TR NEWS

January–February 2021 NUMBER 331

Challenges of Truck Size and Weight

PLUS

What Will Airports Be Like in 2040 and 2070?

Post-Hurricane Supply Chain Resilience

Hawai‘i Interstate High-Tech Revamp

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

TRB
TRANSPORTATION RESEARCH BOARD

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

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

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

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

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

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

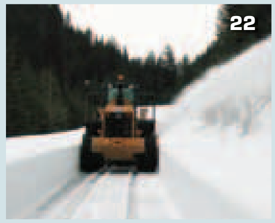
The **Transportation Research Board** is one of seven major programs of the National Academies of Sciences, Engineering, and Medicine. The mission of the Transportation Research Board is to provide leadership in transportation improvements and innovation through trusted, timely, impartial, and evidence-based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

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

TRB

TR NEWS

Number 331 / January–February 2021



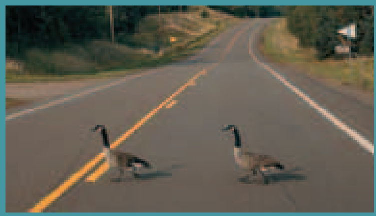
COVER Trucks on I-84 in Oregon sit in stopped traffic, caused by bad weather and crashes on the highway. State crash databases often do not include data on individual truck weight; improved data can help states evaluate truck size and weight regulations, observes author Daniel Haake in this issue of *TR News*. (Photo: Oregon DOT)

TRB COVID-19 Resources

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

Coming Next Issue

In the March–April 2021 issue of *TR News*, read highlights from the 2021Transportation Research Board Annual Meeting and explore mobility and human trafficking, near-road air quality, and how to make safer roadway crossings for small wildlife.



Though efficient, these Canada geese are not crossing the road safely. An article in the upcoming issue of TR News *examines the latest research on safe wildlife crossings.*

Photo: Tony Webster, Wikimedia Commons

Also in This Issue:

TR NEWS

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

***TR News* is produced by**
Transportation Research Board
Publications Staff
Eileen P. Delaney, Director of Publications
Lea Camarda, Editor
Cassandra Franklin-Barbajosa, Editor
Jennifer G. Correro, Assistant Editor

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

Editorial Correspondence: By mail to the Publications Office, Transportation Research Board, 500 Fifth Street, NW, Washington, DC 20001, by telephone 202-334-2986 and 202-334-2278, by fax 202-334-3495, or by e-mail lcamarda@nas.edu and cfranklin-barbajosa@nas.edu.

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

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

Printed in the United States of America.

WAY OF THE FUTURE

Airports at the Horizon of 2040 and 2070

Photo: James Marvin Phelps, Flickr

GAËL LE BRIS

The author is a senior aviation planner and senior technical principal, WSP USA, Raleigh, North Carolina, and a member of the TRB Aviation Group Executive Board.

This article is adapted from a presentation given at the TRB 99th Annual Meeting in January 2020. *The Future of Airports: A Vision of 2040 and 2070* is a research initiative of the Airport Think Tank of ENAC Alumni, which brings together aviation thought leaders from different backgrounds and affiliations. The white papers of this project are available at https://www.alumni.enac.fr/en/the-future-of-airports/publications-3560.

Above: Morning sun greets Terminal 3 of McCarran International Airport in Las Vegas, Nevada. As new air- and landside aviation technologies come into play, airports will be crucial in connecting residents to the world.

The population of the United States will reach about 375 million in 2040 and nearly 420 million in 2070 (*1*). By 2050, this growth will result in the emergence of 11 megaregions, identified by the Regional Planning Association as areas of interrelated population and employment centers sharing common transportation networks, cultures, and environmental characteristics (*2*).

In the meantime, the worldwide population will increase at an even faster pace—approximately 9 billion people in 2040 and approximately 10.5 billion in 2070 (*3*). Most of this growth will occur in Asia and Africa. In the meantime, living conditions in emerging and underdeveloped regions will improve, leading to a dramatic increase in air travel demand and requiring new airports and more regional integration.

Approximately 68 percent of the worldwide population will live in urban areas by 2050. The advent of new, large metropolitan areas will create challenges in mobility but also will lead to new aviation megacities. The size of these conurbations (Figure 1) and the congestion on the ground may promote the development of multiairport systems and secondary airports. Smaller and rural communities may also revive and grow, with people seeking another way of life. Local airports will continue to play a vital role in connecting residents to the world, using a variety of new technologies.

Smart Airports and Intelligent Technologies

The information technology (IT) revolution in the passenger journey is already here (*4*). Passengers are exchanging data and receiving personalized information via their smartphones. Miami International Airport, for example, has installed more than 400 Bluetooth beacons in its terminals to keep passengers connected wirelessly.

These connected technologies can provide georeferenced information that improves accessibility for travelers, with

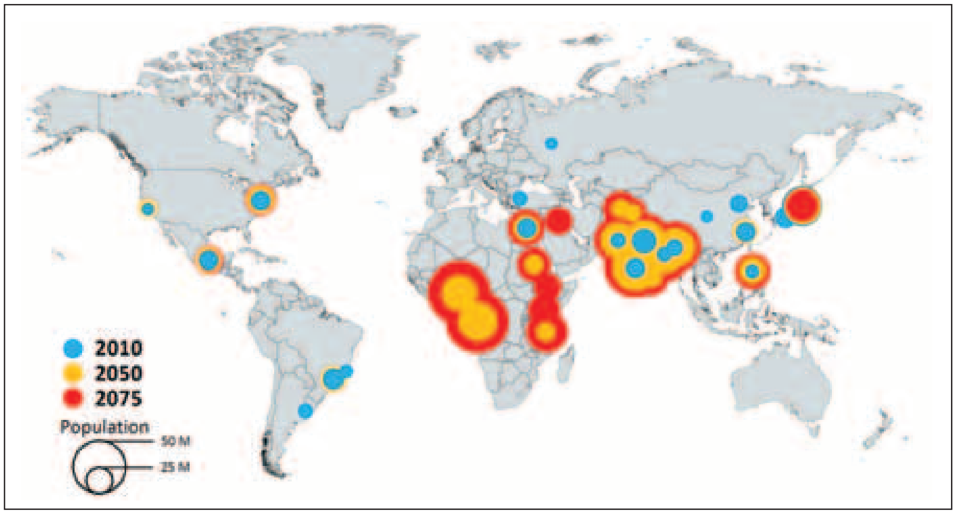


FIGURE 1 **Map of the 20 largest metropolitan areas from 2010 to 2075. (Source: Global Cities Institute, 2014.)**

virtual wayfinding that suits various languages, cultures, neurological expressions, and special needs. In return, the Internet of things and the Internet of everything provides airports with information on their passengers. The collection and treatment of this volume of data requires adequate standards and infrastructure for supporting data transfer and storage; because of this, most commercial airports maintain their own data centers.

Emerging ways and processes to analyze data are dramatically expanding the horizon of possibilities. These intelligent technologies will be the backbone of a second IT revolution. Machine learning and artificial intelligence can already extract patterns and trends for planning, situational awareness, or decision making. In the near future, deep learning using artificial neural networks and deep automation will assist, supplement, and even replace human analysis and decision making in domains such as operational resource management and asset management. However, airports that increasingly rely on information and intelligent systems will become more dependent and, therefore, more vulnerable to cyberattacks and technical incidents (*5*).

Advancing Safety Worldwide

During most of the 20th century, airfield standards were mainly conservative and prescriptive. The progress of the knowledge in flight operations and airfield engineering showed that these standards often overestimated—and sometimes underestimated—risks. These research efforts created a momentum that led to the rise of a risk-based approach and to the redefinition of many standards (*6–7*). Airfield design standards have reached an exceptional maturity (*8*). Mitigations such as engineered materials arresting systems were developed to address the most impactful deviations to these standards. Beyond these design features, the implementation of safety management systems (SMS) at U.S. airports will continue to advance safety (*9–10*).

The next frontier to improve airside safety is real-time information and intelligent systems that will increase both operational performance and safety (Figure 2). For example, a more systematic reporting of accidents and incidents—including those occurring in the non-movement area—as well as the centralization of these data can offer airports a detailed vision of safety issues. The future of airside safety also resides in onboard aircraft equipment such as runway incursion prevention systems, or RIPS, and runway overrun awareness and alerting systems, or ROAAS. Many pilots already have dynamic airport moving charts in their electronic flight bags, which are on tablets. The next step could include, for instance, enhanced

Photo: Federal Aviation Administration

An engineered materials arrestor system (EMAS) bed with side steps to allow access to rescue personnel and passenger egress. For more information on EMAS, see FAA Advisory Circular 150/5220-22B, *Engineered Materials Arresting Systems for Aircraft Overruns.*

FIGURE 2 Long-term trends in aviation safety. (Source: *The Future of Airports,* 2020.)

real-time guidance during taxiing based on controller–pilot data link communications.

It is vital to acknowledge that the level of safety is not the same throughout the world (*11*). Airports and oversight authorities shall work to address the deviations to standards (*12*). Currently, average global effective implementation of the U.N. International Civil Aviation Organization's (ICAO's) aerodromes standards and recommended practices is only 62 percent (Figure 3). Underperforming regions need to facilitate a safety revolution, with specific progress in the funding, governance, and continuous improvement of aviation safety (*13*).

In some cases, institutions such as the World Bank and other assistance mechanisms can provide funding to infrastructure projects and studies. ICAO support is also offered as part of the No Country Left Behind initiative. Direct cooperation between airports and field operations teams to address specific regional and international issues and the dissemination of industry best practices also can efficiently fast-track safety progress.

Accommodating Emerging and Future Users

The fleet of aircraft in the field and in the air is becoming more diverse. Innovative vertical takeoff and landing vehicles promise a new era of aerial mobility. These vehicles will be safer, cheaper, quieter, and more environmentally friendly than today's helicopters.

Electric fixed-wing aircraft prototypes have been tested for a few years and have promising applications for general and regional aviation. Although the feasibility of powering large aircraft with electric-only engines has not yet been clearly established, hybrid–electric propulsion systems are on the horizon. Electric powertrains are powered either by batteries or fuel cells using hydrogen, both of which will require adaptation of airport infrastructure and operations as investigated by the TRB Airport Cooperative Research Program (ACRP) (*14*).

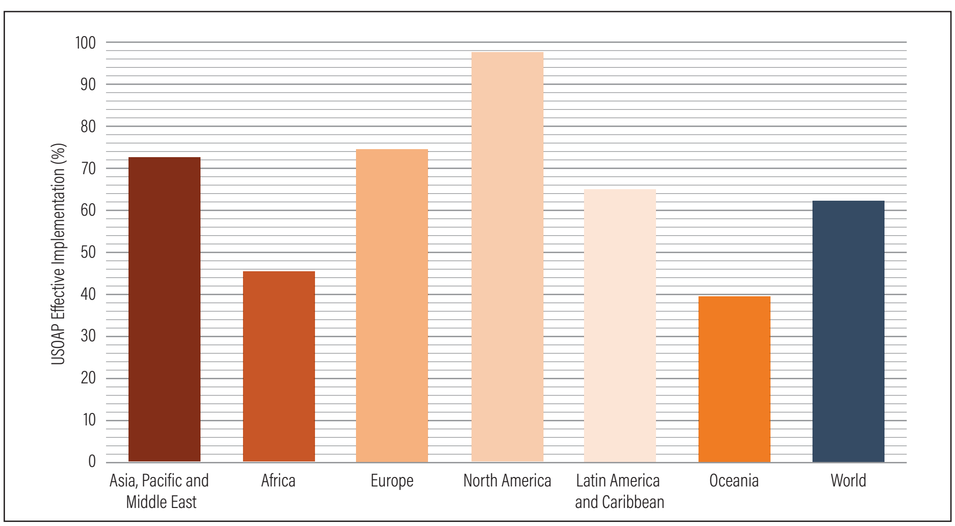


FIGURE 3 ICAO's Universal Safety Oversight Audit Programme (USOAP) effective implementation on aerodrome and ground aids. (Source: ICAO iSTARS API Data Service, 2020.)

Other aviation energy vectors include sustainable aviation fuels and, perhaps as soon as 2035, liquid hydrogen used as a fuel for combustion into turbojets or turboprops.

Single-aisle aircraft are now being used for long-haul international services. This is opening new opportunities for small and medium hub airports, but it calls for more versatile terminal facilities and aprons (Table 1). On the other end, the next generation of jumbo aircraft is already here—the Airbus A350-1000 and Boeing 777-9. In the long term, further urbanization and the scarcity of airside and airspace capacity will still make the case for larger aircraft. Also, the configurations of the next generation of airliners might incorporate groundbreaking features increasing compatibility and efficiency (Table 2).

Supersonic aircraft will likely be back in the air by 2040 (Table 3). It will be more cost-efficient than Concorde, and it will incorporate low-boom technologies that could make the supersonic overflow of inhabited areas socially acceptable. However, this should not hinder industry efforts to reduce aviation's environmental footprint. New standards will be needed to regulate the emissions and noise of these aircraft (*15*). Even faster transport aircraft using hypersonic technology—first proposed at the end of World War II—could appear by 2070. These vehicles could reduce the flight time from New York City to Shanghai from more than 15 hours to about 40 minutes.

Some of these new technologies might change the way we fly and consume air mobility. They also may facilitate such innovative business models as service providers focused on mobility-as-a-service, which would integrate the first and last miles with the airport experience and the flight itself. This can create opportunities

TABLE 1 Characteristics of Selected Airliners at the 2025 Horizon

MANUFACTURER	Airbus	Airbus	Boeing	Embraer	Mitsubishi
TYPE	A220-300	A321XLR	777-9	E195-E2	M100
EXPECTED EIS	2020	2023	2021-2022	2019	2023
WINGSPAN × LENGTH	35.1 m × 38.7 m (115 ft. × 126 ft.)	35.8 m × 44.5 m (117 ft. × 146 ft.)	64.8 m × 76.7 m[3,4] (213 ft. × 252 ft.)	35.1 m × 41.5 m (115 ft. × 136 ft.)	27.8 m × 34.5 m (91.3 ft. × 113 ft.)
ENGINES	2	2	2	2	2
SEATS	120-150	200-244	349-426	120-146	76-84
MAX. RANGE	3,350 NM 6,200 km	4,700 NM 8,700 km	7,300 NM 13,500 km	2,600 NM 4,800 km	1,900 NM 3,550 km
RUNWAY LENGTH REQUIREMENT[1]	2,743 m (9,000 ft.)	2,800 m (9,200 ft.)[2]	3,050 m (10,000 ft.)[2]	1,750 m (5,141 ft.)	1,760 m (5,770 ft.)

NOTE: EIS = entry into service; NM = nautical mile(s).
[1] Takeoff requirement assuming maximum takeoff weight (MTOW), standard conditions (ISA), sea level, and dry runway.
[2] Based on data released for the A321neo and the 777-300ER. Publication of model-specific data pending.
[3] A stretched version of the 777-10X with an overall length of 80 meters (263 feet) has been considered.
[4] The 777-8 and 777-9 will have folding wing tips (FWT). When FWT are unfolded at takeoff and landing, the wingspan will be 71.8 meters (235 feet).

TABLE 2 Innovative Aircraft Features and Their Impact on Airport Compatibility Enhancing Operational Performance and Resilience

DESIGN FEATURE	COMMENTS ON AIRFIELD COMPATIBILITY	EXAMPLE(S)
Prop Fan (Open Rotor)	Fewer emissions but typically noisier than comparable turbojets.	Antonov An-70 Boeing 7J7
Tail-Mounted Engines	Less noise to the ground when airborne than comparable turbojets. Lower hazards for ground handling. Low risk of FOD ingestion. Jet blast hazard at higher height.	Airbus A30X CleanSky HSBJ
High-Aspect Ratio Wings	Wider wingspan might warrant folding wingtip technologies for airport compatibility purpose.	Hurel-Dubois Nasa TTBW
Blended Wing	Aircraft evacuation concepts to be developed. Existing bridge compatibility? Doors are farther from lead-in line (jetbridge compatibility). Larger wheel span for ensuring lateral stability (taxiway compatibility). Larger high-capacity flying wings (if any) will challenge airport compatibility.	Airbus MAVERIC Boeing BWB
Boxed-Wing	Smaller wingspan than comparable turbojets. Opportunity for engines mounted on upper wing.	NASA/Lockheed
Folding Wingtips	Significantly increase compatibility with existing airport infrastructure. Requires airport-friendly concept of operations (see ACI's BACG2 and FAA EB No. 94).	Boeing 777-8/-9

NOTE: FOD = foreign object damage. ACI = Airports Council International.

for developing new markets as well as new types of air carriers and other entrants to existing market segments.

Collaboration among aviation stakeholders of real-time operations has been a game-changer (*16*). Airport operations stakeholders have called for the end of the silo effect—when different teams within an organization do not communicate effectively with each other—and have promoted the concept of Airport Collaborative Decision Making, or A-CDM (*17–19*). The ACRP has researched this concept and investigated opportunities to combine data sharing and joint procedures among stakeholders to predict potential disruptions, trigger preventive actions, and eventually mitigate the effect of disruptions (*20–21*).

Collaboration can also enhance the long-term resilience to sudden shocks such as the COVID-19 crisis. Such a strategy

Photo: Boom Supersonic

In development and with passenger flights expected by 2030, the Boom Overture is part of the new generation of civilian supersonic aircraft.

TABLE 3 **Comparison Between Concorde and Proposed Future Supersonic Aircraft**

MANUFACTURER	Aérospatiale/BAC	Aerion	Spike	Boom Technology
TYPE	Concorde	AS2	S-512	Overture
MARKET SEGMENT	Commercial Service	Business Aviation	Business Aviation	Commercial Service
EXPECTED EIS	1976	2025	2023	2025–2027
WINGSPAN × LENGTH	25.6 m × 61.7 m (84 ft. × 202 ft.)	26.5 m × 45.2 m (87 ft. × 148 ft.)	17.7 m × 37 m (58 ft. × 120 ft.)	18 m × 52 m (60 ft. × 170 ft.)
CRUISE SPEED (MACH)	2.04	1.4	1.6	2.2
ENGINES	4	3	2	3
PASSENGERS	92–128	8–10	18	45–55
MAX. RANGE WITH SUPERSONIC CRUISE	3,900 NM	4,200 NM	6,200 NM	4,500 NM
RUNWAY LENGTH REQUIREMENT*	3,600 m (11,800 ft.)	2,286 m (7,500 ft.)	1,828 m (6,000 ft.)	3,048 m (10,000 ft.)
LOW-BOOM TECHNOLOGY	No	Yes	Yes	No
AIRPORT COMPATIBILITY FEATURES	None	Low-Boom Technology	"Boomless" Technology	Low-Boom Technology
UNIT COST	160 MUSD	120 MUSD	60–100 MUSD	200 MUSD
CLIENTS	Air France British Airways	Flexjet	–	Virgin Group Japan Airlines

NOTE: MUSD = million U.S. dollars.
* Takeoff requirement assuming MTOW, ISA, Sea Level.

requires an interdisciplinary approach between a broad coalition of stakeholders. However, some aspects are beyond the authority of individual airports and may warrant a coordination at the level of industry, governments, and international organizations.

The lessons we can learn from COVID-19 must be used for making our society (and our airports) more resilient (*22*). The vulnerability of our information systems and the effects of human-induced climate change are other threats to aviation (Table 4). Transparency, collaboration, and planning are keys to prevent adverse events and to provide an adequate and timely response.

Integrating Airports into Their Communities

Airports do not have surrounding or neighboring communities: they are a part of them. Airport communities can take different forms and meanings, depending on the issues. For the purpose of this discussion, we will define the concepts of inner and outer communities (Figure 4). The inner community—in the direct vicinity of the airport—is exposed to specific, direct economic benefits but also to negative externalities (e.g., higher noise exposure). This inner community includes the airport's immediate area and the adjacent cities or towns that depend on the airport economically.

Inner community issues go beyond just noise and pollution concerns. Accessibility around an airport can be an issue when all ground transportation is built specifically to support the airport and movement of passengers away from the community. Airports increasingly promote recruitment in their inner communities to reduce unemployment, provide opportunities for social mobility, and grow an airport-centric community. In return, a dynamic inner community can develop a whole ecosystem of small businesses that ultimately connect to airport-based activities. Minority and low-income populations may find more affordable housing in the immediate vicinity of airports. Climate

TABLE 4 Long-Term Threats to Airport Resilience

THREAT	RECENT EXAMPLES	TYPICAL EFFECTS ON AIRPORTS	GLOBAL MITIGATION	AIRPORT-SPECIFIC ACTIONS
Pandemics and epidemics	Ebola, SARS, MERS, COVID-19, Zika	Short-term, brutal drop in air traffic and revenues, workforce on sick leave, overflow aircraft to store on airfield, etc.	International coordination, trans-national transparent collaboration, national readiness, enhanced hygiene, disease-specific actions (e.g., mosquito control, stay-at-home orders, etc.), change in social behaviors, economic relief plans, etc.	Airport response plan, prevention plan, designs preventing airborne spread, regular cleaning of parts touched by passengers and workers, soap and hand sanitizer available, prevention voice messages in terminal buildings, specific measure toward arriving passengers, etc.
Climate change–induced extreme weather	Hurricane Barry, Hurricane Catarina, Typhoon Jebi	Interruption of air traffic, destruction of facilities, higher operating costs and capital expenditures, etc. *Note: Climate change might create favorable conditions for a wider spread of mosquito-borne diseases.*	Climate resilience, strong reduction of overall carbon emissions and "negative emissions," etc.	Airport climate resilience plan, incorporation of future climate in planning and design, financial resilience to more regular extreme weather conditions, etc.
Terrorism	Salafi jihadism, white supremacism, radical anarchism, murder–suicide patterns	Medium-term drop in air traffic and revenues, etc.	Global War on Terrorism, intelligence and police efforts, state security strategies, mitigating the roots of terrorism, etc.	ICAO Global Aviation Security Plan (GASeP), local implementation of state security plan, secure-by-design facilities, airport community awareness programs, etc.
Cyberwarfare	State-sponsored cyberattacks	Power outages, systems out of service, malicious diversion of systems, etc.	National cyber-counterterrorism, cooperation between intelligence community and industry, etc.	IT system hardening, redundancies, operational resilience with low-tech contingency plans, etc.
Conventional warfare	Libyan Civil War, War in Donbass	Drop in air traffic, destruction of facilities	Prevention of conflicts and promotion of enduring peace	Airport-to-airport mutual assistance, evacuation of civilian aircraft toward safe aviation facilities, etc.

gentrification—the process of wealthier populations moving to areas of lower climate vulnerability and displacing current lower-income inhabitants—can increase this phenomenon in certain locations. More specialized attention to social and environmental justice in airport planning and development is needed.

One of the main challenges of the 2040 and 2070 horizons will be airport accessibility from the outer community. Virtually all major metropolitan areas face acute congestion problems. Accessibility has a direct impact on the attractiveness of airports both as transportation provider and as workplace. Connected and autonomous vehicles (CAVs) will not create new capacity on the ground, since they will replace or add vehicles to existing roadway traffic. If they are highly affordable, CAV-based ride-hailing services might even seduce current users of mass transit, reduce public transportation revenues, and worsen congestion issues. We must rethink mobility and think out of the box to develop new systems supplementing existing modes (Figure 5).

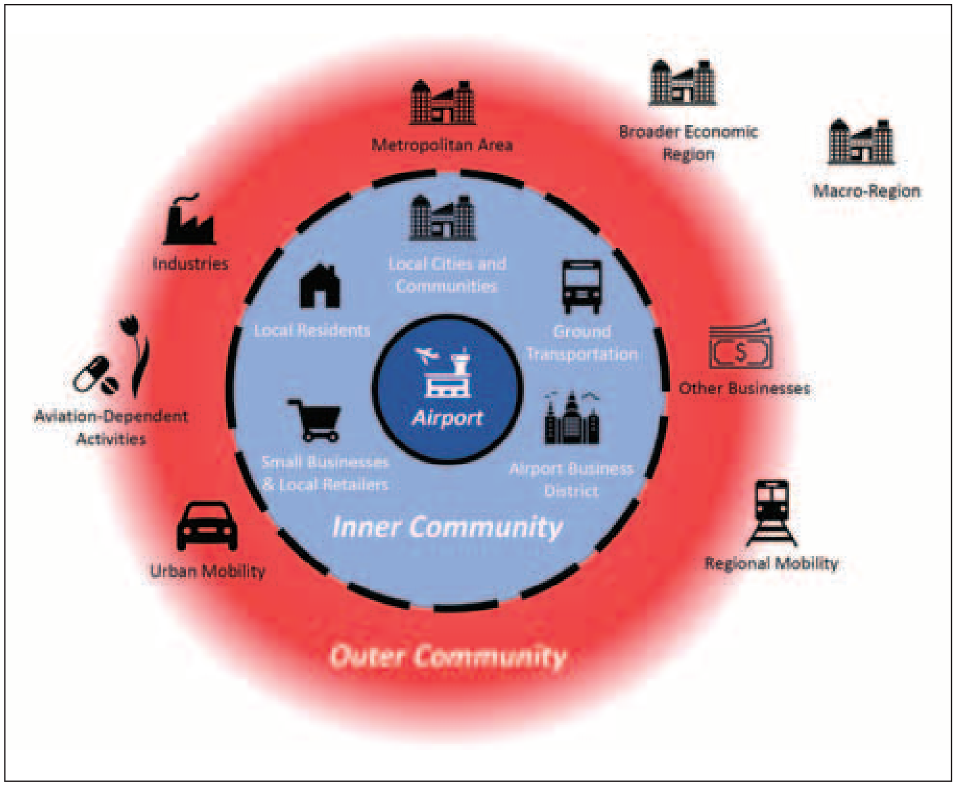


FIGURE 4 **Inner and outer airport communities. (Source: *The Future of Airports,* 2020.)**

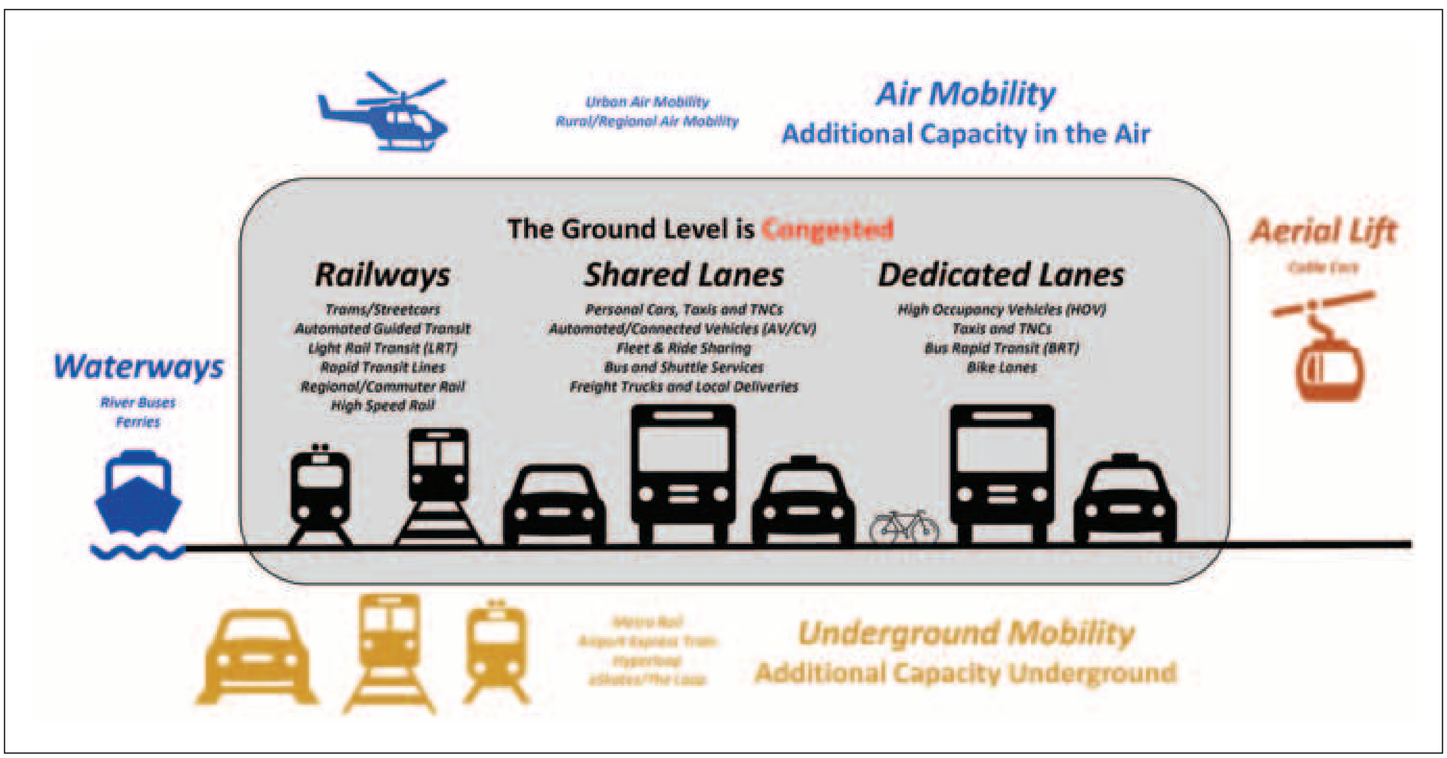


FIGURE 5 **Innovative modes of transportation can enhance airport accessibility. (Source: *The Future of Airports,* 2020.)**

Photo: Clinton Steeds, Flickr

Airports are not just located near communities; they are part of them—offering economic benefits but also working to mitigate noise and environmental concerns.

Emerging Issues in Management and Human Resources

Fifty or even 20 years ago, airports had no community manager or SMS coordinator. Similarly, most of the job descriptions in 2040 and 2070 will include requirements and missions that do not exist today. The workplace itself is changing. Workers increasingly place importance on the values of their organization, the meaning of their work, interaction with management, collaboration with teammates and stakeholders, and flexibility to manage their daily routines.

As new technologies continuously appear and the succession of breakthroughs accelerates, we will need a new approach for change and knowledge management. Technological shocks—similar to the IT revolution that required generations to transition to computers not so long ago—will become more frequent. There will be a growing need for continuing education to align skills to needs. Shared training resources and support from professional organizations such as the American Association of Airport Executives with the Airport Certified Employee program have already proven to be effective ways to address this (*23*).

Change management will be part of regular operations. Successful airports will identify upcoming changes early and adapt their organizations. One of these changes is intelligent technologies that will open a broad field of completely new applications and systems that we can barely envision as of today. They will deeply change our interactions with our world, including the way we move, communicate, enjoy, consume, and work.

The world is our guest, and as aviation industry members we must reflect the diversity of the aviation users and airport

Upcoming Workshop

At the workshop How We Move Matters: Exploring the Connections Between New Transportation and Mobility Options and Environmental Health, scheduled for July 14–15, 2021, participants will explore existing and needed research on the environmental health challenges related to emerging transportation services expected in the next decade.

For more information, see https://www.nationalacademies.org/event/07-14-2021/how-we-move-matters-exploring-the-connections-between-new-transportation-and-mobility-options-and-environmental-health-a-workshop.

communities. A diverse workforce and management are crucial for embracing and addressing the complexity of the challenges to come. Diversity is not limited to gender and ethnicity but also includes age, sexual orientation, special needs, cultural background, and socioeconomic status (*24*).

Studies have shown the clear benefits of diversity in organizations (*25–27*). Although the 20th century fell short in delivering freedom, justice, and progress for all, we must not let the 21st century follow the same path.[1] Discrimination and biases not only go against the fundamental values of aviation expressed in the 1944 Chicago Convention on International Civil Aviation; they prevent talents from emerging, innovations from blooming, and opportunities from being seized.

REFERENCES

1. Vespa, J., L. Medina, and D. M. Armstrong. *Demographic Turning Points for the United States: Population Projections for 2020 to 2060*. U.S. Census Bureau, Department of Commerce, February 2020.
2. Hagler, Y. *Defining U.S. Megaregions—America 2050*. Regional Planning Association, November 2009.
3. *World Population Prospects: The 2019 Revision*. United Nations, Department of Economic and Social Affairs, 2019.
4. *Airport Digital Transformation: Best Practice, Version 1.02*. Airports Council International, 2017.
5. Murphy, R. J., et al. *ACRP Report 140: Guidebook on Best Practices for Airport Cybersecurity*. Transportation Research Board of the National Academies, Washington, D.C., 2015.
6. *Annex 14 to the Convention on International Civil Aviation, Volume I – Aerodrome Design and Operations*, 8th ed. ICAO, Montréal, Canada, July 2018.
7. *Airport Design*. Advisory Circular 150/5300-13B (Draft). Federal Aviation Administration, July 2020.
8. *Engineered Materials Arresting Systems (EMAS) for Aircraft Overruns*. Advisory Circular 150/5220-22B, FAA/AAS-100. Federal Aviation Administration, September 2012.
9. Ludwig, D. A., et al. *ACRP Report 1: Safety Management Systems for Airports*. Transportation Research Board of the National Academies, Washington, D.C., 2007.
10. Kirsch, P., and N. M. Clabbers. *ACRP Legal Research Digest 36: Legal Issues Related to Implementation and Operation of SMS for Airports*. Transportation Research Board, Washington, D.C., 2018. https://doi.org/10.17226/25328.
11. *Safety Report*, 2018 ed. ICAO, 2018.
12. *2017–2019 Global Aviation Safety Plan*. Doc 10004, 2nd ed. ICAO, 2016.
13. Nzuzi, A. A Balanced Approach to Safety Oversight and Management in States with a Low Level of Compliance to ICAO SARPs. *ENAC Alumni Magazine*, No. 20, September 2017, pp. 44–46.
14. Electric Aircraft on the Horizon: An Airport Planning Perspective, ACRP Project 03-51. Transportation Research Board. https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4625. Accessed September 2, 2020.
15. *ACI's Views on the Reintroduction of Supersonic Aircraft and the Development of Appropriate SARPs*. Working Paper A40-WP/225 EX/85. ICAO, August 2019.
16. *A-CDM Impact Assessment*. Final Report, EUROCONTROL, Brussels, Belgium, 2016.
17. *Airport Collaborative Decision-Making: Optimisation Through Collaboration, An Introductory Guide for Air Navigation Service Providers*. Civil Air Navigation Services Organization, 2016.
18. CANSO and ACI Partner on Promoting A-CDM Implementation. ACI World. June 14, 2012. https://aci.aero/news/2012/06/14/canso-and-aci-partner-on-promoting-a-cdm-implementation. Accessed August 29, 2020.
19. Airline Airport Collaborative Decision Making Group A-CDM Coordination, International Air Transport Association, 2018.
20. *ACRP 10-27: Using Collaborative Decision Making to Enhance the Management of Adverse Conditions.* Transportation Research Board. https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4633. Accessed July 29, 2020.
21. Le Bris, G., et al. *ACRP Research Report 229: Airport Collaborative Decision Making (ACDM) for Managing Adverse Conditions.* Transportation Research Board, Washington, D.C., 2021.
22. Le Bris, G. et al. Preparing Airports to the Post-COVID-19 Era. *ENAC Alumni Magazine*, June 2020. www.alumni.enac.fr/en/news/preparing-airports-to-the-post-covid-19-era-832.
23. Airport Certified Employee. American Association of Airport Executives. https://www.aaae.org/aaae/AAAEMBR/AAAEMemberResponsive/PD/Training/Onsite_Training/ACE_PROGRAMS.aspx. Accessed August 15, 2020.
24. Ivey S., M. Powers, and A. Clark. Building a Business Case for Increasing Diversity in the Transportation Workforce. *TR News*, No. 323, September–October 2019, pp. 22–27.
25. McMahon, A. Does Workplace Diversity Matter? A Survey of Empirical Studies on Diversity and Firm Performance, 2000. *Journal of Diversity Management*, Vol. 5, No. 2, 2010, pp. 37–48. https://doi.org/10.19030/jdm.v5i2.808.
26. Lorenzo, R. et al. *The Mix That Matters: Innovation Through Diversity*. The Boston Consulting Group, April 2017.
27. *Preamble, Convention on International Civil Aviation*. Doc 7300/9, 9th Ed. ICAO, 2006.

[1] The Preamble of the Convention on International Civil Aviation specifies that "the future development of international civil aviation can greatly help to create and preserve friendship and understanding among the nations and peoples of the world."

Approximately 68 percent of the worldwide population will live in urban areas by 2050. The advent of new, large metropolitan areas will create challenges in mobility but also will lead to new aviation megacities.

NATIONAL ACADEMIES REPORT

ADVANCING AERIAL MOBILITY A National Blueprint

Photo: Gerry Machen, Flickr

DWAYNE DAY

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

Above: Aerial photography is among the many applications of unmanned aerial vehicles (UAVs), like this sunrise captured via drone camera. The experiences of other industries help to refine UAV technology for its many possible transportation applications.

Electric and hybrid aircraft for urban, suburban, and rural operations—commonly referred to as advanced aerial mobility—has increased dramatically across the globe. Advanced aerial mobility involves the emergence of transformative and disruptive new airborne technology. This technology supports an ecosystem to transport people and goods to locations not traditionally served by current modes of air transportation, including to rural and complex urban environments. These transformative technologies will change the way that goods and people are moved and will affect industries across the economy.

The aircraft being developed are short-range, runway independent, and highly automated. Electric motors and simplified electric controls replace complex transmissions and elaborate flight-critical components. This promises to reduce the manufacturing and operating costs of flight vehicles and could enable flight operations in areas where ground vehicles are used.

Hundreds of different air vehicles are being developed; more than one dozen vehicle projects now receive investment from private industry—both from traditional aerospace companies and companies with little or no prior aviation experience.

This new industry of vertical lift operations, the supporting ground infrastructure, and the required air traffic management systems will challenge today's airspace monitoring systems and regulatory environment. In 2020, the Aeronautics and Space Engineering Board released a report, *Advancing Aerial Mobility: A National Blueprint*, examining a path forward for advanced aerial mobility research.

New Missions Can Fulfill Latent Needs

Advanced aerial mobility can transform industries like transportation, emergency response, and cargo and package logistics; however, it is important to ensure that the societal benefits and costs of implementing these technologies are well communicated to the public to aid adoption and acceptance.

Photo: Pat Sanchez, Sawyer County Emergency Management

In August 2020, Wisconsin National Guard and other emergency agencies deployed UAVs to canvass a heavily wooded area for a missing toddler. The child and the family dog were later found safely.

The commercial cargo market is one of the most visible early adopters of autonomous air vehicle technology and capability, used in rural domestic cargo operations. This includes last-mile local package delivery and middle-mile cargo as one of the first applications by companies, including those that will deliver to an end customer. But capabilities for advanced aerial mobility go beyond air taxi and package express—they can include security and police patrols for safety, rapid response for emergencies and fires, delivery of lifesaving medicines during emergencies, and more.

Future Airspace and Air Traffic Management Environment

The Committee on Enhancing Air Mobility does not envision different infrastructures to control traffic, separation, and paths but, rather, one infrastructure with levels of complexity based on its user. Properly harnessed, a data-sharing network of flight vehicles can achieve breakthrough airspace allocations. Such a network can be useful for advanced aerial mobility operators to facilitate utilization, promote safety, and provide practical traffic management and separation without burdening each vehicle with multiple sensors and their accompanying reliability issues, weight, and cost.

A phased, iterative approach to development, testing, and introduction of new capabilities is required for a system of this degree of multidisciplinary complexity, with many stakeholders and with regulatory involvement at every step. Coordination that leads to interoperability and standards is essential.

Leading the Way

The Federal Aviation Administration (FAA) has a sole mandate to promote safety and regulate the National Airspace System. Other federal agencies, such as the National Aeronautic and Space Administration (NASA), also have an interest based on national security, the environment, and other factors.

NASA is widely considered to be an objective, respected repository of knowledge and research capability; at the same time, the agency has no authority to regulate or decide on technology implementation for the National Airspace System. FAA has the most authority to implement, and NASA can serve as its risk-taking, innovative partner in the development of advanced aerial mobility. Although U.S. leadership in aerospace is in the national interest, and although the United States is uniquely poised to be a leader in this area, no entity within the U.S. government yet has a clear mandate to promote commercial aviation or the development, adoption, and commercialization of new

Committee on Enhancing Air Mobility

NASA asked the National Academies of Sciences, Engineering, and Medicine to conduct a study and develop a vision of the future of "urban air mobility" to be carried out by the Committee on Enhancing Air Mobility. This committee was part of the Aeronautics and Space Engineering Board (ASEB) within the Academies' Division on Engineering and Physical Sciences. The ASEB oversees ad hoc committees that recommend priorities and procedures for informing aerospace issues of national importance, including space policy and programs that focus on human spaceflight and space operations, as well as commercial space activities.

To read a copy of the entire report, go to https://www.nap.edu/catalog/25646/.

technologies or applications.

Implementing a versatile advanced aerial mobility system with multiple applications and users is a complex, multidisciplinary challenge. No entity, public or private, possesses all the necessary skills. Nor does any single entity currently have sufficient oversight or responsibility to effectively make advanced aerial mobility a reality while maximizing societal benefits.

The United States, however, stands uniquely ready to be a world leader, based on several factors: a strong government regulatory establishment, a nationwide social and physical infrastructure that can support new modes of aerial transportation, a mix of strong investment in human and research capital, development of critical artificial intelligence and autonomous technologies, and availability of investment capital.

Photo: Joby Aviation

Joby Aviation began flight testing a prototype for a UAV taxi in 2019. The interplay of performance and safety concerns, as well as operating costs, makes urban air taxi service a particularly demanding application of advanced aerial mobility.

From Urban Air Mobility to Advanced Aerial Mobility

Popular media attention to advanced aerial mobility topics usually focuses on home package delivery by small electric aircraft, as well as on urban air taxi services. Because of requirements related to performance, safety, and operating costs, however, urban air taxi service for the public is one of the most demanding applications of advanced aerial mobility.

Urban air mobility cannot be implemented without first building and gaining experience in other, less demanding areas of aerial mobility. The current development plan for this infrastructure change involves a graduated set of applications, starting today with less challenging, more controlled, lower-density locations as test cases for development of vehicles, control schemes, and networking concepts. New commercial test operations involving package delivery in rural areas have already begun.

Other, less demanding applications can serve as opportunities to build experience and refine technology to establish the full set of capabilities required for urban air taxi services. Near-term applications can include cargo delivery, inspection, and surveillance operations in less densely populated areas. Applications can also include emergency medical services, first responders, disaster relief, corporate transport, and cargo logistics.

Challenges to Achieving the Vision

Acceptance of advanced aerial mobility technology will be challenging without significant coordination, education, and agreement with public and private entities. It will take major changes to current aviation systems, particularly to how the National Airspace System safely introduces new technologies to manage and integrate operations at high-traffic densities. In some ways, the nation is not ready for this transformation, and there are serious barriers to entry by new participants such as small start-ups. Potential negative impacts include community noise concerns, introduction of new safety risks, or even an increased carbon footprint.

The success of advanced aerial mobility systems will depend on the acceptance of many economic, social, and regulatory factors: safety, security, social acceptance, resilience, environmental impacts, regulation, scalability, and flexibility.

Importance of Public Acceptance

Public acceptance of advanced aerial mobility—particularly noise and psychological factors—is the biggest challenge, along with safety. Failure to address these issues could hinder advanced aerial mobility implementation. Noise from aircraft and other transportation modes is a complex topic that spans acoustics, the physiological way humans experience noise, and psychological perceptions of the source of the noise and what it represents.

Early operations may start with a less intense acoustical impact on bystanders (e.g., less frequent operations in rural areas) and with strong positive social impact (e.g., emergency medical services, search and rescue, and disaster relief). These applications can be a valuable test bed to learn about and refine low-noise operations, as well as to actively shape positive public perception of the technology.

Contingency Management

Contingency management is the capability to manage, reduce, or eliminate unanticipated risk to persons, property, or other aircraft due to off-nominal events associated with vehicle operations. Because of the expected increase in the number of aircraft operations per day and a decreasing pilot training pipeline, autonomy for contingency management will be an essential component of advanced aerial mobility. Software-based evaluation tools can be applied to rigorously evaluate autonomy for well-defined deterministic contingency management to reduce the labor and cost required to use today's certification practices.

Advanced aerial mobility will typically rely on a variety of real-time data sources, for example, of information relating to traffic coordination and weather. In addition, cyber resilience—the ability for a vehicle or local vehicle group to safely continue a flight operation despite loss or corruption of data links or server connections—is an essential component of advanced aerial mobility contingency management.

Moving Forward with Implementation

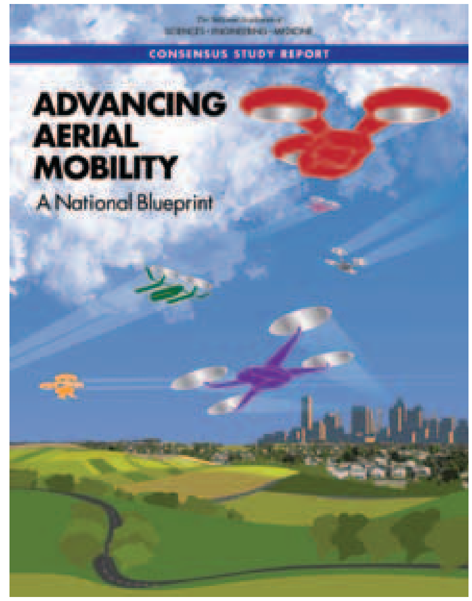
The aviation sector is witnessing the emergence of new vehicle and associated technologies poised to redefine the scale and types of operations in airspace systems. These emerging capabilities can create a variety of new applications for aviation that will have far-reaching societal and economic benefits. To usher in this era of historic change in aviation, public and private institutions will have to work together in close partnership to facilitate safe construction, deployment, and acceptance of new advanced aerial mobility technologies, along with supporting infrastructure and regulatory processes.

The opportunities offered by advanced aerial mobility have brought a range of opinions on how best to proceed with integration into the national airspace. If these capabilities are to provide benefit to society in the near future, strong public leadership is needed to focus the diverse set of opinions and chart a progressive path forward.

Recommendations

Advancing Aerial Mobility: A National Blueprint offers 14 recommendations to guide the implementation of advanced aerial mobility. Some of the key recommendations include the following:

- NASA should establish strategic partnerships with stakeholders, prioritizing research and development of technologies that would integrate advanced aerial mobility into a future National Airspace System.
- NASA, in coordination with FAA, should perform research to extend unmanned aircraft system traffic management concepts to accommodate emerging advanced aerial mobility traffic in all classes of airspace.
- Research should quantify and mitigate public annoyance caused by noise—including psychoacoustic and health aspects—from different types of advanced aerial mobility operations. Research should also assess the societal impacts of advanced aerial mobility vehicles and associated infrastructure (privacy, intrusion, public health, transparency, environmental, and inequity). To carry out this research, NASA should facilitate collaboration among federal government agencies (e.g., FAA, the Department of Defense, the Environmental Protection Agency, the Department of Commerce, and the National Institutes of Health), academia, state and local governments, industry, equipment manufacturers, operators, and nonprofit organizations.
- NASA should conduct research, development, and testing of autonomy for contingency management to support safe advanced aerial mobility.



For more information on *Advancing Aerial Mobility: A National Blueprint*, visit https://www.nap.edu/catalog/25646/advancing-aerial-mobility-a-national-blueprint.

Advanced aerial technologies will change the way that goods and people are moved and will affect industries across the economy.

Strengthening Post-Hurricane Supply Chain Resilience

Observations from Hurricanes Harvey, Irma, and Maria

Photo: Michael Seeley, Wikimedia Commons

LAURIE GELLER, JAMES G. FEATHERSTONE, AND STEVEN STICHTER

Geller is a senior program officer in the Division on Earth and Life Studies at the National Academies of Sciences, Engineering, and Medicine, Washington, D.C.; Featherstone is the principal consultant at Themata Strategic, LLC., Los Angeles, California, and chair of the study committee; and Stichter is the director of the Resilient America Program at the National Academies of Sciences, Engineering, and Medicine, Washington, D.C.

The Federal Emergency Management Agency (FEMA) asked the National Academies of Sciences, Engineering, and Medicine Committee on Building Adaptable and Resilient Supply Chains After Hurricanes Harvey, Irma, and Maria to analyze the function of supply chain networks in four primary areas affected by the 2017 storms in South Texas (Hurricane Harvey), South Florida (Hurricane Irma), and Puerto Rico and the U.S. Virgin Islands (Hurricanes Irma and Maria). Specifically, the committee was asked to identify key lessons from these events related to supply and distribution networks and to offer recommendations for improving the conveyance and distribution of essential supplies and commodities during disaster response and recovery operations—focused on supply chains for food, fuel, water, and pharmaceutical and medical supplies. This article highlights parts of the report that focus directly on transportation issues in the four localities previously mentioned.[1,2]

Above: Ominous clouds—Hurricane Irma's outer bands—draw a crowd to Florida's Satellite Beach to watch the storm come in. The next day, Irma made landfall in the Florida Keys, affecting most of the peninsula and bringing storm surges, severe flooding, tornadoes, and disruptions to moving goods along linear truck routes.

Supply chains facilitate the timely flow of materials and products from suppliers to manufacturers to distributors (wholesalers) to distribution channels (e.g., retailers, clinics and hospitals, and nongovernmental organizations) and, finally, to end users. They do this by transmitting demand information upstream—and other related information downstream—to guide production, transportation, and distribution decisions.

[1] To view the entire publication, visit https://www.nap.edu/catalog/25490/.
[2] To view a digital interactive summary document of the publication, visit https://www.nap.edu/resource/25490/interactive/.

Disruptions to a supply chain can result from several forces, including demand shifts (e.g., spikes in demand for fuel and bottled water), capacity reductions (e.g., when a factory or retail store cannot operate due to damage or power outages), and communication disruptions (e.g., loss of cell phone, Internet, or point-of-sale systems). The resilience of a supply chain depends on how its bottlenecks and lead times are affected by such disruptions and what capabilities exist for swift restoration after a disruption. The objective of supply chain resilience is to minimize the impact of such disruptions on the affected population.

The Hurricanes

HURRICANE HARVEY

Harvey made landfall as a Category 4 storm on August 25, 2017, with winds reaching 152 miles per hour and storm surges ranging from 5 to 10 feet. Most initial wind and wave damage affected the Coastal Bend area on the Gulf of Mexico, with flooding occurring when the storm made a second landfall and stalled over Houston—during which time the region received more than 50 inches of rainfall. Massive flooding occurred across Houston, Beaumont, and many other southeast Texas communities.

HURRICANE IRMA

Irma reached hurricane strength on August 31, 2017, and by September 5 it had intensified, with sustained wind speeds of 185 miles per hour, becoming the strongest hurricane ever observed in the Atlantic Ocean. Irma maintained Category 5 winds for three days as it moved west, slammed the U.S. Virgin Islands, and knocked out Puerto Rico's fragile, aging electrical power system. On September 10, Irma made landfall at Category 4 strength in the Florida Keys. Tropical storm–force winds extended outward up to 400 miles, affecting nearly the entire Florida peninsula. As Irma advanced across Florida, severe flooding, storm surges, and tornadoes occurred across numerous counties.

HURRICANE MARIA

On September 19, 2017, Maria passed over St. Croix in the U.S. Virgin Islands, destroying much of the island's buildings and communications and power infrastructures. On September 20, Maria made landfall in Puerto Rico at Category 5 strength, dumping more than 30 inches of rain. By the time the hurricane weakened, the entire island's power infrastructure had been destroyed and 100 percent of customers had lost service.

Defining Geographical, Supply Chain, and Modal Characteristics

SOUTH TEXAS

Houston is highly flood-prone because of low elevation and flat topography, which offer no natural physical drainage pathways for intense rainfall. During Hurricane Harvey, the city's bayous and drainage systems quickly filled, leading to rapid flooding of freeways and roads. These flooding risks have been exacerbated by sprawling development patterns that displaced wetlands and other green spaces with impervious concrete and asphalt surfaces. The Texas coastline is long and exposed but accessible from inland areas and, thus, not dependent on water-bound shipments for relief efforts. At the same time, the region's widely dispersed development patterns mean that the distribution of goods and services requires considerable, reliable road transport capacity. When roadways

Photo: Unsplash

Cars parked curbside bring a strange sense of order to the chaos of flooded streets in a southeast Texas community, the result of Hurricane Harvey's second landfall in late August 2017, when the storm stalled over Houston. More than 50 inches of rainfall brought massive flooding across Houston, Beaumont, and many other communities in the region.

Photo: Holly Ireland, Pixy

Connecting to part of the Port of Houston, one of the world's busiest seaports, the 52-mile Houston Ship Channel is an important maritime transportation link. Despite the city's well-developed multimodal infrastructure with connectivity and redundancy through rail, truck, barge, ship, and pipeline, the ship channel is a potential point of failure for a critical distribution network.

are cut off by flooding, normal supply chain systems quickly become paralyzed.

The Houston area has a well-developed multimodal infrastructure with substantial connectivity and redundancy through rail, truck, barge, ship, and pipeline options. The area has plentiful capacity in its multimodal transport links and its highly interconnected, multidirectional corridors. Road and rail transport nodes are relatively dispersed. But for maritime transport, the Houston Ship Channel is a critical transportation link and potential single point of failure for a critical distribution network.

FLORIDA

Much of Florida is prone to flooding due to low elevations and development patterns that undermine natural drainage systems. South Florida has underlying porous limestone that allows floodwaters to arise from underground and has coastal exposure to Atlantic as well as Gulf Coast storms. As an 800-mile-long, densely developed peninsula with just a few main transport corridors, Florida's geography exacerbates challenges during mass evacuations from vulnerable areas along congested routes or large-scale delivery of critical goods and services into affected areas. Hurricane Irma caused record-breaking rapid evacuations along congested highway routes. Relief supplies can be sourced from outside the state, but truck drivers must still navigate the peninsula to deliver goods and services, with the uncertainty of when they will be able to return home. Fuel delivery to Florida is primarily by water to port facilities, where it is distributed by tanker trucks.

Truck transport is the dominant mode for most goods, except for petroleum products that arrive primarily by ship. This is augmented by limited rail capacity. Florida is more limited by capacity than South Texas because of its linear, parallel transport links that predominate along the peninsula. Refined petroleum distribution for a large market is concentrated at a limited number of fuel distribution points.

PUERTO RICO AND THE U.S. VIRGIN ISLANDS

Puerto Rico and the U.S. Virgin Islands are grouped together because they share many common characteristics. These islands rely entirely on delivery of goods and relief supplies by ship and barge, primarily from U.S. ports more than 1,200 miles away. Transit times and delays for delivery of goods are an important factor in emergency response planning. Puerto Rico has one large natural harbor (the Port of San Juan, a critical node for most supply chains), plus other smaller ports around the island. The island's mountainous terrain poses challenges for emergency response and goods delivery.

On the island of St. Thomas in the U.S. Virgin Islands, the main industrial port has limited space for unloading shipping containers and staging of large-scale relief supply deliveries (which elevates the likelihood of bottlenecks). And there is even less port capacity on the other islands. Evacuation from an island requires considerable advance planning.

Most goods arrive by ship. Within each island, only truck-based distribution originating at the port of entry is available. Puerto Rico is characterized by circumferential routes around its perimeter. The U.S. Virgin Islands are capacity-constrained by a small number of roads on each island. As a result, people living in isolated inland locations faced severe problems with delivery of critical goods. Both islands have a single port of entry for the majority of supplies imported to the islands, ports that represent critical nodes as well as potential bottlenecks.

Supply Chain Disruptions

TEXAS

Distribution and delivery services for food, bottled water, and other critical goods were interrupted for more than a week when flooding from Hurricane Harvey made road deliveries impossible. But as

Photo: Andrew Heneen, Wikimedia Commons

On the move ahead of Hurricane Irma, residents of the Tampa, Florida, area take advantage of governor-authorized emergency use of the left shoulder along eastbound Interstate 4 toward Orlando. Florida's linear geography—with only a few main transport corridors—poses challenges during mass evacuations and has an adverse effect on large-scale delivery of necessary goods and services.

Photo: U.S. Navy

Strong partnerships and teamwork come together as a U.S. Navy sailor directs a U.S. Army tactical vehicle off a landing craft in St. Thomas, U.S. Virgin Islands. Such cooperation—between service members, as well as civilian responders—was critical to assessing damage and administering relief following Hurricanes Irma and Maria.

Photo: Spc. Agustín Montañez, Puerto Rico National Guard

After Hurricane Maria devastated Puerto Rico, leaving the island flooded, without power, and in a tangle of debris and downed trees, the Puerto Rico National Guard set out to clear blocked roads as quickly as possible. The island's mountainous terrain exacerbates problems with prompt delivery of disaster relief.

waters receded, most grocery stores quickly recovered and reopened. Texas and Louisiana are major fuel-producing hubs, so sustained closure or damage at these facilities can have widespread effects on fuel supply chains, involving critical production nodes and transportation links. During and immediately after Harvey, closure of all major ports along the Texas coastline affected approximately 25 percent of Gulf Coast offshore oil and natural gas production and approximately 50 percent of Gulf Coast refinery capacity.

Supply chains in the South Texas region proved largely flexible and resilient but illustrated that systems will have great difficulties functioning when flooding is too severe and critical infrastructure is damaged. Thus, investments in sustainable development patterns that minimize flooding problems—through, for example, elevating critical roadways and minimizing impervious surfaces—are priorities for building resilience.

FLORIDA

With a long history of hurricane landfalls, Florida has well-organized systems for disaster preparedness and response. Yet Hurricane Irma illustrated limitations and vulnerabilities in current systems. For instance, one vulnerability was the difficulty of maintaining an inflow of supplies in the face of serious transportation bottlenecks caused by fuel limitations, traffic backups, and lengthy deadheading return trips (trips made by truckers pulling an empty trailer with no cargo, thus generating no revenue). Another vulnerability was poor coordination in the movement of trucks and supplies across state lines in the face of information disruptions and communication problems.

Florida has almost no fuel production facilities; rather, it receives the bulk of its fuel from the Gulf Coast region and foreign imports. When Irma approached, most major Florida ports and major petroleum marine terminals temporarily closed. Such short-lived closures did not themselves cause major supply problems. But an array of fuel problems did arise, initially stemming from the evacuation of more than 6 million people and the resulting surge in fuel demand, which caused bottlenecks at many fuel stations.

PUERTO RICO

In the aftermath of Hurricane Maria, many of the post-hurricane supply chain challenges were at the Port of San Juan. Cargo made it to the port, but imported goods could not be processed effectively because of sustained power outages. Then, once processed, many goods could not be removed from the port area because of blocked roads and shortages of trucks and drivers. Thus, the port quickly became overwhelmed as large loads of relief supplies poured in.

Many communities in Puerto Rico faced food shortages and initially were dependent on relief supplies. Grocery stores were adversely affected when truckers were lured away from their normal jobs to run relief supplies or wait at the port. Petroleum terminals were shut down and fuel stations were temporarily closed, but there were no reports of serious shortages of gasoline. Other problems related to fuel distribution included power outages that prohibited the processing of some fuel shipments and prompted the need for security escorts for the tankers. As one positive example of preparedness, the island's propane and liquefied petroleum gas supply and distribution proved resilient because the largest supplier was prepared to sustain the operations of its delivery terminal, storage facilities, truck fleets, and networks of drivers.

U.S. VIRGIN ISLANDS

The U.S. Virgin Islands were greatly affected by both Hurricanes Irma and Maria. Some of their challenges were similar to those in Puerto Rico in terms of being dependent on ship and barge imports for food and other critical goods, and on aging, fragile infrastructure.

The islands also faced unique challenges such as the complexity of meeting the needs of affected populations on three islands (*1*). There were no widescale reports of food shortages, but curfew hours imposed on residents—coupled with damaged and congested roads—made it difficult for many residents to find time to gather needed daily supplies. Despite these challenges, FEMA and others operated relatively efficiently in conveying some critical relief supplies, partly because of the smaller population and fewer communities that needed assistance.

Common Factors and Lessons Learned

Even with the diverse contexts and experiences of the storm-affected areas, there were some common pre- and post-hurricane challenges that unfolded, pointing to lessons to consider moving forward. One lesson is that post-hurricane bottlenecks and disruptions arose more frequently at the distribution level than at the production level. This is in part because distribution occurs within the affected region, while much of the production often occurs elsewhere. In addition, distribution is often carried out by smaller businesses and organizations with less preparedness capacity than large companies have.

Another lesson is that some of the most common factors underlying these last-mile distribution challenges were shortages of trucks and drivers for goods delivery, shortages of other personnel that occurred when workers became storm victims, and damage to critical infrastructure that impeded distribution and selling of goods. Uncoordinated, unsolicited donations sent to affected areas were another common source of bottlenecks at the distribution level. Dealing with these donations drew critical resources (e.g., volunteer efforts and storage space) away from more strategically targeted needs.

Recommendations

The committee proposed four overarching recommendations for advancing the United States' capacity to provide critical supplies to affected populations in the aftermath of hurricanes:

1. Shift the focus from pushing relief supplies to ensuring that regular supply chains are restored as rapidly as possible through strategic interventions.

To advance this recommendation, the committee suggested prioritizing recovery of infrastructure critical for resuming normal supply chain operations. Critical infrastructure (e.g., power, transportation, roads, bridges, and water) enables operation of all supply chains. In most cases, adequate supplies of materials existed in the areas affected by disasters, but the ability to ship and deliver those supplies was impeded by lack of roads, trucks, drivers, fuel, or electricity. Repairing and rebuilding damaged infrastructure is not seen as FEMA's direct role, but the agency could be well positioned to take a more active leadership role in aiding such efforts.

The traditional focus on bringing relief supplies to an affected area to address unmet demand must be augmented by understanding the causes of unmet demand—that is, identifying bottlenecks, gaps, and broken links in local supply chains—and pursuing strategic interventions to assist local stakeholders in returning regular supply chains to normal operation as rapidly as possible.

2. Build a system-level understanding of supply chain dynamics as a foundation for effective decision support.

Supply chain management plays an important role in preparing for, responding to, and recovering from disasters—encompassing activities as diverse as developing early warning systems, pre-positioning and distributing relief supplies, evacuating affected populations, and managing storm debris (*2*). Supply chains rely on critical infrastructure such as power, communication, and transportation facilities (e.g., roads, airports, and ports)—all of which can be damaged and disrupted during a disaster.

The committee suggested key steps and strategies to advance this recommendation. For the given jurisdiction of concern (i.e., local, state, or regional), support pre-disaster assessment of the criticality, vulnerability, and dependencies of key supply chain nodes, links, and supporting infrastructure; and develop protocols and systems for gathering and regularly updating information about demand, supply, infrastructure condition, and supply chain functionality. Many private-sector supply chains already utilize sophisticated tools for sensing supply and demand changes, system bottlenecks and vulnerabilities, and other critical information. Public-sector officials need comparable capabilities and tools that can interface with—and build upon—these private-sector capabilities.

Emergency management offices at the local, state, and regional levels are likely best suited to lead much of this information collection and analysis work. However, FEMA can play a critical leadership role in building capacity and providing support for such efforts, through both financial incentives (i.e., grant programs) and training that brings together local knowledge with knowledge drawn from government and business leaders nationwide.

3. Support mechanisms for coordination, information sharing, and preparedness among supply chain stakeholders.

Opportunities for building resilience come from preparedness efforts undertaken before disasters strike. Examples of critical preparedness actions that businesses or organizations can take include developing and regularly updating emergency preparedness and continuity of operations plans, conducting worst-case scenario drills, testing emergency communication protocols, and developing plans to protect organizational personnel during disaster events. Other critical factors for enabling successful disaster response are clearly defined processes and mechanisms for coordination and information sharing, especially platforms to engage across levels of government and public- and private-sector organizations.

There are many mechanisms for government agencies and responders at the local, state, and federal levels to interact with industry in responding to emergencies that affect supply chains. These include, for instance, the U.S. Department of Homeland Security's Critical Infrastructure Threat Information Sharing Framework and Homeland Security Information Network, the Information Sharing and Analysis Centers, and the Sectoral and Regional Consortium Coordinating Councils. Additional formal and informal mechanisms for coordination and information sharing, such as FEMA's National Business Emergency Operations Center, were utilized during the 2017 hurricane season.

Although each of these mechanisms can provide opportunities for coordination, ongoing consideration is needed to advance this collective "ecosystem" for engagement to minimize the time burdens placed on individual participants.

4. **Develop and administer training on supply chain dynamics and best practices for private–public partnerships that enhance supply chain resilience.**

Many engaged in emergency response have little or no experience working with private-sector entities or training for evaluating the impacts of a disaster on local supply chains and economics. University programs in emergency management and homeland security have few classes that provide the insights necessary to understand how disasters and emergency management strategies can affect supply chains and the economy as a whole.

To help stakeholders evaluate their decisions in a broader context, training should be provided to emergency managers and those supporting disaster operations (e.g., emergency operations center personnel, incident management teams, federal coordinating officers, and those in emergency support functions from other government agencies). Training could be provided through new courses in college emergency management programs; orientation training for new emergency managers, critical emergency operations center staff and stakeholders, and newly elected government officials; and FEMA's in-person and online training classes.

Training programs could enable participants to analyze factors such as economic drivers within their jurisdiction, data that can inform decisions about priorities for restoration assistance to supply chains, ways that supply chain disruptions can impact economic conditions, and the cost of disaster response or mitigation actions versus the costs of not taking those actions.

Conclusions

As FEMA's internal capacity and expertise on supply chain dynamics grow, the agency can play an increasingly valuable role assisting states, communities, the private sector, and other stakeholders with technical assistance and guidance. Although FEMA cannot be responsible for carrying out all of these activities, it can provide leadership for convening, coordinating, and empowering key partners.

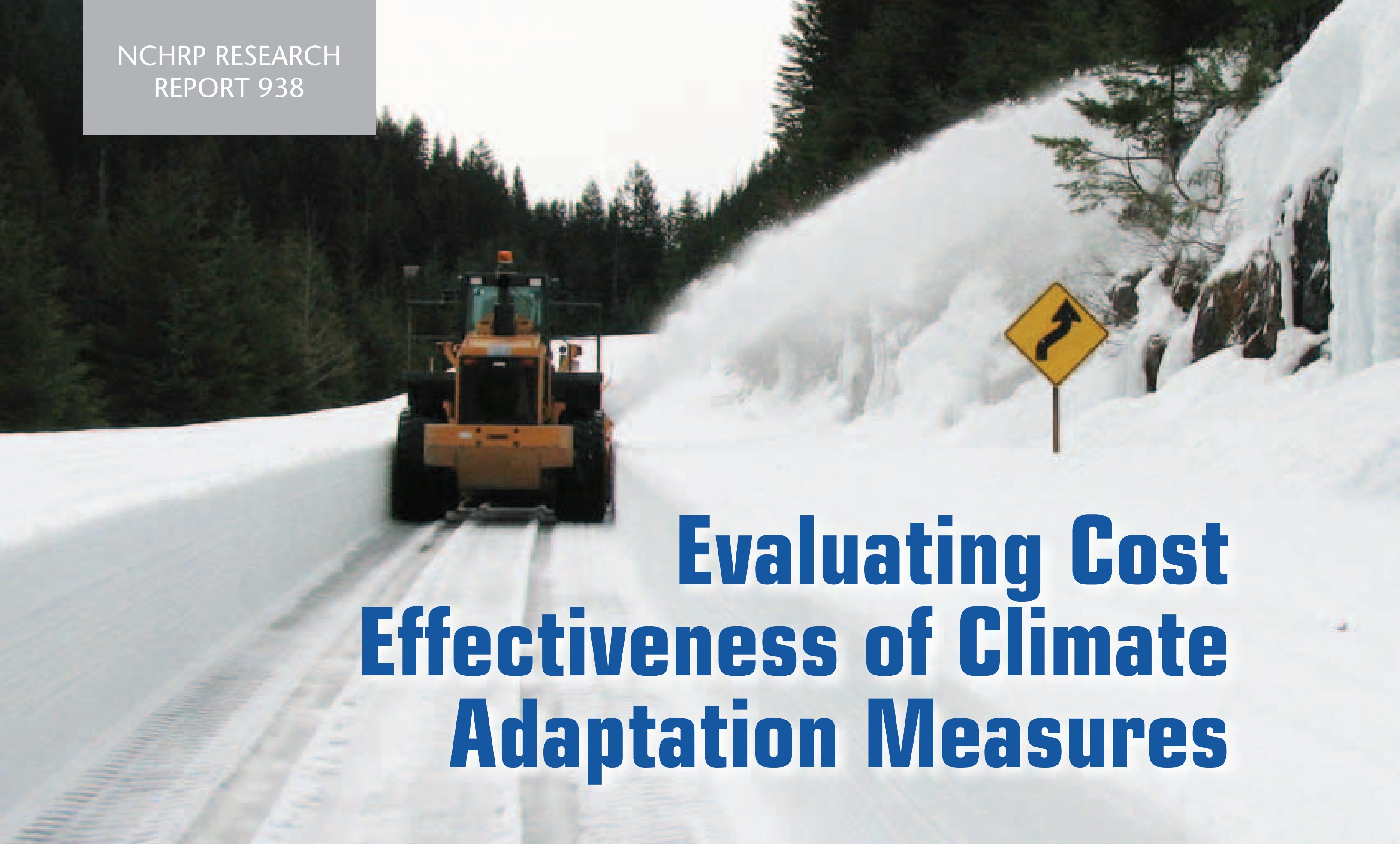
This facilitating role should be proactive, going beyond grant programs to also provide jurisdictions with guidance for increasing understanding and capacity to implement new programs. Many state emergency management offices have significant capabilities but lack information access and sharing. They may have insufficient cooperation with other states, counties, and communities. With FEMA's experience and cross-jurisdictional scope, the agency could advise and guide state and local supply chain preparedness efforts across the country.

As weather disasters get costlier, more frequent, and affect more people, no single government agency can do everything to help communities prepare, respond, and recover. A whole community effort is required, involving federal, state, and local government agencies; the private sector; and nongovernmental organizations and civic groups, as well as individual households. FEMA's 2018 strategic plan highlights the goal of ensuring that communities have robust, adaptable supply chains that can withstand the stresses of extreme weather events. This goal is best attained by facilitating communitywide efforts to build systems and relationships that advance preparedness. The more advances that are made on these fronts, the less time, energy, and resources will be needed for emergency response and recovery.

The National Academies of Sciences, Engineering, and Medicine's Committee on Building Adaptable and Resilient Supply Chains After Hurricanes Harvey, Irma, and Maria was assembled by the Office of Special Projects in the Policy and Global Affairs (PGA) Division. The cornerstone activity of the PGA Office of Special Projects is the Resilient America program, which was established to implement recommendations from the 2012 National Academies report *Disaster Resilience: A National Imperative*. For the purposes of the accompanying article, resilience is defined as "the ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events."

REFERENCES

1. U.S. Virgin Islands Hurricane Recovery and Resilience Task Force. *USVI Hurricane Recovery and Resilience Task Force: Report 2018.* St. Thomas, Virgin Islands. 2018. https://first.bloomberglp.com/documents/257521_USVI_Hurricane+Recovery+Taskforce+Report_DIGITAL.pdf.
2. Çelik, M., Ö. Ergun, and P. Keskinocak. The Post-Disaster Debris Clearance Problem Under Incomplete Information. *Operations Research*, Vol. 63, No. 1, 2015. doi: 10.1287/opre.2014.1342.



NCHRP RESEARCH REPORT 938

Evaluating Cost Effectiveness of Climate Adaptation Measures

Photo: Washington State DOT

LAUREL MCGINLEY

The author is a senior associate at Dewberry in Fairfax, Virginia.

Above: A lone snow blower takes its turn to clear a mountain pass in Washington State. Frequent weather events, such as heavy annual snowfalls—and the efforts to manage them—take a toll on transportation infrastructure and challenge state DOTs to find effective ways to prioritize funding.

For state departments of transportation (DOTs), increasingly frequent severe weather events present a connected set of issues with potentially serious, costly effects on infrastructure. Moreover, much of the United States' transportation infrastructure is reaching the end of its useful life, and—in some cases—competing priorities and limited budgets have resulted in underfunded preventive maintenance programs. In addition to extreme weather events, aging infrastructure is also being stressed by increases in population and development.

What processes and criteria can transportation decision makers use to prioritize projects for funding in the face of changing weather and climate conditions? The Federal Highway Administration (FHWA) has developed a framework for practitioners to evaluate the potential effects of climate change and extreme weather on transportation assets and systems to help determine if and where adaptation would be effective to increase resilience to these changing conditions (*1*). The framework suggested selection criteria based on technical feasibility, political appetite, flexibility, environmental impacts, societal impacts, effectiveness, and costs and benefits. This last criterion—costs and benefits—is a tool that, historically, transportation practitioners have seldom used but warrants additional consideration for agencies trying to demonstrate fiscal responsibility to taxpayers while also trying to meet agency goals and objectives.

National Cooperative Highway Research Program (NCHRP) Research Report 938: Incorporating the Costs and Benefits of Adaptation Measures in Preparation for Extreme Weather Events and Climate Change—Guidebook and accompanying resources provide state DOTs with a relatively simple, screening-level, cost–benefit analysis (CBA) method that incorporates adaptation to improve resilience to climate change and extreme weather into the decision-making process (*2*). Although state DOTs report that the expectation of damage from adverse weather events is becoming a key driver in resilience investment decisions, state DOTs typically do not conduct a formal CBA to address climate resilience. Generally, most transportation agencies conduct CBAs only when they are required as part of funding source reporting or when the agency's internal practices dictate their use. State DOTs cite limitations in existing tools, guidance, and funding as reasons that CBAs are not conducted more routinely. However, state DOTs acknowledge CBA usefulness as a potential tool for evaluating various options, particularly if the analysis can be done relatively easily using available data. In particular, state DOTs expressed that CBAs could be useful at the planning level, given the importance of that stage for programming and understanding long-term demands on and direction for the agency.

To this end, the advisory panel for the research team determined that a CBA methodology should be developed that leverages available existing data, models, tools, and frameworks to create scalable approaches to conducting CBAs. The methodology also should be simple to use to lower the perceived barrier of complex data entry needed to perform CBAs for climate resilience projects. With these objectives in mind, the research team set out to develop an approach for two levels of analysis: one that builds on the other. A sketch-level analysis is useful for identifying which adaptation projects might warrant additional evaluation. A climate resilience–level analysis builds on the sketch-level analysis to generate a benefit–cost ratio.

These analysis levels allow practitioners to complete an analysis based solely on financial considerations or to incorporate environmental and social factors, as well. Each analysis level considers the capital costs associated with the adaptation project, the associated operations and maintenance costs, and any costs that might be associated with delays to asset or corridor users during construction or other implementation of the measure. Benefits are primarily based on losses avoided, which could include physical damages, delays or loss of service to users, detours, and frequency of accidents. Environmental and social factors—such as reduction in greenhouse gas emissions—may also be considered.

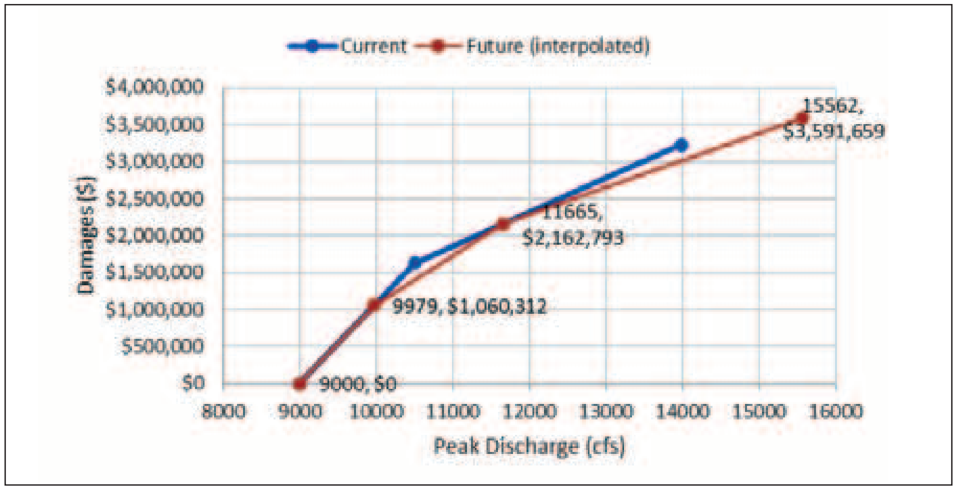


FIGURE 1 The results of a sketch-level analysis demonstrate that the relationship between damages and discharge under current and future conditions remains constant, regardless of climate conditions (cfs = cubic feet per second).

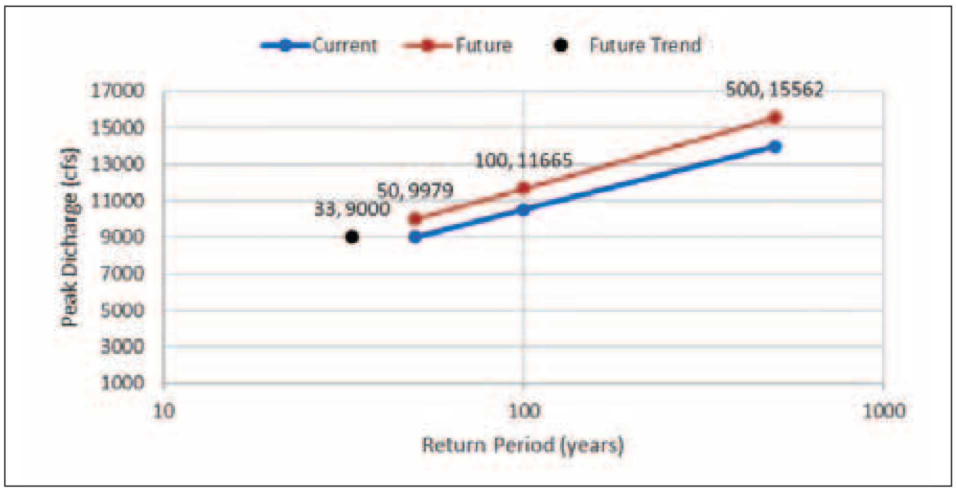


FIGURE 2 The CBA approach developed to evaluate climate adaptation assumes future events of a given magnitude are likely to occur more frequently in the future. The results of a sketch-level analysis show that the return period for a given flow level will decrease under future climate conditions. Stated another way, the flows will increase for the same return period under future climate conditions.

The basic premise of the approaches that were developed is that the relationship between the magnitude of the event and the damages that event causes remains constant (Figure 1) even while the relationship between the event frequency and magnitude may change over time because of evolving climate conditions (Figure 2). The goal of the sketch-level analysis is to determine the net present value of an adaptation project that will maintain the current frequency–damage relationship under future conditions. Adaptation projects—or adaptation components of capital projects—with costs less than or equal to the net present value calculated are likely to be cost-effective and may warrant further evaluation. A climate resilience analysis builds on a sketch-level analysis and improves the accuracy of the projected frequency–damage relationship. In this level of analysis, the future damages considering climate change are calculated with and without adaptation measures in place. Both levels of analysis are intended to be completed using the agency's data and publicly available tools such as SWMM-CAT, FHWA's climate vulnerability tools, and National Oceanic and Atmospheric Administration (NOAA) Atlas 14.

To evaluate the approach that was developed, the research team applied

Photo: Minnesota DOT

After a heavy rainfall, Minnesota DOT road crews block a flooded lane and shoulder to safeguard drivers and to avoid potential damage to pavement. Poor-quality roads can increase wear on vehicles, raise repair costs, and expand travel times, all of which affect regular drivers and freight truck drivers. For the latter, such conditions also can increase the cost of doing business and delay the delivery of goods and services.

examples found in literature to a sketch-level analysis and a climate resilience analysis. For the sketch-level analysis, the research team used information provided in Minnesota DOT's FHWA climate vulnerability study for Culvert 5648 (*3*). Minnesota DOT evaluated three climate adaptation options to replace an existing double-box culvert to determine if any would be cost-effective. The results of the sketch-level analysis completed by the research team were consistent with the results of Minnesota DOT's analysis, completed using other software.

A climate resilience–level analysis was applied to the Gulf Coast 2: Airport Boulevard Culvert case study, included in FHWA's HEC-17 manual as part of their Level 5 analysis (*4*). Similar to the Minnesota DOT project, this case study evaluated options for replacing a culvert to improve its resilience to increased flood flows. The FHWA case study used a Monte Carlo approach to evaluate the cost-effectiveness of various options. Applying the climate resilience–level analysis approach to the data available and extrapolating where necessary, the research team achieved similar results, with net present value and benefit–cost ratios within about 3 percent of those calculated by the FHWA methodology.

Much of the United States' transportation infrastructure is reaching the end of its useful life and is also being stressed by increases in population and development.

State DOTs report that they increasingly are considering climate and extreme weather adaptation in planning and designing their projects, but CBAs are not commonly used in the project planning and development process. *NCHRP Research Report 938* provides state DOTs with a practical CBA method for application to projects that address transportation system resilience. The method establishes a rigorous foundation for decision making that can improve stewardship of limited public monies and overall transportation system resilience. CBAs can help strengthen the case for resilience investments. CBA does have limitations that must also be considered when evaluating transportation projects for funding. These limitations include project benefits and costs that cannot be easily quantified, uncertainties associated with climate projections, and the challenge of selecting an appropriate discount rate to use in the face of uncertainty. Despite these limitations, CBA is a useful tool in a state DOT's toolbox. As state DOTs acknowledge and plan for the increased stress a changing climate and extreme weather are likely to bring, CBA can help them identify when and which adaptation measures should be considered for incorporation into a project. Using a simplified CBA approach to screen projects for cost-effectiveness can provide additional data for decision makers to consider when evaluating and prioritizing projects.

REFERENCES

1. Federal Highway Administration, U.S. Department of Transportation. *Climate Change Adaptation Guide for Transportation Systems Management, Operations, and Maintenance.* 2015. https://ops.fhwa.dot.gov/publications/fhwahop15026/fhwahop15026.pdf.
2. Dewberry Engineers, Venner Consulting, Impact Infrastructure, Inc., and McVoy Associates. *NCHRP Research Report 938: Incorporating the Costs and Benefits of Adaptation Measures in Preparation for Extreme Weather Events and Climate Change—Guidebook.* Transportation Research Board, Washington, D.C., 2020. http://dx.doi.org/10.17226/25744.
3. Minnesota Department of Transportation. *MnDOT Flash Flood Vulnerability and Adaptation Assessment Pilot Project Final Report.* 2014. http://www.dot.state.mn.us/climate/pdf/MnDOTFldVulnPilotFinalRpt.pdf.
4. Federal Highway Administration. *Hydraulic Engineering Circular No. 17, 2nd Edition. Highways in the River Environment—Floodplains, Extreme Events, Risk, and Resilience.* 2016. https://www.fhwa.dot.gov/engineering/hydraulics/pubs/hif16018.pdf.

Data Dive into *Transportation Research Record* Articles

Authors, Coauthorships, and Research Trends

SUBASISH DAS

The author is an assistant research scientist at Texas A&M Transportation Institute in San Antonio, Texas.

Above: An analysis of journal articles from the *Transportation Research Record: Journal of the Transportation Research Board* (TRR) can shed light on today's transportation research trends.

Transportation is vital to people's quality of life. Rapid growth in population, miles traveled, urbanization, and emerging technologies like connected and autonomous vehicles have had a substantial impact on modern living. The rising application of emerging technologies, the increasing number of peer-reviewed journals and conference proceedings, and the significant growth in interdisciplinary collaborations reflect the significance of the size and scope of transportation research. However, transportation challenges and problems have changed over time, and the transportation research scope has also become more diverse. Because of the consistent evolution of the advances in solutions and technologies, transportation research has experienced an upsurge of publications in recent decades.

Predicting future salient issues in any field of science that will dominate research is always a challenge, but as transportation research becomes more complex and cross-cutting, this challenge is critical. Research on statistical models of co-occurrence of trending topics has led to the growth of different, useful topic models. This efficient machine-learning technique helps researchers find concealed trends inside unstructured larger textual contents. To understand the research trends in the realm of complex transportation science and engineering, an analysis of journal articles from the *Transportation Research Record: Journal of the Transportation Research Board* (TRR) may be beneficial. By applying text mining and two topic modeling techniques, this article presents an empirical analysis of 28,987 articles published in the TRR from 1977 to 2018 to identify the publication trends.

History of the *TRR*

The Transportation Research Board (TRB) coordinates the most comprehensive and largest annual transportation conference in the world. Established in 1920 as the National Advisory Board on Highway Research, TRB has provided a platform to convert research results into applicable

Aims and Scope of the *Transportation Research Record*

All modes of passenger and freight transportation are addressed in papers covering a wide array of disciplines, including policy, planning, administration, economics and financing, operations, construction, design, maintenance, safety, and more. The ideal TRR contribution clearly advances knowledge in its area of expertise; explicitly draws out the practical implications of the paper's results, whether for immediate or longer-term application; and is well written with an engaging style.

information about every facet of transportation. Thousands of scientists, engineers, and other transportation practitioners and researchers from the private and public sectors and academia all are included in TRB's various activities.

The year 2020 marked the 57th year of TRB's peer-reviewed journal, which debuted as the *Highway Research Record* in 1963, became the *Transportation Research Record* in 1974, and added the subtitle *Journal of the Transportation Research Board* in 2000. The technical papers in TRR have been accepted for publication through a rigorous peer-review process overseen by TRB technical committees.[1] These papers provide extensive documentation of the research activities undertaken by the transportation research community, and they provide a unique insight into the research topics that have remained active over the long term, as well as topics that have recently emerged into the forefront. To remake TRR into a timelier, more author-friendly, and more widely marketed journal, TRB transitioned the publication of TRR to SAGE Publishing in 2018.

Photo: Risdon Photography

Emiliano Ruiz, University of Texas at El Paso, presents research at the 2020 TRB Annual Meeting. His paper, "Simulation Model to Support Security Screening Checkpoint Operations in Airport Terminals," was published in the TRR the same year.

Data Collection

As a robust, long-standing journal, TRR was chosen as the subject of this analysis of trends in keywords, topics, authors, and coauthorships. The TRR series was selected based on its long history and inclusion of a wide variety of subject matter. The TRR series was also attractive because of its rigorous review process and widespread use among both academics and practitioners. The TRID database then was used to develop the databases for this study. All information associated with TRR articles was first saved in the research information system (RIS) format and then converted into spreadsheet format. The columns in the database include the title of the paper, keywords, abstract, authors, and publication year. This analysis included 28,987 articles published between 1977 and 2018. Publication years of the articles were extracted from TRID metadata.

As shown in Figure 1, the pace of published articles has increased over the years. The publication rate trends from 1977 to 2018 can be divided into four stages. The first stage was from 1977 to 1990. Because of its multidisciplinary nature, TRR published around 530 journal articles per year from its earliest years until 1990. The second stage was from 1991 to 2000. During this period, the number of articles published grew steadily and consistently, increasing to an average of 663 articles per year. The third stage (2001–2010) shows an average of 769 journal articles per year, and the fourth stage (2011–2018) shows an average of 903 journal articles per year.

Prolific TRR Authors

Figure 2 lists the top eight most prolific authors of TRR articles from 2009 to 2018 and illustrates the frequency of yearly publication for each author. As shown in Figure 2, in 2016, Serge Hoogendoorn published 18 TRR articles—the largest number of TRR articles by a researcher as a

Photo: Risdon Photography

The most prolific TRR author of all time, Hani Mahmassani delivered the 2016 Thomas B. Deen Distinguished Lecture to a standing-room-only crowd.

[1] ISSN: 0361-1981, Online ISSN: 2169-4052

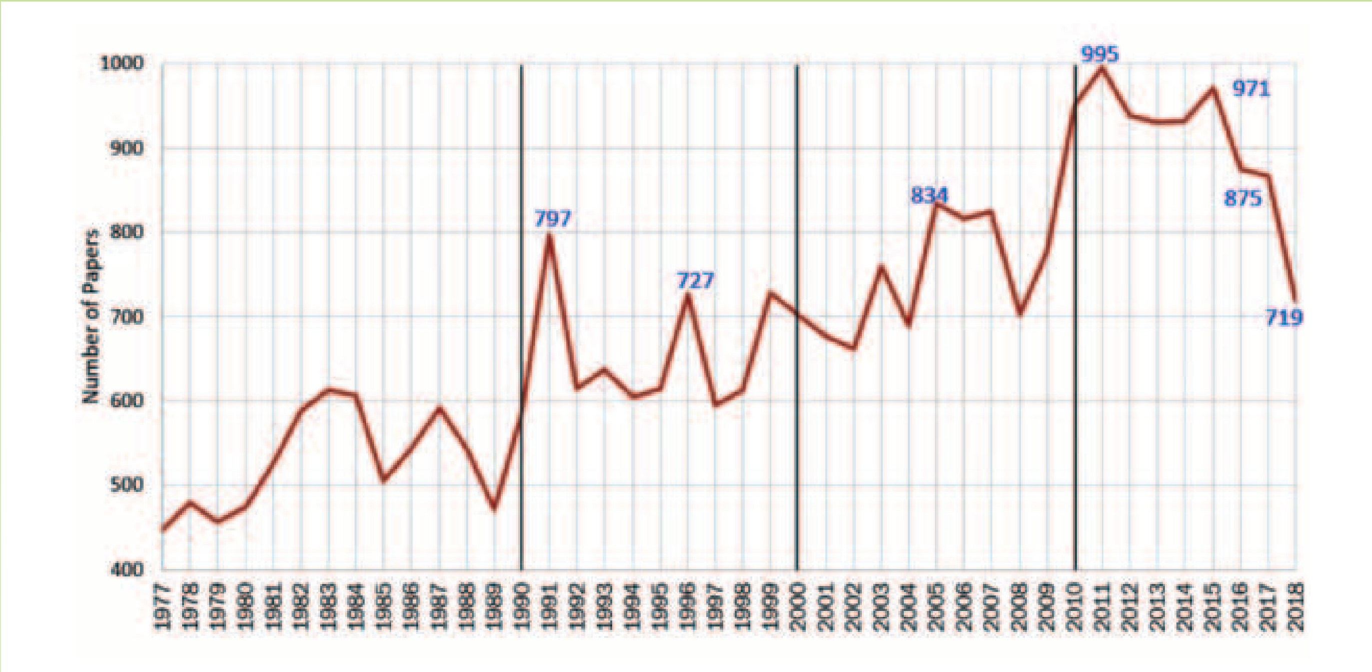


FIGURE 1 TRR journal articles by year.

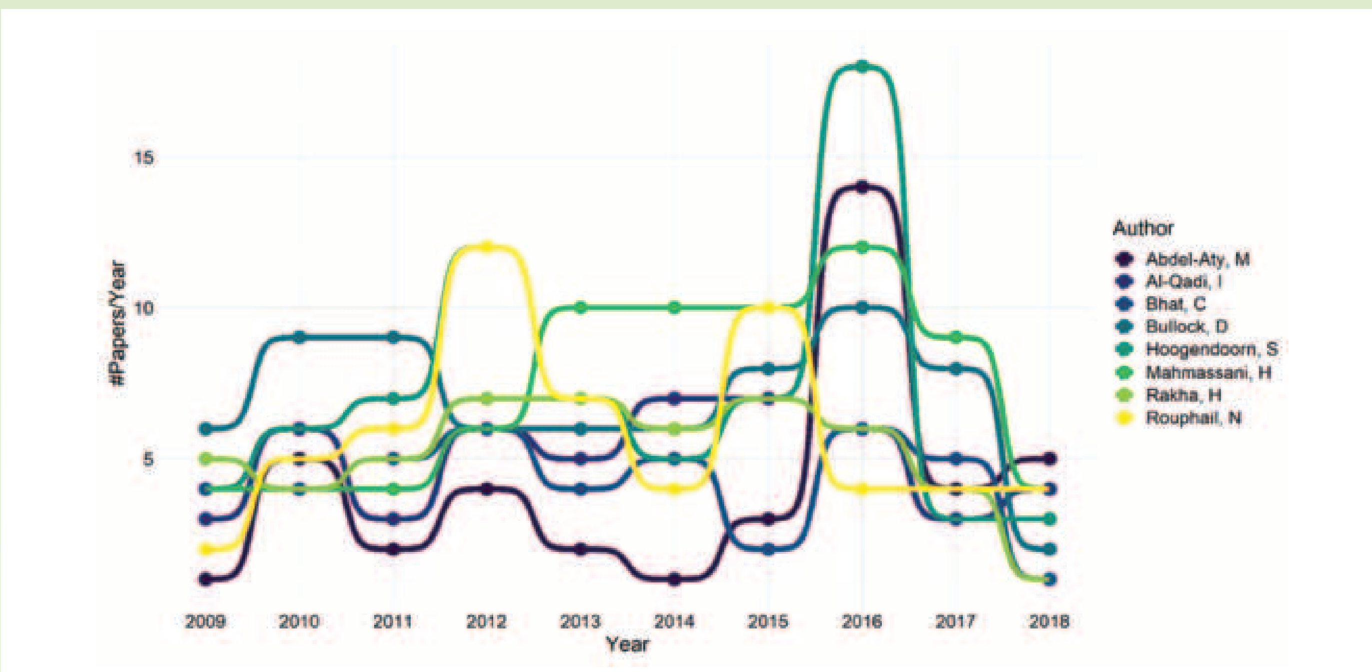


FIGURE 2 Prolific TRR authors (2009–2018).

corresponding author or coauthor in a single year. Hani Mahmassani has published 183 TRR articles since 1984, which makes him the most prolific TRR author overall.

Coauthor Network

Coauthorship networks can be used to investigate the structure of scientific collaborations. As transportation research has become increasingly cross-disciplinary, it is important to investigate author patterns and trends. This article explores a coauthor network plot for a quick understanding of the complex interdisciplinary networks among authors, but future studies can investigate the development of advanced analysis, such as author–topic models. Created using Gephi 0.9.2 software, the plot graph (Figure 3) shows the network patterns of the authors who are author or coauthor of at least one TRR article.[2] The complexity of this network indicates the massive number of nodes and links among TRR authors.

The node sizes are proportional to link-in counts and color by different nodes.

Interactive Tool

Developed as a part of this study, an interactive web tool is available via Github and allows users to explore the TRR coauthorship network interactively. Any TRR author can search their name to see their coauthorship network.

For more, visit http://subasish.github.io/pages/gephi_html/TRR_C/network/.

The authors Imad Al-Qadi and Darcy Bullock have the highest number of coauthor connections (127 and 123, respectively).

Clusters of Key Words by Publication Stages

Four interconnection network diagrams (Figure 4) were developed to explore the shifting research trends over the years. In the first stage (1977–1990), two main clusters formed around *pavement* and *travel models*. Two other keyword groups show higher co-occurrences: 1) *effectiveness* and *measure of effectiveness* and 2) *survey* and *data collection*. A similar trend is seen in the second stage (1991–2000); however, in this stage more keywords are associated with the *pavement* cluster.

By contrast, by the third stage (2001–2010), the *asphalt pavement* cluster has divided into two subclusters: *asphalt pavement* and *mechanistic–empirical pavement*. Some smaller clusters of *driver behavior* and *safety* are visible in this stage. By the final stage (2011–2018), three main clusters have formed: *pavement*, *travel model*, and *highway safety*. This trend analysis clearly shows how the topical shift occurred in transportation research over the years.

Trends from Structural Topic Modeling

Because TRR journal articles cover a wide variety of topics, advanced modeling is needed to unearth research topic trends. Probabilistic topic modeling is a robust method to identify topics from complex text data. The two most common topic modeling methods are latent Dirichlet allocation (LDA) and structural topic modeling (STM). Both methods are Bayesian generative topic models that assume that each topic is a distribution over words and that each document is a mixture of corpus-specific topics (that is, a collection of texts; for example, all abstracts from the 2018 editions of TRR can be considered a corpus).

The STM algorithm identifies document-level structure information (keywords or word groups) to influence topical prevalence (for example, the proportion of topics by document frequency) and topic content (the distribution of the keywords in topics) (*1–4*). Several studies have applied topic modeling techniques to TRB-related journals, conference proceedings, and social media hashtags (*5-7*).

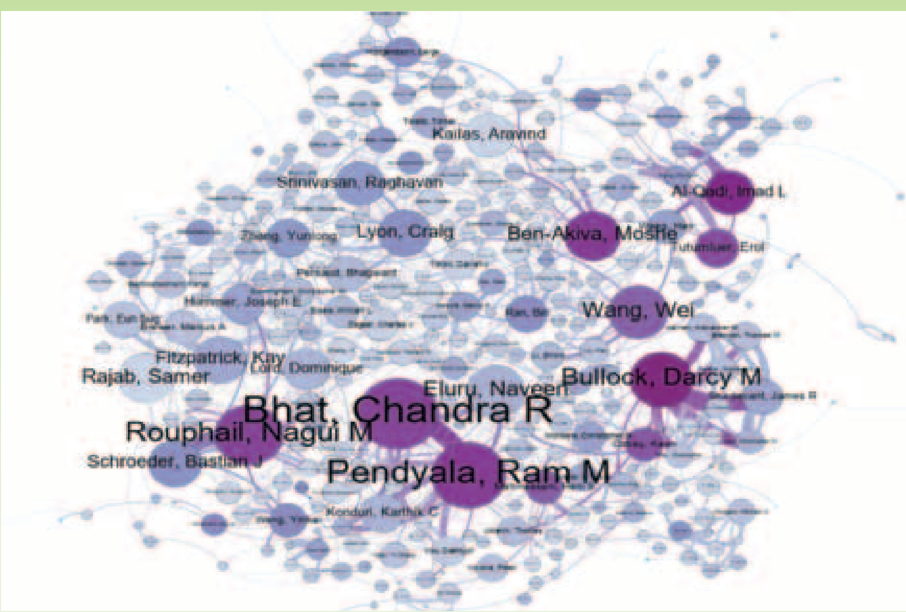
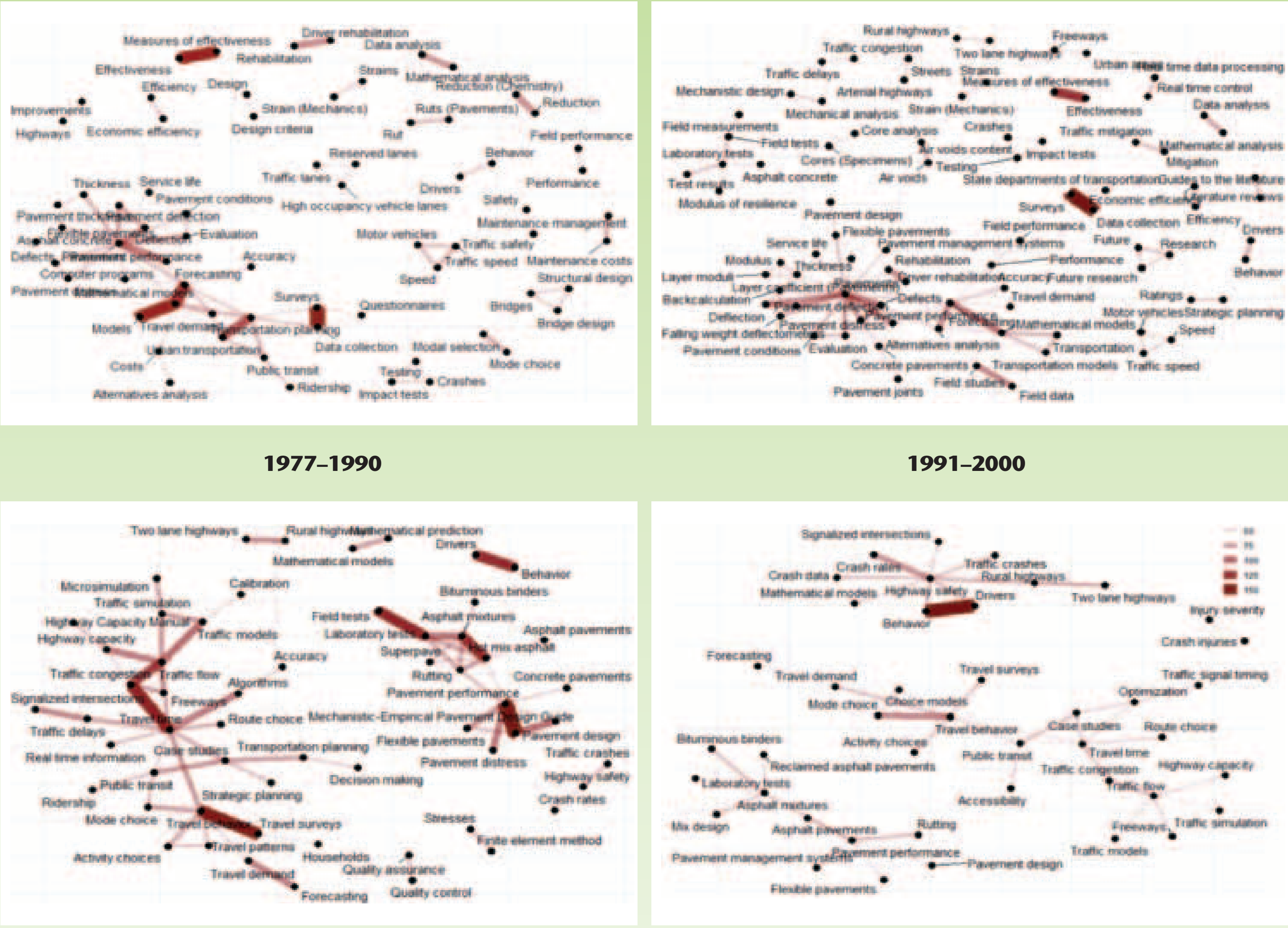


FIGURE 3 TRR coauthorship network.

[2] https://gephi.org/



1977–1990

1991–2000

2001–2010

2011–2018

FIGURE 4 Keyword networks by different year groups.

For this article, an open-source R package STM and topic model (TM) are used in the analysis (*8–9*). The data import process produces documents and metadata (i.e., data that provide information about other data) that is then incorporated by STM into the topic modeling framework. Figure 5 illustrates the corpus-level visualization of the top topics from a 20-topic model, showing the expected proportion of the corpus belonging to each topic. High-frequency topics include travel data (Topic 2), choice model (Topic 7), rehabilitation (Topic 8), freeway (Topic 11), and urban planning (Topic 17).

Interactive Tools Using LDA

By using metadata, STM functions explain the trends over the years. This article examines large textual contents (papers have approximately 305,000 words, and abstracts have approximately six million words), so an interactive and comprehensive topic model is needed. The LDA model was used primarily to visualize the output of TM fit; however, the high dimensionality of the fitted model produces challenges in creating these visualizations.

Normally, LDA is applied to thousands of documents representing topic combinations in the dozens to hundreds, which then are modeled as distributions across thousands of terms. To mitigate these challenges and create LDA visualizations (LDAvis), interactivity—a basic technique that is both compact and thorough—is

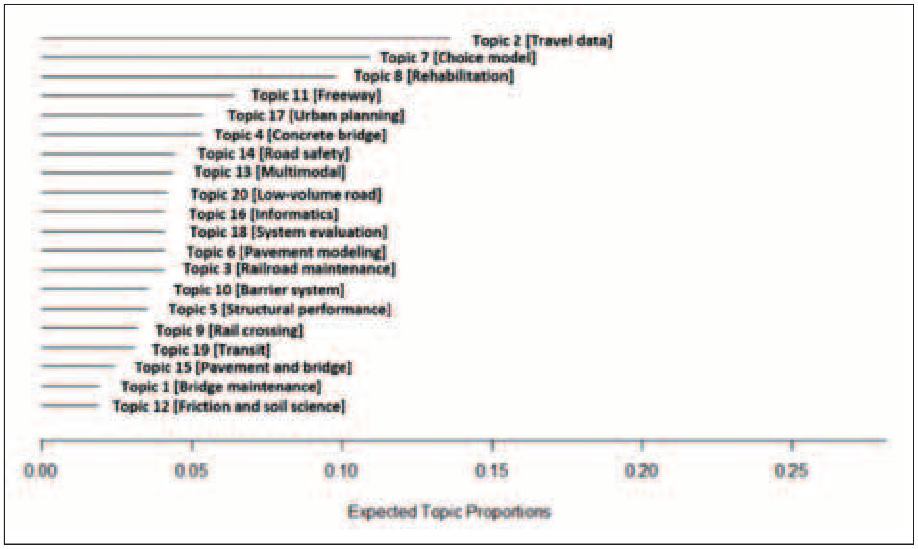


FIGURE 5 Top 20 topic models using STM.

the best technique. For this article, the LDAvis package was employed to develop interactive LDA models (*10*).

Figures 6a and 6b present the web interface of the interactive visualization of LDA topic models.[3] The plots are composed of two sections: 1) on the left, global perspective on the topic models, and 2) on the right, a bar chart of the keywords associated with the highlighted topics.

The topics are plotted as circles in the left section. The locations of the topics are based on the measures of principal component analysis (PCA), a dimension reduction method to show relevance of topics based on the relative distances in a 2-D or 3-D space, in a way to show the general trends of the keywords by showing which topics are similar or different. By measuring the distance between topics, the centers of these topic circles are placed in the visualization. The bar plot represents the individual terms that are the most useful for interpreting the topics on the left, based on which topic is currently selected (keywords are shown horizontally). This allows users to comprehend the meaning of each topic. The overlaid bars in the plot represent both the corpus-wide frequency of a given term and the topic-specific frequency of the term (*11*).

The left and right sections of the plot are interconnected. Selection of a topic circle in the left makes the bar plot on the right highlight the terms most useful to interpreting the selected topic. Additionally, selecting a term from the bar plot reveals the conditional distribution over topics for the selected term. This allows users to efficiently examine many topic–term relationships.

Conclusions

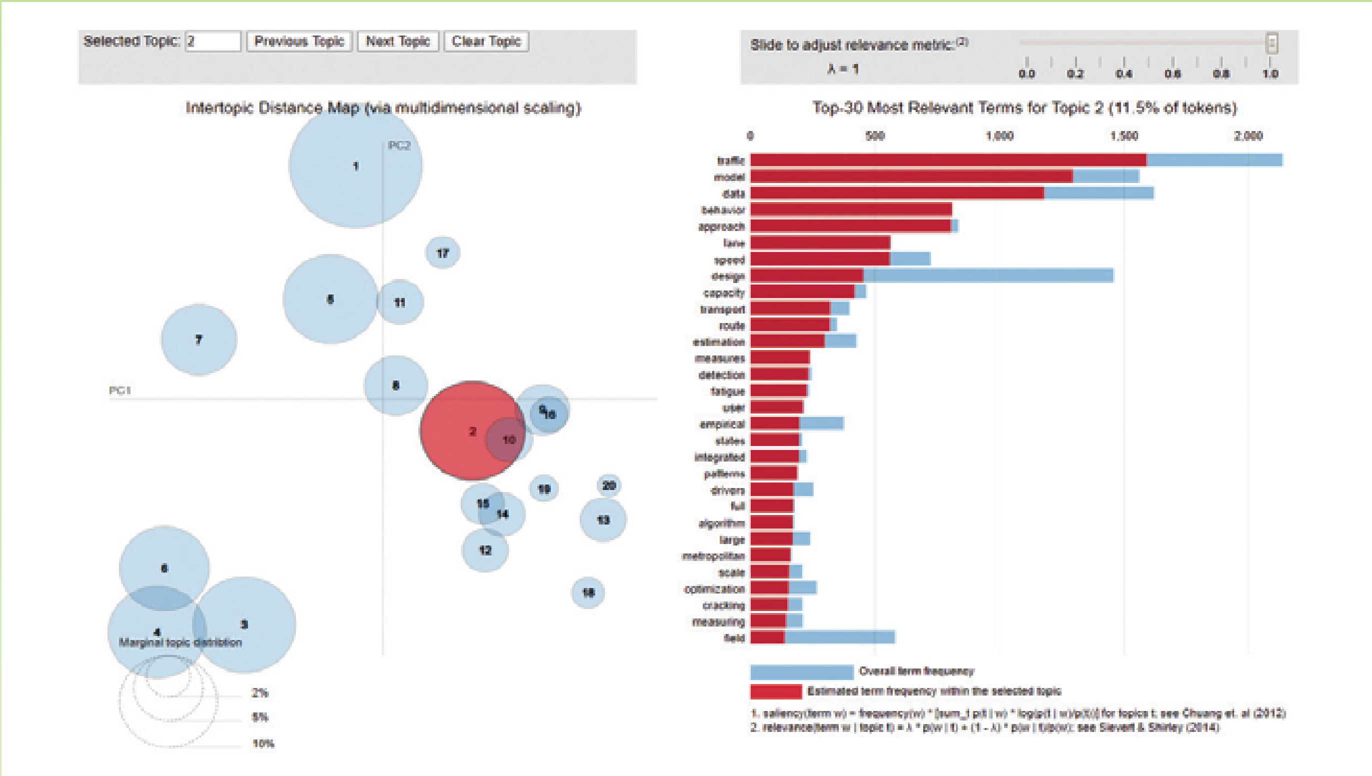
The TRR, as an international transportation journal, has provided a platform for the exchange of method, concepts, policies, and technologies to help transportation agencies to work toward a safe and secure transportation system. The findings of this study show that the pace of published articles has increased over the years. TRR is preferred by many prominent researchers, and the coauthor network shows some clusters around prominent and prolific researchers. The complex nature of the coauthor network plot indicates a wide variety of coauthorships among TRR authors.

TRR has published articles covering a wide array of topics pertaining to transportation. A single topic model is not sufficient to explain the trends and patterns of the keywords over the years. To provide flexibility in understanding the topics, the author developed two interactive LDA topic model tools to help users understand the range of topics and relevant keywords associated with the topics. It is anticipated that the TRR will continue to provide a platform for transportation science and engineering for academics, educators, researchers, enterprise leaders, and policy makers with the vision and mission to help the transportation system of the future.

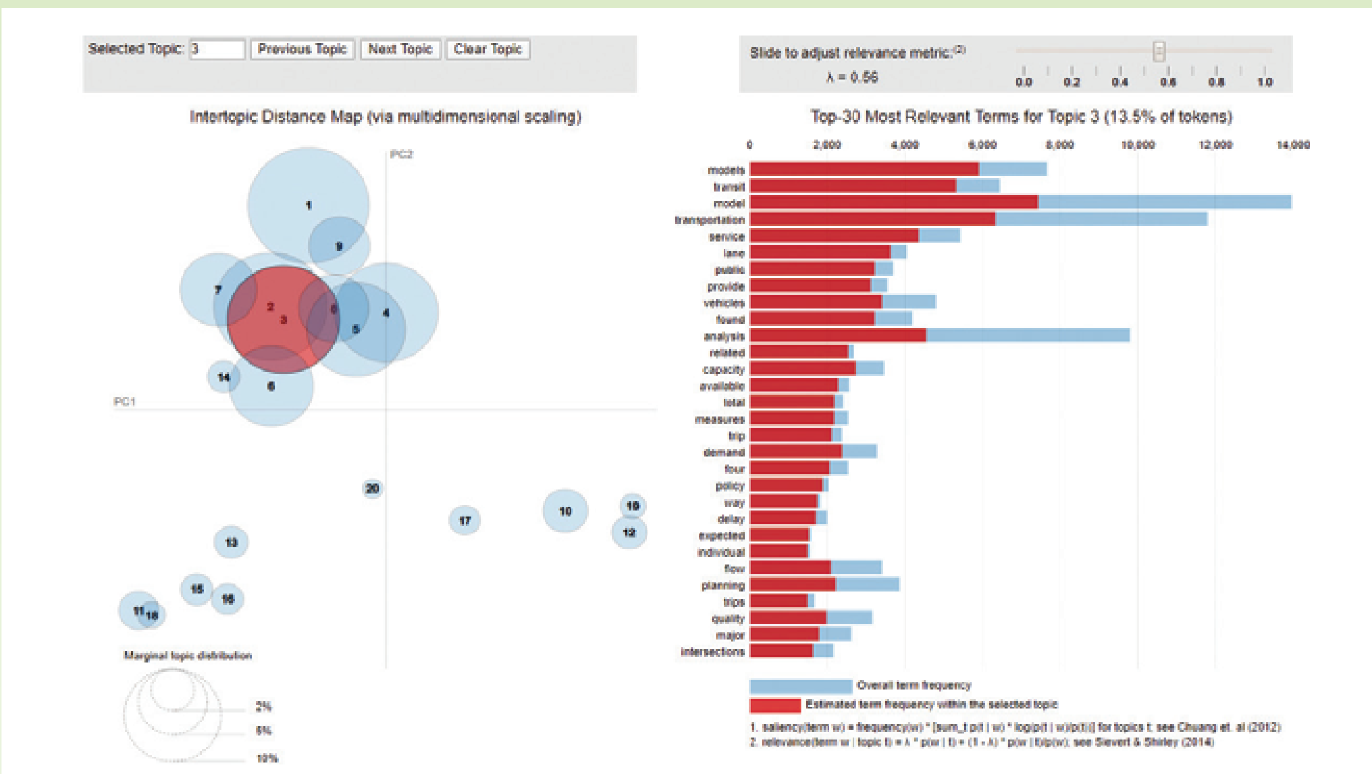
[3] To see the tool based on abstracts, visit http://subasish.github.io/pages/trr_abstract. To see the tool based on titles, visit http://subasish.github.io/pages/trr_title.

REFERENCES

1. Grimmer, J., and B. Stewart. Text as Data: The Promise and Pitfalls of Automatic Content Analysis. *Political Analysis,* Vol. 21, No. 3, 2013, pp. 267–297.
2. Chang, J., J. Boyd-Graber, S. Gerrish, C. Wang, and D. M. Blei. Reading Tea Leaves: How Humans Interpret Topic Models. Advances in Neural Information Processing Systems, Vol. 22, 2009, pp. 288–296.
3. Andrzejewski, D., and X. Zhu. Latent Dirichlet *allocation* with Topic-in-Set Knowledge. *Proceedings of the NAACL HLT 2009 Workshop on Active Learning for Natural Language Processing* (E. Ringger, R. Haertel, and K. Tomanek, eds.), Association for Computational Linguistics, 2009.
4. Andrzejewski, D., X. Zhu, and M. Craven. Incorporating Domain Knowledge into Topic Modeling via Dirichlet Forest Priors, *ICML 09: Proceedings of the 26th Annual International Conference on Machine Learning*, Association for Computing Machinery, 2009, pp. 25–32.
5. Das, S., X. Sun, and A. Dutta. Text Mining and Topic Modeling of Compendiums of Papers from Transportation Research Board Annual Meetings. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2552, 2016, pp. 48–56.
6. Das, S., K. Dixon, X. Sun, A. Dutta, and M. Zupancich. Trends in Transportation Research: Exploring Content Analysis in Topics. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2614, 2017, pp. 27–38.
7. Das, S. #TRBAM: Social Media Interactions from the Largest Transportation Conference. *TR News*, No. 324, November–December 2019, pp. 18–23.
8. Roberts, M., B. Stewart, and D. Tingley. stm: R Package for Structural Topic Models. 2016. http://www.structuraltopicmodel.com. Accessed July 2016.
9. Feinerer, I., K. Hornik, and D. Meyer. Text Mining Infrastructure in R. *Journal of Statistical Software*, Vol. 25, No. 5, 2008, pp. 1–54.
10. Sievert, C., and K. Shirley. LDAvis: Interactive Visualization of Topic Models. R package version 0.3.2. https://CRAN.R-project.org/package=LDAvis. Accessed July 2019.
11. Das, S., A. Dutta, and M. Brewer. Case Study of Trend Mining in *Transportation Research Record* Articles. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2674, 2020, pp. 1–14.



(a)



(b)

FIGURE 6 Interactive topic model tools using TRR journal titles (*a*) and abstracts (*b*).

TRUCK SIZE AND WEIGHT RESEARCH CHALLENGES

Photo: Vistavision, Flickr

DANIEL HAAKE

Daniel Haake is the chair of TRB's Trucking Industry Research Committee and former chair of the Truck Size and Weight Committee. He is a senior transportation planner at HDR, Indianapolis, Indiana.

Above: A tanker truck crosses I-75 over the Great Miami River on a summer evening in downtown Dayton, Ohio. Trucks carry more than 70 percent of the nation's freight by weight.

Each day, the nation's multimodal transportation system moves 51 million tons of freight. Over the next 20 years, this figure is likely to increase by 22 percent. Although freight moves via multiple modes, trucks carry more than 70 percent of the nation's freight by weight (*1*).

Although it is in heavy demand, trucking is a low-margin industry. Legislative efforts to address this disconnect and to support economic development by making targeted industries—such as agriculture and manufacturing—more cost-competitive by lowering transportation costs often focus on increasing truck size and weight (TSW) limits. However, policy analysts and researchers have struggled not only to calculate the impacts but also the benefits of TSW policy changes. These challenges are not new.

In 1962, the American Association of State Highway Officials (AASHO, now AASHTO) conducted its iconic Road Test. Researchers drove several truck configurations around several loops to evaluate how trucks affect pavement (Figure 1). The test found that one fully loaded 18-wheeler caused the same amount of pavement damage as 9,600 passenger cars. Almost 60 years later, this figure is still often frequently cited, even though pavement design, trucks, and truck tires are different than they were in the 1960s.

Is that figure still valid? Right or wrong, it is still being used today. The AASHO Road Test is illustrative of the larger challenges involved in analyzing this research. Research in this area is still in its infancy, and many years later, fundamental questions remain unanswered.

- **Safety.** State crash record systems often do not contain information about a crashed truck's weight. Therefore, it is difficult to say with any certainty how different weights or truck configurations would affect safety quantitatively.
- **Economics.** Increases in TSW could induce a mode shift from rail and, for better or worse, would affect various segments of the trucking industry

FIGURE 1 AASHO Road Test pavement study, 1962. (Source: American Association of State Highway and Transportation Officials.)

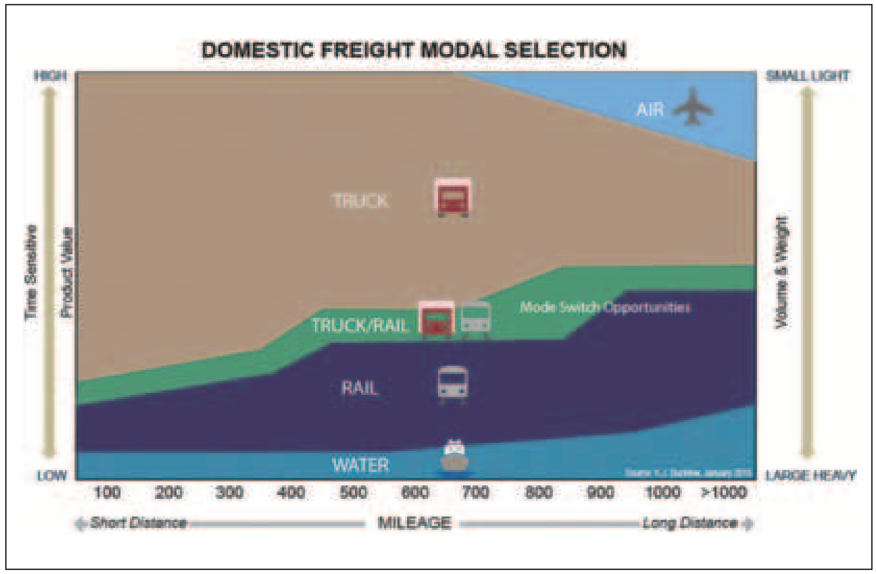


FIGURE 2 Increases to truck size and weight limits may have skewed traditional mode shift decisions made on distance, time, weight, value, and perishability. (Source: Keith Bucklew, HDR.)

(Figure 2). But there is no agreed-upon method to evaluate the potential economic impacts of a change.

- **Impact on infrastructure.** The impact of increased TSW on bridges and certain pavements (those that have received pavement rehabilitation treatments) still is relatively unknown. Resulting modeling challenges limit the ability to calculate the long-term impact of heavier trucks. This may change with increased use of weigh-in-motion bridge and pavement sensors.
- **Regulations.** Policy differences between states make it difficult to undertake national-level research or policy changes. Additionally, border states contend with different weight standards in Canada and Mexico.

Truck Size and Weight Regulation in the United States

In 1956, the Federal-Aid Highway Act authorized the development of the Interstate Highway System (IHS). To support the long-term maintenance of the system and to create national design standards, the Act instituted a gross vehicle weight (GVW) limit of 73,280 pounds and a 96-inch width limit on the IHS. Under this Act, the federal government did not regulate TSW issues outside of the IHS.

In 1974, the overall GVW limit increased to 80,000 pounds and the Federal Bridge Formula was established to limit the weight-to-length ratio of a vehicle crossing a bridge. This formula limits the concentration of weight in one area by spreading the weight over additional axles or by increasing the distance between axles (*2*, Figure 3).

Eight years later, Congress addressed ongoing challenges created by inconsistency among the width and length regulations of various states with the creation of the Surface Transportation Assistance Act of 1982. This Act expanded federal authority over truck length and widths beyond the IHS to a "National Network"

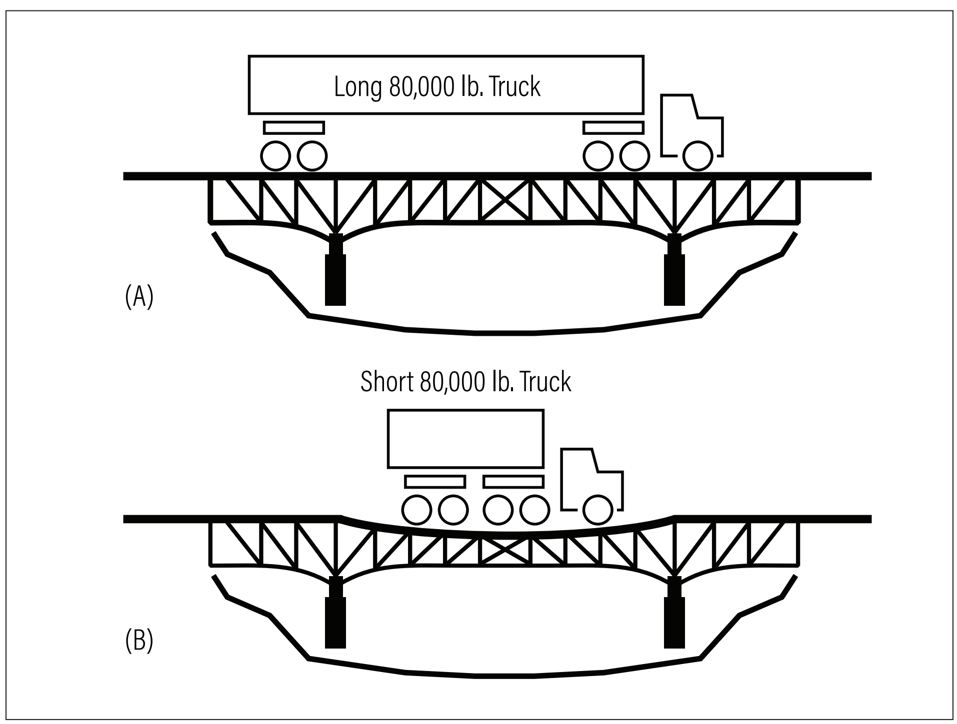


FIGURE 3 Visualization of the federal bridge formula. (Source: FHWA.)


Photo: Flickr

Complicating TSW research are trucks grandfathered by preexisting state laws—notably Rocky Mountain Doubles, or trucks with two linked trailers—that are allowed to exceed 80,000 pounds on the nation's Interstates.

that includes other major federal-aid roads. The Act also standardized minimum lengths for truck trailers and twin trailers. Subsequently, the Intermodal Surface Transportation Efficiency Act of 1991 restricted states from further expanding long combination vehicle corridors (*3*).

EXCEPTIONS TO THE RULE

From a policy standpoint, this pattern of federal regulations appears linear. However, in reality the situation is significantly more complicated. When the Federal-Aid Highway Act of 1956 was enacted, the law grandfathered preexisting state truck size and weight laws. Subsequent federal laws continued this exemption.

By grandfathering preexisting state laws, trucks are allowed to exceed 80,000 pounds on the Interstate System in certain states (e.g., I-90 in Indiana, Ohio, and New York). From a truck size standpoint, the most visible outliers are Rocky Mountain Doubles and triple trailers on non-tolled facilities.

Complicating the situation further, many states make allowances for heavier trucks under certain circumstances to make select industries more cost-competitive—for example, trucks carrying agricultural products, intermodal containers, drilling equipment, and manufacturing parts. Minnesota allows agricultural trucks with six axles to reach 90,000 pounds with an annual permit, and Michigan allows trucks of up to 164,000 pounds across 11 axles to move sawmill logs.

RESEARCH CHALLENGES

Significant research challenges result from the same operational differences created by laws that vary from state to state. Although research can be done within individual states, or among those that do not have grandfathered laws, the results often are not applicable nationwide.

MAP-21 Comprehensive Truck Size and Weight Study

Over the past 70 years, the U.S. Department of Transportation (U.S. DOT) has undertaken seven studies to explore the

TRB's Trucking Industry Research Committee

The TRB Standing Committee on Trucking Industry Research Committee and its Truck Size and Weight Subcommittee are actively developing research to answer many of the questions in this article as well as on other topics like permitting harmonization and multijurisdictional information sharing. For example, the committee cosponsored the 2020 TRB Annual Meeting workshop "Employing Weigh-in-Motion Data to Design, Rate, Manage, and Preserve the Nation's Bridge Structures."

As part of the 2020 TRB Technical Activities Division standing committee reorganization, the Truck Size and Weight Committee transitioned into a joint subcommittee of several related committees but has formally become part of the Trucking Industry Research Committee.

TSW topic (*4*). The latest was prompted by the Moving Ahead for Progress in the 21st Century Act (MAP-21). Enacted in 2012, MAP-21 required U.S. DOT to undertake a comprehensive truck size and weight study that addressed "differences in safety risks, infrastructure impacts, and the effect on levels of enforcement between trucks operating at or within federal TSW limits and trucks legally operating in excess of federal limits; comparing and contrasting the potential safety and infrastructure impacts of alternative configurations (including configurations that exceed current federal TSW limits) to the current federal TSW law and regulations; and estimating the effects of freight diversion due to these alternative configurations" (*5*).

Effectively, the MAP-21 study looked at the differences between trucks operating under the current federal TSW limits and those beyond current limits. Specifically, the project evaluated the effects on:

- Highway safety and truck crash frequency and severity;
- Pavement and bridge infrastructure service life impacts;
- Cost and effectiveness of enforcement; and
- Implications for the national transportation system including the modal share of freight movements.

At the beginning of the MAP-21 study, U.S. DOT identified several data-related issues that limited the ability of the effort to accomplish these goals (Table 1). Similar challenges were identified by a previous U.S. DOT comprehensive

TABLE 1 Data Challenges Identified in the 2016 MAP-21 Comprehensive Truck Size and Weight Study

TOPIC	CHALLENGES
Modal Shift	Freight Analysis Framework (FAF) data set limitations: • Required disaggregation to the county level. Exact origins and destinations are unknown, study used county centers as centroids. FAF does not provide routing (to calculate transportation costs), so calculations used shortest path routes between county centroids. Additionally, chained truck trips are not captured by the FAF. • Commodity groups too broad to identify specific characteristics.
	At the time of the study, the Vehicle Inventory and Use Survey was 13 years old. This aging data set was not able to represent current shipment sizes and annual usage rates for freight flows between distinct origins and destinations.
	Intermodal origins and destinations were not available from the Waybill Sample.
	A broad and exact set of truck rates were "difficult to obtain."
	Unable to undertake precise modal shift modeling due to data confidentiality.
Safety	A lack of truck weight data for individual trucks in state crash databases.
	Limitations in annual average daily traffic and weigh-in-motion data restricted the crash analysis to the Interstate System.
	State crash reports and databases (generally) lack information on the weight and configuration (count of trailers, a count of total axles, and the length of each trailer) of trucks involved in crashes. This significantly limits the ability of researchers to draw national conclusions or analyze the impacts of trucks above or below the federal limit on crash rates.
	AASHTOWare Pavement ME Design software did not accommodate consideration of axle load impacts on overlaid pavement performance.
	The impacts of tire types and tire–pavement interaction were not considered.
	Local roads were not considered because of general lack of pavement layer and traffic information required as inputs to AASHTO Pavement ME Design.
Bridge	No nationally accepted model for analyzing heavy truck or bridge deck interaction and deterioration.
	Inability to account for detour mileage and costs.
	Local bridges were not considered as the design, construction, and management of local bridges vary greatly given that there are thousands of independent local owners across the nation with differing practices.
Compliance	Most states lump funding for truck size and weight enforcement and safety together—hard to separate from a research standpoint.
	Inconsistent interpretations by states submitting compliance data.
	Differences arising between states cannot be solely attributed to differences in truck size and weight limits.
	Vehicles operating under a state-issued permit, including all divisible or non-divisible load movements, were all treated in the same manner.

Source: FHWA.

Photo: Oregon DOT

Trucks line I-84 in Oregon's Columbia Gorge after freezing rain and crashes caused the closure of the highway in 2019. Truck crash data can help further TSW research.

truck size and weight study completed in 2000.

Focused on overcoming these data-related challenges, the study team undertook an extensive outreach effort that focused on the public and subject matter experts to identify any potential new data, methods, or knowledge. The effort did not reveal any new approaches, however.

The MAP-21 study also featured an independent National Academies of Sciences, Engineering, and Medicine study committee that reviewed these challenges. Although the National Academies committee recognized the challenges, it also did not identify new approaches or data sources (*6*).

The study found that the "data limitations were so profound that the results could not accurately be extrapolated to confidently predict national impacts." This finding further suggests "no changes in the relevant federal truck size and weight laws and regulations should be made until these limitations are overcome" (*6*).

To overcome these challenges, U.S. DOT suggested that the Transportation Research Board (TRB) convene an expert panel to develop a research plan to answer many of the more narrowly defined research questions that hinder a comprehensive look at the TSW issue. Specifically, U.S. DOT suggested that the group should focus on the following:

Safety. Determine improvements to crash databases and weigh-in-motion data coverage; testing is also needed to understand stopping distances for difference size and weight configurations.

Compliance and enforcement. Identify approaches to identify truck weight enforcement costs separately from all other truck safety enforcement costs.

Mode shift. Update the Vehicle Inventory and Use Survey (currently under way) and advanced models that reflect mode choice decisions.

Short line railroads. Create a framework for modeling mode shift impacts.

Freight Analysis Framework. Facilitate the ability to disaggregate to the county level and flow goods across a multimodal network.

Truck rates. Create a framework and process for the regular collection of truck rates.

Bridges. A nationally accepted methodology is needed to calculate bridge damage costs and deterioration by truck class.

Pavement. Refinement of AASHTOWare Pavement ME Design is needed to enhance pavement performance modeling capability—specifically for overlay pavements.

Local roads. Gather information about local roads used by trucks as routes to access major freight facilities (*6*).

TRB Research Roadmap

In 2017, the TRB Truck Size and Weight Limits Research Plan Committee (CTSW) began their work at the request of U.S. DOT to explore these issues through the development of a research roadmap in two phases. The committee prepared an initial report that identified potential research topics in five overall categories: safety, bridges, pavements, enforcement, and mode shift. This report was published in 2018 and submitted to Congress (*4*).

The committee's second report, "Research to Support Evaluation of Truck Size and Weight Regulations," developed a series of 27 research problem statements that outlined how the topic improved TSW evaluation methods and data, general approaches, and likely project durations and cost. The problem statements were deliberately patterned after the standard outline used to submit research problems to the National Cooperative Highway Research Program (NCHRP) for funding consideration.

The committee developed the research program around the idea of prioritizing projects that could advance analysis techniques used to inform TSW policy decisions at the federal and state level. The program also included longer-term research concepts that were more complex and outcomes relatively unknown. The core research tracks identified by the committee's report focused on development of the following:

- Truck traffic, weight, and configuration database from nationwide weigh-in-motion installations and other sources;
- Discrete continuous choice model, or suitable alternative, capable of estimating the effect of changes in TSW regulations and other policies on shippers' and carriers' choices of freight mode, vehicle configuration, and shipment size;
- Pavement analysis methods for heavier axle limits, multi-axle groupings, and alternative tire and suspension types;
- Comprehensive model of the relationship of bridge deterioration and service life to vehicle loads;
- Comparative evaluations of crash risks of alternative configurations by the case-control method;
- Protocols for evaluating the performance of truck configurations with simulation, track testing, and field trials; and
- Measurement of relationships between frequency of overloads and enforcement methods and level of effort (*4*).

Although the committee's work was not designed to solve TSW issues, their efforts were intended to move the conversation forward by translating TSW research challenges into fundable research statements for the NCHRP program. Likewise, U.S. DOT's Freight Research and Data Strategy calls out the need to "produce a research and data plan to advance the state-of-practice and knowledge informing commercial motor vehicle size and weight policy" over the near term (*1*). If these plans are carried out, the next CTSW study should produce results that help inform policy makers.

REFERENCES

1. *National Freight Strategic Plan*. U.S. Department of Transportation, Washington, D.C., 2020, pp. 2, 5–6, 96.
2. Office of Freight Management and Operations. *Bridge Formula Weights*. Report FHWA-HOP-19-028. Federal Highway Administration, Washington, D.C., 2019. https://ops.fhwa.dot.gov/freight/publications/brdg_frm_wghts/index.htm.
3. Office of Freight Management and Operations. *Comprehensive Truck Size and Weight Study, Volume 1: Technical Reports Summary*. Federal Highway Administration, Washington, D.C., 2015, p. 5.
4. National Academies of Sciences, Engineering, and Medicine and the Transportation Research Board. *Research to Support Evaluation of Truck Size and Weight Regulations*. National Academies Press, Washington, D.C., 2019, pp. 1–2, 6.
5. Moving Ahead for Progress in the 21st Century Act, Pub. L. 112–141, 126 Stat. 405 (2012).
6. Office of Freight Management and Operations. *Comprehensive Truck Size and Weight Study: Report to Congress*. Federal Highway Administration, Washington, D.C., 2016, pp. 17–25.

CENTENNIAL QUOTE

"I have been conducting research in transportation safety and investigating transportation occurrences for more than 20 years. My work has contributed to road safety policy and practice and to safety improvements in all modes. I hope that, in the future, I can have a positive impact on the world by improving transportation safety—and reducing suffering and pain—internationally. The Transportation Research Board (TRB) helps me to attain that potential impact by publishing my research in the *Transportation Research Record* and the TRB Annual Meeting proceedings. My participation on two Standing Committees allows me to keep abreast of developments in transportation safety, which enhances my ability to have a positive impact. The Annual Meeting, which I attend regularly, provides a place to connect with colleagues and learn—something that can be challenging in today's environment. Finally, TRB webinars are an excellent way to hear about international research, not only for myself but for my team.

—MISSY RUDIN-BROWN
Manager, Human Factors and Macro Analysis
Transportation Safety Board of Canada, Gatineau, Quebec

Innovative Technologies and Precast Pavement Allow Rapid Replacement Along Hawai'i Interstate H-1

Photo: Kiewit Infrastructure West Construction

MARK B. SNYDER

The author is the president and manager of Pavement Engineering and Research Consultants, LLC, in Bridgeville, Pennsylvania.

Above: Morning commuters go with the flow along the new Interstate H-1 on Hawai'i's Oahu Island. Those driving in the shoulder lane travel a safer route that was widened to include previously unavailable space for distressed vehicles to stop. In the future, this extra space also can be used to provide another lane of traffic.

Interstate H-1 on Oahu from Aiea to the Waimalu Viaduct was originally built in 1959 and is Hawai'i's busiest freeway section, carrying more than 230,000 vehicles daily at high speeds on five or more travel lanes in each direction. This section of the H-1 lies between the Koolau mountain range to the north and overlooks Pearl Harbor to the south (Figure 1). Large portions of the alignment were constructed on deep fill between ancient lava flows, and settlement of up to 18 inches has taken place in some areas. By 2018, portions of the eastbound and westbound pavements had been in poor condition for a long time, with considerable pavement roughness and an irregular pavement surface profile, especially in the area of one large, deeply positioned culvert that traversed the roadway.

Since 2006, the Hawai'i Department of Transportation (DOT) had patched and leveled the road using asphalt concrete, but those repairs provided only temporary relief, resulting in potholes and poor ride quality (Figure 2). Hawai'i DOT needed a long-term solution (and a 50-year design life), but prolonged lane closures would create catastrophic and unacceptable traffic problems.

The state DOT found a solution in design–build contracting and innovative design and construction practices that centered on the use of precast concrete pavement, 3-D surface modeling, ground-penetrating radar (GPR), and other cutting-edge technologies. The result was the reconstruction of 3.63 lane-miles of concrete pavement using 1,200 custom-fabricated precast concrete panels in less than four months, with most work performed at night so that daytime rush-hour traffic capacity was unrestricted.

High Expectations, Ambitious Schedule, and Major Constraints

Hawai'i DOT developed plans for a design–build project called Interstate Route H-1 Shoulder Work and PCC Pavement Rehabilitation. The project would use

FIGURE 1 Aerial view of project area. (Source: Yogi Kwong Engineers, LLC.)

FIGURE 2 Typical site conditions before rehabilitation. (Source: Hawai'i DOT.)

precast concrete paving panels to reduce construction time, save money, and require the least possible roadway closure time for construction. Expectations were high, with the governor publicly declaring that this project would be a demonstration of doing highway work faster and smarter.

The original scope of work included two phases. The first was rehabilitation of six badly distressed and settled segments of concrete pavement in the inbound and outbound lanes, along with two areas of shoulder widening improvements. These areas of shoulder work were selected to expedite completion of the project and to provide potential staging areas for the next phase of work. The work also included removing, replacing, and stabilizing the backfill above an existing 96-inch-diameter pipe culvert that crossed both roadways.

Completion of Phase 1 was required within six months—before school began in August—using mainly night work windows of eight hours or less. Work also had to be scheduled around events held at nearby Aloha Stadium.

Phase 2 consisted of the remainder of the shoulder-widening improvements and included demolition and removal of existing shoulder pavement; excavation and embankment work; construction of retaining walls, concrete ditches, and swales; construction of new concrete pavement lanes and shoulders; installation of drainage structures (including a hydrodynamic separator unit to collect and separate debris from stormwater); installation of guardrail and end treatments; relocation of 12-inch and 36-inch water lines; relocation of street lights; installation of a weigh-in-motion system; placement of signage and striping; and installation of erosion-control measures and landscaping.

Proposals for the work were solicited from three design–build teams in September 2017. Proposals were submitted and presentations made in mid-December 2017, and the Kiewit Infrastructure West team was selected in early January 2018. Design work began immediately.

Design Overview

There were many design components to this project, including longitudinal and transverse profile modifications, localized foundation improvements, structural design of pavement and mechanically stabilized earth retaining wall systems, and pavement joint design and layout. These design tasks were complicated by project work window constraints, the need to maintain daily traffic capacity, and the need for design solutions to function adequately with surrounding pavement areas and structures that were not being replaced.

Many aspects of the design work had to be accelerated because of the compressed project schedule. More than 1,200 precast panels would be custom-designed, fabricated, and installed less than seven months after the contract was signed; but the many sets of forms required for casting the panels could not be ordered, fabricated, and shipped to Hawai‘i until a suitable pavement structural design was developed.

Hawai‘i DOT provided traffic volume and classification data for estimating design load spectra for the project, but pre-bid soils information indicated a wide range of existing pavement structures and support conditions—because of the addition of lanes and frequent overlays and repairs over the years—in the six work areas. In some places, there was old concrete pavement under variable thicknesses of asphalt; in other areas, there were 18 inches or more of asphalt over cement-treated or aggregate base materials. But some areas had as little as six inches of asphalt over 10 inches of aggregate base. In each case, it was likely that 10 or more inches of existing pavement would be removed to accommodate the precast panels and bedding material and that the remaining pavement materials would serve as part of the foundation for the new pavement structure.

The pavement thickness design was developed for the lane with heaviest concentration of heavy trucks (generally, one of the two lanes closest to the outside shoulder). The Hawai‘i DOT design manual, which is based on the Portland Cement Association design procedure, was used to develop the thickness design (*1*). The final selected design thickness was 9.75 inches of concrete—which included 1/4 inch of sacrificial thickness for diamond grinding—over at least four inches of cement-treated base and subgrade material with a California bearing ratio of 4 with a modulus of subgrade reaction (k-value) of 120 pounds per square inch/inch. This design is for unreinforced concrete pavement and is conservative for precast pavement because it is heavily reinforced for shipping and handling stresses (up to 0.4 percent steel by area of concrete). The structural and performance benefits of the reinforcing are not reflected in the thickness design.

Panel dimensions and joint design also required special attention. Hawai‘i DOT specifications limited panel aspect ratio—length-to-width or width-to-length—to 1.25 or less. Although such limits are intended for preventing cracking in unreinforced concrete slabs, they were also imposed on this project. Travel lanes were generally 11 feet wide but were narrower or wider in some areas; application of aspect ratio requirements limited panel length to 13.75 feet or less in these areas. Most panels weighed about 10 tons each, but the larger, thicker bridge-approach panels weighed up to 20 tons each.

The precast panels were nominally rectangular (except at bridge approaches), while the existing concrete pavement featured skewed panels with lengths that mostly varied between 12 and 19 feet but included some panels that were nearly 40 feet long at the bridge approaches. When the longitudinal joints were tied, transverse joint locations were matched to avoid sympathy cracking across lanes. Where joints could not be matched, isolation material was used along the longitudinal joint between adjacent transverse joints and tie bars were eliminated in the same areas.

Another key feature of the project design was the improvement of longitudinal pavement profile and transverse cross slope. This work started as soon as the project contract was signed and began with a high-precision survey of the existing roadway to collect location and elevation data (i.e., *x*, *y*, and *z* coordinates) of all important existing features. Key survey points included existing lane lines, transverse and longitudinal joints where new precast panels would meet the existing pavement, median barrier, catch basins, and, most importantly, the contours of the existing pavement surface. As expected, this work revealed that years of settlement, distress, and add-on construction had produced longitudinal profiles and transverse cross slopes that contributed to ride quality and surface drainage deficiencies.

The team wanted to install new panels to a constant cross slope, but it was impossible in some areas because of the amount of localized settlement (which would create large differences in lane elevation during construction), the necessity of lane-by-lane construction, and the need to maintain heavy traffic flows during daytime hours. The project design engineer and precast pavement system design teams worked through several iterations of surface modeling to develop a 3-D pavement surface design model that would provide the best possible longitudinal profile and pavement cross slope within the physical boundary constraints of each area.

The final design model allowed the production of shop drawings for each individual pavement panel. The shape of the final design surface meant that nearly half of the panels were nonplanar, having warped or twisted shapes with one corner displaced as much as three inches above a plane defined by the other three corners. The panels were nominally rectangular, but many were mildly trapezoidal or randomly shaped to accommodate horizontal curves and maintain uniform joint widths.

The final design surface would still have resulted in elevation differences of up to eight inches between lanes during construction. To avoid this problem, the design–build team planned the construction of a temporary asphalt layer with thickness ranging from zero to six inches (or more) to approximate the final surface profile in some areas prior to placing the precast panels. This approach eliminated unsafe elevation differences between lanes during construction.

The project also included the addition of travel lanes and a widened shoulder, which required excavation and the use of retaining walls in depressed areas. This design work was challenging because Hawai‘i DOT would not allow any additional loading on the deep, unconsolidated, and wet subsurface soils. More than a dozen solutions were considered during a month of analysis. A lightweight cellular concrete backfill mechanically stabilized earth wall design was selected as an optimal solution for this project.

Most of the project design related to the pavement was completed by April 2018, although minor design revisions and adjustments, as well as shoulder design work, continued through the summer.

Fabrication and Construction Processes

The tight schedule affected everything the contractor did on the project. For example, the precaster had to begin fabricating paving panels by April 1, 2018, before the project design and shop drawings were fully developed, just to meet the construction schedule.

After receiving the specialized forms and casting beds (for fabricating nonplanar panels)—along with all of the dowels, reinforcing steel, pocket formers, lifting insert and panel jacks, grout ports, distribution channel formers, and other components—the precast concrete supplier manufactured more than 1,200 precast panels in less than three months (Figures 3 and 4). The Super-Slab system used on this project included many features not present on the two previous Hawai‘i DOT precast paving projects (e.g., nonplanar panels, bottom slots, and built-in grout distribution channels). However, fabrication rates approached an average of 20 panels per day after initial startup.

FIGURE 3 **Precast panel fabrication for H-1 project. (Source: Hawai‘i DOT.)**

FIGURE 4 **Stockpiling fabricated precast panels for H-1 project in precaster’s yard. (Source: Kiewit Infrastructure West Construction.)**

When the design surface models were finalized, the contractor used laser-controlled paving equipment to place a temporary, variable-thickness asphalt overlay on the existing pavement to minimize lane elevation differences during construction, as previously described.

The variable nature of the existing pavement structure (i.e., different pavement materials and layer thicknesses) presented a major challenge on this project. The contractor needed to know what existing pavement structure and conditions were going to be encountered during each night's operation so appropriate types of excavation equipment and construction materials were on hand. To meet this challenge, the Kiewit team included American Engineering Testing to perform GPR surveys of all pavement lanes in each work area. These surveys were performed without lane closures during the design phase. They identified layer thicknesses and materials throughout the project with much greater accuracy and detail than was available from pre-bid soil-boring information. This allowed the contractor to plan each work shift efficiently, allowing maximum production while ensuring that the lanes would be reopened to traffic at the end of the shift. The use of GPR in this manner was essential to the successful management and construction of this project.

Kiewit began installing panels during the first week of May 2018, less than four months after design work began. Work typically began in the inside lanes and progressed toward the outside lanes in both directions. After initial startup, installation rates usually ranged from 20 to 30 slabs per 7.5-hour work window in most areas, with much higher numbers over extended weekend closures.

The contractor typically used an excavator to remove sufficient existing pavement materials to make room for the precast panels (Figure 5) and enough cement-treated base (CTB) to provide uniform support without the use of grout or other bedding materials. In some cases, additional material was removed (e.g., when unsuitable materials were encountered or when the desired excavation depth fell within a layer of concrete, CTB, or other similarly hard material). The amount of additional excavation in such areas ranged from only a few inches to as much as 24 inches, in some cases. The removed materials were usually replaced with CTB; thick layers of new CTB were reinforced with a single layer of geogrid to improve CTB stability during compaction and subsequent precast panel placement (Figure 6).

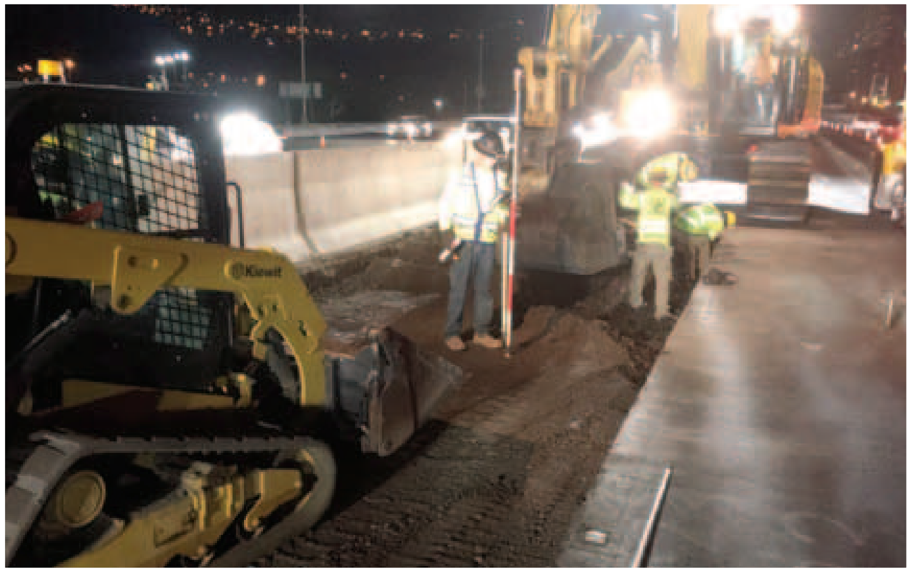


FIGURE 5 Excavation of existing pavement materials. (Source: Hawai'i DOT.)

FIGURE 6 Localized installation of geogrid reinforcing in CTB for improved pavement support. (Source: Kiewit Infrastructure West Construction.)

The precast panels included embedded lifting jacks for final adjustment of panel elevation before injecting grout around the dowels and below the panels (Figure 7). However, the construction process required that the panels be fully supported by the grade immediately after placement, without the use of grout material. This process allowed the slabs to be subjected to construction or short-term service traffic immediately and increased work shift production by eliminating the need for time to cure grout before opening to traffic.

Achieving such accurate grading of foundation materials usually requires the use of fine-graded bedding material—sometimes stabilized with cement—and special grading operations. The contractor decided to eliminate the extra step of using fine-graded bedding material and opted instead to grade the CTB to an accuracy of ±1/8 inch using a laser-controlled skid steer that was programmed to replicate the design surface model at the elevation of the base (Figure 8). This generally worked well, but the coarseness of the CTB made it difficult to grade to the required accuracy. It became necessary to check the elevation of the finished CTB grade on a three-foot grid pattern using a total station survey. Areas that deviated from the design surface model by more than 1/8 inch were corrected by hand. Even with this extra effort, a small number of slabs developed cracks, although fewer than 20 had to be removed and replaced. It should be noted that, while it is not uncommon for a few panels to crack on most precast jobs for various reasons, the cracks rarely deteriorate because the panels are typically heavily reinforced.

FIGURE 7 **Panel elevation adjustment using embedded jacks. (Source: Hawai‘i DOT.)**

FIGURE 8 **Laser screed trimming CTB. (Source: The Fort Miller Company.)**

Panels were placed in sequence using a crane (Figure 9). Grouting of panels—support grout as well as structural grout around dowels and tie bars—was generally performed during the next work shift, so they were grade-supported under live traffic conditions for only short durations (Figure 10). Leveling jacks were activated before grouting, when necessary, to minimize elevation differences across joints. Specifications limited elevation differences to 1/8 inch; greater differences required diamond grinding for smoothness.

Noise levels were monitored throughout the construction operation and sound buffers were adjusted as necessary to control the transmission of sound to nearby neighbors. Noisy equipment operations had to stop by midnight.

The pavement installation work was substantially completed during the second week of August, just over three months after starting.

Highly Successful Project

The H-1 project was completed early and within budget. Hawai‘i DOT had high expectations for the project and those expectations were met or exceeded. The state DOT’s satisfaction with the speed

FIGURE 9 Setting precast panels in outside lane of H-1. (Source: The Fort Miller Company.)

and quality of the work was demonstrated with an additional phase of work composed of 131 precast panels placed in other areas of the corridor at the end of the original project time frame (*2*).

On Monday, October 28, 2019, Hawai'i DOT held a *maile lei* (used for special celebrations) and a blessing ceremony to mark the completion of the substantial project. The following officials praised the project and participants:

- "Projects like this take a team effort to go smoothly," expressed Hawai'i DOT Director Jade Butay, who introduced the project team. "I am proud of the work you all have accomplished."
- "The technology worked out really well," stated Edwin Sniffen, Hawai'i DOT's deputy director of the Highways Division. "If we could not have used the precast concrete panels, we never would have touched this project." He went on to say: "This is the way projects should be. We have better processes, we developed better products, so we can better provide services to the community."
- Governor David Ige also shared his satisfaction with the project, adding, "I am proud that this project finished ahead of schedule, and hopefully this becomes the new normal."

The American Council of Consulting Engineers Hawai'i Chapter also recognized the project with an Engineering Excellence Award in 2020.

This high-profile project affected a majority of Oahu's residents, who are concentrated in the project area near Honolulu. They witnessed the transformation of a roadway with some of the worst pave-

FIGURE 10 Grouting panels after installation. (Source: The Fort Miller Company.)

ment conditions in the state into a much smoother, safer roadway using long-life repair and reconstruction techniques. This was accomplished in a short time frame with no disruption to traffic during normal and peak traffic hours, which resulted in huge savings of travel time and costs to the public. The success of this project makes it a model for highway rehabilitation projects in Hawai‘i and elsewhere.

Acknowledgment

The author thanks the following for their contributions to the H-1 project: Kiewit Infrastructure West Construction, R.M. Towill Corporation, The Fort Miller Company, Pavement Engineering Research Consultants, KAI Hawaii, Yogi Kwong Engineers, Grace Pacific Rocky Mountain Prestress, Penhall Company dba Concrete Coring Company of Hawaii, and American Engineering Testing.

REFERENCES AND BIBLIOGRAPHY

1. Portland Cement Association. *Thickness Design for Concrete Highway and Street Pavements.* Engineering Bulletin EB109.01P. Skokie, Illinois, 1984.
2. Sniffen, E. Hawaii DOT Precast Pavement Past, Present, and Future. Presented at the FHWA Expert Task Group for Implementation of Precast Concrete Pavement Technology, Honolulu, Hawai‘i, 2018.
3. Hawai‘i Department of Transportation. *Pavement Design Manual—Revision March 2002.* Honolulu, 2002.
4. National Precast Concrete Association. Paving Slabs a Real Winner for Hawaii Project. *Precast Solutions Magazine*, Fall 2019.
5. Smith, P. and M. Snyder. *Manual for Jointed Precast Concrete Pavement*, 3rd ed. National Precast Concrete Association, Carmel, Indiana, 2019.
6. Wood, D. Hawaii DOT Finds Innovative Precast Solution to Replace Portions of H-1. *California Builder and Engineer*, January 25, 2019. https://www.acppubs.com/articles/8236-hawaii-dot-finds-innovative-precast-solution-to-replace-portions-of-h-1.

NATIONAL ACADEMIES RESEARCH

Photo: Pixabay

Social Isolation and Loneliness in Older Adults

Opportunities for the Health Care System

DAN BLAZER, TRACY LUSTIG, AND MEGAN KEARNEY

Blazer is the J.P. Gibbons Professor Emeritus of Psychiatry and Behavioral Sciences at Duke University, Durham, North Carolina. Lustig is a senior program officer and Kearney is an associate program officer in the Health and Medicine Division at the National Academies of Sciences, Engineering, and Medicine, Washington, D.C.

Above: The life-draining effects of isolation and loneliness in older adults stem from many sources: loss of a partner, declining health, lack of transportation, diminished social interaction, and more. But health care systems and community programs can help seniors once again embrace a vital and relevant life.

Social isolation (the state of having few social relationships or infrequent social contact with others) and loneliness (a subjective feeling of being isolated) are serious yet underappreciated public health risks that affect a significant portion of the older adult population. Factors that influence social isolation and loneliness at the community level include availability of transportation, access to broadband, consequences of natural disasters, gentrification, and housing displacement.

To explore the phenomenon of social isolation and possible solutions, the Committee on the Health and Medical Dimensions of Social Isolation and Loneliness in Older Adults was charged with summarizing the evidence for how social isolation and loneliness affect health and quality of life in adults age 50 and older, particularly among low-income, underserved, and vulnerable subpopulations. In addition, the committee was charged with identifying and recommending opportunities for health care clinical settings to reduce the incidence and adverse health impacts of social isolation and loneliness and to examine avenues for disseminating information to health care practitioners. Although the committee was not charged exclusively with a specific transportation-related objective, the role of transportation is clear in considering causes and solutions to social isolation. This article highlights parts of the report that discuss transportation as related to social isolation.[1]

A number of factors contribute to social isolation. For instance, chronic illness is associated with emotional or psychological issues, mobility limitations, a lack of or limitation in transportation or employment options, new or ongoing issues related to coping with disabling conditions, and strained social relationships (*1–2*). In some cases, chronic illness may increase individuals' social

[1] To view the entire publication, visit https://www.nap.edu/catalog/25663/.

Photo: iStock

Exercise does more than benefit the body. It also has a positive psychological effect by releasing serotonins that trigger a sense of well-being and helps older adults cope with chronic illnesses.

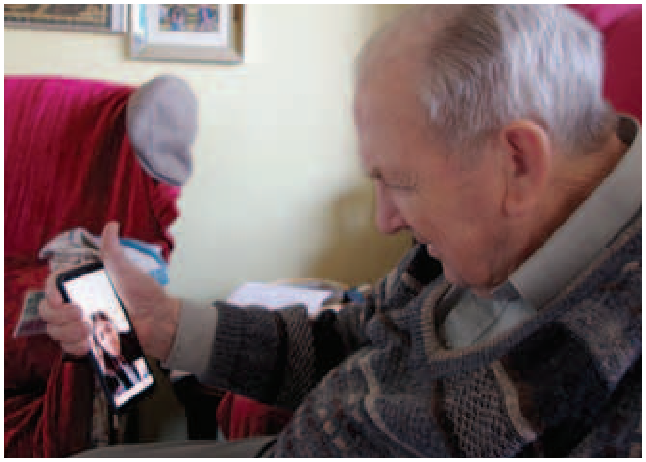


Photo: Pixabay

The loneliness and isolation that come with aging in place have heightened with the onset of the coronavirus pandemic, which dictates that people socially distance. Cell phone and Internet access help older adults maintain connections with loved ones. Those without such options are not so lucky.

support networks and decrease their likelihood of being socially isolated because addressing health issues may increase social interactions in the form of medical or therapy appointments and other health-related activities (*3*).

In addition, Finlay and Kobayashi found that people who lived closer to a city center reported more social interactions than individuals who lived in the suburbs (*3*). City dwellers credited those social interactions to daily connections in their residential spaces and numerous places for socialization (e.g., parks, libraries, and coffee shops), which provided avenues for impromptu social interactions. Generally, study participants in the outer suburbs reported greater loneliness than those closer to the city center, with loneliness decreasing with moves into the inner suburbs and closer to the city center.

Another factor that could be a risk factor for social isolation and loneliness is aging in place, a particular problem with the current social distancing restrictions brought on by the COVID-19 pandemic. This happens if social networks or opportunities for affordable and convenient transportation are not readily available, especially for people who cannot afford sociable leisure activities outside the home (*3–4*).

Photo: iStock

The independence that comes with driving helps delay the effects of isolation in older adults. But life can change drastically once the keys must be handed over.

Drivers Licenses and Social Isolation

One issue often mentioned when discussing social isolation in older adults is driving cessation. In 2017, nearly 37 percent of the more than 225 million licensed drivers in the United States were 50 years of age or older (*5*). Driving is important for adults who want to maintain independence and mobility; however, declines in physical health, cognitive function, or deficits in reaction time or coordination can cause older adults to stop driving (*6–9*). Additional reasons for driving cessation include an increased insecurity in driving skills or ability; having had previous car accidents or traffic citations; the high cost of driving; requests by family members, friends, or a medical professional to stop driving; or forfeiting driving privileges in compliance with state driving licensure laws (*8*, *10*).

This National Academies of Sciences, Engineering, and Medicine committee was assembled by the Board on Health Sciences Policy within the Health and Medicine Division in collaboration with the Board on Behavioral, Cognitive, and Sensory Sciences within the Division of Behavioral and Social Sciences and Education.

The Board on Health Sciences Policy oversees activities focused on the basic biomedical and clinical research enterprises needed to ensure and improve the health and resilience of the public, especially the ethical, legal, and social contexts of scientific and technologic advances. The Board on Behavioral, Cognitive, and Sensory Sciences provides vision on how to advance public policy and practice by leveraging cutting-edge research in behavioral, cognitive, and sensory sciences.

Driving cessation has been associated with a decrease in social engagement and an increase in social isolation and feelings of loneliness (*6–9*, *11–12*). No longer driving is especially difficult for those who live in areas that lack alternative transportation options, such as rural or lower-density neighborhoods (*3–4*). Without reliable and affordable alternatives to driving, some former drivers may resume their driving despite their initial reasons for stopping (*9*).

Solutions from the Health Care Industry

Some studies have examined access to health care and its relationship with social isolation and loneliness. A lack of transportation resources limits a person's ability to get to medical appointments, and living in remote areas limits an individual's social networks and other resources, including rural health services (*13–14*).

Health care delivery systems are exploring the feasibility and effect of practice-based strategies to identify and address social determinants of health as social isolation and loneliness. Some health care organizations are undertaking interventions that target social isolation in the health care system.

UnitedHealthcare, a large health insurance company, launched the Navigate4Me program in fall 2017 for individuals enrolled in its Medicare Advantage plans who have complex health issues such as diabetes, congestive heart failure, or multiple chronic conditions (*15*). The program offers health navigators, who support and guide individuals through the complicated health care system, provide clinical and administrative assistance, and address the social determinants of health

Related National Academies Work

The National Academies of Sciences, Engineering, and Medicine's 2019 report, *Integrating Social Care into the Delivery of Health Care: Moving Upstream to Improve the Nation's Health*,[1] authored by the Committee on Integrating Social Needs Care into the Delivery of Health Care to Improve the Nation's Health, examined the potential for integrating services that address social needs and the social determinants of health into the delivery of health care to achieve better health outcomes.

In their deliberations, the committee identified the following five complementary activities that can better facilitate this integration and provided the corresponding transportation-related examples:

- Awareness—Ask people about their access to transportation.
- Adjustment—Reduce the need for in-person health care appointments by using other options, such as telehealth.
- Assistance—Provide transportation vouchers so that patients can travel to health care appointments. Vouchers can be used for ridesharing services or public transit.
- Alignment—Invest in community ridesharing or time-bank programs.
- Advocacy—Promote policies that fundamentally change the transportation infrastructure within the community.

Although all of the activities will ultimately benefit patients, Adjustment and Assistance focus on improving care delivery provided specifically to individual patients based on information about their social needs. Alignment and Advocacy relate to roles that the health care sector can play in influencing and investing in social care resources at the community level. All of these delivery and community-level activities are informed by efforts that increase awareness of individual or community-level social needs in a health care system's geographic region or for its served population.

[1]To view the entire publication, visit https://www.nap.edu/catalog/25467/.

(e.g., by connecting individuals with reliable transportation or housing assistance). The company's early results showed a 14 percent reduction in hospitalizations and a 9 percent reduction in emergency room visits for people with congestive heart failure (*15*).

Humana, also a large health insurance company, created a Loneliness Toolkit that includes information on health-related issues (e.g., stress, substance abuse, and vision and hearing impairment), staying engaged (e.g., transportation alternatives, housing options, and use of social media), supporting loved ones (e.g., personal coping skills and caregiver support groups), and general community resources (e.g., area agencies on aging, ridesharing services, and support groups).

Moving Forward

One of the report's recommendations was for health care providers, organizations, and systems to partner with social service providers—including those serving vulnerable communities—to create effective, team-based care (such as transportation and housing support services) and to promote the use of tailored community-based services to address social isolation and loneliness in older adults. If implemented on a large scale, transportation will indeed become part of the solution to addressing social isolation and health outcomes of older adults.

REFERENCES

1. Holley, U. A. Social Isolation: A Practical Guide for Nurses Assisting Clients with Chronic Illness. *Rehabilitation Nursing*, Vol. 32, No. 2, 2007, pp. 51–56.
2. Warner, C. B., A. R. Roberts, A. B. Jeanblanc, and K. B. Adams. Coping Resources, Loneliness, and Depressive Symptoms of Older Women with Chronic Illness. *Journal of Applied Gerontology*, Vol. 38, No. 3, 2017, pp. 295–322.
3. Finlay, J. M., and L. C. Kobayashi. Social Isolation and Loneliness in Later Life: A Parallel Convergent Mixed-Methods Case Study of Older Adults and Their Residential Contexts in the Minneapolis Metropolitan Area, USA. *Social Science and Medicine*, Vol. 208, 2018, pp. 25–33.
4. Herbert, C., and J. H. Molinsky. What Can Be Done to Better Support Older Adults to Age Successfully in Their Homes and Communities? *Health Affairs*, Vol. 38, No. 5, 2019, pp. 860–864.
5. Federal Highway Administration, U.S. Department of Transportation. Distribution of Licensed Drivers—2016: By Sex and Percentage in Each Age Group and Relation to Population. https://www.fhwa.dot.gov/policyinformation/statistics/2016/dl20.cfm.
6. Chihuri, S., T. J. Mielenz, C. J. DiMaggio, M. E. Betz, C. DiGuiseppi, et al. Driving Cessation and Health Outcomes in Older Adults. *Journal of the American Geriatrics Society*, Vol. 64, No. 2, 2016, pp. 332–341.
7. Hwang, Y., and G. R. S. Hong. Predictors of Driving Cessation in Community-Dwelling Older Adults: A 3-Year Longitudinal Study. *Transportation Research Part F: Traffic Psychology and Behaviour*, Vol. 52, 2018, pp. 202–209.
8. Johnson, J. E. Urban Older Adults and the Forfeiture of a Driver's License. *Journal of Gerontological Nursing*, Vol. 25, No. 12, 1999, pp. 12–18.
9. Johnson, J. E. Informal Social Support Networks and the Maintenance of Voluntary Driving Cessation by Older Rural Women. *Journal of Community Health Nursing*, Vol. 25, No. 2, 2008, pp. 65–72.
10. Ratnapradipa, K. L., J. Wang, M. Berg-Weger, and M. Schootman. Coming Out of "Retirement"—Predictors of Driving Resumption Among Older Drivers. *Innovation in Aging*, Vol. 2, No. 3, 2018, pp. 1–10.
11. Barrett, A. E., and C. Gumber. Feeling Older and Driving Less: The Effect of Age Identity on Older Adults' Transition from Driving. *Innovation in Aging*, Vol. 3, No. 1, 2019, pp. 1–8.
12. Edwards, J. D., M. Lunsman, M. Perkins, G. W. Rebok, and D. L. Roth. Driving Cessation and Health Trajectories in Older Adults. *Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*, Vol. 64, No. 12, 2009, pp. 1290–1295.
13. Hadley Strout, E., L. Fox, A. Castro, P. Haroun, B. Leavitt, et al. Access to Transportation for Chittenden County, Vermont, Older Adults. *Aging Clinical and Experimental Research*, Vol. 28, No. 4, 2016, pp. 769–774.
14. King, S., and H. Dabelko-Schoeny. "Quite frankly, I have doubts about remaining:" Aging-in-Place and Health Care Access for Rural Midlife and Older Lesbian, Gay, and Bisexual Individuals. *Journal of LGBT Health Research*, Vol. 5, Nos.1–2, 2009, pp. 10–21.
15. UnitedHealth Group. United Healthcare Expands Navigate4Me to Bring Personalized, Holistic Care to More People. https://www.unitedhealthgroup.com/newsroom/2018/2018-12-09-uhc-expandsnavigate4me-program.html. Accessed Nov. 4, 2019.

RESOURCES

National Conference of State Legislatures. Medicaid 1115 Waivers by State. http://www.ncsl.org/research/health/medicaid-1115-waivers-by-state.aspx. Accessed Nov. 13, 2019.

Verma, S. CMS Approves North Carolina's Innovative Medicaid Demonstration to Help Improve Health Outcomes. *Health Affairs Blog*, October 24, 2018. https://www.healthaffairs.org/do/10.1377/hblog20181024.406020/full/. Accessed Dec. 2, 2019.

Driving is important for adults who want to maintain independence and mobility; however, declines in physical health, cognitive function, or deficits in reaction time or coordination can cause older adults to stop driving.

NATIONAL ACADEMIES WORKSHOP

INNOVATIONS IN THE FOOD SYSTEM

EXPLORING THE FUTURE OF FOOD

Photo: Lance Cheung, USDA

MELISSA MAITIN-SHEPARD

The author is a public health policy writer, analyst, and strategist, and is founder and principal, MMS Health Strategies, LLC, Washington, D.C.

Note: The photos in the following pages are meant to illustrate this article and were not used by Food Forum presenters.

Above: Trucks sit ready to load at the Food Maven food distribution center in Colorado Springs, Colorado. Examined in this article are the transportation implications of innovations for modern food systems.

In August 2019, the Food Forum of the National Academies of Sciences, Engineering, and Medicine convened a public workshop in Washington, D.C., to review the status of current and emerging knowledge about innovations for modern food systems and the extent to which they are, or could be, designed to optimize environmental, health, social, and economic outcomes. The workshop explored new consumer demands related to high-quality, nutritious, sustainable foods, along with policy and marketplace strategies in response to such demands. Although the workshop was not planned with a specific objective related to transportation, the role of transportation emerged during some of the presentations and discussions.

This article highlights select parts of the workshop proceedings that discuss transportation as related to the food system.[1] In July 2020, the Food Forum hosted a follow-on workshop to further discuss the integration of the health, societal, economic, and environmental effects and future needs of the food system.[2]

Logistics for Supply-Chain Segments

Michelle Miller, University of Wisconsin, discussed how logistics and opportunities to improve market access and food access are different for each supply chain segment. The key logistical segments are first-mile (farm to processor or warehouse); over-the-road, or regional (distance to the

---

[1] The full publication, *Innovations in the Food System: Exploring the Future of Food—Proceedings of a Workshop*, can be accessed at https://www.nap.edu/catalog/25523/innovations-in-the-food-system-exploring-the-future-of-food.

[2] The resulting *Proceedings of a Workshop—In Brief* can be accessed at https://www.nap.edu/catalog/25988.

Photo: USDA

Peppers at Pilot Mountain Pride Cooperative in North Carolina travel on a conveyor belt to be washed and graded. Thanks to a U.S. Department of Agriculture grant, the cooperative purchased a refrigerated truck to distribute high-value specialty crops.

wholesale market); and last-mile (within the destination city) (*1*).

Logistics involve monitoring and control of product movement through a system. Key factors shaping supply chains include who owns the product and pays for the distribution at each step along the supply chain, the amount and diversity of supply to be transported, and the distance of each segment (*2*). For first-mile, distance from the farm to the aggregation point should be as short as possible. For over-the-road and regional trip segments, Miller explained, the distance to wholesale market is the most important factor. Depending on whether the segment is over-the-road or regional, efficiencies can be realized with tractor trailers. For instance, regional trip segments do not require a sleeper car and may use alternative fuels since the route is short enough to allow for refueling at home base.

Miller identified supply of the product as another key factor in supply chain efficiency. Efficiency, she explained, requires enough of a product to fill at least a single pallet and enough pallets to fill a truck. For last-mile distribution, Miller stated that the focus is on distribution within a market area, such as a city. She pointed out that small farmers who drive their own product into the city for distribution need to consider the distance traveled to be fuel-efficient, as well as access to short-term cold storage warehousing and trucks of appropriate size to navigate congestion and city streets.

Any among the consumer, wholesaler, retailer, or farmer may pay for the last-mile distribution. Miller stressed that challenges with last-mile distribution have made it difficult for small businesses to compete, although there are solutions that could allow them to remain in business. For example, e-commerce with a single point of pickup, such as a grocery store, is increasing in popularity for last-mile distribution, especially for small businesses that serve unique populations with specific food preferences, such as foods consumed by people of particular ethnicities.

The July 2020 workshop further considered supply chains in the context of their role as a key component of the food system, how they have been affected by COVID-19, and their role in food safety and food security.

Use of Autonomous Vehicles and Drones

Brent Heard, University of Michigan, spoke about the use of connected autonomous vehicles (CAVs) and unmanned aerial vehicles, or drones, in food distribution. He stated that self-driving vehicles and drones could either improve or impede the sustainability of the food system, depending on how they are used and the conditions surrounding their adoption.

Heard cited motivations for addressing use of self-driving vehicles and drones within the food system: the current food system is unsustainable, contributing between 19 and 29 percent of greenhouse gas (GHG) emissions. Additionally, nearly 12 percent of U.S. households are food insecure. He expects that the food distribution industry will be an early adopter of self-driving vehicles and drones because of their ability to deliver perishable food quickly; help reduce food losses by decreasing food distribution and storage times; increase capacity through 24/7 service; and lower marginal costs through fuel savings, improved logistic efficiencies, and reduced driver wages.

Heard argued for an approach that considers the impact of the technologies and one that assesses consumer behavior; public policies; and their environmental, economic, and social implications.

Photo: Joseph Schneid, Flickr

A Kroger employee loads groceries for a curbside pickup customer. Since the COVID-19 pandemic began, online shopping with a single point of pickup has grown more popular as a last-mile distribution option.

Pre-Retail Food Distribution

Heard expects autonomous trucks to replace long-haul trucking in pre-retail food distribution and both drones and self-driving vehicles to be used in the last mile of the supply chain. He suggested that CAVs could provide efficiency and environmental improvements by optimizing routing, speed changes, and food transport time while reducing road fatalities. Platooning, in which a series of vehicles closely follow each other to reduce aerodynamic drag, could reduce the energy use of heavy trucks by 10 to 25 percent (*3*). Heard added that 71 percent of all transportation emissions associated with the U.S. food supply come from pre-retail food distribution, typically involving trucks (*4*).

Heard observed that if autonomous vehicles replaced rail or inland water transportation with lower carbon or energy intensity than traditional trucking, emissions could increase. An emissions rebound effect could occur, he added, whereby the reduction in emissions from behavior change would result in increased trip lengths or numbers of trips, affecting emissions that could otherwise be expected. He highlighted the importance of this benefit by reporting that there were nearly 5,000 deaths from crashes involving large trucks in the United States in 2017; overall, fatalities from such crashes increased 12 percent over a recent 10-year period (*5*).

Heard also expects that distribution companies adopting CAV technology will see increased profits from efficiency savings, increased sales volume, and reduced costs of driver wages, noting that 36 percent of truck operating costs currently are attributable to driver wages (*6*), which could be displaced by self-driving vehicles.

Heard acknowledged that reducing truck drivers would increase unemployment—not only for truck drivers but also for businesses such as food and lodging stops along the highway. He pointed out that the U.S. tractor–trailer driving industry for food distribution employs more than 63,000 people and that although new jobs (e.g., food distribution or warehousing) may be created in their place, they would require different skills, necessitating retraining for displaced workers (*7*).

Last-Mile Food Distribution

For last-mile food distribution—bringing food to the consumer—Heard observed that drones have become advanced enough to find and scan a barcode on a package and know where to deliver it. He then described the environmental impact of delivery using drones in comparison with truck delivery.

Research has found that the impact varies based on the size of the package being delivered and the size of the drone. Heard referenced a study that tested delivery of a half-kilogram package using a small drone and delivery of an 8-kilogram package using a large drone, modeling the impact of warehouse placement and operation to support drone delivery (*8*). The study found lower GHG emissions for the small drone than for truck delivery with the small package. For the large drone, there was a 9 percent reduction in emissions when the drone was charged with low-carbon electricity, but a 24 percent increase when it was charged using the U.S. electricity grid (*8*). Heard noted, however, that use of either type of drone resulted in lower emissions relative to use of a personal vehicle to make a round trip to the store.

Heard stated he believes that drone delivery will raise profits, employment, and crash considerations similar to those raised by autonomous vehicles. He added that flights in neighborhoods may also entail additional zoning and urban planning considerations, as more warehouses will be needed to support drones' shorter delivery range. For example, he reported that the delivery range of tested drones in the above study was about 4 kilometers, requiring 112 warehouses to support an area the size of metropolitan San Francisco (*8*).

Heard observed further that, as package delivery by drones is likely to occur in urban areas, locations for new warehouses will be particularly challenging to obtain. He explained, moreover, that the regulatory scheme for drone flight is still being established; package delivery by drones is currently approved by the Federal Aviation Administration on a pilot basis. He pointed out further that drones also have social acceptability issues, including the noise they produce and their military associations.

Food Forum

The Food Forum, part of the Health and Medicine Division of the National Academies of Sciences, Engineering, and Medicine, convenes scientists, administrators, and policy makers from academia, government, industry, and public sectors on an ongoing basis to discuss issues related to food, food safety, and regulation and to identify possible approaches for addressing those issues.

The Forum offers a unique way to connect diverse interest groups. It does not make recommendations or offer specific advice, but it does compile information, develop options, and bring interested parties together.

To read more about the Food Forum, see https://www.nationalacademies.org/our-work/food-forum.

Photo: Angela McMellen Brannigan, USDA

Workers sort lemons at a packing house in California. Because California is by far the largest supplier of lemons—and a great deal of other produce—in the United States, the state originates many of the nation's major food supply chains.

Heard added that the use of self-driving vehicles for the last mile of the supply chain is likely to have efficiency, crash, and employment impacts similar to those of the drones, including the possibility of an emissions rebound effect resulting from increased consumer purchasing. At the same time, they also have the potential to facilitate e-commerce and stimulate increased home delivery of groceries, which Heard stated would reduce such burdens on grocery retailing as food loss resulting from overstocking and the need for refrigeration, while increasing options for healthy foods in places with limited access to such foods.

As package delivery by drones is likely to occur in urban areas, locations for new warehouses will be particularly challenging to obtain.

Heard pointed out, however, that if changes in delivery mode led to increased consumption of foods produced using high GHG emissions, adverse environmental and health effects could result. In response to a question from an audience member, he added that the extent of any gains would also depend on whether the drone or autonomous vehicle was delivering food to a single customer on demand or to a centralized location at a predetermined time.

Conclusions

Looking at supply-chain issues and innovations for delivering food is only one aspect of managing the nation's food system and examining strategies to meet future needs and emerging technologies. The role of transportation is and will remain a key consideration in ensuring that food can be delivered in a safe, sustainable, and cost-efficient manner throughout all stages of the supply chain.

REFERENCES

1. Pullman, M., and Z. Wu. *Food Supply Chain Management: Economic, Social and Environmental Perspectives*. Routledge, New York, 2012.
2. Miller, M., W. Holloway, E. Perry, B. Zietlow, S. Kokjohn, et al. *Regional Food Freight: Lessons from the Chicago Region*. Center for Integrated Agricultural Systems, Madison, Wisconsin, 2016. https://localfoodeconomics.com/wp-content/uploads/2018/02/miller-et-al-2016-Regional-food-freight-final-2.pdf. Accessed December 9, 2019.
3. Wadud, Z., D. MacKenzie, and P. Leiby. Help or Hindrance? The Travel, Energy and Carbon Impacts of Highly Automated Vehicles. *Transportation Research Part A: Policy and Practice*, Vol. 86, 2016, pp. 1–18.
4. Weber, C. L., and H. S. Matthews. Food-Miles and the Relative Climate Impacts of Food Choices in the United States. *Environmental Science & Technology*, Vol. 42, No. 10, 2008, pp. 3508–3513.
5. National Center for Statistics and Analysis. *Large Trucks: 2017 Data*. National Highway Traffic Safety Administration, Washington, D.C., 2019.
6. Grenzeback, L. R., A. Brown, M. J. Fischer, N. Hutson, C. R. Lamm, et al. *Freight Transportation Demand: Energy-Efficient Scenarios for a Low-Carbon Future*. U.S. Department of Energy, Washington, D.C., 2013.
7. Bureau of Labor Statistics. Heavy and Tractor–Trailer Truck Drivers. 2018. https://www.bls.gov/ooh/transportation-and-material-moving/heavy-and-tractor-trailer-truck-drivers.htm. Accessed October 28, 2019.
8. Stolaroff, J. K., C. Samaras, E. R. O'Neill, A. Lubers, A. S. Mitchell, et al. Energy Use and Life Cycle Greenhouse Gas Emissions of Drones for Commercial Package Delivery. *Nature Communications*, Vol. 9, No. 1, 2018, p. 409.

Socorro (Coco) Briseno

Retired, California Department of Transportation

For **Coco Briseno**, retired Deputy Director of Planning and Modal Programs for the California Department of Transportation (Caltrans), her career has been about the journey and the people she met on her path to success. "My career in public service has been an amazing journey," she explains. "I started as a seasonal office assistant with the State of California, which led to working for a number of public agencies where I learned about the range of services offered. After several years in human resources, I went to work for Caltrans."

Briseno states that the Caltrans Research Division was a perfect match. "I've always enjoyed collaborating, discovering, and growing," she shares. "My coursework at Chapman University in California, was in organizational leadership. Prior to joining Caltrans, most of my professional background was in human resources and organizational management. However, transportation research became my new educational and development platform, and Caltrans became my extended family."

That family dynamic was bolstered by the relationships Briseno built across the state, inside and outside the organization—and always focused on learning. "It was during this part of my career that I was introduced to the Transportation Research Board (TRB)," she recalls. "And, just like Caltrans, it became my extended family. TRB introduced me to topics, people, and communities that allowed me to continue to learn and exchange ideas and information."

Working at one of the largest state departments of transportation afforded Briseno the opportunity to navigate across many aspects of transportation, such as planning, data and information management, and modal connectivity. Whatever the topic, she notes, TRB was a resource of researchers and practitioners that she could collaborate with. "TRB also offered me a variety of roles, such as being a

"The experience of the journey and the people I encounter along the way are more important than the destination."

friend of a committee—where I met many people who shared the same interests—and serving on National Cooperative Highway Research Program (NCHRP) panels, where—as part of a team—I helped shape research," she comments. "Now that I'm retired, TRB continues to offer me the chance to contribute and learn."

Briseno has embraced opportunities to volunteer with TRB, where she has held 22 positions on standing committees, Cooperative Research Programs panels, policy studies, forums, conferences, and planning committees. Specifically, she is the chair of the Data and Data Science Section; a member of the standing committees on Data for Decision Making and Transportation Planning Policy and Processes; and a member of the Data, Planning, and Analysis Group. She also is a member of the NCHRP Project Panel on Synthesis of Information Related to Highway Problems.

While still employed, Briseno also was a member of the American Association of State Highway Transportation Officials, where she served on several committees and task forces pertaining to transportation policy. In May 2018, she received the California Transportation Foundation Emerson Rhyner Award, which recognizes non-engineering Caltrans managers for their contributions to transportation.

Briseno's work has given her much pride throughout her 37 years at Caltrans and other public agencies. "Since people and relationships matter so much to me, I'm most proud of serving as a manager, leading teams and programs, and yes, working on TRB committees," she confides. "Working with people, especially helping individuals create and develop their own paths, is one of the most rewarding aspects of my career."

For younger professionals entering into her field, Briseno advises that they build relationships, pursue formal as well as informal mentors, and recognize that these mentors can come from all areas of one's life, many times from where they least expect them. "We all can benefit from having a mentor and serving as one," she suggests. "For me, the experience of the journey and the people I encounter along the way are more important than the destination. TRB has been an integral part of my professional and personal journey."

When she first joined Caltrans as a Research Associate, Briseno never imagined she would retire as the Deputy Director of Planning and Modal Programs, where she oversaw the Aeronautics, Research, System Information, Planning, Rail, Mass Transportation, and Local Assistance divisions. She adds, "My journey is a story of opportunities and relationships—those I created myself, as well as those so many mentors offered me along the way."

Todd Ripley

Maritime Administration

As a member of the Office of Safety under the Associate Administrator for Environment and Compliance in the U.S. Department of Transportation's Maritime Administration (MARAD), **Todd Ripley** has contributed to many agency and industry programs supporting maritime safety and research. These have included the U.S. Department of Transportation (DOT) Research, Development and Technology (RD&T) Planning Team, the Marine Board and Transportation Research Board (TRB), the Ship Operations Cooperative Program (SOCP), the Committee for the Marine Transportation System (CMTS) Maritime Innovative Science and Technology Integrated Action Team, and standards development efforts.

Ripley has been instrumental in the establishment of, and activities associated with, the CMTS COVID-19 Working Group. This includes supporting the compilation of guidance from government and industry for best practices in support of mariner health and welfare. In addition, Ripley has played a significant role in discussions regarding additive manufacturing technologies that can advance domestic production capabilities, as well as autonomous technologies that could provide an operational advantage for domestic operations.

With SOCP, Ripley worked with MARAD staff, as well as representatives from government, industry, and labor groups — to address common challenges and identify solutions to improve ship operations. He facilitated SOCP activities that address and promote commercial operations via new methods, procedures, and technologies designed to improve the competitiveness, productivity, efficiency, safety, and environmental responsiveness of U.S. vessel operations.

Ripley also brings his safety expertise to bear in facilitating information exchange activities with the National Transportation Safety Board (NTSB), MARAD, and industry, as well as keeping NTSB staff updated on pertinent safety concerns of the commercial maritime industry. He has been part of the numerous planning teams for the Biennial National Harbors Safety Committee Conference, including the 18th Biennial National Harbors Safety Committee Conference to be held in Boston, Massachusetts, in 2022.

In assisting MARAD with coordinating R&D activities, Ripley facilitates collaboration with other U.S. DOT agencies and coordinates MARAD input for U.S. DOT RD&T Planning Team tasks. This includes participation in the U.S. DOT Office of the Assistant Secretary for Research and Technology (OST-R) activities, including the development of the MARAD Annual Modal Research Plans, University Transportation Center (UTC) matters, and other modal joint research. He also coordinated the collection and update of MARAD-sponsored research and studies for the U.S. DOT Research Hub and other associated research reporting requirements in support of OST-R and U.S. DOT. Additionally, Ripley engaged with OST-R and U.S. DOT administrations on topics such as freight-flow harmonization, cybersecurity, emerging technologies, artificial intelligence, block-chain technology, and navigational resiliency to support a more robust and integrated transportation system.

"Research is the unsung hero in moving our society forward and should be aggressively promoted."

"Research is the unsung hero in moving our society forward, especially in the maritime sector, and should be aggressively promoted," Ripley comments, listing examples of potential opportunities such as autonomous maritime technologies, additive manufacturing, alternative green-energy opportunities, and alternative propulsion technologies for vessels including hydrogen, battery, and micronuclear reactors. "Without pushing forward in these and other areas, we cannot advance," he continued.

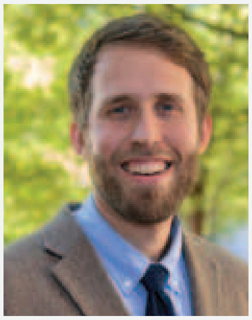
Ripley also has engaged MARAD staff in TRB activities, including the TRB Annual Meeting, other TRB events, and Marine Board activities, as well as managing the cooperative agreement with the National Academies of Sciences, Engineering, and Medicine. Additionally, he kept MARAD leadership and staff aware of relevant TRB and Marine Board activities, technical reports, and other pertinent information.

Ripley chaired the TRB Standing Committee on Marine Safety and Human Factors, and successfully handed off committee leadership to a representative from the Centers for Disease Control and Prevention in 2020. He encourages MARAD staff to join and become active in TRB technical committees, as well. Ripley also serves on the American Association of State Highway and Transportation Officials Special Committee on Research and Innovation, which contributes technical input to the National Cooperative Highway Research Program.

Ripley is a past chair and current member of ASTM Committee F25 on Ships and Marine Technology and helped transition ASTM leadership to a new set of offices in 2020 and 2021. He established working groups that have led to the development of new standards to improve safety, efficiency, and compliance in the maritime industry. He also served a term on ASTM International's Committee on Technical Committee Operations, which is responsible for technical committee oversight and governance for the entire standards organization.

A graduate of the University of Maryland, Ripley suggests that students and young transportation professionals follow the career goals that inspire them: "I recommend pursuing your passion. Don't waste your time elsewhere."

TRANSPORTATION INFLUENCER



Benjamin Bowers

Benjamin Bowers is an assistant professor in the Department of Civil and Environmental Engineering at Auburn University in Auburn, Alabama, where he also is the graduate coordinator for the Pavements and Materials group. He is the chair of the Transportation Infrastructure Group Young Member Subcommittee, a member of the Standing Committee on Asphalt Materials Selection and Mix Design and the Standing Committee on Pavement Structural Testing and Evaluation, a co-representative of the Transportation Infrastructure Group to the Young Members Coordinating Council, and a friend to many more committees and groups.

How did you first hear about and become involved with the Transportation Research Board (TRB)?

I first became involved with TRB when I was a graduate student at the University of Tennessee. Each year, our graduate program loaded a dozen or more students into vans and sent us from Knoxville, Tennessee, to the TRB Annual Meeting in Washington, D.C., to give presentations, participate in meetings, and learn. It was such a fun adventure!

How has TRB influenced your career so far?

I attended my first committee meeting during one of those trips. When I realized that these meetings really shaped the conversation between agencies, industry, and academics around the state of the practice and determining research needs, I knew I needed to become involved. As I was finishing graduate school, I had the opportunity to join what was then called the Non-Binder Components of Asphalt Mixtures Committee as a Young Member. Having a seat at the table really helped build my confidence and expand my network beyond what I was gaining from presenting and participating in other ways.

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

There are so many, from my first presentation to celebrating the Chinese New Year. But one of my greatest memories was delivering a poster presentation with my colleague, Brian Diefenderfer. Brian and his wife, Stacey (chair of the Standing Committee on Asphalt Materials Selection and Mix Design), are both active at TRB and had a very young son who couldn't be left with family. Stacey was leading a committee meeting during our poster presentation, so their 3-month-old son joined us. It was a lot of fun to be a part of such a wonderful group of professionals who wanted to talk about our research but also try to make the little guy smile.

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

CENTENNIAL QUOTE

I fell into transportation as an urban planning graduate student and found that transportation access is a key issue within the discipline. As a practitioner in the ensuing years, I have worked for a variety of agencies and on a variety of projects that aim to consider transportation equity as a key element in the planning process. Since COVID-19, the inequities around transportation access are more glaring than ever. I plan to continue to work with the Communications and Engagement Committee to highlight issues of concern and how we as practitioners can work to create a more just transportation system.

—STEPHANIE BROOKS
Project Manager, Community Engagement
Fitzgerald & Halliday, Inc., New York, New York

New Blue Ribbon Award for Standing Committees

At its December 2020 meeting, the Transportation Research Board's (TRB's) Technical Activities Council (TAC) voted to add a new category—Diversity—to its Blue Ribbon Awards. These awards have recognized exemplary best practices of standing committee activities and volunteer efforts in the following areas:

- Research: Identifying and Advancing Ideas for Research
- Renewal: Attracting and Preparing the Next Generation of Professionals and Scholars in TRB
- Implementation: Moving Research Ideas into Transportation Practice
- Leadership: Contributing to Improving the Management and Operation of TRB Committees

By adding Diversity, TAC will formally recognize efforts made by standing technical committees to increase membership from underrepresented groups and to increase diversity in a way that allows the committee to better meet its mission. Races and ethnicities that are underrepresented include people who identify as African American/Black, Hispanic/Latinx, and Native American/Native Alaskan/Native Pacific Islander. TAC plans to use the Diversity award as a way to look for noteworthy practices that are transferable to other committees and to communicate the importance of standing committees' efforts to address diversity.

MEMBERS *ON THE MOVE*

Three TRB Executive Committee members have been appointed to senior positions in President Joe Biden's administration:

Vicki Arroyo, 2019 Chair of the Executive Committee, has been appointed Associate Administrator for the Office of Policy at the U.S. Environmental Protection Agency.

Nuria Fernandez, an Executive Committee member, has been appointed Deputy Federal Transit Administrator.

Steve Cliff, the ex officio member representing the California Resources Board, has been appointed Deputy National Highway Safety Administrator.

More than one-third of new appointees to key U.S. Department of Transportation leadership positions have volunteered their service to or engaged with TRB in the past.

COOPERATIVE RESEARCH PROGRAMS NEWS

University Design Competition for Addressing Airport Needs

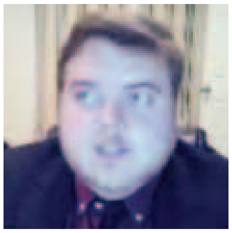
This Airport Cooperative Research Program (ACRP) event engages individual students—or teams of students—at U.S. universities in addressing airport operations and infrastructure issues and needs. Under the guidance of a faculty mentor, students focus on challenges in one of the following four categories:

1. Airport Operations and Maintenance,
2. Airport Management and Planning,
3. Runway Safety/Runway Incursions/Runway Excursions, and
4. Airport Environmental Interactions.

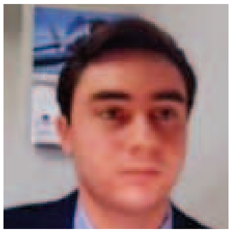
Participants are required to seek input from airport operators and industry professionals for feedback on the practicality of their designs. Students win cash awards for winning submissions, and first-place winners present their winning designs at the Airport Consultants Council Airports Technical Workshop in Washington, D.C., and an appropriate competition partner workshop or conference in the fall.

In 2019, a Next Step Award was added to the competition to allow a small number of promising student proposals identified by the selection panel to be taken to the next step in their design/development.

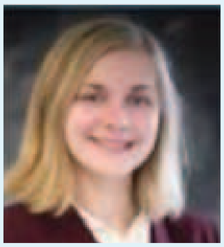
The competition is funded by the Federal Aviation Administration and managed for ACRP by the Virginia Space Grant Consortium. The electronic and hard copy deadline for the 2020–2021 competition is April 29, 2021. Visit the competition's website at vsgc.odu.edu/acrpdesigncompetition.



Cooper Burleson (*right*) was part of the 2019–2020 Purdue University team that won top honors in the Airport Management and Planning category.

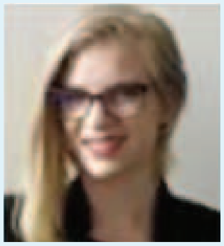


Member of another Purdue University team, Zachary Alexander Marshall (*left*) shared the 2019–2020 win in the Airport Environmental Interactions category.



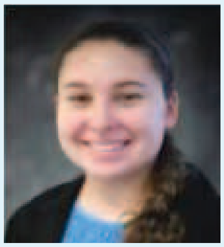
Lindsey Anderson

- Third-year undergraduate
- Pursuing a bachelor's degree in civil engineering and an international Spanish minor



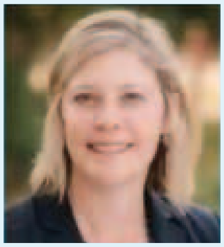
Skylar Callis

- Fourth-year undergraduate
- Pursuing a double bachelors' degree in civil engineering and applied mathematics



Kaitlyn Wehner

- Third-year undergraduate
- Pursuing a bachelor's degree in civil engineering



Audra Morse

- Faculty Advisor for the Built World Enterprise
- Ph.D., P.E., BCEE, F.ASCE
- Department Chair, Civil and Environmental Engineering

Left to right: Lindsey Anderson, Skylar Callis, and Kaitlyn Wehner won first place in 2019–2020 for Michigan Technological University in the Runway Safety/Runway Incursions/Runway Excursions category. Audra Morse (*at right*) served as their faculty advisor.

How Is Life in *Your* Community?

QUALITY OF LIFE AND AIRPORTS

Airports serve as critical economic engines for their local communities and in a broader regional context. They are employment hubs, and they support regional and global transportation networks while striving to limit environmental impacts. Airports regularly study their economic benefits and environmental effect on surrounding communities by examining indicators such as employment, spending, noise, and air quality. Over the past two decades, airports have sought to integrate sustainability into their planning by considering social impacts in addition to economic and environmental effects. By considering a variety of factors that contribute to or detract from the community's quality of life (QOL), airports can determine how their actions influence these factors and engage community stakeholders in a constructive dialogue over how to improve overall QOL.

WHAT IS QUALITY OF LIFE?

There is no single, universal definition of QOL, but, generally, it is a broad, multidimensional concept that refers to an individual's or a community's perception of and actual well-being and position in life. Different organizations have developed several QOL reporting tools and related frameworks to serve diverse purposes. These tools are generally intended to inform decision making on micro to macro scales.

Examples include the Organisation for Economic Co-operation and Development Better Life Index[1], and the U.S. Green Business Council Leadership in Energy and Environmental Design (LEED) for Cities and Communities rating system.[2] However, airports have lacked a readily applicable tool to evaluate all their benefits and

[1] Organisation for Economic Co-operation and Development Better Life Index. http://www.oecdbetterlifeindex.org/#/22435525535.

[2] LEED for Cities and Communities. https://www.usgbc.org/leed/rating-systems/leed-for-cities.

impacts in a comprehensive and holistic manner. Recognizing this gap, the Transportation Research Board's Airport Cooperative Research Program (ACRP) undertook a project titled "Measuring Quality of Life in Communities Surrounding Airports."[3]

ACRP QOL ASSESSMENT PROJECT

This project developed a framework for airports to increase their knowledge of QOL in surrounding communities and the factors that contribute to QOL to help identify communities' challenges and concerns and increase understanding of how the airport can address existing or emerging challenges. This QOL Assessment Methodology is described in *ACRP Research Report 221*.[4]

The guidebook—authored by HMMH with research partner ERG—contains information relevant to a variety of audiences and stakeholders. The tool is flexible to accommodate organizations with varying resources and can easily be adapted for use by entities other than airports (e.g., municipal governments, planning departments, economic development agencies, and others) that have an interest in understanding the factors that affect the prosperity, health, and welfare of their citizens.

The ACRP QOL Assessment Methodology takes a mixed-methods assessment approach. This means that both qualitative and quantitative data are utilized to form a comprehensive picture of QOL. The ACRP QOL Assessment Methodology includes 99 QOL indicators (quantitative and qualitative) organized into six categories (Figure 1): Economic, Environmental, Health, Local Governance and Community Services, Social Relationships, and Transportation. The 100th indicator is a qualitative indicator that addresses overall QOL. Examples of indicators in each category are listed in Table 1.

The ACRP QOL Assessment Methodology is flexible so that any airport or organization undertaking the study can realize benefits, including gaining an understanding

FIGURE 1 **Quality of Life indicator categories. (Source: HMMH, *ACRP Research Report 221*.)**

TABLE 1 **Example Quality of Life Indicators for Airports**

INDICATOR CATEGORY	TYPE	INDICATOR DESCRIPTION
General	Qualitative	Overall quality of life
Environmental	Quantitative	Outdoor air quality
Health	Qualitative	Level of stress
Economic	Qualitative	Housing affordability
Transportation	Qualitative	Traffic congestion
Social Relationships	Qualitative	Experience of discrimination
Local Governance & Community Services	Qualitative	Community safety

Source: *ACRP Research Report 221*

of the factors that contribute to low or high QOL in their surrounding communities. The methodology works as a tiered approach through which stakeholders accrue benefits from each sequential step. The steps of the assessment process are described in the guidebook and include the following:

1. Initiate QOL dialogue internally,
2. Engage external stakeholders,
3. Determine study area and gather quantitative data,
4. Administer survey,
5. Analyze data, and
6. Review or update assessment at future date.

Benefits can accrue even if an organization does not undertake all six steps. As the steps progress, the depth and breadth of engagement with stakeholders advances, culminating in the development of a full-scale QOL assessment.

CONCLUSION

The decisions made by airports with regard to infrastructure development and operations affect communities for decades. Communities expect to be a part of the planning process and increasingly expect to provide input and recommendations into airport decisions. Undertaking a QOL assessment is an effective process to enhance community engagement efforts and increase transparency of airport benefits and impacts.

[3] ACRP Project 02-83. http://www.trb.org/Publications/Blurbs/181139.aspx.
[4] *ACRP Research Report 221: Measuring Quality of Life in Communities Surrounding Airports.* https://doi.org/10.17226/25918.

First Electric Bus for Fairfax County Public Schools

Fairfax County, Virginia, public schools kicked off 2021 on January 5 with the rollout of their first electric school bus, one of eight to be added to its fleet of 1,625 diesel-fueled buses.

Funded by a grant from Dominion Energy, the bus is among a total order of 50 to be deployed throughout the state's school systems by the end of the year. The energy-efficient vehicles will help improve air quality, which is 5 percent worse inside a diesel-powered bus. The buses also will reduce operations and maintenance costs by as much as 60 percent for the school districts.

Learn more about these buses' energy efficiency at https://patch.com/virginia/herndon/fcps-receives-first-electronic-school-bus-under-dominion-grant.

Photo: Peggy Fox, Dominion Energy

All set to serve students, Fairfax County's electric school bus's engine is on display. Electric buses operate at the equivalent of 17 miles per gallon compared with 6 miles per gallon for diesel-fueled buses.

Satellite Imagery of Angled Parking Helps Planners Design Bike-Lane Networks

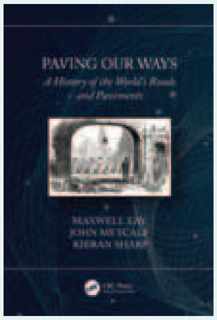
When it comes to street parking for cars and the safe movement of bicycles in the United States, automobiles—right or wrong—get first priority over bike lanes. Such privilege is seen in allocating curbside parking space for cars rather than reserving it for bike lanes. But it is even more apparent in angled parking, which takes up nearly double the right-of-way space as parallel parking and leaves even less room for bike lanes. Although many experts consider angled parking a traffic-calming measure, several studies report that this parking design results in higher collision rates compared with parallel parking. However, transportation planners have been challenged to understand the effects of angled parking on safety and bicycle infrastructure because some cities do not maintain accurate records of where such parking is located.

With part of the focus on San Francisco, California, a 2020 University of California, Berkeley, study used satellite imagery to fill the gap in data, which shows that the city dedicates 50 miles of street curbs to angled parking. But not because San Francisco's hills require angled parking. However, four of those 50 miles overlap the city's network of bike lanes. Satellite imagery offers an opportunity for planners in other cities to identify angled parking and to design more equitable infrastructure for bike traffic.

Read the study report at https://doi.org/10.1177/2399808320954205.

Photo: iStock

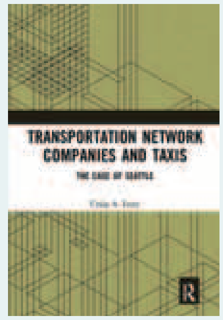
Angled parking takes up nearly twice the space as parallel parking and decreases room for bike lanes.



Paving Our Ways: A History of the World's Roads and Pavements

Maxwell Lay, John Metcalf, and Kieran Sharp. CRC Press, 2020. $46.95, 314 pp., 978-0-367-520-786.

This book addresses the international history of road paving—from Egypt and Mesopotamia to pavement's resurgence in France and England—and offers an overview of paving technologies in a historical context. The advances needed to bring pavements to their current development are explored, as are the tools for financing, constructing, managing, and maintaining pavements.



Transportation Network Companies and Taxis: The Case of Seattle

Craig A. Leisy. Routledge, 2020. $48.95, 316 pp., 978-0-367-729-653.

This book is a modern economic case history and thorough analysis of the impact of the transportation network company (TNC) industry on the taxicab industry in Seattle, Washington, beginning in 2014. The author, the regulator of the taxicab and TNC industries during this period, discusses the taxicab industry, economic deregulation, competitive market failure, market disruption, price elasticity of demand, and more.

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

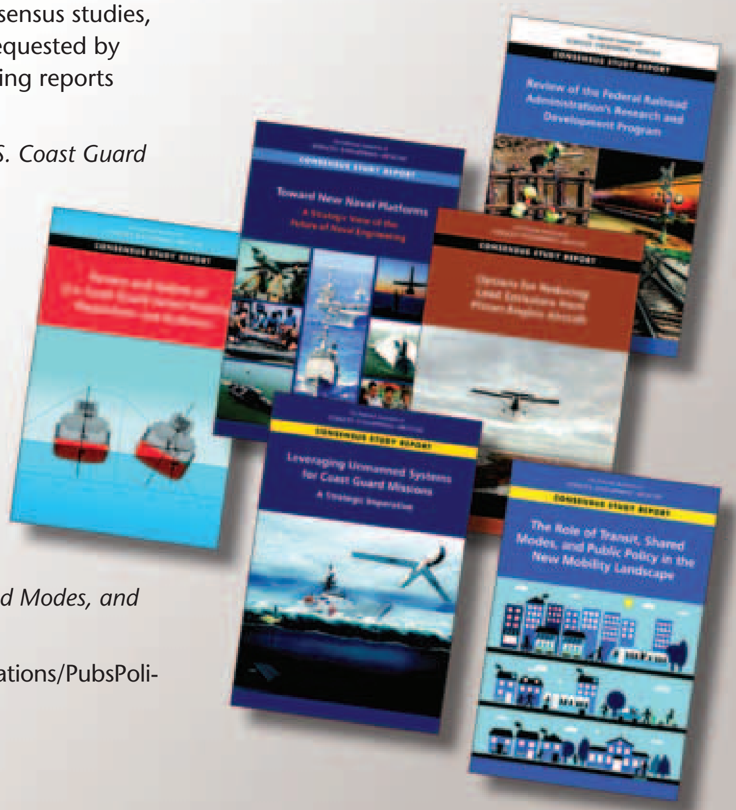
TRB PUBLICATIONS

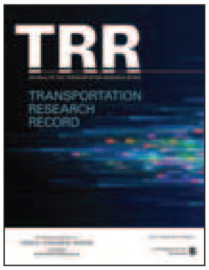
SPECIAL REPORTS

TRB Special Reports present the results of consensus studies, including studies mandated by Congress or requested by Executive-branch federal agencies. The following reports were published in 2020 and early 2021:

- *Special Report 332: Review and Update of U.S. Coast Guard Vessel Stability Regulations and Guidance*
- *Special Report 333: Toward New Naval Platforms: A Strategic View of the Future of Naval Engineering*
- *Special Report 334: Review of the Federal Railroad Administration's Research and Development Program*
- *Special Report 335: Leveraging Unmanned Systems for Coast Guard Missions*
- *Special Report 336: Options for Reducing Lead Emissions from Piston-Engine Aircraft*
- *Special Report 337: The Role of Transit, Shared Modes, and Public Policy in the New Mobility Landscape*

For more information, visit www.trb.org/Publications/PubsPolicyStudiesSpecialReports.aspx.





Transportation Research Record 2674
Issue 11

The papers in this volume examine topics including evaluating the dynamic accessibility of metro systems in overcrowded conditions, multiple uses of big data for model validation and express lanes traffic forecasts, and internal and external costs of motor vehicle pollution.

2020; 925 pp. For more information, visit http://journals.sagepub.com/home/trr.

Transportation Research Record 2674
Issue 12

Mapping universal access experiences for public transport in Latin America, spatial access by public transport and likelihood of healthcare consultations at hospitals, and applying a home-based approach to the understanding distribution of economic impacts of traffic crashes are some of the topics presented in this volume.

2020; 607 pp. For more information, visit http://journals.sagepub.com/home/trr.

Guide to Ensuring Access to the Publications and Data of Federally Funded Transportation Research
NCHRP Research Report 936

This report is designed to help state departments of transportation (DOTs) and other organizations that do transportation research better understand and consider how they will comply with the U.S. DOT policy.

2020; 138 pp.; TRB affiliates, $61.50; nonaffiliates, $82. Subscriber categories: administration and management, data and information technology, research.

Guidebook for Implementing Alternative Technical Concepts in All Types of Highway Project Delivery Methods
NCHRP Research Report 937

This report is designed to help guide alternative technical concepts (ATCs) in the state highway project delivery process. The ATC process—used with design–build highway project delivery—solicits design modification ideas offered by respondents during the bidding process.

2020; 102 pp.; TRB affiliates, $54.75; nonaffiliates, $73. Subscriber categories: administration and management, transportation, general.

Strategies for Work Zone Transportation Management Plans
NCHRP Research Report 945

This report provides a practitioner-ready guidebook on how to select and implement strategies that improve safety and traffic operations in roadway construction work zones.

2020; 256 pp.; TRB affiliates, $76.50; nonaffiliates, $102. Subscriber category: construction.

Implementing Information Findability Improvements in State Transportation Agencies
NCHRP Research Report 947

This report identifies key opportunities and challenges in information findability faced by state DOTs and provides practical guidance for agencies wishing to tackle this problem. It describes four specific techniques piloted within three state DOTs.

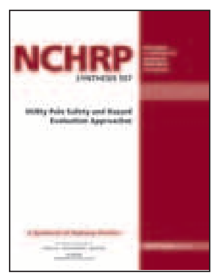
2020; 44 pp.; TRB affiliates, $42; nonaffiliates, $56. Subscriber categories: administration and management, data and information technology.

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

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

This report presents a methodology to analyze and determine the seismic capacity requirements of bridge elements expressed in terms of service and damage levels of bridges under a seismic hazard. The methodology is presented as proposed American Association of State Highway and Transportation Officials (AASHTO) guidelines for performance-based seismic bridge design.

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



Utility Pole Safety and Hazard Evaluation Approaches
NCHRP Synthesis 557

This synthesis summarizes the strategies, policies, and technologies that state transportation agencies and utility owners employ to address utility pole safety concerns.

2020; 190 pp.; TRB affiliates, $69.75; nonaffiliates, $93. Subscriber categories: design, highways, safety and human factors.

Emerging Challenges to Priced Managed Lanes
NCHRP Synthesis 559

This synthesis provides an overview of the state of practice for how state DOTs address challenges to implementing tolling, or pricing, on their managed lane systems.

2020; 96 pp.; TRB affiliates, $54.75; nonaffiliates, $73. Subscriber categories: highways, operations and traffic management, data and information technology.

Guidance for Diversity in Airport Business Contracting and Workforce Programs
ACRP Research Report 217

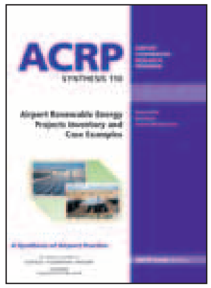
This report provides guidelines to assist airport operators and various stakeholders at airports of all types and sizes to identify and quantify the benefits, costs, and regional economic impacts of diversity contracting for airport businesses.

2020; 154 pp.; TRB affiliates, $65.25; nonaffiliates, $87. Subscriber categories: administration and management, aviation.

Measuring Quality of Life in Communities Surrounding Airports
ACRP Research Report 221

This report addresses an emerging need for airports to take a more holistic look at how they affect their neighbors and how they can build stronger community relationships. Airports can benefit from a more comprehensive understanding of the variables affecting their surrounding communities, over which they may have little to no control.

2020; 124 pp.; TRB affiliates, $58.50; nonaffiliates, $78. Subscriber categories: aviation, environment, planning and forecasting.



Airport Renewable Energy Projects Inventory and Case Examples
ACRP Synthesis 110

This synthesis draws on existing literature and data to present the state of practice for airport renewable energy. It examines the integration of renewable energy projects—including solar photovoltaic, geothermal, bioenergy, solar thermal, and small wind projects—into airport development and operations.

2020; 120 pp.; TRB affiliates, $58.50; nonaffiliates, $78. Subscriber categories: aviation and energy.

Equity Analysis in Regional Transportation Planning Processes: Guide
TCRP Research Report 214, Volume 1

This report helps metropolitan planning organizations analyze and address equity effectively in long-range, regional, multimodal transportation planning and programming processes. The guide walks through public engagement, identifying populations for analysis, identifying needs and concerns, measuring impacts, further understanding those impacts, and developing strategies to avoid or mitigate inequities.

2020; 118 pp.; TRB affiliates, $58.50; nonaffiliates, $78. Subscriber categories: public transportation, planning and forecasting, policy.

Equity Analysis in Regional Transportation Planning Processes: Research Overview
TCRP Research Report 214, Volume 2

This report describes the results of the research effort and identifies ways in which equity in public transportation can be analyzed and adapted by metropolitan planning organizations in partnership with transit agencies. This report discusses research findings and recommendations organized around a five-step equity analysis framework that is built upon a foundation of public involvement.

2020; 162 pp.; TRB affiliates, $65.25; nonaffiliates, $87. Subscriber categories: public transportation, planning and forecasting, policy.

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 Memoriam

Douglas Smith, Senior Environmental Planner at AECOM in Phoenix, Arizona, and Emeritus Member of the Standing Committee on Environmental Analysis and Ecology, died January 10, 2021.

MEETINGS, WEBINARS, AND WORKSHOPS

March

15–17 **Sixth Biennial Marine Transportation System Innovation Science and Technology Conference**
Online
For more information, contact Scott Brotemarkle, TRB, 202-334-2167, sbrotemarkle@nas.edu.

17 **Moving Past COVID-19: Lessons Learned from Responses Around the World—Syndemics Webinar**
Online
For more information, contact Charlie Minicucci, Health and Medicine Division, 202-334-2157, cminicucci@nas.edu.

18 **Measuring Resiliency: Tools for Analyzing Resilient Transportation Systems**
Online
For more information, contact Elaine Ferrell, TRB, 202-334-2399, eferrell@nas.edu.

23 **The New Virtual Reality: Hosting NEPA Public Hearings Virtually**
Online
For more information, contact Elaine Ferrell, TRB, 202-334-2399, eferrell@nas.edu.

24 **Emerging Challenges for Congestion Pricing on Managed Lanes**
Online
For more information, contact Elaine Ferrell, TRB, 202-334-2399, eferrell@nas.edu.

25 **Analyzing Corridors and Systems with the Highway Capacity Manual**
Online
For more information, contact Elaine Ferrell, TRB, 202-334-2399, eferrell@nas.edu.

30 **Real-Time Response: A Pandemic Playbook for Public Transportation Agencies**
Online
For more information, contact Elaine Ferrell, TRB, 202-334-2399, eferrell@nas.edu.

31 **Evaluating Tack Coat Materials' Durability in Asphalt Pavements**
Online
For more information, contact Elaine Ferrell, TRB, 202-334-2399, eferrell@nas.edu.

April

6–8 **Measuring and Managing Freight System Resilience Workshop**
Online
For more information, contact Tom Palmerlee, TRB, 202-334-2907, tpalmerlee@nas.edu.

29–30 **Research and Technology Coordinating Committee Meeting**
Online
For more information, contact Michael Covington, TRB, 202-334-2265, mcovington@nas.edu.

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

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

CENTENNIAL QUOTE

"Creating communities where active transportation is a real choice for people is how I want to have an impact on the world. Research and information from the Transportation Research Board (TRB) help me learn what practices can work and how and when to apply these practices. They also connect me to other planners and engineers who seek to have a similar impact on the world. By focusing on all modes of transportation, TRB meetings and conferences provide a forum for professionals working across the many sectors of transportation to learn from one another and find solutions to problems that result in true transportation improvements that can benefit everyone, not just certain users.

—CHARLES DENNEY
President, Potomac and Chesapeake Cycling
Arlington, Virginia

INFORMATION FOR CONTRIBUTORS TO **TR NEWS**

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

ARTICLES

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

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

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

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

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

OTHER CONTENT

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

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

SUBMISSION REQUIREMENTS:

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

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

TRANSPORTATION RESEARCH BOARD
500 Fifth Street, NW
Washington, DC 20001

ADDRESS SERVICE REQUESTED

TR News Issues on MyTRB

Subscribers can now access PDF copies of *TR News* in their entirety via MyTRB. To view the current and past issues and to update subscription preferences, visit http://MyTRB.org. After logging into MyTRB, go to “My Account” and select the button labeled “*TR News*.”

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

The nation turns to the National Academies of Sciences, Engineering, and Medicine for independent, objective advice on issues that affect people’s lives worldwide.
www.nationalacademies.org

T R N 3 3 1