Collaboration and Innovation at MnROAD Research Facility

Transit Network Strategies for New Mobility Options
Airport Ancillary Facilities Design Guidance
Prototype Hazmat Risk Assessment Tool
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3 MnROAD Research Facility: Three Decades of Collaboration, Studies, Innovation, and Deployments
Glenn Engstrom, Bernard I. Izevbekhai, Benjamin Worel, Jeff Brunner, and Lauren Dao
This article examines the history of the MnROAD research facility near Saint Paul, Minnesota, as well as its technical achievements and collaboration with TRB, state transportation agencies, pooled fund studies, and more. Offered is a broad overview of the many studies conducted at MnROAD over its 30-year history—from concrete overlays to subsurface design and drainage to environmental factors in design and preservation.

10 TCRP RESEARCH REPORT 221
Redesigning Transit for the New Mobility Future
Lora B. Byala
For some time, transit agencies have realized that their decades-old networks are not serving the needs of today’s communities. Now, many agencies are redesigning their transit networks to meet current challenges and innovations presented by changes in demographics, land use, economics, technology, and the increase in new mobility options in major U.S. cities.

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Jens Vange and Alan Howell
Authors present research findings on planning and design of airport restrooms and ancillary spaces—from required spaces such as lactation rooms and animal relief areas, to waiting amenities like worship and ablution spaces, to sleeping spaces and other layover amenities—in an update to the 2015 ACRP Report 130: Guidebook for Airport Terminal Restroom Planning and Design.

20 Airport Restrooms and COVID-19
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Understanding Systemic Risks of Railroad Hazmat Transport: Development of a Prototype System
Ravi Palakodeti
The need for railroads to have insights into the systemic risks associated with transporting hazardous materials prompted the research team at FACTOR, a risk assessment company in Nashville, Tennessee, to develop an innovative prototype. The application also would allow users to perform hypothetical analyses to evaluate risk impacts on hazmat traffic changes, as well as to compare the effectiveness of risk mitigation options.

26 NCHRP PROJECT 08-120
Systems Engineering for Rural Connected Vehicle Corridors: Customizable Model Documents
Barbara Staples, Peiwei Wang, and Kathy Thompson
To overcome the challenge of deploying connected vehicles (CVs) in rural roadway systems, an NCHRP project identified CV applications most relevant to rural corridors, scalable ways to integrate CVs into traffic operations and management plans, resource needs, and more. The research team developed model concepts of operation and systems requirements documents for adaptation by transportation agencies.

COVER Research conducted on the three test tracks of the MnROAD research facility—a two-lane, 3.5-mile stretch of I-94; an Old Westbound route used for periodic testing; and a two-lane, 2.5-mile low-volume road test track—have led to many pavement-related innovations. The history of MnROAD and its partnership with TRB are explored in this issue of TR News. (Photo: Minnesota DOT)
Talent for Today and Tomorrow: New Research on the Transportation Planning Workforce

Ann Hartell

The technological and societal trends that affect transportation are evolving rapidly, raising new challenges and reshaping the dimensions of long-standing transportation issues and practices. The author looks at how the transportation workforce also is evolving, as reflected in the recent NCHRP Research Report 980: Attracting, Retaining, and Developing the Transportation Workforce—Transportation Planners.

Also in This Issue

Profiles


Transportation Influencer

Greg Macfarlane, Brigham Young University

TR COVID-19 Resources

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

Coming Next Issue

Among the topics examined in the January–February 2022 issue of TR News are a strategic approach to preservation, maintenance, and renewal; a guide for pedestrian and bicyclist safety at alternative intersections and interchanges; and green bonds and the transit industry.

Alternative intersections and interchanges—such as this green-T, or seagull, formation—help enhance motorist safety. But do they also enhance safety for those on foot or on bicycles? An NCHRP report offers guidance for transportation practitioners to improve pedestrian and bicycle safety at these types of intersections.

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In the 1980s, a group of visionary engineers at the Minnesota Department of Transportation (DOT) explored the idea of building a Cold Regions Pavement Research Test Facility. This led to a task force composed of Minnesota DOT engineers and officials, along with administrators, industry representatives, and university experts from FHWA and the first Strategic Highway Research Program (SHRP).

The task force identified the need to test pavement types in Minnesota’s cold-weather climate—and its pavement-relevant freezing and thawing patterns—to develop the most economical pavement systems for the region. Testing pavement concepts in a real-life scenario would help Minnesota DOT understand how to build the best roads for the state’s budget. The initial goal was to evaluate pavement performance under actual, existing conditions to improve pavement design methods and increase pavement performance.

Construction of the MnROAD research facility took place from 1989 through 1993 and cost $25 million. Funding for the Interstate portion was approved by FHWA through the standard federal aid process; the low-volume, closed-loop test section was paid for with Minnesota state funds. A partnership between Minnesota DOT and the Minnesota Local Road Research Board (LRRB) provided much of the operational funding in the facility’s first decade. Today, funding comes from a combination of LRRB, federal and state sources, and industry and other private partners.

MnROAD has three main functions:

1. **Operations** including testing and monitoring test cells; adding traffic to the low-volume road (LVR) test track; and maintaining the site, instrumentation, and data systems;

2. **Research projects** funded by the National Road Research Alliance (NRRRA), LRRB, Minnesota DOT, FHWA, other states (via pooled funds), the National Cooperative Highway Research Program (NCHRP), and other agencies.

Engstrom is the director of the Office of Materials and Road Research, Izevbekhai is a research operations engineer, Worel is the MnROAD operations engineer, Brunner is a research manager, and Dao is the communications coordinator at the Minnesota Department of Transportation in Maplewood.
3. **Construction**, including the design, manufacture, and instrumentation of test cells.

MnROAD has flourished over the past three decades—in collaboration with the Transportation Research Board (TRB)—as a research site for many ideas conceived by TRB standing committees in their triennial strategic plans and research needs statements (RNSs). One example is the newly completed unbonded overlay pooled fund study, led by MnROAD staff, that was initiated by a TRB standing committee RNS in 2010.

MnROAD has maintained this symbiotic relationship with TRB, with many Minnesota DOT and MnROAD staff serving on TRB standing committees and providing guidance to committees on transitioning RNSs to actual research. Many prospective bidders for NCHRP projects request collaboration with MnROAD to facilitate the research process.

**Technical Accomplishments**

Located 40 miles northwest of Saint Paul, the MnROAD research facility consists of three test tracks: 1) The Mainline, a two-lane, 3.5-mile stretch of I-94 parallel to 2) an Old Westbound route (OWB), to which live traffic is occasionally diverted to facilitate periodic testing, and 3) a two-lane, 2.5-mile LVR test track.

MnROAD researchers have continuously incorporated pavement instrumentation not previously used for civil engineering structures under live traffic, including test cell instrumentation technology with automated data storage and retrieval that facilitate quick responses to data requests. Sensor types now include vibrating wire strain gauges, moisture sensors, trees with watermarks and thermocouples, clip gauges for joint movements, concrete maturity data loggers, and fiber-optic sensors.

A wide range of test cell pavement designs and pavement textures also are available within the test track’s closed low-volume track and interchangeable sections of I-94. In 2010 and 2011, researchers from Virginia Transportation Research Council performed initial testing and validation of various friction devices, including the grip tester and the continuous friction device. These tests facilitated better understanding of the sensitivity of grip testers when measuring friction in curves and superelevals.

A pooled fund study with FHWA, Minnesota DOT, and Texas DOT retained the Technical University of Gdansk (TUG), Poland, to measure rolling resistance of MnROAD test cells in 2011 and 2014 (1). Rolling resistance is an important predictor of fuel economization, as it measures pavement–tire interaction. The study brought the Mark 4 TUG Device—the only internationally approved equipment for rolling resistance—to MnROAD and measured all the test cells in a continuum.

**Developing Asphalt Pavement Design and Construction Practices**

A significant result of Phase I was the development of ROADENT M-E, a mechanistic–empirical (ME) pavement design software. This later evolved into Minnesota’s Pavement Design Program, MnPAVE, a damage response software that saved the state millions of dollars in construction costs.

MnROAD also contributed significantly to the development of the original Mechanistic–Empirical Design Guide (MEPDG), which eventually became the implemented AASHTOWare Pavement ME Design software (2). Test Cells 33, 34, and 35 were designed at the facility to evaluate three binders from the original Superpave® program. These test cells demonstrated the immense benefit of using a polymer-modified performance grade (PG) 58-34 binder instead of the unmodified PG 58-28 binder in the top four inches of hot-mix asphalt (HMA) in Minnesota. Superpave test cells exhibited much less transverse cracking than conventional mixes. Although low-temperature asphalt pavement cracking is discussed in the context of seasonal effects, these MnROAD research findings significantly enhanced the predictability of asphalt pavement performance (3).

**Innovations in Concrete Pavement Design, Construction, and Technology**

MnROAD data from 23 test sections contributed to many design improvements for concrete overlays on both asphalt pavement and existing concrete pavement. Consequently, state, local, and national agencies can build these
overlay economically and sustainably with confidence.

MnROAD studies also helped refine optimization of concrete pavement thickness. These studies showed that test cells designed with older AASHTO-based concrete pavement designs were quite conservative. Though Cells 7 through 9 on The Mainline were designed in 1992 for a five-year service life, they continue to carry Interstate traffic after more than 28 years—at a thickness of only 7.5 inches.

Cells 113 through 513—also known as “how thin can you go?”—demonstrated that, although a five-inch-thick concrete pavement can withstand nearly five years of Interstate traffic, pavement six inches thick is the minimum required for a sufficient built-in safety factor to resist distresses caused by nonuniform support from aggregate base layers and local damage (4).

A recently completed study challenged the long-held belief that a minimum concrete strength of 250 psi flexural strength was needed before opening a new pavement to traffic. Results suggest that—under certain conditions—the minimum thickness needed to open for traffic could be reduced to 170 psi without the conventionally expected reduction in service life, leading to a potential reduction of construction and user costs (5). Test cells were subjected to various degrees of early load repetitions. Periodic examination of the test sections using a falling weight deflectometer, petrographic analysis, and ride measurements revealed minimal strain or distress levels similar to the control segments that received no early loading. The research team also developed a software for practitioners to compute the expected service life associated with early opening to traffic.

Studies on pavement surface characteristics have helped researchers and practitioners understand the factors that enhance pavement friction and pavement acoustics. In collaboration with the American Concrete Paving Association and the International Grinding and Grooving Association, various quiet grinding configurations were tested in 2007, 2008, and 2009. This led to the 2010 Next-Generation Concrete Surface (NGCS). The quietest concrete surface in the world, NGCS measures less than 98 dB in the “A” weighted scale, compared with 105 dB for a transversely tined surface or 101 dB for a broom-dragged surface texture (6). NGCS has been implemented nationwide, as well as in some European countries and Australia.

Subsurface Design and Drainage

The first tests of scouring—that is, water pumping out through pavement joints as vehicles pass over—in concrete pavement bases made at MnROAD was observed in nondrainable bases and underscored how subsurface drainage extends pavement life (7). MnROAD studies have documented that nondrainable bases cause HMA cracks to deteriorate prematurely from the bottom up. Research work on geocomposite barrier drains showed effective removal of excess water even when used with nondrainable materials. Such drainability minimized pavement damage.

In 1996, a pooled fund study demonstrated that, in certain portland cement concrete (PCC) test cell failures, the cells lacking drainable bases displayed a peculiar scouring phenomenon evident of cavitation and hysteresis. As a result, the geocomposite joint drain (GJD) was devised. The three-layer system of nonwoven geofabric sandwiches a geonet placed under transverse joints in concrete. This has successfully improved subsurface drainage through lateral transmissivity, moving the water that enters the joint to the daylighted shoulder without the added thickness that would be required if a drainable aggregate base layer was used.

GJD has been implemented in new construction throughout the state and is gaining national popularity. Many studies of different subsurface drainage designs and pavement performance at MnROAD have proved that subsurface drainage is indispensable to pavement longevity.
Intelligent Construction Technology in Quality Management

In 2017, NRRA and Ingios Geotechnics studied a geogrid-reinforced aggregate base performance specification on MnROAD test sections LVR 328, 428, 528, and 628. Researchers conducted automated plate load testing and validated intelligent compaction monitoring. Light weight deflectometers also were deployed to document the construction process and validate pavement design inputs. Itasca Consulting was retained by Minnesota DOT to enhance its commercially available distinct-element software, Particle Flow Code 3D, to estimate the increased stiffness of geogrid-reinforced aggregate base for use in MnPAVE-Flexible, which is now available at no cost to all state DOTs (8).

Environmental Factors in Design and Preservation

MnROAD studies have shown the impact of environmental factors in overall pavement performance. For example, studies and analysis of pavements on the LVR test track highlighted some degradation in the outer lane, where environmental factors are the primary stresses (no traffic loadings). This analysis led to better designs protecting against traffic and environmental factors.

MnROAD research also facilitated the implementation of seasonal load limits, also known in Minnesota as spring load restrictions (9–10). Test sections built in 1993 (the LVR and Mainline 10-year sections) were added to the testing cycle along with the first batch of MnROAD bituminous sections (Mainline five-year test sections). The initiative first included a verification of the suitability of various sensors for documenting pavement response and then studied seasonal changes. As the section sample size grew, along with the length of performance, a knowledge base of freezing and thawing characteristics and their corresponding load capacity developed. This provided Minnesota DOT the information the agency needed to implement seasonal load limits for asphalt pavements and extended the limits for aggregate-surfaced roads.

Additionally, some published reports have accentuated MnROAD’s technical contributions to pavement design, construction, and maintenance, as well as profiler certification and equipment validation outlined in various other published reports (11–13).

Benefits to Date

The nearly 30 years of extensive research associated with MnROAD have benefited the state of Minnesota and its partners in quantifiable and invaluable ways, for drivers and for the pavement engineering industry. MnROAD has consistently been able to show calculated benefits that have been greater than the cost of research. These numbers do not include the additional benefits of educating future pavement engineers, learning what not to do, and demonstrating and highlighting technologies road owners can use today. Engineers have benefited from open communication to solve real world problems though the NRRA, the National Center for Asphalt Technology (NCAT), and other MnROAD partners in shared research efforts. This means research partnerships across state DOTs and industry drive successful implementation. Some of the benefits of MnROAD initiatives over the years are detailed in the following sections.

PHASE I

The calculated Phase I (1994–2006) benefits have made positive impacts within Minnesota and the nation at large. Increases in performance and pavement life resulted in a reduction in costs for maintenance, repairs, user delays, and congestion. MnROAD studies have been estimated to save the state of Minnesota $33 million per year—and many other states and organizations have benefited, as well (Table 1).

**TABLE 1 Calculated Savings Based on Phase I Research**

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Savings/Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring load restriction policy</td>
<td>$14,000,000</td>
</tr>
<tr>
<td>Winter load increase policy</td>
<td>$7,000,000</td>
</tr>
<tr>
<td>Low-temperature cracking</td>
<td>$5,700,000</td>
</tr>
<tr>
<td>reduction</td>
<td></td>
</tr>
<tr>
<td>ME flexible design method</td>
<td>$4,000,000</td>
</tr>
<tr>
<td>ME rigid design method</td>
<td>$1,200,000</td>
</tr>
<tr>
<td>Sealing pavement/shoulder joints</td>
<td>$1,200,000</td>
</tr>
</tbody>
</table>

NOTE: ME = mechanistic-empirical.

PHASE II

During Phase II (2007–2016), MnROAD test cells were designed around studies developed by partners representing local, international, and national interests.

The National Road Research Alliance (NRRA) is a pooled fund with the goal of improving the future sustainability of roads via research and a commitment to cooperative implementation. The alliance sponsors research at the MnROAD test track, one of the most sophisticated cold-weather pavement facilities in existence, as well as at other locations.

NRRA’s membership currently includes 11 state agencies and DOTs, 21 academic programs, six associations, and 41 industry partners. Together, five technical teams covering asphalt, concrete, geotechnics, intelligent construction technologies, and preventive maintenance share expertise and learn about new tools and methods to improve and expand transportation systems nationally.

For more information, visit mndot.gov/mnroad/nrra.
state, national, and international interests, including several pooled fund studies. The test cells included new construction and rehabilitation along with various asphalt and concrete pavement surfaces.

Construction of Phase II test cells began in 2007 and continued with projects in 2008, 2010, and 2011. Almost 40 test cells were reconstructed on the LVR and Mainline test tracks, representing more than 20 research projects. This second phase resulted in further positive impacts within the state of Minnesota and across the nation. With more insights from the research, Minnesota was estimated to have saved $10.3 million per year (Table 2).

**TABLE 2 Calculated Savings Based on Phase II Research**

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Savings/Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigation of low-temperature cracking in asphalt pavements (Phase II): TPF-5(132)</td>
<td>$14,000,000</td>
</tr>
<tr>
<td>Development of an open-graded aggregate base (stable and drainable)</td>
<td>$7,000,000</td>
</tr>
<tr>
<td>Thin and ultrathin concrete overlays of existing asphalt pavements: TPF-5(165)</td>
<td>$5,700,000</td>
</tr>
<tr>
<td>Development of design guide for recycled unbound pavement materials: TPF-5(129)</td>
<td>$4,000,000</td>
</tr>
<tr>
<td>Full-depth reclamation stabilized with engineered emulsion</td>
<td>$1,200,000</td>
</tr>
<tr>
<td>Field investigation of highway base material stabilized with high carbon fly ash</td>
<td>$1,200,000</td>
</tr>
</tbody>
</table>

**PHASE III**

Now in Phase III (2016–present), research efforts are nearing completion and the benefits will be calculated as the research is finalized and implemented. This will include data, analysis, and implementation from more than 40 NRRA projects. A partnership between MnROAD and NCAT for cracking studies and pavement preservation has studied built test cells at MnROAD; test track on Lee Road in Auburn, Alabama; and test sections in Pease, Minnesota, since 2016 (Table 3). This collaboration is expected to provide quantifiable advantages of preservation treatments and better understanding of low-temperature cracking.

A great many researchers from around the nation and the world have utilized MnROAD facilities and data. With nearly 30 years of detailed data, including weather, traffic, pavement performance, environmental and dynamic instrumentation, and supporting research reports on hundreds of test sections and experiments, MnROAD developed an online database for researchers. This data is now part of FHWA’s InfoPAVE.1

Another critical benefit offered by MnROAD is its contribution to education. It has been used as a staging facility for a variety of demonstrations, technology transfer, and verification testing for all members.

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1 For more on InfoPave, visit https://infopave.fhwa.dot.gov/mnroad/index.
of the pavement community. Although the facility itself provides the data, its true legacy is in the careers of graduate engineers. MnROAD has been excellent training for many engineers who have gone on to other positions in pavement engineering and who have cited their time at MnROAD as a key experience. The facility’s extensive database and archive of well-documented research ensures that MnROAD will continue to educate pavement engineers far into the future.

Future Efforts

Every few years, test cells of completed projects go through a construction overhaul. MnROAD teams and partners are deep into the planning, approval, and sourcing of funds for the 2022 construction phase. The current primary partners of the test track are NRRA, LRRB, and NCAT.

Near-future research is focused on current high-priority topics of sustainability, alternative materials, and intelligent construction technologies for asphalt and concrete pavement construction and maintenance. As the global sustainability landscape shifts to an emphasis on study and precautions for reduced environmental impact, MnROAD seeks to lead the industry in that direction.

Proposed projects in line with this initiative will test ideas for new materials in pavements and seeing their impact on the surrounding ecology. Ideally, revised pavement material recycling techniques and use of technology will reduce dependence on virgin materials throughout the pavement structure and limit waste products. Industry and academia partners could learn from these new test sections, implementing new technology and construction methods that maximize productivity and reduce user delays.

The list of MnROAD research partners continues to expand. The future promises even more quality research through the cooperative efforts of state agencies, academia, industry, manufacturers, and consultants.

REFERENCES


Established in 1959 through state legislation, the Local Road Research Board (LRRB) has sponsored more than 200 individual research projects over the past 15 years. Current LRRB-funded research falls primarily into the following categories: design, construction, maintenance and operations, environmental compatibility, administration, and implementation.

The transportation practitioners who are responsible for county highways and city streets best understand the problems and challenges in providing safe, efficient roadways. LRRB makes it easy for them to participate in setting the research agenda. Transportation practitioners submit ideas to the LRRB, which selects and approves proposals. The Minnesota Department of Transportation (DOT) provides administrative support and technical assistance. Researchers from Minnesota DOT, universities, and consulting firms conduct the research, and LRRB monitors the progress.

Research sponsored by LRRB helps improve the quality of Minnesota’s transportation systems. The impact of this research multiplies as more and more engineers see potential applications through the technology transfer efforts of LRRB’s Research Implementation Committee. Past LRRB research projects include exploring better methods to inspect and maintain timber bridges, identifying best design practices when applying Complete Streets principles, and evaluating the impacts of implements of husbandry on Minnesota roads and bridges.

For more information, visit www.lrrb.org.

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V O L U N T E E R  V O I C E S

Transportation is an important part of the U.S. economy. Without transportation, there would be no trade or social economic development. Transportation makes it possible for people to experience and share cultures by traveling to and from cities, states, and continents. It is an important part of modern society.

—ALENA MIKHAYLOVA
Product Manager
Geneva Pipe and Precast, Orem, Utah
Redesigning Transit for the New Mobility Future

Over the past decade, many transit agencies have undertaken comprehensive redesigns of their bus networks. These agencies realized that their legacy network—often still based, in part, on mid-20th century streetcar routes—were not serving the needs of communities today. There have been changes in demographics, land use, economics, technology, and—most recently—the emergence of new mobility options in major U.S. cities, all of which have spurred agencies to reexamine not only where bus service is provided, but the types and levels of service available, the multimodal connections needed, how to leverage new capital infrastructure, and identifying additional capital investments that need to be made.

At the same time, the availability and prevalence of new mobility options—such as microtransit, transportation companies (TNCs), carsharing, and micro-mobility—has greatly expanded. Transit agencies across the United States are exploring ways to integrate new mobility options with their existing and redesigned bus service. The availability of enhanced data to aid service planning and the recognition that the bus can play a big role in improving mobility also have contributed to the rise in bus network redesigns.

This article highlights the findings of Transit Cooperative Research Program (TCRP) Research Report 221: Redesigning Transit Networks for the New Mobility Future, which was undertaken to provide a better understanding of existing work on the topic of bus network redesigns and how transit agencies are integrating emerging mobility options within system redesigns. Within TCRP Research Report 221 are three toolkits designed to aid transit agencies in implementing the findings.

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1 Microtransit is a technology-enabled passenger service that uses dynamically generated routes, usually between designated stop locations rather than door to door. It provides transit-like service but on a smaller, more flexible scale.

2 Micromobility describes bikeshare and related modes, such as shared scooters and electric-assist bicycles.
of the research: one on conducting a bus network redesign, one on leveraging intra-agency and interagency partners for a better bus system, and one on partnering with the private sector.

Since the work for this study began in January 2019 and was finalized in July 2020, it did not incorporate the impacts of the COVID-19 pandemic other than to allude in the introduction that COVID-19 has impacted ridership and travel patterns and that the report contents pre-date the pandemic. Anecdotally, bus network redesigns—which largely dropped off during 2020—have made a resurgence in 2021 and are more likely to include new mobility elements than those conducted before the pandemic.

Research Methodology
A robust research agenda was used to develop a broad sense of what was then the current state of the practice for bus network redesigns, as well as goals and challenges transit agencies were facing related to their bus networks. This work included a detailed literature review, a review of relevant surveys conducted for previous TCRP syntheses and reports, interviews with transit agencies and other relevant organizations, and a focus group with transit industry researchers and private-sector companies.

A diverse set of 15 transit agencies were selected for inclusion in the research based on size (annual bus revenue hours), geographic diversity, and whether they operated fixed guideway services. The goal of the interviews was to understand how transit agencies and jurisdictions were reevaluating and redesigning their bus networks to address changes to demand, customer expectations, and the new mobility option landscape. The interviews were conducted in 2019 and included discussions about partnerships, introduction of new service types, and other tools and approaches to meeting the customer needs of today and the coming years.

Key Findings

PATHWAY TO IMPROVEMENTS
Transit agencies see bus network redesigns as a way to implement better bus service, address recent changes in their service or their region, and pass through a variety of improvements under one umbrella.

Even in regions with extensive rail (or other types of fixed guideway) networks, buses carry a significant percentage of transit trips, and changing the bus network has major impacts. As a result, bus network redesigns are seen as a way to make wholesale changes to the transit agency’s services, and the desire to improve the quality of bus service is typically a fundamental motivator for transit agencies undertaking a bus network redesign.

For example, Capitol Metro’s Cap Remap bus network redesign in Austin, Texas, implemented in 2018, was undertaken with the intent to remove duplication and increase service frequency. In metropolitan Kansas City, Missouri, RideKC’s bus network redesign addressed shifts in regional employment and residential growth patterns, with the aim of better serving their customers’ travel needs and reversing ridership declines.

Transit agencies also integrated a variety of improvements under the umbrella of a bus network redesign, such as the introduction of high-frequency corridors with bus-priority treatments, bus stop optimization, new and expanded transit centers, and even new branding and online and print materials. This was the case for IndyGo, an Indianapolis, Indiana, effort that incorporated a transition from a hub-and-spoke service model to a frequent grid, as well as the introduction of three new bus rapid transit lines.

STRONG GUIDANCE NEEDED
Bus network redesigns should be framed by strong decision-making processes and leadership guidance. Most successfully planned bus network redesigns have strong support and leadership from someone in a senior position, such as the transit agency chief executive officer or an influential board member. Having a transit agency leader who champions the redesign is key to generating buy-in for the endeavor with the public, internal stakeholders, local jurisdictions, and other key partners. Gwinnett County Transit Division in Gwinnett County, Georgia, attributes its successful bus network redesign to internal persistence, with internal champions consistently pushing the same agendas. In Houston, Texas, a strong board champion and a supportive mayor were key to the successful implementation of Houston Metro’s new bus network.
ESTABLISH GOALS EARLY
Transit agencies should establish bus network redesign parameters and goals early to set expectations for stakeholders, the board, and the public. Without clearly stated goals for a bus network redesign, the focus can vary even across an organization, with some departments aiming to maximize operational efficiency, some to maximize accessibility, and some to facilitate revenue generation. It is important to have well-articulated and coordinated goals so that everyone is working toward the same goals for the bus network redesign. In instances where a transit agency is pursuing a cost-neutral plan (i.e., no net change in the amount of service provided), goals and objectives also encourage the discussion of trade-offs and reveal the must-haves for service in a community. For example, the Maryland Transit Administration developed a set of four goals with associated measurable objectives to guide their BaltimoreLink bus network redesign (Figure 1).

COMING TO CONSENSUS
Bus network redesigns should be built on agreed-upon design principles, service types, and design guidelines. Given the breadth of changes that will be recommended through a bus network redesign, transit agencies use the occasion to review and update some of their key service planning guidance documents, including service design and service performance guidelines (i.e., documents that guide the types, levels, and expected performance for their bus service). This not only provides transit planners with a structure under which to conduct the planning but also provides the transit agency with documented reasoning that can be used in discussions with the public and stakeholders.

For Hampton Roads Transit in Virginia, the Transit Transformation and Transit Strategic Plan projects jointly updated the transit agency’s service standards and design guidelines, while also redesigning the entire bus network to fit within the newly updated service parameters. The service plan includes the creation of 13 high-frequency bus routes to be implemented over the next three years and a timeline that will guide Hampton Roads Transit toward meeting each of the standards by service type by FY 2031.

IMPORTANCE OF OUTREACH
The importance of frequent and meaningful engagement with stakeholders and the public cannot be overstated; there is no such thing as too much outreach, engagement, and communication when planning and implementing a bus network redesign. Outreach is a key element of all phases of the bus network redesign process. Even with significant amounts of engagement, transit agencies still encounter challenges come implementation time.

Bus network redesigns often involve at least two rounds of public engagement, in addition to ongoing maintenance of communications through website updates and other means. At the beginning, the public is offered an opportunity to identify issues and priorities and, later, to provide feedback on possible service alternatives. Transit agencies use a wide variety of strategies to engage the public, from workshops to pop-up surveys at transit centers to social media. Incorporating inclusive engagement strategies that provide meaningful

![An exchange between LA Metro’s Wayne Wassell and local residents at a public meeting focuses on the needs of people with disabilities and reflects the transit agency’s commitment to engage local communities in its NEXTGen bus line redesign plan.](Photo: LA Metro)
involvement opportunities for under-resourced and diverse populations is especially important in bus network redesigns, as bus riders typically comprise a higher proportion of minority and low-income persons than the community at large.

IndyGo cited robust public engagement as a critical factor in ensuring support of their IndyGo NEXT bus network redesign. IndyGo’s outreach for their redesign included more than 500 engagements and directly reached more than 30,000 individuals. They conducted events such as public meetings, stakeholder group presentations, and pop-up meetings at festivals and fairs. This was in addition to the public engagement and advertising that was undertaken by partner community groups. One partner group, IndyCan, made more than 150,000 phone calls to residents and conducted outreach at meetings and through speaking with riders at bus stops. The transit agency also had robust website-based engagement and education, with more than 300,000 webpage views.

PILOT STAGE
When TCRP Research Report 221 was developed, transit agencies were predominately in the stage of piloting and experimenting with the integration of new mobility in their services. Planning for new mobility has not been widely integrated into bus network redesigns. Microtransit, TNC partnerships, micromobility, and the development of mobility hubs were typically considered in parallel or as pilot efforts loosely associated with the bus network redesign.

Most transit agencies interviewed were in the process of implementing pilots or limited deployments of partnerships with a variety of new mobility options. The report identified four common use cases for the integration of new mobility with fixed-route bus networks:

- Microtransit to enhance service coverage and quality;
- TNC, micromobility, and carsharing to enhance system access;
- New mobility as an alternative service model to reduce costs; and
- New mobility to increase transportation equity.

The most common of these was the use of microtransit to enhance service coverage and quality. For example, the Utah Transit Authority (UTA) began a microtransit pilot in November 2019 to explore how microtransit could serve part of their service area that has relatively low ridership on their route deviation services. Within the first three months of UTA’s microtransit pilot, ridership expectations were met—even though the existing route deviation transit service in the pilot’s service area remained unchanged. UTA staff believe that the microtransit pilot’s strong performance indicates previously unmet transit demand in the pilot’s service area, and they have since incorporated microtransit into their service choices bus network redesign planning process.

EQUITY CONSIDERATIONS ARE INTEGRAL
At most transit agencies, buses serve a higher proportion of low-income, minority, limited-English-proficient, and other historically underresourced populations than other transit modes. The impact of changes to the bus network on these populations must be closely considered.

TCRP Research Report 221 explored the integration of equity primarily through the lens of compliance with Title VI of the Civil Rights Act of 1964 and the Americans with Disabilities Act (ADA). However, several transit agencies noted that their bus network redesign’s analyses of equity went...
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Some transit agencies that have implemented or are planning to implement bus network redesigns have grandfathered in either specific users or geographic areas to ensure continuity of paratransit service. This was the case with Capital Metro’s Cap Remap bus network redesign that resulted in a simpler system and a smaller paratransit service area.

Participation by all

Implementation of bus network redesigns—on the operating side and with supporting capital elements—requires participation from all parts of the transit agency, local jurisdictions, and other key stakeholders.

At its simplest, a bus network redesign can be implemented with limited capital investments, such as new bus stop signs, new or expanded layover facilities, and additional space for transfers at existing facilities. More capital-intensive bus network redesigns require transit agencies to work closely with their local jurisdictions to invest in bus priority treatments, new and expanded passenger stops and transfer facilities, and first- and last-mile improvements.

Transit agencies vary in how they deploy bus network redesigns in terms of an all-at-once change or implementing the plans over time. Deploying over time can occur for a variety of reasons, including availability of funds or resources (e.g., buses, operators, and facilities), or both. However it is done, a proper launch ensures that the changes to the system are understood by the public to make certain that the system will continue to attract and retain riders (Figure 2). This requires extensive public education, as well as educating and empowering front-line employees as ambassadors for the changes.

Prior to launch, every stop in the Central Ohio Transit Authority’s system got a temporary sign explaining what would happen at that stop, and additional staff were assigned to the Customer Service...
Center before and after implementation to handle rider questions. The transit agency also hired temporary workers—many of whom were transit users—as brand ambassadors to conduct direct outreach in the community.

**Conclusion**

The key findings represent common themes, challenges, and considerations observed across the research for *TCRP Research Report 221*. However, bus network redesigns are an evolving topic, with numerous redesigns being planned and undertaken across the United States. Transit agencies currently undertaking bus network redesigns must consider the long-term travel behavior impacts of the COVID-19 pandemic, as well as the evolving role of new mobility in their communities and how these new modes can complement the agency’s services. The growing recognition of the importance of equity and delivering bus and new mobility services in an equitable fashion also is shaping those bus network redesigns. Transit agencies across the country will continue to learn from one another’s experiences in planning and delivering bus network redesigns, advancing the state of the practice to deliver higher-quality transit services that are responsive to the travel needs of today’s public.

**Additional Resources**

Continue the dialogue and learn what issues experts are addressing on TRB’s public transportation committees at [www.trb.org/PublicTransportation/TRBCommittees.aspx](http://www.trb.org/PublicTransportation/TRBCommittees.aspx).

The Standing Committee on Transportation Demand Forecasting and the Standing Committee on Community Resources and Impacts are two of several TRB committees related to planning and forecasting at [www.trb.org/PlanningForecasting/TRBCommittees.aspx](http://www.trb.org/PlanningForecasting/TRBCommittees.aspx).

To learn more and get involved, go to [www.trb.org/AboutTRB/GetInvolvedCommitteesTF.aspx](http://www.trb.org/AboutTRB/GetInvolvedCommitteesTF.aspx).

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**VOLUNTEER VOICES**

The key words that describe the strength of TRB are “convening” and “participation.” TRB convenes professionals from around the world to participate in the Annual Meeting, as well as on committees and in research programs. There is something for everyone, based on their professional field, interests, and willingness to get involved. Viewing the Annual Meeting program and the detailed structure of TRB’s committees and programs is somewhat amazing. The complex structure of TRB and its diverse components and activities work because of dedicated staff and volunteers at all levels. I got involved in TRB’s programs in the early 1990s and have always viewed them as my most rewarding extracurricular activity.

—RICHARD BICKEL
Senior Advisor
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Planning and Design of Airport Terminal Restrooms and Ancillary Spaces

In 2013, immersed in Airport Cooperative Research Program (ACRP) Report 130: Guidebook for Airport Terminal Restroom Planning and Design, the research team became aware of a broader scope of customer service-oriented spaces appearing at airports. FAA was developing their service animal relief area (SARA) guidelines, and report author Alan Howell was invited to speak at one of their symposiums regarding the SARA prototype the design team developed for the Minneapolis–Saint Paul International Airport (MSP) in Minnesota.

At the time, lactation rooms—a requirement for most places of work—were also under consideration by FAA as a mandated space in airports. Unfortunately, the research scope for ACRP Report 130 was set, so in the report’s summary the research team noted that ancillary spaces such as these were of growing importance for airports and that guidance would be needed in a future guidebook update.

This update is now available as ACRP Research Report 226: Planning and Design of Airport Terminal Restrooms and Ancillary Spaces. In the volume, the original restroom content has been updated, and planning and design information has been added for the spaces and amenities that follow:

- **Required or essential spaces.** These areas are required by FAA or by building codes or are considered essential for travelers and include SARAs, lactation spaces, nursing mothers’ spaces, companion care, etc.

For more information on ACRP Research Report 226: Planning and Design of Airport Terminal Restrooms and Ancillary Spaces, visit [https://dx.doi.org/10.17226/26064](https://dx.doi.org/10.17226/26064).

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JENS VANGE AND ALAN HOWELL

Vange is a senior associate with Alliance, and Howell is a senior airport architect with the Metropolitan Airports Commission in Saint Paul, Minnesota.

Above: An inviting play area for children awaiting flights with their caregivers is among the ancillary spaces at San Francisco International Airport (SFO) in California. Recently released ACRP research has studied ancillary spaces such as these in airports across the globe and offers guidance in their design.

For more on SARAs, see ACRP Synthesis 64: Issues Related to Accommodating Animals Traveling Through Airports, available at [https://doi.org/10.17226/22120](https://doi.org/10.17226/22120).
Researchers also interviewed MSP’s Travelers with Disabilities Advisory Committee—as they had for the original restroom guidebook—to collect their invaluable insights and experiences with these types of spaces. They then attended three conferences to engage with attending airport managers about their amenity space initiatives: Universal Access in Airports in San Francisco, California, and Future Travel Experience Global in Las Vegas, Nevada, in 2018, and the Airport Planning Design and Construction Symposium in Denver, Colorado, in 2019.

Updates and Changes
ACRP Research Report 226 follows the content structure of ACRP Report 130, guiding the reader through the process of planning, design, and construction. Additionally, the restroom content has been updated to reflect lessons learned and feedback from the many airports and airport workers the researchers talked with, worked with, and presented to since the publication of the original report.

The amenity content follows the restroom content in each chapter, as there is significant overlap between restroom and amenity features, particularly with the regulated amenities. For example, lactation rooms have a similar sink node as a companion care restroom: sink, mirror, and restrooms with adult-sized diaper changing tables.

- **Waiting-related amenities.** These spaces offer distraction and accommodation for travelers awaiting their flights: children’s play areas, sensory rooms, meditation or quiet rooms, yoga spaces, worship spaces, ablution spaces, and companion waiting areas at restrooms.
- **Layover-related amenities.** Spaces for travelers with a lengthy or overnight stay at the airport between connecting flights can offer space for sleeping, fitness, showers, changing clothes, and health and urgent care needs.

For continuity, the team followed the same research approach as in the original guidebook. They selected 10 airports for case studies, including two international airports to glean cultural nuances and initiatives. The airports the researchers visited in North America included Dallas–Fort Worth International Airport in Texas; McCarran International Airport in Las Vegas, Nevada; MSP; Orlando International Airport in Florida; San Francisco International Airport in California; and Toronto Pearson International Airport and Vancouver International Airport in Canada. The team also examined Gatwick Airport and Heathrow Airport near London, UK, and Hamad International Airport in Doha, Qatar.

The researchers felt stakeholder outreach was important, but with a twist. Instead of focusing on airports as done in the original research, they interviewed two non-airport organizations, the University of Minnesota (in Minneapolis and outstate Minnesota) and the Mall of America in Bloomington, Minnesota. These organizations both had very large, ever-changing, diverse populations and had made efforts to provide some of the amenities on the list.

And restrooms with adult-sized diaper changing tables.

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At Heathrow Airport near London, travelers can follow clearly marked signs to flight gates, as well as required amenities (restrooms) and waiting-related amenities (a worship space). Researchers studied Heathrow and nine other airports for ACRP Research Report 226.
An overarching theme throughout the guidebook, so the spacing of SARAs on the secure side makes the most of the time and effort a person with a mobility, sensory, or cognitive impairment must take to journey between flights, to the baggage claim area through customs, and among other airport areas. Researchers determined that the master plan spacing for restroom sets aligned with those for the regulated amenities. These provide a basis of design that recommends adjacencies and placement of the nodes and their components.

Some amenity spaces, like fitness centers and hotels, tend to be tenant-provided spaces at airports, so developing prototype plans was impractical. However, guidance is provided for their placement within an airport—that is, whether in the secure or nonsecure section of the airport—along with drivers that might suggest their need.

An interesting example is the rise of health clinics in airports. These were originally intended for travelers and so were located on the secure side to accommodate travelers in need of a prescription refill during their travels or who suddenly felt ill. But a large hub airport is like a small city, with thousands of employees, and now clinics may have multiple locations throughout the campus; so employees do not have to leave work for routine procedures and pharmacy refills.

Focus on Accessibility
Just like a master plan is vital for planning and optimizing restroom locations throughout an airport campus, it is critical to consider travel distance, adjacencies, and best use locations for the successful placement of amenities. Accessibility is an overarching theme throughout the guidebook, so the spacing of SARAs on the secure side makes the most of the time and effort a person with a mobility, sensory, or cognitive impairment must take to journey between flights, to the baggage claim area through customs, and among other airport areas. Researchers determined that the master plan spacing for restroom sets aligned with those for the regulated amenities. So, in addition to co-locating restrooms and ancillary

![Photo: Brian Johnson and Dane Kantner, Flickr](A dog inspects the service animal relief area at Chicago O'Hare International Airport in Illinois. Usually indoors, these spaces incorporate artificial turf, drains, and hoses for washing the area after use.)

![ Graphic: Jens Vange and Alan Howell](A prototype of the “restroom of the future” layout features (a) accessible bathroom stalls, (b) a handwashing and baby changing area and (c) ambulatory stalls, (d) a companion care and changing table restroom, (e) a janitor’s closet and storage area, and (f) a waiting area with art display.)
spaces because of plumbing infrastructure efficiency, restrooms and amenity spaces have a synergy based on need, much like rest stops along a highway.

ACRP Report 130 introduced the “restroom of the future” concept, which lined a common corridor with accessible, all-gender restroom compartments. It had a spacious entry and waiting area with seating and a semiprivate baby changing area.

ACRP Research Report 226 presents many improvements to this concept, among them accessible compartments with both left- and right-handed grab bar configurations, as well as ambulatory stalls. In addition, a changing table restroom is available for any person with mobility impairments. It includes a powered, adjustable-height changing table, a ceiling-mounted sling hoist to assist a person from the wheelchair to the toilet and changing table, and a handheld shower for cleaning.

Space innovations like those in the changing table restroom have inspired the research team to evaluate potential hazards within these new accommodations. This has led to the development of a prototype fall detection system currently being tested at MSP. An invisible, two-by-two-foot infrared grid is projected onto the floor and can detect if a person is standing (an area of two grids is sensed from body heat) or laying on the floor (with an easily distinguishable large, irregular pattern of approximately six grids). After a short time, if there is no movement, an intercom is activated, and a person in a remote airport facilities location asks if the person is okay. If there is no response, a 911 call is initiated, and emergency responders are dispatched. An emergency button using the same intercom system also is provided.

Although airport managers worldwide know that providing for a traveler’s needs is the primary customer service initiative and, therefore, critical to an airport’s success, accommodating passengers and staff with global origins can create friction. Unfamiliar restroom practices can create hygiene and cleaning issues for the facility and can result in travelers with unaccommodated needs, resorting to unhealthy and sometimes unsafe restroom practices. ACRP Research Report 226 suggests multicultural accommodations, such as dedicated space for ablution (washing as part of religious practice), to further awareness and, hopefully, inspire more conversations towards more inclusive solutions.

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Airport Restrooms and COVID-19

Public restrooms are not known as the cleanest spaces. A 2017 newspaper article from the United Kingdom examined the amount of bacteria per square inch of various surfaces in a typical household bathroom (1). The toilet had 295 bacteria per square inch, but the faucet had 6,267. Imagine how that manifests in a public restroom—especially in airports, where travelers come from multiple destinations.

Though the timing of the COVID-19 pandemic might have suggested a focus on restroom germs in ACRP Research Report 226: Planning and Design of Airport Terminal Restrooms and Ancillary Spaces, the authors chose not to reference the current public health crisis directly. A primary, crucial tenet of excellent airport restroom planning and design is a focus on the health and well-being of passengers. The research in the original airport restroom guidebook, ACRP Report 130: Guidebook for Airport Terminal Restroom Planning and Design, and in ACRP Research Report 226, highlighted the need for the following public health-conscious strategies.

**Touchless Operation**
A touch-free environment in a restroom is recommended not just for hygiene but for throughput, as well. An entrance without doors keeps people moving and better accommodates their belongings in tow.

The ability to wash hands with an automatic faucet and soap dispenser, dry them with automatic paper towels or a hand dryer, and throw the paper into an open receptacle reduces the time spent within the restroom.

Likewise, toilet stalls that feature out-swinging doors and lever handles allow users to operate the door without using their hands and to get in and out of stalls quickly without awkwardly maneuvering around an in-swinging door. And, of course, toilets with touchless flush further reduce contact and time spent in the stall. Fewer touched surfaces mean less spread of bacteria, viruses, and germs.

**Efficient and Effective Airflow**
Keeping the air moving through the restroom keeps fresh air circulating and moves bacteria out of the airstream. The researchers’ recommended strategy in restrooms is to place air supply vents low (e.g., closer to the ground) at the sinks and exhaust vents high (e.g., above toilets). Air moving across the floor from under the sinks helps dry water spills more quickly, preventing slippery spots and eliminating places for bacteria to collect.

The most obvious benefit of pulling air from the space above the toilets is eliminating odors. Even more importantly in the COVID-19 pandemic, however, is that this ventilation eliminates the “toilet plume”—a phenomena in which bacteria and viruses from fecal matter are swirled into the air via tiny, suspended water droplets when the toilet is flushed. These droplets tend to linger, potentially infecting the next person entering the stall.

Recent recommendations propose providing toilet lids to trap the plume so that it is sucked down with the flush (2). This assumes, however, that a person touches the toilet lid before they flush, which is unlikely; further, toilet lids in public restrooms are very often unsanitary. Instead, placing exhaust vents above the toilets pulls the plume up and away before the next person arrives.

To aid the development of the prototype restrooms at Minneapolis–Saint Paul International Airport in Minnesota. Hygienic, well-ventilated bathroom facilities not only contribute to a positive airport experience but also reduce the spread of disease.
In the end, small, positive user experiences like hygienic, pleasant restrooms have the greatest impact on an airport’s bottom line.

—Jens Vange, Alliance, and Alan Howell, Metropolitan Airports Commission, Saint Paul, Minnesota

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FIGURE 1 Diagram of airflow within a restroom, with arrows on floors and walls indicating the flow path and different colors showing different airflow velocities (red = faster; blue = slower).

International Airport, engineers modeled the airflow within a typical restroom, which helped them understand how the toilet plume can be efficiently mitigated.

Figure 1 shows the airflow in a restroom. Air is supplied below the sinks (located opposite the toilet stalls) at a high velocity, then quickly disperses throughout the room. The figures in the stalls demonstrate how air then moves around them and up into the exhaust grille.

Individual Nodes

The prototype restroom layouts presented in ACRP Report 130 suggested individual nodes for each station in the restroom. The toilet and urinal nodes are compact, their function efficiently located within dividers. Common hand washing layouts, on the other hand, are more spread out, with the sink in one place and hand drying across the room from the sink, creating a path of water drips that can be a slip hazard and a bacteria collection site.

The idea of a node is that everything is within reach for a user, reducing their movement around the room: washing hands at the sink near the location for drying hands and throwing away paper towels. This limited movement makes the task very efficient—and more accessible for those with limited mobility.

Frequent Cleaning

Frequent and effective cleaning is the heart of a hygienic restroom environment. Easy-to-clean, nonporous, monolithic surfaces are recommended for floors and walls and are less likely to harbor bacteria. Some airports periodically power wash their restrooms after hours to deep clean them (in these cases, ceiling surfaces should be water-resistant, as well).

The usage of airport restroom sets, as well as the supply of paper products, fullness of trash cans, and more are increasingly monitored by restroom management systems. These systems are available as turn-key solutions or are customized by the airport. Currently, their primary function is monitoring the number of persons using the restroom; when a threshold is reached, a cleaner is dispatched.

One method used by some airports is to assign a cleaner to one or more restrooms. These workers stay on site to clean up water drips, replace supplies, and more. This method is effective because the restroom does not need to be shut down for cleaning, and when people see someone cleaning the restroom, it gives the impression that it’s a sanitary space.

In the end, small, positive user experiences like hygienic, pleasant restrooms have the greatest impact on an airport’s bottom line.

—Jens Vange, Alliance, and Alan Howell, Metropolitan Airports Commission, Saint Paul, Minnesota

ACRP Infectious Disease Resources

To view ACRP’s many resources addressing public health preparedness, communicable disease and airports, emergency response, and other relevant topics, visit www.trb.org/ACRP/ACRPInfectiousDiseaseResources.aspx.
FACTOR wanted to apply an innovative framework to develop an application prototype that provides railroads with systemic insights into hazmat transportation risks. The prototype also would enable users to perform “what-if” analyses for evaluating risk impacts of hazmat traffic changes and for comparing the effectiveness of risk mitigation options. To support the effort, the research team initiated a project through the Transportation Research Board’s (TRB’s) Rail Safety Innovations Deserving Exploratory Analysis (IDEA) Program.¹

A Look at the Problem
Hazmat transportation by rail plays a vital part in sustaining the modern society and economy. Because of their obligation as a common carrier, railroads are required to carry hazardous materials. Hazmat shipments account for only a fraction of overall rail freight traffic—approximately 7.5 percent, according to the Association of American Railroads’ (AAR’s) 2018 statistics.² However, any accidental or nonaccidental release—although considered a rare occurrence—can have significant impacts on the railroads, the public, and the environment. Although railroads continually invest in improving the safety of freight transportation, a constant need to identify new opportunities for managing the unique risks associated with hazmat shipments remains.

When making safety-related decisions and optimizing resource and investment allocations, railroads must consider the impacts those decisions will have on operations throughout their entire network and for all freight traffic. For example,


Railroads must routinely make decisions about improving overall network safety by identifying network locations to upgrade signalization, improve track quality, or install additional wayside detectors. These decisions typically are made by considering factors such as overall freight volumes, projected capacity changes, and potential impacts on high-traffic service areas, to name a few. Though these considerations are essential to optimizing business and operational practices, the incorporation of risks that are due to hazmat movement as a decision support layer is a critical component.

Existing hazmat risk assessment tools are suitable for evaluating safety risks posed by individual hazmat materials (e.g., toxic-by-inhalation substances such as chlorine and sulfur dioxide; flammable products; and specific radioactive substances such as a highway route controlled quantity of Class 7 [radioactive] materials transported in Type B packaging). Such tools also are appropriate for assessing risks on specific routes or for selecting between potential alternative routes. These assessment tools do not, however, provide the holistic information on hazmat risks needed to support prioritization of infrastructure improvements and efficient allocation of finite risk-reduction resources.

**Determining the Solution**

The main objective of the project was to design and develop a prototype tool that supports railroad decision makers by applying the concept of safety risk accumulation and amplification resulting from the totality of hazmat shipment movements through their networks (Figure 1). Development of the prototype leveraged a quantitative systems-based approach, along with advanced methods for processing and organizing large-scale commodity flow data, associating the hazmat traffic flows to a geographic information system spatial rail network, and calculating the spatial and temporal aggregation of safety risks.

The prototype development spanned two stages of effort. The goal of Stage I activities was to select a suitable analytical and quantitative risk framework by comparing two available frameworks: railcar-based and train-based methodologies. These frameworks have differing data requirements, with the train-based framework generally requiring more information on the consist (i.e., a train’s makeup of railcars and locomotives), position of the railcar in the train, train length, and so on. The project team applied the two frameworks to the aggregation of risk for multiple commodities within two rail corridors to better understand the effect of framework choice on results. The results indicated that both frameworks were consistent in their relative comparison of the corridors and both performed similarly in identifying higher-risk locations within the corridors—a key requirement to support railroads’ capability for focusing safety investments. The accumulation rate of the hazmat safety risk along the corridors also was consistent (Figure 2).

**FIGURE 1** Concept of safety risk aggregation for all hazmat movements to support development of networkwide measures of hazmat safety risk.

**FIGURE 2** Aggregated safety risk accumulation for railcar-based and train-based frameworks for an example network corridor.
This finding led to selecting the relatively less complex railcar-based analytical framework for the prototype system.

Stage II activities focused on designing and developing the prototype System for Managing and Analyzing Rail Transport Enterprise Risks of Hazmat (SMARTER Hazmat). The SMARTER Hazmat prototype was developed as an HTML5-based web application accessible through standard web browsers. The system was constructed using React JavaScript communicating with a Microsoft .NET Core application programming interface, with all spatial and tabular data managed through Microsoft SQL server databases. The prototype was deployed for testing on an Amazon Web Services cloud server to promote ease of access and future scalability. The resulting prototype includes the following three modules:

- **Home**—Shows summary and detailed views of total network risk from aggregated hazmat traffic, supported by data visualizations of the spatial and temporal risk distributions (Figure 3);
- **Risk Assessment**—Analyses new business or planned hazmat movements and their impact on the current network risk distribution; and
- **Risk Controls**—Allows users to model modification of safety risk factors (e.g., track characteristics) and to perform “what-if” analyses to investigate the impact of the risk factors on network safety.

### Review and Testing

Collaboration with Norfolk Southern Railway (NS) provided invaluable feedback on the practical implementation of the prototype. This feedback helped to ensure that the eventual production version of the prototype will be well positioned to integrate seamlessly with existing railroad data management systems. A key testing outcome was confirmation from NS that the overall system design and data presentation methods provide more holistic views of quantitative hazmat safety risks at various scales of interest (i.e., from the network segment, subdivision, and entire network). Additionally, the prototype's databases were verified to be able to process the hazmat commodity data in standard formats that are aligned with current industry workflows. Testing and review identified future enhancements to the prototype, including the capability to directly inject commodity flow data; support additional data visualizations (e.g., normalized segment risk for the entire network and visualize overall hazmat footprint); and model railcar fleet composition and detailed tank car characteristics, which will expand the types of practical “what-if” analyses in the Risk Controls module.

### Projected Benefits

The SMARTER Hazmat prototype represents an advance for the state of the practice in evaluating and understanding hazmat safety risks. The prototype supports railroads with new risk data visualization and decision-making capabilities to integrate seamlessly with existing railroad data management systems. A key testing outcome was confirmation from NS that the overall system design and data presentation methods provide more holistic views of quantitative hazmat safety risks at various scales of interest (i.e., from the network segment, subdivision, and entire network). Additionally, the prototype’s databases were verified to be able to process the hazmat commodity data in standard formats that are aligned with current industry workflows. Testing and review identified future enhancements to the prototype, including the capability to directly inject commodity flow data; support additional data visualizations (e.g., normalized segment risk for the entire network and visualize overall hazmat footprint); and model railcar fleet composition and detailed tank car characteristics, which will expand the types of practical “what-if” analyses in the Risk Controls module.

To learn more and become a friend of the committee, visit [http://sites.google.com/site/trbcommitteeat040](http://sites.google.com/site/trbcommitteeat040).
improve overall network safety, including the following:

- Determining and prioritizing high-risk areas and seasonal or temporal rhythms in hazmat risks when considering the totality of hazmat movements across operational networks,
- Evaluating impacts from introducing additional shipments for new hazmat customers,
- Monitoring network safety risk for significant changes in trends and identifying seasonal and other temporal patterns in risk accumulation, and
- Allocating and comparing the effectiveness of risk mitigation strategies to achieve the greatest benefit for finite safety investments.

Acknowledgments
The author thanks representatives of AAR, NS, and the Dow Chemical Company for their guidance as the expert review panel.

RESOURCES


It is important to me to leave the world better than I found it. As a mother, I take my job seriously. The problems I solve today will create a better world for my children and theirs. The work we do at TRB is helping to accomplish that. We take on serious and difficult problems, and we work collaboratively to perform research that moves toward solutions. TRB attracts thinkers with new ideas, concepts, and dreams. They work as a community to research and advance transportation. Through TRB, all of us can come together to innovate and develop in a forum that allows for critical review, discussion, dissent, and partnership so all of us may move ahead. This is especially important in these times when technology is changing faster than ever before. Though I am involved in TRB in a cursory way, I use its research, I value its collaborative approach, and I appreciate the forum it provides for the greatest minds in transportation to take on important topics that can shape our world.

—NICOLE KATSIKIDES
Research Scientist
Texas A&M Transportation Institute,
San Antonio
Although systems engineering (SE) processes are well documented to be good engineering practice, some transportation agencies find the structured process cumbersome and choose to skip it. To facilitate the process, agencies can use model SE documents as a starting point to develop their customized, local concept of operations (ConOps) and system requirements (SyRS) documents. The model documents can save time and money while addressing challenges in an effective, secure, and interoperable way (Figure 1, page 27).

Across the United States, state and local transportation agencies are preparing to deploy connected vehicle technologies to address safety, mobility, and efficiency challenges. Although most connected vehicle projects have focused primarily on applications in urban areas, there is significant interest in and potential for deploying, operating, and maintaining connected vehicle technologies on rural corridors.

Rural corridors exist in all states, ranging from traditionally rural states like South Dakota to states generally perceived as more urban, like California. These corridors often include long stretches of highway with limited power, communications, and intelligent transportation systems (ITS) infrastructure; long distances between cities or services for travelers; different traffic and roadway characteristics (e.g., higher posted speed limits, higher percentage of truck volume, and roadway geometry); and significant rerouting distances.

To overcome the challenge of deploying connected vehicles in rural roadway systems, states along the rural I-90 and I-94 corridors between Wisconsin and Washington State (Figure 2, page 27) joined forces to establish the North/West Passage Transportation Pooled Fund Study (NWP PFS). Primarily focused on the integration of ITS, the NWP PFS developed an initial ITS integrated strategic plan and since then has developed and implemented yearly project work plans that focus on developing effective methods for sharing,
Research Approach

A ConOps is a foundational document that directs the technical course for the project, so getting it correct early in the implementation process is crucial. The document is used to convey a high-level view of the system to be developed so stakeholders can understand how it will be operated and maintained. A ConOps also identifies high-level user needs and system capabilities to develop the requirements of the proposed system.

The project team used an SE approach to develop model ConOps and model SyRS coordinating, and integrating traveler information and operational activities across borders of pooled fund member states: Idaho, Minnesota, Montana, North Dakota, South Dakota, Washington State, Wisconsin, and Wyoming.

Motivated by the work being done under the NWP PFS, in 2019, the National Cooperative Highway Research Program (NCHRP) launched Project 08-120, “Initiating the Systems Engineering Process for Rural Connected Vehicle Corridors.” The project specifically sought to identify the following:

- Connected vehicle applications most relevant to rural corridors;
- Scalable ways for connected vehicles to be integrated into transportation agencies’ traffic operations and management plans;
- Requirements of connected vehicles and cyberphysical infrastructure within rural corridors;
- Anticipated roles and responsibilities of transportation agencies in authorizing, deploying, operating, and maintaining ITS and other transportation systems management and operations technologies within rural corridors; and
- Related staffing and resource needs.

An initial review of literature on the SE process as it relates to rural connected vehicle corridors revealed that there were not any model rural SE documents available. In fact, researchers found little SE documentation for rural connected vehicle deployments. They sought to fill the gap by developing SE-based model ConOps and SyRS documents to help agencies assess their needs, operational concepts, scenarios, and requirements as they deploy connected vehicle technology along rural corridors.

As a first step in developing this documentation, the NCHRP Project 08-120 team engaged in stakeholder outreach to understand how invested parties could benefit from using these products to support their deployments. Targeted stakeholders included the following organizations, communities, and people:

- All state agencies listed in the AASHTO Committee on Transportation System Operations,
- County- and city-level agencies from the American Public Works Association Technical Committee and the FHWA Local Technical Assistance Program,
- Tribal communities from the U.S. Department of Transportation (U.S. DOT) Tribal Communities and Tribal Technical Assistance Program, and
- Other connected vehicle stakeholders identified by the project panel.

FIGURE 1 The model ConOps reflects core, common priority user needs and lays the foundation for the model SyRS. Both the ConOps and SyRS parts of the development process are highlighted in blue. (Source: FHWA, modified by Noblis.)

FIGURE 2 The I-90 and I-94 corridors (red lines) and the NWP PFS member states. (Source: https://www.nwpassage.info.)
Ten follow-up interviews were conducted. Researchers collected in-depth input on the needs, challenges, and opportunities of interest to rural corridor stakeholders.

Next, the project team conducted a webinar. Its purpose was to present, discuss, and validate the gaps and challenges—both crosscutting and by topic area—with the highest-rated criticality levels.

Literature review findings and stakeholder feedback from the survey and interviews were incorporated in the model ConOps and SyRS development. Following development of the model documents, a second...
Although IEEE 1362-1998, the ConOps follows IEEE Standard 1362-1998. This model ConOps includes two items not typified found in a ConOps: 1) a preface to set the background for the specific document and 2) several notes to the reader, placed strategically throughout to help practitioners tailor the document.

The structure of the model ConOps follows IEEE Standard 1362-1998. This model ConOps includes two items not typically found in a ConOps: 1) a preface to set the background for the specific document and 2) several notes to the reader, placed strategically throughout to help practitioners tailor the document.

The project team included a context diagram to illustrate the current (and, eventually, proposed) system as a whole and its inputs from and outputs to external entities or actors (Figure 6). The model ConOps file itself and all diagrams in the document are available as editable files, making it efficient for practitioners to tailor the text and diagrams to their specific implementation.

In addition to the context diagrams, the project team developed user needs and requirements for project-specific concept development (Table 1). These 10 examples can be leveraged or to cover all possible needs in rural corridors, but to provide illustrative and relevant starting points for further tailoring. These 10 examples can be leveraged for project-specific concept development in addressing similar needs for a specific corridor and can be used to help structure use cases for other targeted scenarios.

The model ConOps provides a more comprehensive description of each use case, including goals, constraints, geographic scope, actors, preconditions, main and alternate flows, postconditions, information requirements, and related user needs, along with illustrations available as editable files.


1 For more on ARC-IT service packages, visit https://local.iteris.com/arc-it/html/servicepackages/servicepackages-areasport.html. The user needs also are consistent with SAE J2735 standard candidate J3067: Candidate Improvements to Dedicated Short Range Communications Message Set Dictionary Using Systems Engineering Methods.
As mentioned, the project team also developed a companion model SyRS, in which the technical details for a project are formed. This document takes the user needs from the model ConOps and develops them into more detailed and specific requirements describing what the system or subsystem must do, without stipulating how the system must do it.

The structure of the model SyRS follows IEEE Standard 1233-1998. Like the model ConOps, the model SyRS was written to be modular so that the reader can keep or edit the requirements applicable to their proposed system or project and delete or ignore those that are not. The model SyRS also includes a preface and several notes to the reader to aid in tailoring the document.

The project team developed roughly 400 system-level requirements in eight categories, which can all be adapted by practitioners to reflect local implementation:

1. Functional requirements
2. Physical requirements: construction, durability, adaptability, and environmental conditions
3. System performance characteristics
4. System security

Notes:
ITC = intelligent transportation systems.

### TABLE 1 Model ConOps User Needs in Six Major Rural Connected Vehicle Groups

<table>
<thead>
<tr>
<th>User Needs Category</th>
<th>User Needs</th>
</tr>
</thead>
</table>
| Center Specific Needs         | Back Office  
|                               | Maintenance Management System  
|                               | Traveler Information System  
|                               | Emergency Management/Public Safety System  
|                               | Other Jurisdiction Traffic Management System  
|                               | Weather Service System  
|                               | Fleet and Freight Management System  
|                               | Event Promoters  
|                               | Third-Party Providers  
| Field Specific User Needs     | ITS Roadway Equipment  
| Agency Personnel Specific User Needs | Rural Agency Personnel  
| Support Environment Specific User Needs | Security Needs  
|                               | Positioning and Timing System  
| Vehicle-Specific Needs        | Basic Vehicle  
|                               | Commercial Vehicle  
|                               | Public Safety Vehicle  
|                               | Maintenance and Construction Vehicle  
|                               | Vulnerable Road User  
| System Level Needs            | Back Office  
|                               | Connected Vehicle Devices  

**NOTE:** ITS = intelligent transportation systems.

### TABLE 2 Example of Model ConOps User Needs

<table>
<thead>
<tr>
<th>Center Specific Needs</th>
<th>BACK OFFICE</th>
</tr>
</thead>
</table>
| C01                   | The Back Office needs the capability to collect aggregate, and fuse near-real-time traffic conditions (e.g., speeds). Traffic conditions may be obtained from a variety of sources, including ITS Roadway Equipment (e.g., loop detectors), Other Center Systems, Third-Party Providers, and from Vehicles through Connected Vehicle Roadside Equipment and the Cloud. Connected vehicles will provide probe data through basic safety messages (BSMs) to the Back Office that can be aggregated with other traffic data to support traffic management strategies, including but not limited to traffic signal operations, disseminating information on queue warnings or delays, and disseminating traveler information.  

**NOTE:** ITS = intelligent transportation systems.

### TABLE 3 Ten Sample Use Cases in the Model ConOps

<table>
<thead>
<tr>
<th>ID</th>
<th>Model ConOps Use Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>General Situational Awareness (collecting and disseminating connected vehicle data)</td>
</tr>
<tr>
<td>2</td>
<td>Rural Corridor Traffic Management &amp; Operations Strategies</td>
</tr>
<tr>
<td>3</td>
<td>Road Weather Management</td>
</tr>
<tr>
<td>4</td>
<td>General Freight—Freight-Specific Situational Awareness (data collection and dissemination)</td>
</tr>
<tr>
<td>5</td>
<td>Incident Response &amp; Management</td>
</tr>
<tr>
<td>6</td>
<td>Freight Event Notification—I2V Freight-Specific Information and Advisories</td>
</tr>
<tr>
<td>7</td>
<td>Work Zone Management</td>
</tr>
<tr>
<td>8</td>
<td>Animal Crossing Warning</td>
</tr>
<tr>
<td>9</td>
<td>Pedestrian/Cyclist</td>
</tr>
<tr>
<td>10</td>
<td>Non-Signalized Intersection Safety</td>
</tr>
</tbody>
</table>

**NOTE:** I2V = infrastructure-to-vehicle.

### Sample Note to Reader in Model SyRS

Note to reader: The key sections of this SyRS are Section 3 System Requirements, Section 4 System Interfaces, and Appendix A, the Needs-to-Requirements Traceability Matrix.
The model SyRS is provided as an editable file, and the context diagrams within the document are provided through a separate model ConOps file. In addition, the NRTM is provided as an editable table that can be used as a template for practitioners.

Field Utilization

The research project was completed in January 2021, and the two model systems engineering documents were posted as NCHRP Web-Only Documents for state agencies and practitioners to review and utilize. While the project was active, the team presented the project materials in several meetings and working groups to introduce the initiative and research products to the connected vehicle community.

The project team developed a plan that can be submitted to the NCHRP Implementation Support Program to help put the research into practice via webinars and workshops with target audiences and a pilot activity to tailor the two products with an agency planning a connected vehicle technology deployment on a rural corridor. The webinars would delve deeper into the process of how ConOps and SyRS content is developed and would prime participants to begin thinking about their local needs and unique situations. The workshop would expand on the webinars by providing walk-throughs, diagramming use cases and user needs development, and offering an introduction to breaking down user needs into requirements. The pilot activity then would guide agencies that participated in the webinars and workshop through the tailoring process. Specific activities would include helping agencies develop a stakeholder survey, reviewing interview questions, assisting in a stakeholder session, and developing use cases and user needs development, and offering an introduction to breaking down user needs into requirements.

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The needs-to-requirements matrix (NRTM) provides traceability among all user needs in the model ConOps and all system requirements in the model SyRS. This is invaluable to good SE practice when starting the design process. During the creation of the draft model SyRS, the project team identified system requirements that had no user need to which they could be logically traced. These requirements dealt primarily with physical aspects of connected vehicle roadside equipment and onboard units.

To remedy this gap, researchers added five new user needs. Normally, these would have been sent to a configuration control board or similar mechanism before being added to the ConOps. This demonstrates the value of creating the traceability matrix so that gaps can be addressed early when it is easier and cheaper to fix them. The final model ConOps reflects these five new user needs.

5. Information management
6. System operations: human factors, maintainability, and reliability
7. Policy and regulation
8. System life-cycle sustainment

Functional requirements form the backbone of what the system needs to accomplish. Researchers identified functional requirements for the six application needs areas: traffic conditions, work zones, road weather, incidents, rural safety, and freight operations. Table 4 shows an example of a parent requirement with three child requirements related to work zone management. Where appropriate, requirements may contain a note to the agency to assist in the agency’s understanding.

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### Table 4: Example of a Parent Requirement with Three Child Requirements

<table>
<thead>
<tr>
<th>Functional Requirements</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR-01</td>
<td>The following system requirements define the functions of the traffic management applications.</td>
</tr>
<tr>
<td>FR-01.01</td>
<td>The OBU shall broadcast messages containing traffic conditions data in accordance with SAE J2735 defined messages.</td>
</tr>
<tr>
<td>FR-01.02</td>
<td>The Connected Vehicle Roadside Equipment shall collect traffic conditions data from OBUs traveling through its coverage area.</td>
</tr>
<tr>
<td>FR-01.03</td>
<td>The Data Collection subsystem shall collect traffic conditions data from ITS Roadway Equipment.</td>
</tr>
</tbody>
</table>

NOTE: OBU = on-board unit; ITS = intelligent transportation systems.
Keeping our transportation system working in a way that supports communities, industry, and the broader economy requires more than vehicle fuel and technology. It takes transportation professionals with talent and experience to plan, design, build, operate, and maintain the system. For any transportation agency, having a workforce that is well matched to current and future needs is essential to fulfilling its mission. Today, technological and societal trends that affect transportation are evolving rapidly, raising new challenges and reshaping the dimensions of long-standing transportation issues and practices. And the transportation workforce is evolving, too. Younger generations of workers have priorities and preferences for professional development, workplace culture, and the issues they are most interested in that are different from other generations. Harnessing the right talent to work on the transportation issues of today and tomorrow means that agencies need to take a strategic approach to defining their needs and then recruiting and managing the right people.

To help agencies do this, the Cooperative Research Programs at the Transportation Research Board (TRB) has taken up many workforce topics. Recently published reports include:

- Airport Cooperative Research Program (ACRP) Research Report 217: Guidance for Diversity in Airport Business Contracting and Workforce Programs; and

The author is a senior program officer with the Transportation Research Board of the National Academies of Sciences, Engineering, and Medicine in Washington, D.C.
A Futurist Perspective

ANN HARTELL

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

Among them is NCHRP Research Report 980: Attracting, Retaining, and Developing the Transportation Workforce: Transportation Planners. Released in 2021, the report presents research into how transportation planners can contribute not only to the traditional functions of an agency’s planning office but also to broader, strategic decision making. The research included outreach to young planning professionals and more seasoned planners to explore generational differences that agencies need to understand so they can effectively recruit and retain the talent they need. Additional insights came from human resources staff. The research supported the development of a tool designed to help planning directors, human resources staff, and agency leadership define current and future planning workforce needs and develop talent profiles that can be used for recruiting, as well as for workforce training and development programs.

A full list of recent reports—along with current research on workforce topics—is available in the regularly updated Snap Search from the TRB library at http://onlinepubs.trb.org/onlinepubs/snap/workforce.pdf.

REFERENCE

Robert C. Hazlett is fond of the saying attributed to President Dwight D. Eisenhower—plans are nothing, planning is everything. As an engineer and planner, he works across the entire transportation infrastructure spectrum—from early concept stages through implementation and, if needed, the defense of a project. Much of his success has come from ensuring that plans are flexible enough to change in response to innovations, funding changes, and discoveries of needs previously unidentified. “Planning,” notes Hazlett, “is a continual process. In transportation, issues emerge, and new topics are realized throughout the life of a project.”

After 15 years with the Maricopa Association of Governments (MAG) in Phoenix, Arizona, Hazlett now oversees Act 11 Consulting, where he provides planning for transportation infrastructure. He also is an associate at Matrix Design Group, Inc., focusing on the company’s planning efforts throughout the western United States and in Guam, where he is assisting with the planning for a new medical center.

His engineering and management experience taps a systemwide view that is mindful of efficiency, value, and safety. He has a talent for connecting with people at different organizational levels and building trust for decisions among different—and often competing—entities.

These skills were honed over a long and fulfilling career that includes managing the Maricopa region’s voter-approved, $9 billion freeway program. “Most efforts were technical,” he explains, “and involved the review of engineering and planning documents, as well as coordinating with the Arizona Department of Transportation, FHWA, and more than 30 local agencies.”

Hazlett found the Transportation Research Board (TRB) to be a valuable resource. “There were many opportunities where the latest research supported the best work products for delivering this program,” he points out. Under his leadership, more than 860 lane-miles of transportation infrastructure were delivered through projects centered on public transportation and traffic operations, as well as bike, pedestrian, stormwater, and utility improvements.

Hazlett is no stranger to innovative, outside-the-box management. Many MAG efforts were performed during challenging times when expected revenues were not realized or project costs exceeded program resources. He met economic constraints by advocating cost-risk analysis programs, recommending practical designs, and promoting alternative project delivery choices whenever feasible, such as design–build and public–private partnerships. He also launched strategic high-capacity corridor analyses to establish context-sensitive recommendations, environmental statements, and transportation systems management and operations recommendations. Hazlett informed regional policy efforts on emerging technologies.

If asked to point to one defining moment in his career, without hesitation, Hazlett mentions Interstate 11, which will provide a trade corridor in the Intermountain West between Reno, Nevada, and Nogales, Arizona. Hazlett’s project management of long-range framework studies to identify infrastructure in emerging areas of Maricopa County led directly to U.S. congressional approval of the Interstate 11 designation.

Hazlett brings this view to two courses he teaches at Arizona State University’s School of Sustainable Engineering and Built Environment, a part of the Ira A. Fulton Schools of Engineering. Although his engineering business practices class is what one would expect—a comprehensive tour of engineering economics, ethics, business practices, and professional responsibilities—Hazlett’s transportation systems planning class focuses on policy and process. His lectures identify methods for planning, programming, designing, operating, and maintaining transportation infrastructure and, as he notes, “clearly demonstrate the role that research has played—and its value. Not only does research shape technical work products, but research is active in forming the backbone for many policy decisions about transportation infrastructure.”

Hazlett’s teaching is well informed by his experience: “In my career, it was working with elected officials where research proved to be most valuable. New ideas emerged—topics such as project delivery, asset management, express toll lanes, and automated vehicles were but a few matters studied and researched to help metro Phoenix decision makers decide transportation policy. The worldview provided by TRB and its community on these, and many other matters, helped shape local policies.”

Hazlett chaired the TRB Standing Committee on Transportation Planning Applications from 2013 to 2018 and now co-chairs TRB’s Transportation Planning and Analysis Section. He has participated in TRB’s Automated Travel and Shared Mobility Forum and chaired the TRB Conference on Performance and Data in Transportation Decision-Making. He has received the Arizona Engineer of the Year Award sponsored by ASCE and the American Public Works Association and has presented and participated in policy initiatives for AASHTO and the Association of Metropolitan Planning Organizations.
Soheil Nazarian believes in the power of curiosity. From his days as a civil engineering graduate student at the University of Tehran, Tufts University, and The University of Texas at Austin to his award of the Mr. and Mrs. McIntosh Murchison IV Chair of Engineering in 2004 at The University of Texas at El Paso (UTEP), Nazarian has followed his curiosity to the research lab and lecture hall, where he has imbued students with a zest for learning and a desire to foster innovation.

For four decades, Nazarian has watched—and participated in—UTEP’s growth from a teaching school to a well-respected research institution. He serves concurrently as director of UTEP’s Civil Engineering Graduate Program, director of the Center for Transportation Infrastructure Systems, and campus director and leader of the transportation thrust for the National Science Foundation’s (NSF’s) recently created Engineering Research Center for Advancing Sustainability Through Powered Infrastructure for Roadway Electrification (ASPIRE). “In addition to UTEP,” Nazarian explains, “ASPIRE’s multi-university consortium includes lead institution Utah State University, Purdue University, University of Colorado at Boulder, and University of Auckland, New Zealand.”

Designed to revolutionize the transportation and electric utility industries, research is focused on eliminating barriers to electric vehicle use. “This includes vehicles from passenger cars to heavy-duty trucks,” observes Nazarian. “Consider innovative charging solutions that bring power to the vehicle instead of bringing the vehicle to a power source, as it is common today. Perhaps we enable the wireless charging of vehicles while parked or moving at speed on a highway.” If electric power is provided sustainably and equitably, Nazarian sees these advances as “a way to make transportation more attainable and affordable for everyone.”

NSF funding of ASPIRE promotes engineering workforce development and emphasizes a culture of diversity. This is a good fit for Nazarian, a champion of the local community who has worked to make education attainable for minorities, women, and very low-income families. Since 2009, he has reformulated master’s and PhD programs to improve access for El Paso community members while maintaining the scholarly rigor of UTEP’s civil engineering graduate programs. “Providing one of the nation’s best value-added public educations was recognized in a 2017 Brookings Institution study ranking UTEP as the best of 342 public universities for research productivity and student social mobility,” Nazarian comments.

Nazarian has been a catalyst for change before. About 25 years ago, he and a colleague started a research center that is now UTEP’s Center for Transportation Infrastructure Systems. With a research portfolio of more than 30 diverse transportation projects, the center supports about 50 undergraduate and graduate students while preparing them to become the new professionals for the transportation workplace of the 21st century. “I have been lucky to be associated with the best undergraduate and graduate students,” he notes. “That they happened to be mostly local, Hispanic, and represent a balance of genders is very gratifying.” Nazarian credits the TRB Minority Student Fellows Program with introducing his students to the broad scope of the transportation engineering field and for repeatedly demonstrating how rewarding it can be to work in transportation research.

Nazarian, who has been engaged in the Texas Department of Transportation (DOT) research program continuously for his entire career, points out that “research and innovation drive the amazing advancement we see in the transportation field.” He acknowledges “my many Texas DOT colleagues, who have shown me that one must balance technical innovation with the practicality and simplicity required to implement it effectively.”

As faculty adviser for multiple engineering honor societies, Nazarian urges his students to maintain a work-life balance. He advises younger colleagues and students to “stay curious and try to learn something new every day to expand your own horizon.” This personal philosophy has enabled the diversification of Nazarian’s research from nondestructive testing to evaluation of infrastructure to material characterization and—now—to electrification of transportation infrastructure.

Nazarian, who chairs TRB’s Standing Committee on Geotechnical Instrumentation and Modeling, has been principal or co-principal investigator for more than 110 research projects and authored hundreds of papers and technical reports, primarily with his UTEP students. He is the recipient of several Texas DOT top innovation awards, numerous UTEP excellence in research awards, and the 2019 UTEP President’s Meritorious Service Award. The portable version of his commercially available seismic pavement analyzer, for which he holds a patent, has been used extensively to evaluate the properties and conditions of bridge decks and pavement layers.
How has TRB influenced your career so far?
The connections I have made through TRB committees and subcommittees have been the biggest thing for me. TRB allows junior members to meet senior professionals and puts us in the same place as creative peers from around the country.

What was one of your most memorable TRB Annual Meeting moments?
The seemingly annual D.C. snowstorms and related travel cancellations were always memorable, but the 2015 switch from the Connecticut Avenue hotels to the Walter E. Washington Conference Center was a big change. The meeting is definitely more centrally located now. At the same time, I loved the chilly walk from the Hilton to the Marriott after dark, when I could think about something I had heard in a committee meeting earlier that day.

How did you first hear about and become involved in TRB?
When I was an undergraduate, my professor was gone for the entire first week of the semester because he was off at the TRB Annual Meeting. Three years later, I went for the first time and became a friend of a committee immediately.

Greg Macfarlane
Greg Macfarlane is an assistant professor in the Civil and Construction Engineering Department of Brigham Young University in Provo, Utah. He is a member of the TRB Standing Committee on Transportation Demand Forecasting, the TRB Standing Committee on Economic Development and Land Use, and the Young Members Coordinating Council.

MEMBERS ON THE MOVE

National Academies of Sciences, Engineering, and Medicine members Frances Arnold, Eric Lander, and Maria Zuber have been named co-chairs of the President’s Council of Advisors on Science and Technology (PCAST). President Joe Biden also named 17 additional National Academies volunteers to PCAST: Dan E. Arvizu, Lisa A. Cooper, William Dally, Sue Desmond-Hellmann, Inez Fung, Andrea Goldsmith, Laura H. Greene, Paula Hammond, Eric Horvitz, Steve Pacala, Saul Perlmutter, William Press, Jennifer Richeson, Lisa T. Su, Kathryn Sullivan, Terence Su, and Catherine Woteki.

National Academy of Medicine and National Academy of Sciences member David Julius and National Academy of Sciences member Ardemen Patapoutian have won the 2021 Nobel Prize in Physiology or Medicine for their discoveries of receptors for temperature and touch. National Academy of Sciences members Syukuro Manabe and Giorgio Parisi have each won the 2021 Nobel Prize in Physics. National Academy of Sciences member David W. C. MacMillan received the 2021 Nobel Prize in Chemistry for the development of a molecular construction tool. National Academy of Sciences member David Card was awarded a Nobel Prize in Economic Sciences for empirical contributions to labor economics.

Monica Feit, deputy executive director for the Division of Behavioral and Social Sciences and Education at the National Academies, is the new executive director for the Health and Medicine Division.

Nathaniel P. Ford, Sr., and Shawn Wilson have been named chair and vice chair, respectively, of the 2022 TRB Executive Committee. Their terms begin during the 101st TRB Annual Meeting in January.

Ahmad Abu-Hawash joins TRB as an NCHRP senior program officer. Previously, Abu-Hawash was the chief structural engineer at the Iowa Department of Transportation.
Ensuring a Productive TRB Annual Meeting Experience for All Young Attendees

Through its Special Committee on Diversity, Equity, and Inclusion, TRB jointly hosted a webinar with the Council of University Transportation Centers on Friday, November 5. The webinar aimed to provide students and those early in their transportation careers with practical advice on how to get the most out of the TRB Annual Meeting.

TRB Senior Program Officer James Bryant opened by explaining, “I was in your shoes at one time—I was a student.” He encouraged attendees to get involved with TRB’s standing committees, all of which meet at the Annual Meeting, an event he described as a time to embrace “lifelong networking development opportunities. Everyone is welcome,” he emphasized, pointing out the new attendee orientation session. “Don’t be shy; allow the leaders in this industry to get to know you.”

Moderator Tanisha Hall of Fairpointe Planning in Nashville, Tennessee, was joined by panelists Nancy Beltran, Cement Council of Texas; April Greenhouse, Metropolitan Transit Authority of Harris County, Texas; Manny James, Washington State Department of Transportation; and Eleftheria Kontou, University of Illinois, Urbana–Champaign.

The panelists also encouraged attendees to get involved in some of TRB’s 170 standing committees. James became a member of the Standing Committee on Native American Transportation Issues by “submitting a paper and attending that committee. Because my paper was an expression of my interest, I took the initiative, introducing myself to the chair, attending its meeting, and I kept in the loop.”

Hall asked how panelists overcame the lack of diversity, that feeling that “when I walked into the room, there were not a lot of people who looked like me.” Beltran mentioned encouragement. “When you see somebody who looks like you or has a similar cultural background, you get encouraged—you get motivated. In my earlier years, I was, maybe, the only female in the room—and I’m Hispanic.” Now, if Beltran notices others who speak Spanish, she approaches them. “It feels good. You feel represented and encouraged. Efforts like the minority fellowship are important for that.”

Hall also asked why it is important to have different voices in committee discussions. Greenhouse, who represents an authority that provides public transportation, remarked that “we are required to focus on low-income [people], seniors, individuals with disabilities, and those who would not otherwise have modes of transportation. It’s imperative that you have those unique and different backgrounds sharing their experiences so we can identify research needs and problems. But sometimes, it can be challenging when you’re the only one who looks like you in the room.”

Kontou, who is originally from Greece, commented on the role of international attendees’ unique perspectives and the technical experiences they can add to the dialogue and presentations at the Annual Meeting.

Panelists also provided practical Annual Meeting tips. James reminded attendees to follow up with other attendees they meet, as these people may someday serve as job references. Kontou recommended that, before arriving, attendees practice for networking opportunities and for presenting their research: “Practice in low-stakes environments, with other students. This will help you be confident. Go to the speakers and ask questions on other people’s research. Network! Always follow up.” Greenhouse suggested that attendees download the TRB app to help them organize their schedules and to attend sessions with cross-cutting issues rather than just hone in on a single topic for the entire conference. “It’s helpful to print business cards to give out to fellow attendees,” Beltran advised, “as well as to write something on the back of a card about what was discussed with the person when you received their card.”

A recording of the webinar is available at https://vimeo.com/642850279.

—Karen Febey, Senior Report Review Officer, Transportation Research Board, National Academies of Sciences, Engineering, and Medicine
Investing in Transportation Resilience
A FRAMEWORK FOR INFORMED CHOICES

JOSEPH L. SCHOFER AND MONICA A. STARNES

Schofer is a professor emeritus of civil and environmental engineering at Northwestern University in Evanston, Illinois, and served as the chair of the study committee. Starnes is a senior program officer, Consensus and Advisory Studies Division, TRB, National Academies of Sciences, Engineering, and Medicine, Washington, D.C., and served as the study director for this project.

Natural hazards—from hurricanes to earthquakes—too often become disasters that wreak havoc on transportation systems. Damaged infrastructure is expensive to repair, restore, and replace, and travel disruptions adversely affect the economy and people’s quality of life. Resilience is a powerful concept that can be used to diminish these harms, especially when it is made a routine and deliberate part of transportation infrastructure planning and investment decision making.

For transportation systems, resilience—the ability to prepare for, and adapt to, changing conditions and to withstand and recover rapidly from disruption—is vitally important but increasingly challenging. With design lives of more than 50 years, long-lived and ubiquitous transportation systems have always been exposed to a wide range of natural hazards and their inevitable extremes. However, climate change is compounding the intensity and expanding the scale of natural hazards. It is increasing the likelihood of cascading events, where multiple hazards interact. It is creating new stressors on transportation assets constructed for different temperature and precipitation norms.

Meanwhile, the smooth and safe functioning of transportation infrastructure is under stress from everyday use. Across the country, many major transportation assets have outlasted their planned service lives by decades, yet they continue to be essential for accommodating traffic flows at levels unimagined in their original planning and design. Under these circumstances, ensuring that transportation systems are resilient—that is, able to withstand and recover rapidly from adverse conditions and events—has become vitally important but increasingly challenging.

At the request of Congress, a special committee of the National Academies of Sciences, Engineering, and Medicine (see box, page 40) was charged with identifying and developing metrics that can be used to support informed choices for investments in transportation system resilience. The committee’s report, Investing in Transportation Resilience: A Framework for Informed Choices, offers recommendations to Congress and the U.S. Department of Transportation (U.S. DOT) aimed at strengthening the resilience practices and capabilities of thousands of state, regional, and local transportation agencies.

The report explains how the country’s transportation system, along with hazards it faces, are too varied for a single metric—or even a small set of metrics—to have universal application in assessing resilience and guiding resilience investments. However, the committee’s review of both practice and research suggests that more can be done to make the assessment of resilience a more deliberate part of transportation asset management and investment decision making.

Investing in resilience requires decision makers to spend money today to gain benefits that may or may not be realized in the future. Where these risk-reducing projects compete with typical highway investments that may produce nearer-term and more certain benefits, decisions can be challenging. This makes estimating the prospective benefits of resilience investment options essential. The report describes a...
These steps lead to estimates of the likelihood and consequences of asset damages with and without the resilience investment—the costs avoided—which are the benefits expected from the investment. With estimates of implementation costs, this information can be used in a benefit–cost analysis framework to guide resilience investment decisions.

The report points out that, to estimate the benefits of investing in resilience, transportation agencies need high-quality data and analytic tools, including the following:

- Information on the characteristics of natural hazards and their likelihood in the location of existing and planned assets;
- Science-based and updated projections about future impacts of climate change on natural hazards and on temperature and precipitation norms in these locations;
- Strong asset management programs that include evaluations of asset vulnerabilities and functional criticality;
- Mode-specific data and modeling tools to estimate the direct and indirect consequences of asset damage and functional losses; and
- Data and tools that can reveal the economic and social importance of the asset to users, directly affected communities, and the broader region.

The report also emphasizes the importance of pilot activities for showing how resilience evaluations can be made a routine part of investment decision making and for demonstrating the application of the appropriate data and tools.

**RECOMMENDATIONS**

Although the report’s recommendations are directed at Congress and U.S. DOT, their ultimate purpose is to strengthen the resilience practices and capabilities of thousands of state, regional, and local transportation agencies. The five recommendations are the following:

- To ensure the routine and deliberate consideration of resilience to support the selection of major transportation investments, Congress should consider a requirement for which all projects that involve long-lived assets and are candidates for federal funding undergo well-defined resilience assessments that account for changing risks of natural hazards and environmental conditions stemming from climate change. These assessments could be integrated into environmental impact assessments or other project evaluation efforts, such as during benefit–cost analysis. The level of analytical effort expected in these resilience assessments should be reasonably related to the cost of the project being considered.
- The U.S. DOT Office of the Secretary of Transportation (OST) should promote the use of benefit–cost analysis for project justifications that consider the resilience benefits estimated using the multistep analytic framework recommended earlier. The benefits from adding resilience (reduced future losses), in relation to the life-cycle costs of doing so, should be promoted as the basis for selecting investments in resilience.
Given the success of the InfoPave web portal, FHWA developed additional portals to provide users with easy access to a large amount of data and information on highway infrastructure assets (bridges and pavements) and technologies that may be used to assess them. Information contained in these portals is obtained through various methods such as data collected by state departments of transportation (DOTs) and FHWA-sponsored research and materials testing.

**InfoPave**

InfoPave offers the transportation community easy access to more than three decades of pavement performance data. The purpose of the LTPP Program is to gather high-quality data needed to understand pavement performance and the variables affecting it and to make this data available for research and product development well into the future. Users of InfoPave can select, download, and view these data through a variety of features available within the portal.

Since its initial release, InfoPave has evolved to accommodate changing technology, additional data, and enhanced features and tools. InfoPave consists of eight primary hubs accessible via the menu system: home, data, visualization, analysis, tools, library, operations, and non-LTPP.

**InfoBridge**

The Long-Term Bridge Performance (LTBP) Program was established to help the bridge community better understand bridge performance. The objectives of the LTBP Program is to gather high-quality data needed to understand pavement performance and the variables affecting it and to make this data available for research and product development well into the future. Users of InfoPave can select, download, and view these data through a variety of features available within the portal.

Since its initial release, InfoPave has evolved to accommodate changing technology, additional data, and enhanced features and tools. InfoPave consists of eight primary hubs accessible via the menu system: home, data, visualization, analysis, tools, library, operations, and non-LTPP.

**FHWA Expands Access to Highway Infrastructure Engineering Research Data**

**DEBORAH WALKER**

The author is a research civil engineer with FHWA in Washington, D.C.

In recent years, FHWA has developed a series of web portals to provide greater access to its highway infrastructure engineering research data and information. Users can access these portals without a username or password.

The FHWA family of “Info” web portals—InfoPave, InfoBridge, InfoMaterials, and InfoTechnology—began with the 2014 release of the Long-Term Pavement Performance (LTPP) Program’s InfoPave, which provides easy access to the pavement performance data collected from more than 2,500 LTPP test sections located throughout North America.
a variety of tools and research results such as historical changes to bridge design specifications and deterioration models for predicting the future condition of bridges and their components.

The portal includes multiple tools for storage, retrieval, dissemination, analysis, and visualization of bridge data collected through state, national, and LTBP Program efforts. With InfoBridge, users can holistically assess bridge performance on a network or individual-bridge basis.

**InfoMaterials**

InfoMaterials is a web-based portal that provides easy access to FHWA’s infrastructure materials testing and research data. First released in January 2020, InfoMaterials is designed as a user-friendly portal to host data sets containing asphalt and concrete materials characterization data, pavement performance testing and analysis results, and many other types of structured and unstructured research data.

In its first release, InfoMaterials contained three data sets. The January 2021 release included six additional FHWA pavement- and materials-related research data sets.

InfoMaterials offers storage, retrieval, dissemination, and visualization capabilities for highway infrastructure engineering

(Continued on page 42)
research data collected through FHWA research projects. InfoMaterials incorporates features, such as maps, graphs, and filters, to facilitate data set visualization and navigation.

InfoTechnology
Launched in the summer of 2021, InfoTechnology educates practicing transportation engineers, university students, and others about nondestructive evaluation (NDE) technologies used to assess highway infrastructure components.

This web portal is based on an earlier NDE Web Manual, an FHWA research project that created a framework for NDE technologies addressing bridge assets. InfoTechnology, offering a completely new user interface design, expands the content of the NDE Web Manual to include NDE technologies for bridge, pavement, and tunnel components. In the future, FHWA plans to enhance the portal and incorporate structural health-monitoring technologies and other features.

For more information about the FHWA Info portals, contact Jean Nehme of FHWA at jean.nehme@dot.gov.

(Continued from page 41)
**Improving Departure Management to Save Jet Fuel**

North Carolina’s Charlotte–Douglas International Airport saved more than one million gallons of jet fuel from September 29, 2017, to May 16, 2021, thanks to NASA’s Airspace Technology Demonstration-2, or ATD-2.

Departures can be prone to a lack of information sharing during the gate-to-cruising-altitude phase. This can cause overloaded runways and excessive taxi and hold times. Significant uncertainty in the duration of the taxi-out, takeoff, and climb phases also may lead to inaccurate demand predictions, decreased situational awareness, and overly conservative airspace restrictions that traffic managers may apply to compensate for this uncertainty.

Using precision scheduling technology to improve departure management, ATD-2 created a significant savings in jet fuel and enabled fewer CO\(_2\) emissions, less wear and tear on engines, lower flight crew costs, and passenger time savings valued at approximately $4 million.

According to NASA, the FAA plans to roll out this technology to 27 major airports. Shawn Engelland, NASA’s ATD project manager, sees this as “only a drop in the bucket of what’s possible in the future.”

**Pedaling Away**

During the COVID-19 pandemic, 2020 bike sales soared, and fitness apps captured record increases in bicycling. Whether for leisure, fitness, adventure, or leaving the home office, Americans pedaled more.

In 2021, states like Utah responded. The Utah Department of Transportation (DOT) completed more than 550 miles of newly designed bike routes on the U.S. Bicycle Routes System, an AASHTO-approved cycling route network that traverses more than 17,734 miles across 31 states and the District of Columbia.

Utah now boasts 960 total bike miles that include streets, highways, and trails crisscrossing the state. East–west routes touch Colorado’s western edge and lead to Nevada. North–south routes stretch from the Idaho border to Arizona.

Adventure Cycling, a national cyclist advocacy group working to add more miles of safe, connected routes in the United States, partnered with the Utah DOT and Move Utah to develop the north–south state-to-state route.

*For more information on ATD-2, see [https://www.nasa.gov/aeroresearch/nasa-testing-saves-airlines-one-million-gallons-of-jet-fuel](https://www.nasa.gov/aeroresearch/nasa-testing-saves-airlines-one-million-gallons-of-jet-fuel).*
Guide to Bridge Preservation Actions, 1st Edition
AASHTO, 2021, 375 pp., AASHTO members, $240; nonmembers, $324, 978-1-560-51745-0.

This book offers guidance on selecting specific, cost-effective preservation and maintenance actions and treatments for agencies wishing to extend service life and estimate needed budgets to optimize performance of bridge inventories. It can be used to help preserve bridges and extend their service life by selecting cost-effective actions and treatments for various bridge elements based on exposure.

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

Transportation Research Record 2675
Issue 5
Among the topics explored in this volume are the role and evolution of factors influencing rapid transit planning in Ecuador, considering monthly traffic demand and battery performance variations when placing electric vehicle chargers in Michigan, and an exploratory analysis of unmanned aircraft sightings using text mining.
2021; 452 pp. For more information, visit http://journals.sagepub.com/home/trr.

Transportation Research Record 2675
Issue 6
Authors present research on sidewalk static obstructions and their impact on clear width, a cross-national focus group response to autonomous vehicles, and more. This issue also includes papers from the TRB Graduate Research Award Program on Public-Sector Aviation Issues.

2021; 464 pp. For more information, visit http://journals.sagepub.com/home/trr.

Transportation Research Record 2675
Issue 7
An arterial-friendly local ramp metering control strategy, geofencing to enable differentiated road user charging, and a multistage approach for empty container repositioning under coordination among liner carriers are examined in this volume.
2021; 628 pp. For more information, visit http://journals.sagepub.com/home/trr.

Transportation Research Record 2675
Issue 8
Authors present research on free transit passes and school attendance among high school students, an evaluation of a transportation incentive program for affordable housing residents, exposure-based models of trail user crashes at roadway crossings, and more.
2021; 683 pp. For more information, visit http://journals.sagepub.com/home/trr.

Asphalt Binder Aging Methods to Accurately Reflect Mixture Aging
NCHRP Research Report 967
This report documents research conducted to improve laboratory binder conditioning methods to accurately simulate the short-term and long-term aging of asphalt binders and to calibrate the improved procedures to the aging that occur during mixture production, transport, and placement, as well as during the service life of the pavement structure.

SAGE is the publisher of the Transportation Research Record: Journal of the Transportation Research Board (TRR) series. To search for TRR articles, visit http://journals.sagepub.com/home/trr. To subscribe to the TRR, visit https://us.sagepub.com/en-us/nam/transportation-research-record/journal203503#subscribe.
Mainstreaming System Resilience Concepts into Transportation Agencies: A Guide
NCHRP Research Report 970
This report offers transportation officials a self-assessment tool to evaluate agency efforts to improve the resilience of the transportation system by mainstreaming resilience concepts into agency decision making and procedures. The tool can be applied to a broad array of natural and human-caused threats to transportation systems and services.

Performance Metrics for Public–Private Partnerships
NCHRP Synthesis 563
This synthesis documents key performance metrics used in various long-term public–private partnership contracts for the delivery of highway projects, including services by state departments of transportation (DOTs).

Practices for Selecting Pedestrian and Bicycle Projects
NCHRP Synthesis 564
This synthesis documents and summarizes state DOT practices for selecting pedestrian and bicycle projects, excluding design elements. State DOTs conduct planning and administer funding programs for the implementation of pedestrian and bicycle projects. The amount of federal funds available for these projects has grown steadily since 1992 under programs implemented as part of the Intermodal Surface Transportation Efficiency Act.

Evaluating the Traveler’s Perspective to Improve the Airport Customer Experience
ACRP Research Report 231
Today’s airports are becoming places to dine, shop, relax, work, and interact. This report presents information and tools to better understand the traveler’s perspective of the airport journey and how airports might respond to the evolving needs of travelers. Supplemental materials include a multimedia tool.

Playbook for Cultivating Talent in the Airport Environment
ACRP Research Report 232
The airport environment is facing a shortage of individuals who can lead, guide, manage, and carry out airport-centric initiatives to support the aviation industry. This report provides inspiring, proven, and readily implementable techniques for airport leaders and managers to use to enhance talent cultivation and knowledge transfer within airport organizations.

Legal Implications of Data Collection at Airports
ACRP Legal Research Digest 42
As technology evolves, airports collect more data from passengers, employees, tenants, concessionaires, airlines, and others. This digest includes a survey of applicable law; considerations for the collection and safekeeping of data; and a review of the issues that arise related to data collection among airports, their tenants, and other users. It also offers an understanding of the expansion in law around data collection and use.

An Update on Public Transportation’s Impacts on Greenhouse Gas Emissions
TCRP Research Report 226
This report offers an updated national analysis of public transportation’s role as a climate solution by documenting its 2018 greenhouse gas emissions impacts.

Transit Agency Relationships and Initiatives to Improve Bus Stops and Pedestrian Access
TCRP Synthesis 152
This synthesis summarizes the current state of practice for bus stop and pedestrian infrastructure improvement programs and processes in place at transit agencies and other public organizations.
of headway-based service operations and focuses on the proactive use of intelligent transportation systems technologies to optimize these services.

2021; 96 pp.; TRB affiliates, $55.50; nonaffiliates, $74. Subscriber categories: operations and traffic management, public transportation.

Innovative Practices for Transit Planning at Small to Mid-Sized Agencies
TCRP Synthesis 154
This synthesis documents innovative practices for solving transit planning challenges faced by small and mid-sized transit agencies. These challenges include concerns about ridership, demographic shifts, first- and last-mile transportation, land-use changes, regulation changes, service design, funding challenges, service delivery, and technology changes. These challenges are applicable to fixed-route, flex-route, and demand-responsive transit services.

2021; 160 pp.; TRB affiliates, $66; nonaffiliates, $88. Subscriber categories: planning and forecasting, policy, public transportation.

Intelligent Transportation Systems in Headway-Based Bus Service
TCRP Synthesis 155
Intelligent transportation systems and computer-aided dispatch and automatic vehicle location have become quasi-universal in urban bus operations and support a variety of functions. This synthesis presents the current state of the practice want to develop and adopt a data-driven culture.

2021; 98 pp.; TRB affiliates, $55.50; nonaffiliates, $74. Subscriber categories: data and information technology, public transportation.

Let’s Hear from You!
Many of you are familiar with the TR News Centennial Quotes feature borrowed from the musings you posted in the Tell Us Our Story segment of TRB’s website. You’ve had such great things to say, and with TRB’s centennial year officially over, TR News has continued publishing your words in our Volunteer Voices segment. Now, we’re going a step further by introducing our own question-and-answer spinoff, and you’re invited to participate.

In each issue, we will pose a single—and mostly light and fun—transportation-related question. To answer, just e-mail us at TRNews@nas.edu and follow these few simple rules:

• Include “Volunteer Voices: [the question you’re answering]” in the subject line;
• Answer the question thoroughly, but keep it brief (sorry, but we can’t publish the first chapter of your new book); and
• Attach a current high-res (300 dpi and/or 1 MB minimum) headshot of yourself.

That’s it!
When the issue is published, we’ll send you a PDF of the page that features your response. Please note that, like all TR News content, your response will be subject to editing for grammar, length, and TRB style. And we may need to contact you for clarification, so add us to your contact list.

Now that you have the details, here is the question:

What TRB resource have you found yourself going back to time and time again?

To order the TRB titles described in Bookshelf, visit the TRB online bookstore, www.TRB.org/bookstore, or contact the Business Office at 202-334-3213.
In 1973, Horst Rittel and Melvin Webber, urban planning theorists and professors at the University of California, Berkeley, published *Dilemmas in a General Theory of Planning*. The academic paper presented a formal theory of the typical problems that planners work on, dubbing them “wicked problems” (1). According to the theory, what makes a problem wicked is not just that it is hard to solve, but it also has the following characteristics—among others—shown in Figure 1:

- **It is hard to define.** Without already knowing about its context, causes, and how it might be solved, a wicked problem is not sufficiently clear to enable identification of the best solution. This means that planners have to work on understanding the solutions at the same time they are defining the problem, which makes it hard to apply straightforward, linear models or decision-making processes.
- **It has no “stopping rule” that indicates when the problem has been solved.** Instead, planners stop working on a wicked problem for other reasons. Maybe they ran out of time or resources or found a good enough solution that stakeholders accept.
- **It is a symptom of another problem.** Planners often find that they are “peeling the onion” as they work through a problem; that is, they are discovering new levels and layers and seeing more dimensions of what is causing the problem and where solutions might lie. Any solution can create or reveal a new problem.
- **It is unique.** Planners can’t assume that a solution that worked in the past for a seemingly similar problem will work again because the particular context and people involved can create very different conditions and may have very different ideas about what solutions are acceptable.
- **Solutions are judged to be good or bad, depending on individual values and perspectives rather than on an objective standard.** For example, a solution that charges everyone the same amount of money to use a toll road could be considered equitable by some and deeply inequitable by others.

Rittel and Webber’s theory of wicked problems is a cornerstone of planning theory. It provides a valuable framework for thinking about how to tackle the sorts of problems transportation agencies routinely face in making policy decisions, allocating resources, balancing stakeholder needs, and considering trade-offs among potential solutions.

—Ann Hartell, Senior Program Officer, Transportation Research Board, National Academies of Sciences, Engineering, and Medicine, Washington, D.C.

**REFERENCE**


**FIGURE 1** Characteristics of wicked problems. [Source: Christian Sarkar, Wikimedia Commons, adapted from Rittel and Webber (1).]
## MEETINGS, WEBINARS, AND WORKSHOPS

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<td>TRB Webinar: Power Up! Implementing an Airport Microgrid</td>
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<td>8</td>
<td>TRB Webinar: Examining Exclusions—What’s Missing in the Historic Review Process?</td>
<td>For more information, contact, Elaine Ferrell, TRB, 202-334-2399, <a href="mailto:TRBwebinar@nas.edu">TRBwebinar@nas.edu</a>.</td>
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<td>8–10</td>
<td>Accelerated Bridge Construction Conference*</td>
<td>Online For more information, contact Stephen Maher, TRB, 202-334-2955, <a href="mailto:SMaher@nas.edu">SMaher@nas.edu</a>.</td>
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<td>15</td>
<td>TRB Webinar: The Mighty River—Inland Waterway Resilience Analysis</td>
<td>For more information, contact, Elaine Ferrell, TRB, 202-334-2399, <a href="mailto:TRBwebinar@nas.edu">TRBwebinar@nas.edu</a>.</td>
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<tr>
<td>16</td>
<td>TRB Webinar: Hit the Ground Running—Innovative Concrete Pavements in Roundabout Design</td>
<td>For more information, contact, Elaine Ferrell, TRB, 202-334-2399, <a href="mailto:TRBwebinar@nas.edu">TRBwebinar@nas.edu</a>.</td>
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### January

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<th>Date</th>
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### In Memoriam

Juanita Michelle Owens, a member of the AASHTO Research Advisory Committee and the NCHRP Project Panel on IDEA (Innovations Deserving Exploratory Analysis), died July 10, 2021, in Tuscaloosa, Alabama.

### Volunteer Voices

Two of my most memorable TRB Annual Meeting experiences include having the opportunity to present my research work in front of a group of smart professionals. I also was fortunate to meet some of the world’s top-notch researchers.

—KOHINOOR KAR

Transportation Engineer Manager

Arizona Department of Transportation, Phoenix

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*TRB is cosponsor of the meeting.
INFORMATION FOR CONTRIBUTORS TO TR NEWS

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

ARTICLES

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

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

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

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

RESEARCH PAYS OFF highlights research projects, studies, demonstrations, and improved methods or processes that provide innovative, cost-effective solutions to important transportation-related problems in all modes. Research Pays Off articles should describe cases in which the application of project findings has resulted in benefits to transportation agencies or to the public, or in which substantial benefits are expected. Articles (approximately 750 to 1,000 words) should delineate the problem, research, and benefits, and be accompanied by the logo of the agency or organization submitting the article, as well as one or two photos or graphics. Research Pays Off topics must be approved by the RPO Task Force; to submit a topic for consideration, contact Nancy Whiting at 202-334-2956 or nwhiting@nas.edu.

OTHER CONTENT

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

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

SUBMISSION REQUIREMENTS:

» Articles submitted for possible publication in TR News and any correspondence on editorial matters should be sent to the TR News Editor, Transportation Research Board, 500 Fifth Street, NW, Washington, DC 20001, 202-334-2986 or 202-334-2278, and lcamarda@nas.edu or cfranklin-barbajosa@nas.edu.

» Submit graphic elements—photos, illustrations, tables, and figures—to complement the text. Images must be submitted as TIFF or JPEG files and must be at least 3 in. by 5 in. with a resolution of 300 dpi. Large photos (8 in. by 11 in. at 300 dpi) are welcomed for possible use as magazine cover images. A detailed caption must be supplied for each graphic element.

Note: Authors are responsible for the authenticity of their articles and for obtaining written permissions from publishers or persons who own the copyright to any previously published or copyrighted material used in the articles as well as any copyrighted images submitted as graphics.
The Transportation Research Board (TRB) 101st Annual Meeting will be held January 9–13, 2022, in Washington, D.C. The event is expected to attract thousands of transportation professionals from around the world.

The meeting program will cover all transportation modes, with sessions and workshops addressing topics of interest to policy makers, administrators, practitioners, researchers, and representatives of government, industry, and academic institutions.

A number of sessions and workshops will focus on the spotlight theme for the 2022 meeting: Innovating an Equitable, Resilient, Sustainable, and Safe Transportation System.

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