Performance-based program delivery**. State DOTs are becoming more focused on incorporating performance measures into program delivery. A performance-based program delivery approach increases transparency and accountability, encourages innovation, and helps stakeholders make decisions based on real information and performance. More than half of the agencies studied in *NCHRP Synthesis 504* track the performance of their program delivery with the measures such as scope, budget, and schedule performance.

◆ **Public and political support and trust**. At the highest level, properly conducted programmatic delivery creates trust-based relationships among state DOTs, the public, and political officials. When a program is delivered as promised, state DOTs realize substantial value—from improved relations with the traveling public to the important political support and capital needed to gain the necessary funding for a program.

Knowledge Gaps

NCHRP Synthesis 504 identified several gaps in knowledge and practices for implementing strategic program delivery. First, the synthesis found that project and program management processes and procedures vary widely. State DOTs face inconsistencies in project and program management practices, as well as a lack of tools, techniques, and processes to assess and evaluate the potential benefits, costs, and risks of program delivery. Formal processes and procedures are needed to help state DOTs and local planning agencies effectively and efficiently deliver and manage their programs.

Second, *NCHRP Synthesis 504* indicated that strategic program delivery changes the culture and organizational structure of the DOT and its associated management. Addressing major needs within a state's transportation system can result in many different types of projects within a program. For complex and high-risk projects, state DOTs typically deploy D-B, CM-GC, and other ACMs to infuse more innovation into the program.

In some cases, however, state DOT personnel lack expertise, experience, and training in program delivery. Agencies need assistance to better understand new project and program management and alternative delivery approaches. Successfully implementing program delivery requires that state DOTs promote and sustain a culture of innovation and improvement across all levels of the department.

NCHRP Synthesis 504 also highlighted that program and enterprise risk management are important components of successful program delivery. Although program and enterprise risk management recently have been used in transportation asset management, deployment for delivery of construction programs still is new to state DOTs. Future research on this topic could help promote the effective use of project and program delivery in the transportation construction industry. The results could provide guidance and policies for and risk-based approaches to program delivery.

Photo: Utah DOT

Widening US-189 in Utah. Utah DOT focuses on clearly defined goals, the local construction industry, and innovation in project planning.

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NCHRP Synthesis 504: Strategic Program Delivery Methods, is available from the TRB online bookstore, www.mytrb.org/Store/Product.aspx?ID=8455; to view the book online, visit www.trb.org/Publications/Blurbs/175825.aspx.

Photo: Aysha Cohen

Collaborative Convening at TransportationCamp

KAREN FEBEY

The author is Senior Report Review Officer, Transportation Research Board, Washington, D.C.

The format of and preparation for a typical research conference are familiar to many professionals—the poster sessions, lectern sessions, and committee meetings set months in advance so that attendees can plan their schedules. But what if conference planning was turned on its head? What if attendees had no prepared conference program and what if sessions were planned on the spot by participants, so that neither the attendees nor the organizers knew the content of all of the sessions until after the conference actually started?

TransportationCamp, called an "unconference," answers these questions. The camps are a series of events held across the country and hosted by different organizations. The Washington, D.C., TransportationCamp is held on the Saturday before the TRB Annual Meeting in January and is organized by Mobility Lab, an Arlington, Virginia–based nonprofit transportation research and advocacy organization.

Photo: Aysha Cohen

(*Above:*) TransportationCamp's unique approach allows participants to create the sessions after arriving at the conference.

(*Right:*) After participants submit session ideas, the ideas are arranged on a wall. Attendees can then choose their schedule based on their own interests.

Developing a Conference Onsite

At these unconferences, attendees submit session proposals upon arrival. Each participant writes a proposed title, session format (e.g., a slide presentation with a question-and-answer period, a panel discussion, a brainstorming session, or a demonstration of innovative transportation software), and any other relevant information on a piece of paper and submits it to the organizers.

Organizers then select a variety of proposals, using their discretion to determine the topics that will be of greatest interest to attendees, and arrange the sessions in a large grid on the wall so that attendees can view the schedule and select which sessions

to attend. The sessions are sorted into hour-long periods, offering a variety of topics for attendees to choose from. If two proposals have similar topics, the organizers and presenters can decide to merge them into a single session—allowing for spontaneous collaboration between people who may have never met before.

The sessions in each period are not grouped by theme; rather, when planning each period, organizers strive for a variety of sessions that represent multiple transportation modes and mobility concerns and try to avoid overlaps of similar or complementary sessions. After the periods—typically four or five per camp—are over, attendees can network at a reception and continue the day's discussions.

At the 2018 TransportationCamp D.C., some attendees resumed their conversations the following day at the Innovation Caucus, held during the opening reception for the Exhibit Hall at the TRB Annual Meeting. The Caucus offered a casual forum for innovators to discuss ideas for a new transportation product or service and to take their ideas from proof of concept to a live business.

Since 2010, TransportationCamps have taken place throughout the United States and Canada, including in New York City; Houston, Texas; Atlanta, Georgia; Toronto, Ontario; and Los Angeles, California. Holding the camps in diverse locations has allowed for robust discussions of various transportation issues and for the events to reflect each region's unique demographic characteristics and issues.

TransportationCamp D.C.

The biggest and longest-running of the camps, TransportationCamp D.C. draws those who want to get an early start on the Annual Meeting as well as those who only are able to attend weekend events. The cost of the camp is subsidized by several corporate sponsors; this helps ensure participation by students and young professionals. The registration fee generally is $50 or less, and student discounts are offered.

This year's D.C. camp drew approximately 400 people from private, public, nonprofit, and academic organizations in the engineering, planning, advocacy, and technology sectors. Attendees hailed not just from the Washington, D.C., metro area, but also from around the country and the world.

According to Paul Mackie, Mobility Lab's Director of Research and Communications, more than half of Transportation Camp D.C.'s attendees every year are students or young professionals, who appreciate that the session-planning structure allows everyone to have an equal voice in developing and managing sessions.

Other participants are further along in their

careers, attending TransportationCamp because they find it invigorating to learn about students' and younger professionals' new ideas and because they are curious about what others have to say, Mackie notes. These seasoned professionals can learn about emerging topics and the concerns of the next generation of transportation researchers and practitioners.

Informal and Innovative

Although the TRB Annual Meeting includes research that has been rigorously peer-reviewed before the conference, TransportationCamp focuses more on transportation innovations and how those innovations are applied across sectors. Many attendees describe themselves as "transportation nerds" and are eager to spend the day with academics, practitioners, and professionals who are equally passionate about transportation policy, innovation, and infrastructure.

TransportationCamp's informal nature is part of its appeal—the variety of session formats generally allow for highly interactive discussions. These formats include laid-back discussion groups, lightning talks, and PechaKucha presentations—that is, 20

Photo: Aysha Cohen

Sessions at TransportationCamp tend to be highly interactive, and participants can switch sessions midway through if they so choose.

PHOTO: AYSHA COHEN

The welcome session offered participants the opportunity to network and to discuss their research interests.

slides shown for 20 seconds each. Attendees are encouraged to "vote with their feet" and to move among sessions while they are going on, based on session quality or personal interest.

During sessions, a designated attendee takes notes in a document that is made available online during and after TransportationCamp for other attendees and the general public. Participants can also add to or revise the notes, much like a Wikipedia entry.

The notes from TransportationCamp D.C. are available at the event's website, under "Propose a Session."[1] According to Mackie, 60 to 70 percent of the sessions at the 2018 TransportationCamp D.C. are documented online, making it possible to track ideas and outcomes of the various discussions.

Getting Started

The nearly 10-hour Washington, D.C., event began with breakfast and a welcome from Mackie, who encouraged attendees to tweet throughout the day using the #Transpo18 hashtag. According to Mackie, in 2017, TransportationCamp D.C. trended nationally on Twitter for five hours. Mackie announced later that the 2018 camp was a top nationally trending hashtag for eight straight hours during the event.

[1] http://transportationcamp.org/events/dc-2018.

Aimee Custis (*left*) and TRB's Lisa Berardi Marflak (*right*) use multimedia to explore transit agency advertising.

After the welcome remarks, each of the 400 attendees introduced themselves to the group using three words that best described them or their transportation interests. Some introductions, like "state legislatures matter," revealed attendees' place of employment; others, like "jargon confuses people," described pet peeves; and yet others, like "pedestrian safety rocks," "women bike together," and "I'll model that," described transportation passions. "Need more coffee" reflected the start time of 8:30 a.m., and "we are hiring" and "need a job" demonstrated the desire of participants to network with one another.

After the introductions, attendees began to propose session ideas. The camp offered five one-hour time slots, with each time slot offering 12 to 13 sessions for a total of 62. Although the 12 sessions in the first time slot were chosen in advance, the remaining 50 were proposed and selected during the introductions and the first session. Most of the 2018 sessions can be categorized broadly into the following topics:

- Connected–automated vehicles,
- Big data,
- Public transit,
- Shared mobility,
- Pedestrian and bicycle infrastructure,
- Accessibility and equity issues for specific populations, and
- Transportation governance.

Examples of Sessions

The use of innovative data collection efforts to examine a large number of transit systems was the topic a session by Dan Malouff of the Arlington County Division of Transportation. In "Eleven Things I Learned When I Looked up the Busiest Bus Lines in Every U.S. City," Malouff demonstrated how, through

crowdsourcing, he collected data on the busiest bus lines in the 70 largest U.S. and Canadian urban areas to examine ridership trends. He then was able to determine the highest-ridership bus line in most of these urban areas.

According to Malouff's findings, cities with lines that have an average daily ridership of 25,000 or more are rare, and lines with a daily ridership of less than 8,000 are not optimal. During the ensuing discussion, attendees brought up questions that included the following:

- How do bus rapid transit lines appear in the data?
- What conditions result in high ridership peaks versus low ridership peaks?
- Can these data work as a proxy for overall transit ridership?

At the end of his presentation, Malouff provided a link to an online spreadsheet so that attendees could input ridership numbers for other U.S. and Canadian cities he is looking to examine.

Another session, "At the Movies," used a multimedia approach to examine transit agency advertising approaches. In this session, Paul Mackie joined Lisa Berardi Marflak, TRB's Communications Director, and Aimee Custis, Deputy Director for the Coalition for Smarter Growth, to show seven videos produced by U.S. and Canadian transit agencies.

Each video promoted a particular transit system, and after each one played, Marflak, Mackie, and Custis scored it on a scale of one to ten and explained their scores. They commented on the extent to which each video was accessible to the general public, its production value, and whether each video's length allowed it to communicate its message effectively. Audience members provided additional commentary, leaving with the takeaway lesson that the most-effective videos include both a goal and a call to action—regardless of a high-end or budget production value.

"The Role of U.S. DOT: Laws, Regs, Funding, Policy? What Do You Think—An Open Discussion" featured a dialogue about the role and challenges of the U.S. Department of Transportation (DOT). In this session, Eric Plosky, Chief of Transportation Planning at U.S. DOT's Volpe Center, asked attendees to consider both the role of the agency and the extent to which U.S. DOT's resources are aligned with its strategic plan for 2018 through 2022.

First, attendees shared their perceptions of the primary roles of U.S. DOT. The dozen or so items they came up with included the following: making transportation-related funding decisions, drafting environmental impact statements, and facilitating the use of open-source data. Attendees then discussed the U.S. DOT's Strategic Plan and considered the role of the courts in U.S. DOT rulemaking.

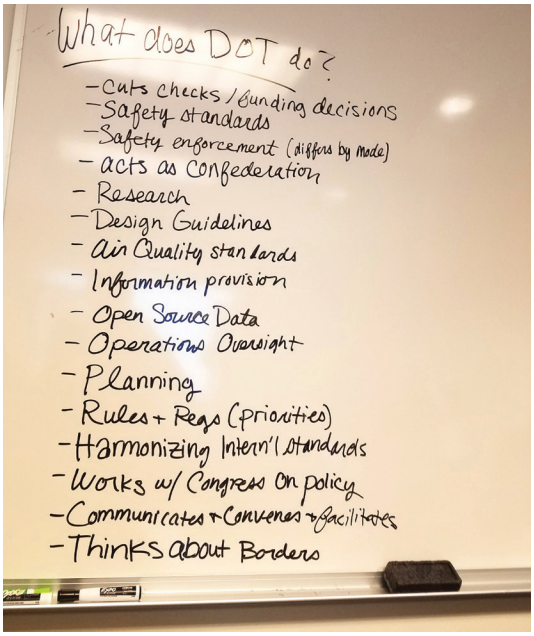

Photo: Aysha Cohen

Session leaders encouraged active audience participation.

In addition, participants also discussed how U.S. DOT employees can strike a balance between exercising leadership in implementing the agency's programs and policies and carrying out the priorities of the current presidential administration. At the session's conclusion, attendees better understood how they can shape U.S. DOT's mission as it fulfills its Strategic Plan.

Looking Toward the Future

Several additional camps have occurred or are planned throughout 2018, including Atlanta in February; Philadelphia, Pennsylvania, and Boston, Massachusetts, in April; Baltimore, Maryland, in May; and Ithaca, New York, in June. Other camps may also take place in Iowa, Colorado, and California.

According to Mackie, groups can contact him about how they can host their own TransportationCamp and he will provide advice on planning logistics and will publicize the event through Mobility Lab. He adds that Mobility Lab is working on a guidance document for anyone interested in planning their own camp. The motivations for those seeking to plan their own camps are varied: many camp planners are seeking ways to innovate and effect change in organizations that often are described as too bureaucratic. Other camp planners wish to create a forum to learn about cutting-edge trends in the transportation field and to facilitate networking among a diverse array of professionals.

Learn More

For more information or to attend a TransportationCamp, visit transportationcamp.org. As in years past, the 2019 TransportationCamp D.C. will be held on the Saturday before the TRB Annual Meeting in January.

MONTANA STATE UNIVERSITY
Western Transportation Institute

Wyoming Intercity Bus Service Study

Finding and Filling the Gaps in Rural Areas

DAVID KACK

The author is Program Manager, Mobility and Public Transportation, and Director, Small Urban and Rural Livability Center, Western Transportation Institute, Montana State University, Bozeman.

PHOTO: WIKIMEDIA COMMONS

In Wyoming, some rural transit services, like the Southern Teton Area Rapid Transit system in the Jackson area, operate more frequently during the busy winter season.

Intercity bus (ICB) service, which provides scheduled transportation between cities and towns, is an important component of public transportation—particularly for residents of smaller towns and rural areas. Since the 1980s, however, ICB services have been on the decline nationwide. In Wyoming, an evaluation of ICB access resulted in a methodology for determining whether the state's transportation needs are being met, identifying potential routes, and developing new partnerships with transportation providers.

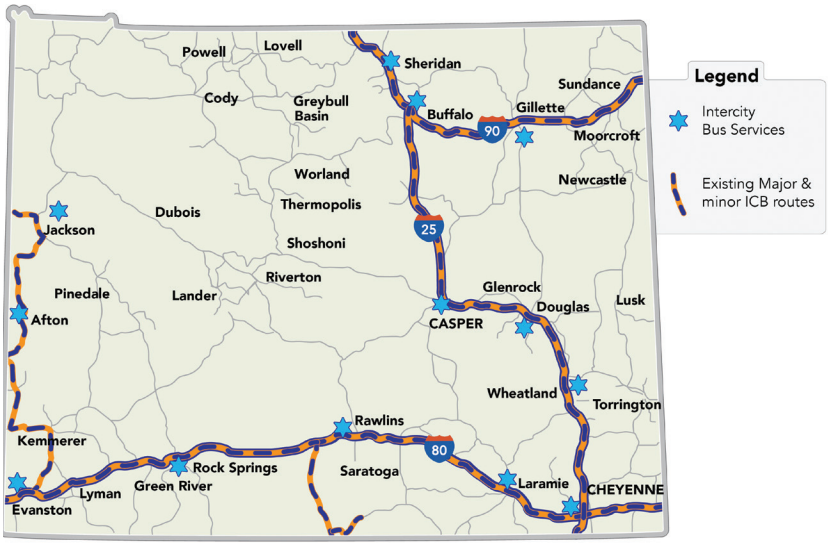

FIGURE 1 The major Interstate highways and intercity bus (ICB) routes in Wyoming before the research study was conducted.

Problem

Only half of Wyoming residents (51 percent) have access to intercity bus service. National providers travel along Interstates 25, 80, and 90, and along U.S. Highways 191 and 89. These routes serve only the southern and eastern parts of the state, however; western areas have very little service and central or northern regions have virtually no service (Figure 1, at left). At the end of 2014, for example, service on a long route connecting central Wyoming to more urbanized cities was discontinued.

Because of recent route eliminations and the fact that only half the state's residents had access to ICB services, the Wyoming Department of Transportation (DOT) was concerned that residents' needs were not being met and sought an assessment tool to determine whether ICB services were sufficient and to prioritize funding decisions that could increase service availability. Although ICB providers often are private entities, services generally are subsidized by a mix of federal, state, and local funds, to expand access.

Research and Solution

On behalf of Wyoming DOT, researchers at the Small Urban and Rural Livability Center, a university transportation center located at the Western Transportation Institute at Montana State University, assessed the state's ICB services.

To gather background information, the research team conducted

- An extensive literature review of ICB service in other states,
- A survey of other rural states to identify funding practices and barriers to service, and
- A survey of ICB riders to understand their attitudes and use of services.

Using input from a survey of local transit managers from across the state, the team also performed a connectivity analysis of existing ICB services. As part of this analysis, team members identified corridors that previously had offered ICB service as well as corridors that would connect high-population rural areas to a more urbanized city. These tasks helped to identify routes that could provide what researchers called "meaningful connections" for residents in underserved areas.

In addition to assessing the status of ICB service, the study produced a process that Wyoming DOT can use on a triennial basis to determine if the state's intercity bus service needs are being met. If it was determined that these needs are not met, the study offered a method to prioritize the locations in which service should be implemented—that is, if sufficient funding exists.

The primary steps in this triennial evaluation included the following:

- Review existing ICB services.
- Determine level of support for existing services.
- Determine funding balance available for new ICB services.
- Using route analysis and consultation, determine funding needs for new services.
- Determine whether the state's ICB transportation needs are being met.

To assist Wyoming DOT with the final step, the study proposed thresholds for whether ICB customer needs are being met; specifically recommending that Wyoming DOT evaluate whether a minimum of 85 percent of the largest, or most-populated, cities in the state receive some level of intercity service. The figure of 85 percent was selected because it is a threshold widely used for transportation analysis, including setting most speed limits.

PHOTO: WASHINGTON STATE DOT

Intercity Transit in Lacey, Washington. Washington State's ICB funding program was among those studied by researchers at the Small Urban and Rural Livability Center.

Application

Applying the findings and tools to Wyoming, researchers determined that only 17 of the largest 28 cities in the state—defined as those with populations of 2,000 or more—have ICB service. That is approximately 60 percent of Wyoming's large cities. To reach the proposed threshold of 85 percent, the study recommended that Wyoming DOT explore adding ICB connections to at least seven more communities.

Wyoming DOT identified many specific corridors for further analysis—all of which lacked any ICB service and would serve communities of 2,000 people or more—and selected potential routes that connect smaller communities with larger cities in Wyoming. Considering these factors, the research team identified six routes for Wyoming DOT to consider for implementation, assuming an availability of funding, service providers, and other essential resources.

The identified routes are summarized in Table 1 (below). Although ridership was not estimated for

TABLE 1 Proposed ICB Routes and Major Destinations

Route	Cities	Population	Major ICB Destination
1	Lander	7,642	Casper
	Riverton	10,953	
2	Cody	9,740	Billings (Mont.)
	Lovell	2,404	
	Powell	6,407	
3	Thermopolis	3,020	Casper
	Worland	5,366	
4	Lusk	1,578	Cheyenne
	Torrington	6,738	
5	Greybull	1,868	Billings (Mont.)
	Worland	5,366	
6	Newcastle	3,513	Gillette

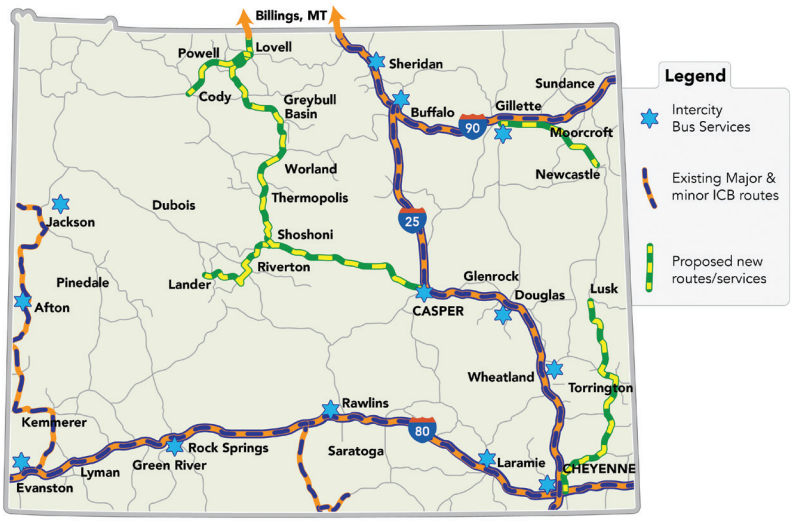

FIGURE 2 Proposed ICB routes in Wyoming (in green).

each proposed route, the population of the cities were noted and estimated implementation costs were discussed in the full report.[1]

Benefits

The Wyoming ICB study has resulted in immediate and ongoing benefits. The analysis of services, routes, and connectivity provides a snapshot of the locations of available ICB services and of large gaps in service (see Figure 2, above). This information—along with the triennial review process—serves as an important tool for planning new service, prioritizing route selection, and maximizing the use of federal funds for ICB services.

In addition, the rider survey offered Wyoming DOT a greater understanding of ICB riders: who riders are, where they go, how they get information about services, and why they use intercity bus service. For example, more than two-thirds of the respondents reported having incomes of less than $30,000 per year; this suggests that ICB service provides critical access to long-distance transportation for low-income residents.

For residents of small, rural communities, transportation to larger towns and regional hubs is essential for reaching jobs, health care, shopping and other necessities. If all six of the proposed routes were implemented, approximately 63,000 more Wyoming residents would have access to ICB services in their communities. This would increase the percentage of residents who have access to service from 51 to 62 percent and would exceed the recommended goal of serving 85 percent of Wyoming's largest cities.

Perhaps most importantly, the study has led directly to the expansion of available services in Wyoming. After reading the report, Chris Przybylski of Alltrans (now The Driver Provider) contacted Wyoming DOT to discuss a partnership to implement services on some of the routes proposed in the recommendations. The new service, which began in January 2017, takes riders from Worland to Casper two days a week and from Worland to Billings, Montana, two days a week, with stops in Cody and Powell.

"The report was a great starting point to understand where the needs were and for knowing who to talk to and work with in those communities to get the service off the ground," Przybylski noted.

"It is not often that a study has had such a tangible result—but in this case, the study was directly responsible for bringing a more efficient ICB provider to the Bighorn Basin," observed Talbot Hauffe, Wyoming DOT Transit Program Coordinator. "We are encouraged that, as word gets around about the new ICB service, more and more people will use it."

For more information about the study, contact David Kack, Program Manager, Mobility and Public Transportation, and Director, Small Urban and Rural Livability Center, Western Transportation Institute, Montana State University, P.O. Box 174250, Bozeman, MT 59717-4250; dkack@montana.edu; 406-994-7526.

EDITOR'S NOTE: Appreciation is expressed to Claire Randall, Transportation Research Board, for her efforts in developing this article.

[1] http://surlc.org/wp-content/uploads/2016/09/WYDOT-ICB-Study-Final-Report.pdf.

One of the proposed routes would connect Thermopolis (shown) and Worland to Shoshoni, as well as to another proposed route to Casper; this route extension would serve approximately 8,000 more people.

PHOTO: T. NOVOTNY, FLICKR

Suggestions for Research Pays Off topics are welcome. Contact Stephen Maher, Transportation Research Board, Keck 486, 500 Fifth Street, NW, Washington, DC 20001; 202-334-2955; smaher@nas.edu.

CALENDAR

April

16–18 International Conference on Advances in Materials and Pavement Performance Prediction*
Doha, Qatar

16–19 Transport Research Arena 2018*
Vienna, Austria

May

2–4 8th Symposium on Pavement Surface Characteristics 2018*
South Brisbane, Australia

16–18 Road Safety on Five Continents*
Jeju Island, South Korea

20–22 10th National Aviation System Planning Symposium
Anchorage, Alaska

22 ITF Summit: Transport and Security Research Day 2018*
Leipzig, Germany

27–30 4th GeoShanghai International Conference*
Shanghai, China

June

1–4 3rd International Conference on Infrastructure and Materials*
Tianjin, China

6–8 International Transportation and Economic Development Conference
Washington, D.C.

18–20 6th National Bus Rapid Transit Conference
Los Angeles, California

18–21 2018 World Transport Convention*
Bejing, China

19–21 5th Biennial Marine Transportation System Research and Technology Conference
Washington, D.C.

24–27 7th International Conference on Innovations in Travel Modeling
Atlanta, Georgia

July

9–12 Automated Vehicles Symposium*
San Francisco, California

9–13 9th International Conference on Bridge Maintenance, Safety, and Management*
Melbourne, Australia

14–17 12th National Conference on Transportation Asset Management
San Diego, California

15–18 57th Annual Workshop on Transportation Law
Boston, Massachusetts

17–19 12th Access Management Conference
Madison, Wisconsin

23–25 GeoChina 2018 International Conference*
Hangzhou, Zhejiang, China

29–Aug. 1 2018 Association for Commuter Transportation International Conference*
Anaheim, California

August

8–9 National Household Travel Survey Data for Transportation Applications Workshop
Washington, D.C.

22–24 16th National Tools of the Trade Transportation Planning Conference
Kansas City, Missouri

September

5–6 Freight Fluidity Performance Measurements Implementation
Washington, D.C.

10–13 TRB Workshop at the 69th Highway Geology Symposium 2018*
Portland, Maine

19–21 2018 Annual Conference of the Florida Association of Environmental Professionals*
Orlando, Florida

25–27 2018 Workshop on Managed Lanes
Bellevue, Washington

30–Oct. 3 23rd National Conference on Rural Public and Intercity Bus Transportation
Breckenridge, Colorado

Upcoming Webinars

April

9 Road Safety and Vulnerable Road Users in Low- and Middle-Income Countries

11 Modern Traffic Signal Preemption at Highway–Rail Grade Crossings

16 Public–Private Partnerships and the Mobility on Demand Sandbox Program

17 Bases/Subbases for Concrete Pavements: State of the Practice

19 TCRP Research Report 196: Private Transit: Existing Services and Emerging Directions*

26 Generating Revenue from Commercial Development on or Adjacent to Airports

May

3 TCRP Project E-11: Relationship Between Transit Asset Condition and Service Quality*

Additional information on TRB meetings, including calls for abstracts, meeting registration, and hotel reservations, is available at www.TRB.org/calendar, or e-mail TRBMeetings@nas.edu.

*TRB is cosponsor of the meeting.

Raquelle (Kelly) Myers

National Indian Justice Center

When Raquelle (Kelly) Myers was an engineering student at the University of California, Berkeley, she worked during summer breaks at the National Indian Justice Center (NIJC), the nonprofit training and technical assistance center founded by her father, Joseph. Located in California, NIJC is dedicated to the improvement of justice systems, health, and welfare in tribal communities.

"I witnessed tribal communities thrive when they used their culture and community dynamics to address their own concerns," Myers notes. Created in 1983, NIJC receives requests for training and technical assistance on a variety of topics, she adds, including transportation issues related to legal concerns such as tribal jurisdiction and sovereignty.

Myers attended law school at the University of Utah, focusing on federal Indian law, family law, and securities regulation. She continued to work at NIJC as a development officer and, later, as a training coordinator, managing training materials for tribal court systems personnel. She also clerked for a judge in Utah. In 1997, Myers received a J.D. and started as staff attorney at NIJC.

"Tribal transportation issues are intriguing, multifaceted problems that require a combination of strategies to resolve."

Myers's introduction to tribal transportation issues came via her service on the Native American Advisory Committee to the California Department of Transportation (Caltrans) and also via Cynthia Gomez, former Chief of the Native American Liaison Branch of Caltrans, first tribal advisor to the Governor of the State of California, and former chair of TRB's Standing Committee on Native American Transportation Issues. These transportation issues were related to the application of California Tribal Employment Rights Ordinances to Caltrans-funded projects, as well as concerns about right-of-way. "Tribal transportation issues are intriguing, multifaceted problems that require a combination of strategies to resolve," she observes.

In 2007, Gomez recommended that Myers go to the TRB Annual Meeting—so she did, attending workshops and committee meetings and presenting her first poster. "It was overwhelming and fascinating," she recalls. "It compelled me to think about transportation from a more global perspective. Around the world, indigenous communities were facing similar transportation-related concerns."

Myers wanted to learn more about these issues and about the partnerships developed by tribal communities to resolve transportation concerns—for example, the San Diego Association of Governments Interagency Technical Working Group on Tribal Transportation Issues. She joined the Native American Transportation Issues Committee in 2007 and served as its chair from 2010 to 2016. Myers also served as liaison to a Transit Cooperative Research Program panel on Developing, Enhancing, and Sustaining Tribal Transit Services and as chair of the Subcommittee on Tribal Historical and Archeological Preservation.

In 2007, NIJC became the administrator of the Western Tribal Transportation Training and Technical Assistance Program (WTTAP), one of seven centers serving 566 tribes throughout the United States; WTTAP worked with tribes in California and Nevada. The TTAP centers acted as conduits between tribal transportation personnel to the TRB Tribal Transportation Committee, which was comprised of representatives from federal agencies, university research departments, and tribal organizations.

"The relationship between the seven TTAP Centers and the TRB Tribal Transportation Issues Committee was invaluable," Myers comments. The committee conducted midyear meetings and workshops at the National Tribal Transportation Conferences coordinated by the TTAP centers. In 2014, Myers and the committee developed a theme issue of TR News on tribal transportation.

The Federal Highway Administration is launching a new national TTAP program, so NIJC is winding down WTTAP and administering a Tribal Transportation Safety and Planning Program and collaborating with UC Berkeley SafeTREC to launch an online crash data tool for California tribal communities, as well as developing online courses related to tribal transportation. "This important tool is providing a user interface with the Statewide Integrated Traffic Records System database so that tribal communities can view, chart, and report the crash data on and near their tribal lands," Myers notes.

"Tribal communities vary in size and scope of transportation related issues, and may also be research-weary," Myers comments, adding that these populations often are the subjects of research but rarely benefit directly from the research results. "It is important that researchers share their results with tribal communities."

"Research may be conducted within a value system that differs significantly from the tribal community's value system," Myers observes. "As such, a researcher's findings and conclusions may carry a different meaning for the tribal community." To ensure that the cultural context of research findings and conclusions are meaningful for the tribal community, researchers should include tribal community representatives on their teams, with the tribal community as the primary entity to address findings and conclusions.

Erol Tutumluer

University of Illinois at Urbana–Champaign

As professor in the Department of Civil and Environmental Engineering (CEE) at the University of Illinois at Urbana–Champaign (UIUC), Erol Tutumluer specializes in transportation geotechnics, developing an understanding of the properties and engineering behavior of the soils and rocks that support such transportation facilities as highway and airport pavements and railroad track structures. Tutumluer serves as Director of International Programs at CEE and is active in global outreach, coordinating education and research partnerships between UIUC and other institutions across the globe. He also is a Paul F. Kent Faculty Scholar.

Tutumluer has focused his research on designing and building a sustainable transportation infrastructure by applying geotechnical engineering and geomechanics principles. Geotechnical materials or geomaterials include aggregate that is bound either with asphalt or with cement to form surface layers in pavements or that is unbound and used in base or subbase pavement layers, in ballast or subballast layers of track structures, or in subgrade or roadbed soil. Geosynthetics also are used to reinforce, stabilize, drain, separate, and filter roadways and railroad track.

"The study of transportation geotechnics provides knowledge that is key to building sustainable, long-lasting pavement and railroad track infrastructure."

"The study of transportation geotechnics provides knowledge that is key to building sustainable, long-lasting pavement and railroad track infrastructure," Tutumluer observes, adding that improved selection and appropriate use of geomaterials and geosynthetics will lead to safer, more cost-effective, and longer-lasting transportation facilities.

In his work testing and modeling pavement and railroad track geomaterials and geosynthetics, Tutumluer incorporates recent advances in materials characterization and in the application of advanced discrete and finite element methods and artificial intelligence. This creates a more accurate, mechanistic-based structural analysis and leads to better field performance.

Tutumluer currently is leading an effort to develop advanced mechanistic-based flexible pavement design and evaluation tools clustered around a public-domain, 2-D axisymmetric finite element software package for the U.S. Army Corps of Engineers' Engineer Research and Development Center. He also is conducting multiyear research projects for the Federal Aviation Administration to analyze airport pavement deformation data generated from their National Airport Pavement Test Facility under full-size multiple wheel gear loads and for North Carolina Department of Transportation (DOT) to develop better rutting models for unbound aggregate materials commonly used in the state for pavement base and subbase applications.

Aggregates constitute 70 to 100 percent by weight of all bound and unbound pavement layers in road applications; accordingly, their types and properties significantly affect the end performance. As sand and gravel mines and rock quarries are depleted or lost to other land uses, Tutumluer notes, less and less high-quality aggregate material is available—and advances in engineering practice are needed.

"Transportation projects must make better use of locally available materials through beneficiation and use of marginal aggregate materials; by increasing the effective use of recycled aggregate products, such as recycled crushed concrete and reclaimed asphalt pavement; and by conserving water and energy in pavement and railroad track construction and at the same time targeting long life and performance improvement," he muses.

For much of his 25-year engineering career—beginning with his doctoral studies at the Georgia Institute of Technology—Tutumluer has investigated structural considerations of unbound aggregate pavement layers and has developed aggregate models for the resilient and permanent deformation behavior from laboratory and full-scale testing.

Recent research projects have focused directly on pavement sustainability issues. An Illinois Center for Transportation project, sponsored by Illinois DOT, investigated the effects of aggregate type and quality—including recycled asphalt product used as aggregate—in pavement base layers and on characterization of Illinois aggregates for subgrade replacement and subbase.

"Through test-section construction and accelerated pavement testing, we are evaluating in the field large-sized aggregates and aggregate quarry byproducts to build more sustainable, longer-lasting, and resilient road infrastructure," Tutumluer comments about his most recent and ongoing research focus.

Tutumluer is an active affiliate of the Transportation Research Board (TRB) and serves as chair of TRB's Geological and Geoenvironmental Engineering Section. He is a member of the Standing Committee on Geosynthetics and, from 2011 to 2016, was chair of the Standing Committee on Aggregates. He also served as chair of the Subcommittee on Applications of Nontraditional Computing Tools Including Neural Nets. In 1999, Tutumluer received the Fred Burggraf Award for excellence in transportation research by researchers age 35 or younger.

COOPERATIVE RESEARCH PROGRAMS NEWS

ENHANCING AIRPORT CAPACITY—(*left to right:*) Gail Staba, Transportation Research Board (TRB); Melinda Pagliarello, Airports Council International—North America; and James Crites, former TRB Executive Committee Chair, examine successful airport sustainability projects in order to identify outreach methods, tools, and leadership that were instrumental in gaining stakeholder acceptance. The ACRP Synthesis panel for Sustainability's Role in Enhancing Airport Capacity met in Washington, D.C., at the Keck Center in December 2017.

ACRP INSIGHT EVENTS—A new program of events from the Airport Cooperative Research Program (ACRP) convene airport industry leaders, experts, and researchers together to discuss critical, emerging topics. Located in Washington, D.C., these ACRP Insight Events promote communication and collaboration, foster innovation, and help identify areas of future interest and research. The first-ever ACRP Insight Event was held March 6–7 and addressed Airport Roles in Reducing Transmission of Communicable Diseases. Speakers included representatives from the Centers for Disease Control and Prevention (CDC), major U.S. and international airports, public health organizations, and the International Civil Aviation Organization. Martin Cetron, CDC, delivered the keynote address.

Specification Updates for Moveable Highway Bridges

The design and installation of the nation's 1,000 movable highway bridges provide significant challenges for designers, contractors, and owners. Although the American Association of State Highway and Transportation Officials' (AASHTO's) *Load and Resistance Factor Design (LRFD) Movable Highway Bridge Design Specifications*, have been updated three times since they were published in 2000, reliability-based design methodology must be added as well as advances in electrical, mechanical, and traffic and marine safety systems.

Modjeski & Masters has received a 38 month, $500,000 contract (National Cooperative Highway Research Program Project 12-112, FY 2017) to develop a design methodology and to propose revisions to the *LRFD Movable Highway Bridge Design Specifications*.

For more information, contact Waseem Dekelbab, TRB, 202-334-1409, wdekelbab@nas.edu.

PHOTO: C HANCHEY, FLICKR

Michigan's Portage Lake Lift Bridge, completed in 1960, provides a critical connection between Copper Island and the Keweenaw Peninsula. It serves 25,000 cars a day (and up to 2,000 snowmobiles per weekend in winter).

Photo: Airport K9

Airport K-9 Off Duty

After patrolling 1,917 mi and chasing 8,376 birds from the grounds of Cherry Capital Airport in Traverse City, Michigan, border collie Piper has been laid to rest. As a member of the airport's wildlife management team, Piper worked 40 h per week clearing birds from runways and neighboring fields, flushing rodents and small mammals that attract birds, and patrolling perimeter fences for wildlife holes. He died in January of cancer.

Piper was one of only a handful of wildlife control K-9s across the country. According to the Federal Aviation Administration (FAA), approximately 142,000 wildlife–aircraft strikes occurred between 1990 and 2013, resulting in 25 human deaths, 279 human injuries, and a recorded loss of $639 million. Research has shown canines to be a highly effective wildlife management resource.

Piper joined the airport staff in 2014, after more than a year of training with handler Brian Edwards. Specialized goggles, earmuffs, and a harness allowed Piper to navigate the airport grounds by SUV and by paw. Indoors, he interacted with airport personnel and visitors and was dubbed Chief Morale Officer.

For more information on Piper and on wildlife control at Cherry Capital Airport, visit www.airportk9.org.

Deicing Materials Disrupt Environment

Two recent studies show the impact of road salt on rising salinity of freshwater and its ecosystems. In January, researchers from the University of Maryland published results of a study showing the long-term damage on freshwater of salt compounds from road salt runoff. Analysis of data from 232 monitoring sites over the past 50 years showed sharp chemical changes in many of the country's major rivers. Salt not only drove up the salinity but also the alkalinity, affecting many communities' drinking water, according to the study.

Researchers at Rensselaer Polytechnic University examined the effect of increased salinity from road salt on freshwater ecosystems. In a university lab setting, biologists studied changes in zooplankton as salinity rose. This revealed complex changes on circadian rhythms, which affect cell function, growth, body temperature, and immune responses. The research suggests that these environmental pollutions also could affect humans in a similar way.

For more information about the University of Maryland study, visit www.nsf.gov/news/news_summ.jsp?cntn_id=244099. For information about the Rensselaer Polytechnic University study, visit https://theconversation.com/can-road-salt-and-other-pollutants-disrupt-our-circadian-rhythms-89211.

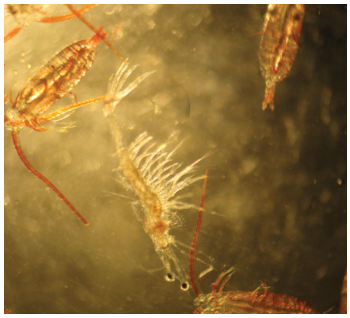

Photo: NOAA

Increased salinity of freshwater ecosystems from deicing materials in stormwater runoff has physiological effects on zooplankton.

INTERNATIONAL NEWS

Wildlife Deterrents Studied for Railroad Safety

An increased rate of collisions between Japan's trains and its deer has led researchers to study various methods to deter wildlife from railway tracks. The methods examined have ranged from the traditional (fences) to the creative (lion feces), but the most effective deterrent, according to researchers at the Railway Technical Research Institute (RTRI), is noise.

Sika deer, a species of deer native to East Asia, are attracted to railroad tracks and often lick the iron filings to fulfill a dietary need. Last year, 613 animals—mostly deer—died in train collisions in Japan, delaying trains and increasing costs.

Scientists at RTRI attached speakers to trains and played sounds of deer snorts—a short, shrill sound used to warn other deer of danger—combined with sounds of dogs barking, which frighten deer. The 23-s recording successfully scattered herds well before the arrival of the train. According to researchers, recent trials of the sound deterrent have resulted in 45 percent fewer deer seen near train tracks.

Researchers plan to finish the system in time to release it across Japan this year.

For more information, visit www.asahi.com/ajw/articles/AJ201801170001.html.

Photo: crankymessiah, Flickr

A deer crosses a set of railway tracks in Japan.

Back on Track: American Railroad Accidents and Safety, 1965–2015

Mark Aldrich. Johns Hopkins University Press, 2018; 304 pp.; $59.95; 978-1-42-142415-6.

A comprehensive history of the safety of modern American railroads, Back on Track examines railroad accidents beginning in 1965 and the impact of government and economic regulations on the industry.

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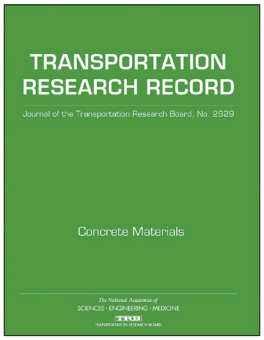

Concrete Materials

Transportation Research Record 2629

Topics related to concrete, including cement content, the effects of curing conditions, and the ability to minimize deicing salt damage, are addressed in this volume.

2017. Subscriber category: materials. For more information, visit http://trrjournalonline.trb.org/toc/trr/2017/2629/+.

Construction

Transportation Research Record 2630

The eighteen papers in this volume examine such construction topics as design–build projects, lateral bridge slides, concrete pavements, and more.

2017. Subscriber categories: materials, pavements. For more information, visit http://trrjournalonline.trb.org/toc/trr/2017/2630/+.

Asphalt Materials and Mixtures, Volumes 1–3

Transportation Research Record 2631, 2632, and 2633

New cracking test methods for asphalt mix, use of nonlinear acoustic measurements for estimating fracture performance, and various aspects of asphalt fatigue testing are covered in these volumes.

2017. Subscriber categories: materials, pavements. For more information, visit http://trrjournalonline.trb.org/toc/trr/2017/2631/+, http://trrjournalonline.trb.org/toc/trr/2017/2632/+, or http://trrjournalonline.trb.org/toc/trr/2017/2633/+.

Developing Countries

Transportation Research Record 2634

The papers in this volume address transportation issues facing such developing nations as China, India, Mexico, and Columbia.

2017. Subscriber categories: pedestrians and bicyclists, safety and human factors, public transportation. For more information, visit http://trrjournalonline.trb.org/toc/trr/2017/2634/+.

Safety Management

Transportation Research Record 2635

Authors present research on safety tracking tools, policy case studies, secondary crashes, and intelligent transportation systems.

2017. Subscriber category: safety and human factors. For more information, visit http://trrjournalonline.trb.org/toc/trr/2017/2635/+.

Highway Safety Performance

Transportation Research Record 2636

The papers in this volume explore factors influencing crash frequency, the performance of flashing yellow arrows, horizontal curves on rural highways, and more.

2017. Subscriber category: safety and human factors. For more information, visit http://trrjournalonline.trb.org/toc/trr/2017/2636/+.

Motorcycles, Trucks, Buses, and Roundabouts

Transportation Research Record 2637

Among the topics covered in this volume are roundabout-related single-vehicle crashes, long-term

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TRB PUBLICATIONS *(continued)*

effects of changes to the universal helmet law, and the transition from differential to uniform speed limits on two-lane highways.

2017. Subscriber categories: safety and human factors, motor carriers, operations and traffic management. For more information, visit http://trrjournalonline.trb.org/toc/trr/2017/2637/+.

Highway Design
Transportation Research Record 2638

This volume includes 13 papers that address such topics as stopping sight distance, the potential effects of heavy vehicles, contextual design, and skew superelevation runoff.

2017. Subscriber categories: hydraulics and hydrology, safety and human factors. For more information, visit http://trrjournalonline.trb.org/toc/trr/2017/2638/+.

Pavements, Volumes 1–3
Transportation Research Records 2639, 2640, and 2641

In these volumes, authors present research on a statistical model to detect voids for curled or warped concrete pavements, the impact of concrete pavement structural response on rolling resistance and vehicle fuel economy, and the influence of operating parameters on braking distance.

2017. Subscriber categories: pavements, environments. For more information, visit http://trrjournalonline.trb.org/toc/trr/2017/2639/+, http://trrjournalonline.trb.org/toc/trr/2017/2640/+, or http://trrjournalonline.trb.org/toc/trr/2017/2641/+.

Structures
Transportation Research Record 2642

Authors present research on elastomeric concrete plug joints and other new materials, the evaluation of structures such as steel multigirder bridges and performance-based concrete deck panels, and more.

2017. Subscriber category: bridges and other structures. For more information, visit http://trrjournalonline.trb.org/toc/trr/2017/2642/+.

Data and Methods to Understand Travel
Transportation Research Record 2643

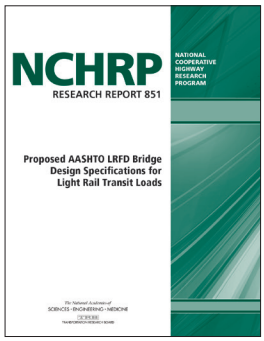
Collecting and analyzing data for travel issues such as ridership profiles, tire pressure monitoring systems, salt usage during snowstorms, and speeds on arterial corridors are explored in this volume.

2017. Subscriber categories: data and information technology, planning and forecasting, operations and traffic management. For more information, visit http://trrjournalonline.trb.org/toc/trr/2017/2643/+.

Traffic Monitoring
Transportation Research Record 2644

Bicycle and pedestrian counts at signalized intersections, annual daily traffic calculation methods, and trail network monitoring are the topics of some of the 13 papers presented in this volume.

2017. Subscriber categories: operations and traffic management, administration and management, pedestrian and bicyclists. For more information, visit http://trrjournalonline.trb.org/toc/trr/2017/2644/+.



Proposed AASHTO LRFD Bridge Design Specifications for Light Rail Transit Loads
NCHRP Research Report 851

Based on the monitoring of Colorado bridges, specifications are presented in this volume for bridges carrying light rail transit loading, including those subjected to both light rail and highway traffic loading.

2017; 210 pp.; TRB affiliates, $63.75; nonaffiliates, $85. Subscriber category: bridges and other structures.

Method Selection for Travel Forecasting
NCHRP Research Report 852

Guidelines for travel forecasting methods and techniques—particularly methods addressing constraints in budget, institutional, and model development time—are presented in this volume.

2017; 276 pp.; TRB affiliates, $71.25; nonaffiliates, $95. Subscriber categories: highways, planning and forecasting, public transportation.

Guidance for Design Hydrology for Stream Restoration and Channel Stability
NCHRP Research Report 853

Presented in this volume are interactive tools and guidance to assess current conditions adjacent to stream crossings and upstream watersheds for the design of stream crossing channels.

2017; 78 pp.; TRB affiliates, $48; nonaffiliates, $64. Subscriber category: hydraulics and hydrology.

Guide for Identifying, Classifying, Evaluating, and Mitigating Truck Freight Bottlenecks
NCHRP Research Report 854

State-of-the-practice information on truck bottlenecks from truck probe data is provided in this report. The comprehensive classification of types of truck freight bottlenecks offers a standard approach for defining bottlenecks and for quantifying their impacts.

2017; 128 pp.; TRB affiliates, $55.50; nonaffiliates, $74. Subscriber categories: highways, freight transportation, planning and forecasting.

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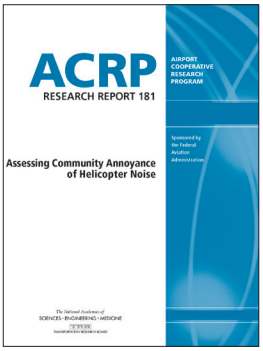

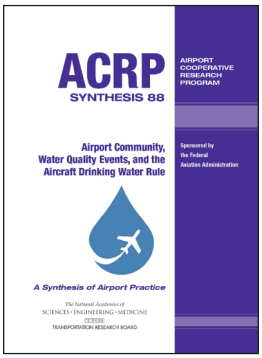

Specifying and Measuring Asphalt Pavement Density to Ensure Pavement Performance
NCHRP Research Report 856

This report examines agency practices to measure and specify the in-place density of asphalt pavements and identifies knowledge gaps that need to be addressed as comprehensive density standards are established.

2017; 57 pp.; TRB affiliates, $42.75; nonaffiliates, $57. Subscriber categories: construction, materials, pavements.

Performance-Related Specifications for Pavement Preservation Treatments
NCHRP Research Report 857

The guidelines in this report assist highway agencies in the preparation of performance-related specifications for pavement preservation treatments and in determining pay adjustment factors.

2017; 158 pp.; TRB affiliates, $59.25; nonaffiliates, $79. Subscriber categories: maintenance and preservation, materials.

Consequences of Delayed Maintenance of Highway Assets
NCHRP Research Report 859

Presented in this report is a process for quantifying the consequences of delayed maintenance of highway assets, taking into consideration asset preservation, budgets, and agency-defined application schedules.

2017; 80 pp.; TRB affiliates, $48; nonaffiliates, $64. Subscriber category: maintenance and preservation.

Best Practices in Rural Regional Mobility
NCHRP Research Report 861

This report offers lessons learned on addressing needs for rural regional mobility and the development of services that fall between intercity buses and rural public transportation. Included is a checklist for developing a rural regional route.

2017; 182 pp.; TRB affiliates, $63.75; nonaffiliates, $85. Subscriber categories: highways, public transportation, administration and management.

Guide to Deploying Clean Truck Freight Strategies
NCHRP Research Report 862

The analytical tool and user manual in this guide assist decision makers in identifying and evaluating appropriate strategies to deploy fuel-efficient and low-emission truck freight strategies.

2017; 72 pp.; TRB affiliates, $42.75; nonaffiliates, $57. Subscriber categories: environment, freight transportation, vehicles and equipment.

Material Properties of Cold In-Place Recycled and Full-Depth Reclamation Asphalt Concrete
NCHRP Research Report 863

In this research volume, authors present guidelines and procedures for determining materials of cold-recycled asphalt mixtures that can then be input into pavement structural design programs for transportation agencies.

2017; 74 pp.; TRB affiliates, $45.75; nonaffiliates, $61. Subscriber categories: construction, maintenance and preservation, materials.

Assessing Community Annoyance of Helicopter Noise
ACRP Research Report 181

This report presents a protocol for conducting a large-scale community survey to assess annoyance related to civil helicopter noise. The factors affecting communities affected by helicopter noise are examined.

2017; 148 pp.; TRB affiliates, $55.50; nonaffiliates, $74. Subscriber categories: aviation, environment.

Guidance for Planning, Design, and Operations of Airport Communications Centers
ACRP Research Report 182

This report offers guidance for airports to determine which type of communications center bests meets their operational needs. Functions considered include police dispatch, emergency response, maintenance requests, and airport systems monitoring.

2017; 172 pp.; TRB affiliates, $63.75; nonaffiliates, $85. Subscriber categories: aviation, data and information technology, design.

Airport Community, Water Quality Events, and the Aircraft Drinking Water Rule
ACRP Synthesis 88

This volume explores how airports, airlines, ground service providers, and ice and food caterers can ensure that their operations have safe drinking water; how to distribute essential information about water quality; and how to minimize the time it takes for notifications to reach tenants.

2018; 48 pp.; TRB affiliates, $42; nonaffiliates, $56. Subscriber category: aviation.

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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, etc.). Manuscripts should be no longer than 3,000 words (12 double-spaced, typed pages). Authors also should provide charts or tables and high-quality photographic images with corresponding captions (see Submission Requirements). Prospective authors are encouraged to submit a summary or outline of a proposed article for preliminary review.

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, whether they pertain to improved transport of people and goods or provision of better facilities and equipment that permits such transport. 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 one or two illustrations that may improve a reader's understanding of the article.

NEWS BRIEFS are short (100- to 750-word) items of interest and usually are not attributed to an author. They may be either text or photographs or a combination of both. Line drawings, charts, or tables may be used where appropriate. Articles may be related to construction, administration, planning, design, operations, maintenance, research, legal matters, or applications of special interest. Articles involving brand names or names of manufacturers may be determined to be inappropriate; however, no endorsement by TRB is implied when such information appears. Foreign news articles should describe projects or methods that have universal instead of local application.

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◆ All manuscripts should be supplied in 12-point type, double-spaced, in Microsoft Word, on a CD or as an e-mail attachment.

◆ Submit original artwork if possible. Glossy, high-quality black-and-white photographs, color photographs, and slides are acceptable. Digital continuous-tone 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. A caption should be supplied for each graphic element.

◆ Use the units of measurement from the research described and provide conversions in parentheses, as appropriate. The International System of Units (SI), the updated version of the metric system, is preferred. In the text, the SI units should be followed, when appropriate, by the U.S. customary equivalent units in parentheses. In figures and tables, the base unit conversions should be provided in a footnote.

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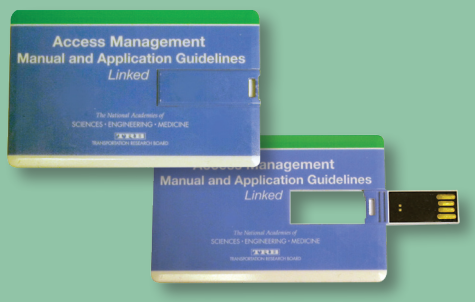
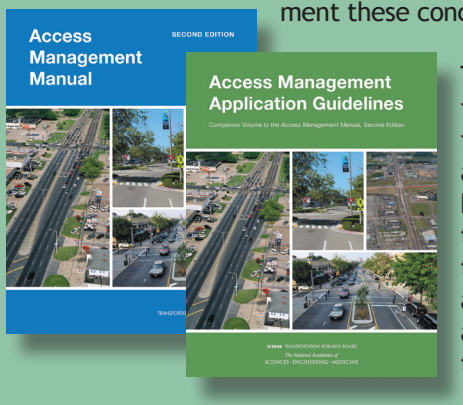
Access Management USB!

Access Management: Manual and Applications Guidelines—Linked

TRB's *Access Management Manual, Second Edition* (AMM2) and *Access Management Application Guidelines* (AMAG) are now available together on a USB flash drive. This USB includes the complete text of each volume with links between material common to both. Content is linked within each volume and between the two. Where possible, references are linked to their online versions. The drive also includes the AMAG's Microsoft Excel workbooks and self-calculating spreadsheet tools. The workbooks demonstrate the basic concepts introduced in the books, and the spreadsheet tools enable users to implement these concepts in their own projects.





The AMM2 comprehensively addresses issues related to access management, including its role in corridor, network, and land use planning. The AMAG is a how-to tool for continuing the evolution of access management applications in the United States and provides additional rationale and guidance for applying the guidelines and concepts in the AMM2.

To order your copy of *Access Management: Manual and Applications Guidelines—Linked* and find out more about special discounts on the AMM2 and AMAG, visit **http://www.trb.org/amm14**.

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