TR NEWS

July–August 2021 NUMBER 334

INNOVATIONS ON THE HORIZON

Research Needs for the Marine Transportation System of the Future

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Mary R. Brooks, Scott Brotemarkle, Edward Comstock, and Jim Kruse

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COVER Waltershofer Hafen affords a clear view of container ships, like CSCL *Venus*, in harbor at the Port of Hamburg in Germany. The global marine transportation system is the subject of this *TR News* theme issue. (Photo © Port of Hamburg, Peter Glaubitt)

Coming Next Issue

Since the terrorist attacks of September 11, 2001 (9/11), transportation has broadened its role to include response and operations—from traffic incident management as a multiagency function to aviation security. But in the 20 years since 9/11, natural disasters, technology changes, and pandemics have presented new challenges. In the September–October 2021 issue of *TR News*, authors address these challenges, as well as how transportation agencies can incorporate resilience to respond quickly and effectively to an ever-shifting landscape.

A Transportation Security Administration (TSA) worker screens airline passengers before their flights. Created two months after 9/11, TSA quickly became integrated into many transportation modes, particularly aviation.

Photo: TSA

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

TR NEWS

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

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Publications Staff
Eileen P. Delaney, Publications Senior Advisor
Natalie Barnes, Director of Publications
Lea Camarda, Editor
Cassandra Franklin-Barbajosa, Editor
Jennifer G. Correro, Assistant Editor

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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.

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INNOVATIONS ON THE HORIZON

Research Needs for the Marine Transportation System of the Future

MARY R. BROOKS, SCOTT BROTEMARKLE, EDWARD COMSTOCK, AND JIM KRUSE

Brooks is a Professor Emerita at the Rowe School of Business at Dalhousie University in Halifax, Nova Scotia, Canada, and a past Marine Board chair. Brotemarkle is the Marine Board program director and a senior program officer at the Transportation Research Board (TRB) of the National Academies of Sciences, Engineering, and Medicine in Washington, D.C. Comstock is the former senior executive and chief Naval architect of the Naval Sea Systems Command and a past Marine Board chair. Kruse is the director of the Center for Ports and Waterways of the Texas A&M Transportation Institute in Houston and the TRB Marine Group chair.

Marine transportation activities generally take place over the horizon of most people's daily lives—how many of us have been stopped in traffic by a container ship or grain barge on the way to the office? Without the marine transportation system (MTS), however, the quality of life, economy, and security enjoyed by modern society would be at risk.

Marine Transportation System

The MTS consists of several systems working together to meet the nation's needs of prosperity, sustainability, resilience, safety, and security. The articles in this special issue of *TR News* introduce some high-priority areas that merit research focus to achieve the necessary innovative strides in emissions reduction, automation, big data, and resiliency by 2050. The research needed to transform the MTS is substantial, challenging, and urgent.

The issues facing the MTS demand a cross-cutting approach from the research community—everything from information technology and cybersecurity to human and intellectual capital to ship, vehicle, and offshore platform design, construction, and safe operation. Their complex interactions and interdependencies—both internally and with other transportation systems—must be understood.

You can have the world's most efficient port, but if the marine, land, and air transportation systems are not properly integrated, the delivery of goods and services can be severely disrupted. This is where the Transportation Research Board (TRB) is uniquely positioned to advance the knowledge necessary for timely and effective innovation.

Marine Group and Marine Board

The five committees in TRB's Technical Activities Division Marine Group propose and share research and provide forums for transportation professionals to address

Photo: PANYNJ/CMA CGM Group

In September 2020 the CMA CGM *Brazil*—then (at 15,072 20-foot equivalent units, or TEUs) the largest container ship to call on the East Coast of the United States—arrived at the Port Authority of New York & New Jersey's APM Terminal. This record was surpassed in May 2021, when the even larger CMA CGM *Marco Polo* called on APM Terminal. The research needs of the marine transportation system are diverse, from cybersecurity to safety to ship design and construction.

issues related to ports and channels, inland water transportation, marine environment, marine safety and human factors, and ferry transportation.

Internationally recognized, the TRB Marine Board provides a forum for the exchange of knowledge relating to new technologies, laws and regulations, economics, the environment, and other issues affecting the MTS. Marine Board members apply their expertise to identify research needs and support the National Academies of Sciences, Engineering, and Medicine Consensus and Advisory Studies' efforts related to MTS challenges, working in partnership with federal agency sponsors fulfilling stewardship missions related to the nation's waterways, coastal ports, offshore waters, and the global maritime commons.

The committees in the Marine Board and Marine Group depend upon TRB affiliates from industry, government, and academia with expertise across all components of the global supply chain. The global maritime commons, our waterways, and coastal ports—our marine highways—accommodate a wide range of vessel types and uses, just as a highway must accommodate trucks, buses, cars, and motorcycles.

Marine transportation services must be performed efficiently, effectively, and profitably in the harshest conditions with high priority for the environment and safety. In addition, experts serving marine-related TRB entities must be flexible to address rapidly emerging research needs—like those arising from the COVID-19 pandemic and its impacts on the MTS.

In preparation for this issue, members of the Marine Board and Marine Group committees chose five critically important topics for innovation and research in the MTS. The articles in this issue reflect these priorities. The knowledge the authors share will advance the field as they identify what gaps must be addressed and the timelines that are necessary for future research and innovation.

The *TR News* Editorial Board thanks Micah Himmel, TRB, for his work in assembling and developing this issue.

The research needed to transform the MTS is substantial, challenging, and urgent.

Transforming Ocean Shipping

Alternative Energy Sources and Practical Issues

Photo: Eric Bakker, Port of Rotterdam

LEE KINDBERG AND JIM CORBETT

Kindberg is Head of Environment and Sustainability for North America at Maersk in Charlotte, North Carolina, and Corbett is Professor Emeritus at the University of Delaware in Newark.

Above: As Europe's largest port, the Port of Rotterdam handles 30,000 seagoing vessels per year. Ocean shipping is vital to today's global supply chains and is responsible for 2 to 3 percent of the world's total anthropomorphic CO_2 emissions. A transformation to carbon-neutral shipping is beginning.

Climate change is the top challenge of the 21st century. Transforming ocean and inland marine shipping is essential to achieving the low- or no-carbon supply chains needed to meet the Paris Agreement's goal of limiting global temperature rise to 1.5 to 2 degrees Celsius. Shipping currently accounts for 2.9 percent of global carbon dioxide (CO_2) emissions, and the industry has committed to halving overall greenhouse gas (GHG) emissions by 2050.

The magnitude of this transition is enormous for the entire industry and its suppliers and customers. But what seemed like a monumental and disruptive change just a few years ago is already evolving from a "moon shot" visionary goal to something that actually can be implemented within the lifetimes of the vessels being designed today.

Cargo owners, vessel owner–operators, fuel and engine suppliers, classification societies, government entities, and many other stakeholders have critical roles in making this transition successful. This transformation has been compared to "painting the ship while sailing," because supply chains must adapt without disruption, and reliability is increasingly important. Support from the transportation research community is essential to provide the energy and agility needed to match the accelerating rate of change.

Broad-based action is needed. In this article, marine energy research challenges are grouped into the following five categories, addressing technical, operational, economic, and structural and regulatory aspects:

1. Optimization of maritime energy efficiency;
2. Design and shipper acceptance of carbon-neutral products;
3. Innovation in new fuels and energy for propulsion and operations;
4. Design and operation of carbon-neutral and low-emitting vessels; and
5. Adaptation of regulatory frameworks, standards, and metrics at all levels.

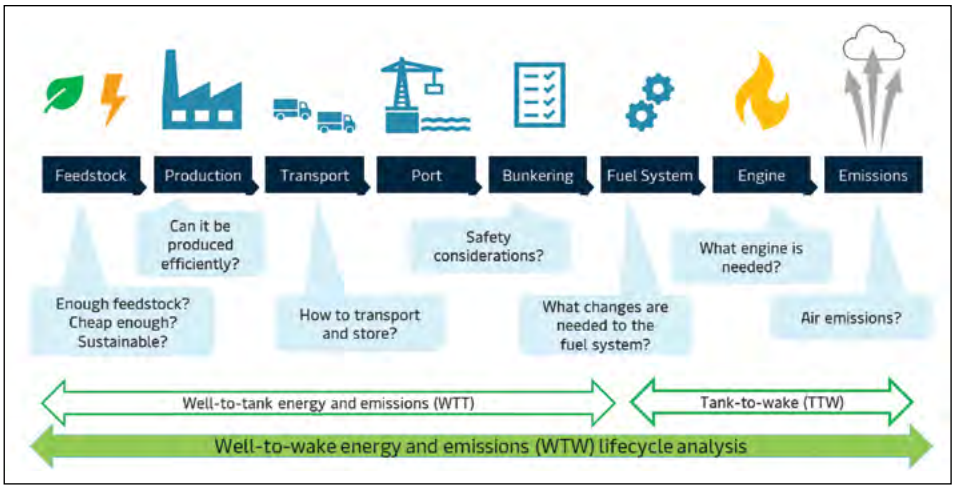


FIGURE 1 **Transformation must happen across the entire supply chain.**

Innovations in port energy and cargo-handling technologies are also critical to complement and enable the step changes required across the marine transportation system. Achieving these goals may provide the best environmental performance and meet the most ambitious sustainability goals in the history of shipping. When maritime energy systems change, every aspect of global transportation must adapt (Figure 1).

The lifetime of an oceangoing vessel is typically 20 to 25 years. Therefore, to achieve a dramatically lower carbon (or even net-zero carbon) operation for the global fleet by 2050, the vessels launched in 2030 must be powered by—or ready for conversion to—new fuels and technologies. This means creating new designs between 2025 and 2027 and ordering them by 2028.

The process will not be linear, with differing speeds for various fuels and energy systems. Thus, it is important to start testing and implementing new fuels and technologies quickly. This has begun with a biomethanol-fueled vessel announced recently by one company and plans to expand the service of vessels using liquefied natural gas (LNG) as a fuel announced by another company.

Vessel lifetimes and fleet turnover are considerably longer for vessels in inland and freshwater operations, which—combined with seasonality and lower freight rates—make this part of the sector even more difficult to decarbonize. Urgent action is needed within this decade to achieve global climate goals.

Fortunately, progress is under way and accelerating.

Energy Efficiency

Over the past 15 years, many shipping companies have made major improvements in energy efficiency. This has been driven by operating costs and by customer and stakeholder demand for more environmentally friendly supply chains. According to the International Maritime Organization's (IMO's) *Fourth Greenhouse Gas Study*, or GHG4, between 2008 and 2018 the carbon intensity of international shipping decreased by approximately 30 percent.[1]

Some major carriers report even greater efficiency improvements. These dramatic changes in efficiency are due to optimization of networks and operational policies, deployment of more energy-efficient new vessels, retrofits on existing vessels, and new applications of big data and near-real-time data acquisition technologies to improve performance. Dramatically larger vessels and lower speeds have provided economies of scale in both costs and CO_2 generation.

From a total emissions perspective, however, industry growth has offset efficiency improvements—GHG4 states that total GHG emissions from shipping increased by 9.6 percent from 2012 to 2018.

[1] Based on IMO's *Energy Efficiency Operational Index* (average of methods).

Photo: IMO

As part of an IMO training exercise, state control officers practice inspecting air pollution and energy efficiency compliance aboard a container ship in Johor Port, Malaysia. IMO is part of an increasing number of coordinated efforts to reduce the carbon impact of the maritime industry.

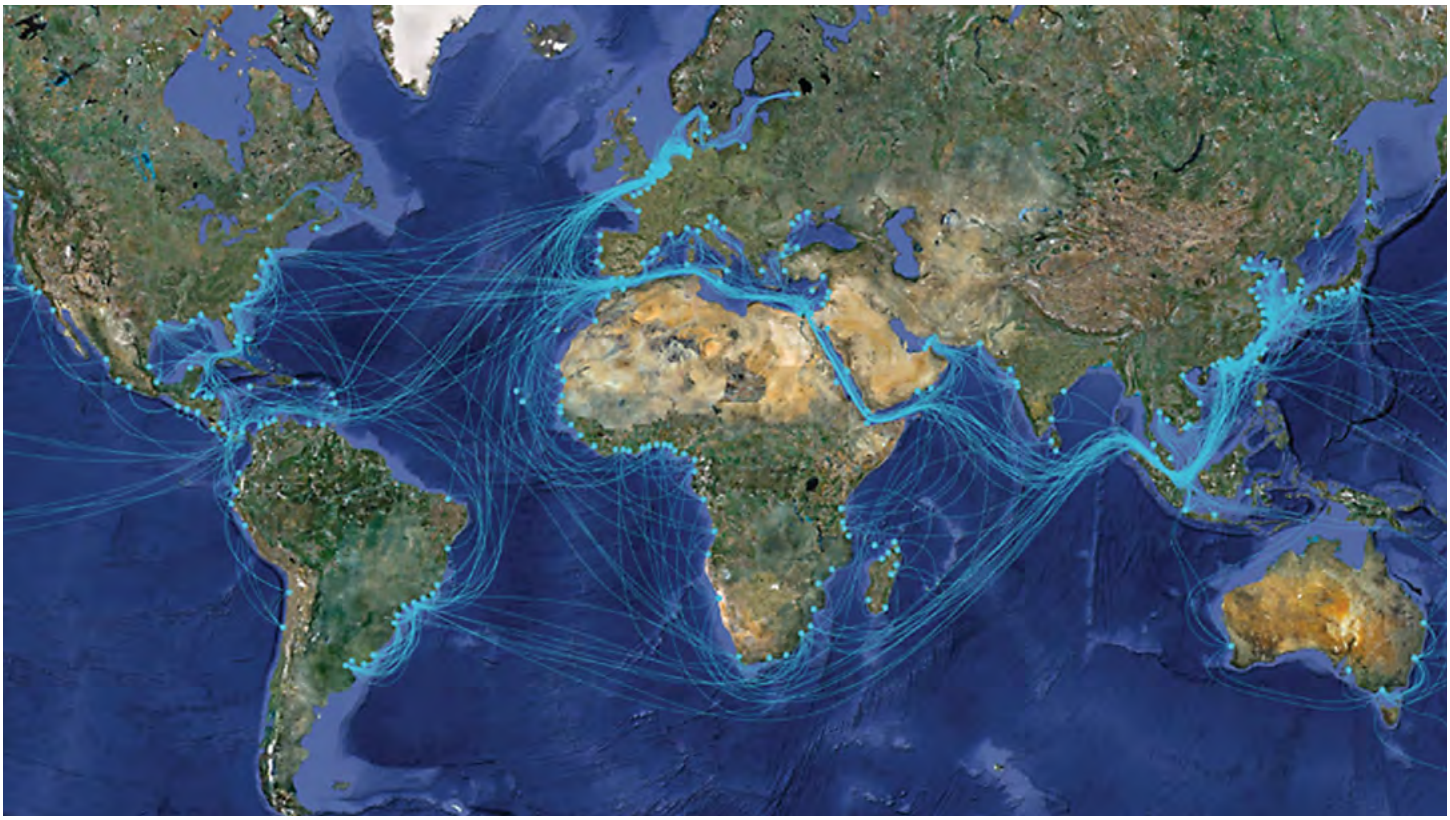


Photo: Maersk

Only recently considered improbable and idealistic, zero-carbon goals are now a primary goal of many cargo owners and vessel operators across the vast and vital shipping industry.

This analysis considered carbon dioxide equivalent, or CO_2e, which includes the full suite of GHGs, particularly CO_2, methane, and nitrogen oxides (NO_x). Meeting future reduction targets, therefore, must consider and include underlying drivers such as population growth and consumption.

In the longer term, IMO's actions in international regulations strive for a more energy efficient, lower carbon future while addressing other environmental impacts such as toxic air emissions and invasive species, as well as emerging topics such as underwater noise. Unfortunately, solutions to these latter concerns also require capital investments and additional energy and so compete for funding. The additional energy required to operate systems to treat ballast water or reduce air emissions, for example, may also result in increased GHG emissions.

Efficiency gains and operational controls will continue to be important, but they cannot deliver a fully carbon-neutral shipping future. This can only be achieved through new propulsion solutions based on carbon-neutral fuels and energy systems.

Customer acceptance of systemwide change can help establish demand to accelerate the zero-carbon transition. Today, leading cargo owners and vessel operators have begun adopting aggressive zero-carbon goals, and cargo owners have started to demand—and be willing to pay for—carbon-neutral shipping options.

Goals that once seemed visionary are starting to be questioned: Are they ambitious enough? More major companies are adopting the detailed frameworks defined by the Science-Based Targets Initiative, which include addressing emissions beyond their own operations—such as in the supply chain—and do not give credit for carbon offset purchases.[2] A few major cargo owners have begun to purchase the net-carbon-neutral marine shipping services now becoming available or have engaged in projects to accelerate the development of innovative fuels.

From the perspectives of shippers and vessel operators, success in meeting the decarbonization target will require a balance of safe and reliable operations; predictable and affordable economics; and clear, understandable, and actionable metrics and goals. Such programs must also address the demands of port communities and regulators for significant reductions in toxic pollutants.

Fuel and Energy Innovation

EARLY APPROACHES

Innovations in fuels will drive new engine and vessel designs and will define requirements for port fuel delivery systems and fuel production infrastructures. Figure 2 (page 8) shows several of the options in order of increasing complexity of the required change.

[2] For more information, see https://sciencebasedtargets.org.

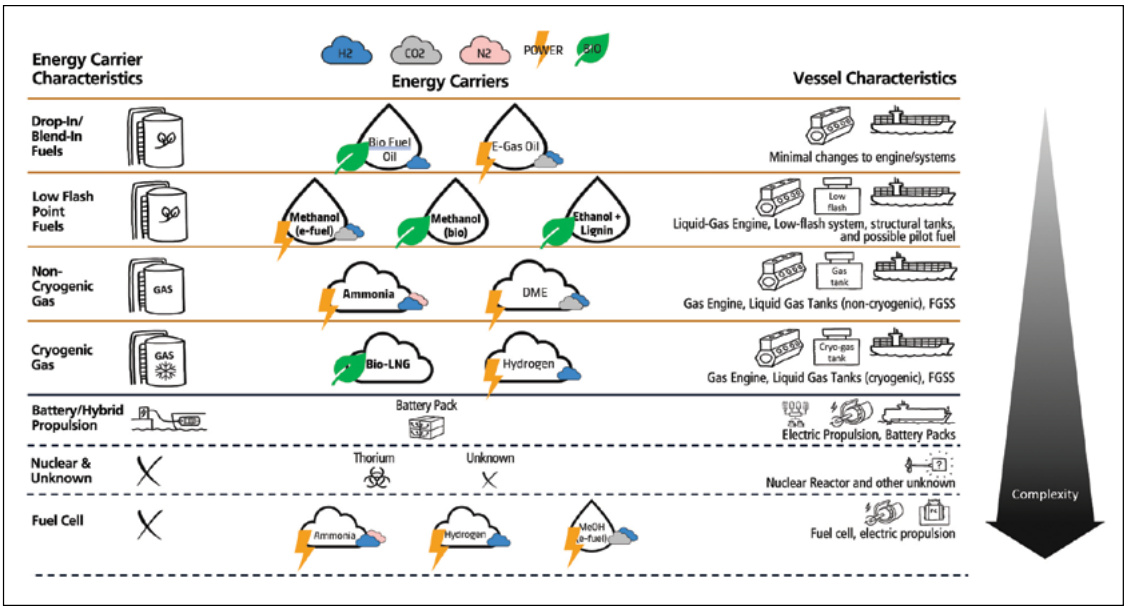


FIGURE 2 Potential carbon-neutral fuels.

In the evolution of marine fuels, early attention focused on "bridge fuels" such as LNG, which has been successful in limited implementation and infrastructure development. This encourages optimism that the industry's transformation is achievable with the right concerted global efforts. LNG has a lower carbon content than standard marine fuels and may be less polluting, but it is currently derived from fossil fuel sources. Questions also remain about methane slip and other components in a full well-to-wake life cycle analysis.

Other concerns include NO_x emissions from some engine types and at certain loads. In the future, bio-LNG could address some of the questions raised about LNG and similar fossil fuels. It also could be manufactured from bio-based materials or even derived from waste, providing mutually beneficial, circular-economy solutions.

Another early approach is the use of biofuels in marine applications. Some biofuels may require only limited vessel modifications and fuel supply changes, enabling rapid scale-up and implementation (these are called "drop-in fuels").

Operational experience with such fuels is limited, however, and significant challenges remain in defining acceptable sustainable feedstocks and finished product standards, traceability, and certification, as well as audit standards for carbon credit or taxation standards. Scalability also will depend on feedstock availability, infrastructure development, and the risk of competition with other transportation modes for limited bio-based fuel supplies.

As shown in Figure 1, other innovative fuels are likely to require more substantial changes to vessels, ports, and fueling infrastructure. The current outlook is the end of the existing diesel-fueled marine system, with future systems becoming more complex and diverse as new fuels and energy sources are developed to meet the wide range of maritime applications.

Photo: JAXPORT

TOTE Maritime Puerto Rico's *Perla Del Caribe* is one of two 3,100-TEU (20-foot equivalent units) LNG-powered container ships out of the Jacksonville Port Authority's Blount Island Marine Terminal. Although it is still derived from fossil fuels, LNG is seen by some as an early step in the evolution away from diesel marine fuels.

NEW POSSIBILITIES

Evolving energy carrier options and breakthroughs in energy storage may be game changers. For shipping, possibilities could include new liquid and gaseous fuels, battery storage, fuel cell technologies, on board carbon capture and after-treatment technologies, or even new nuclear options. Choices for international marine operations must

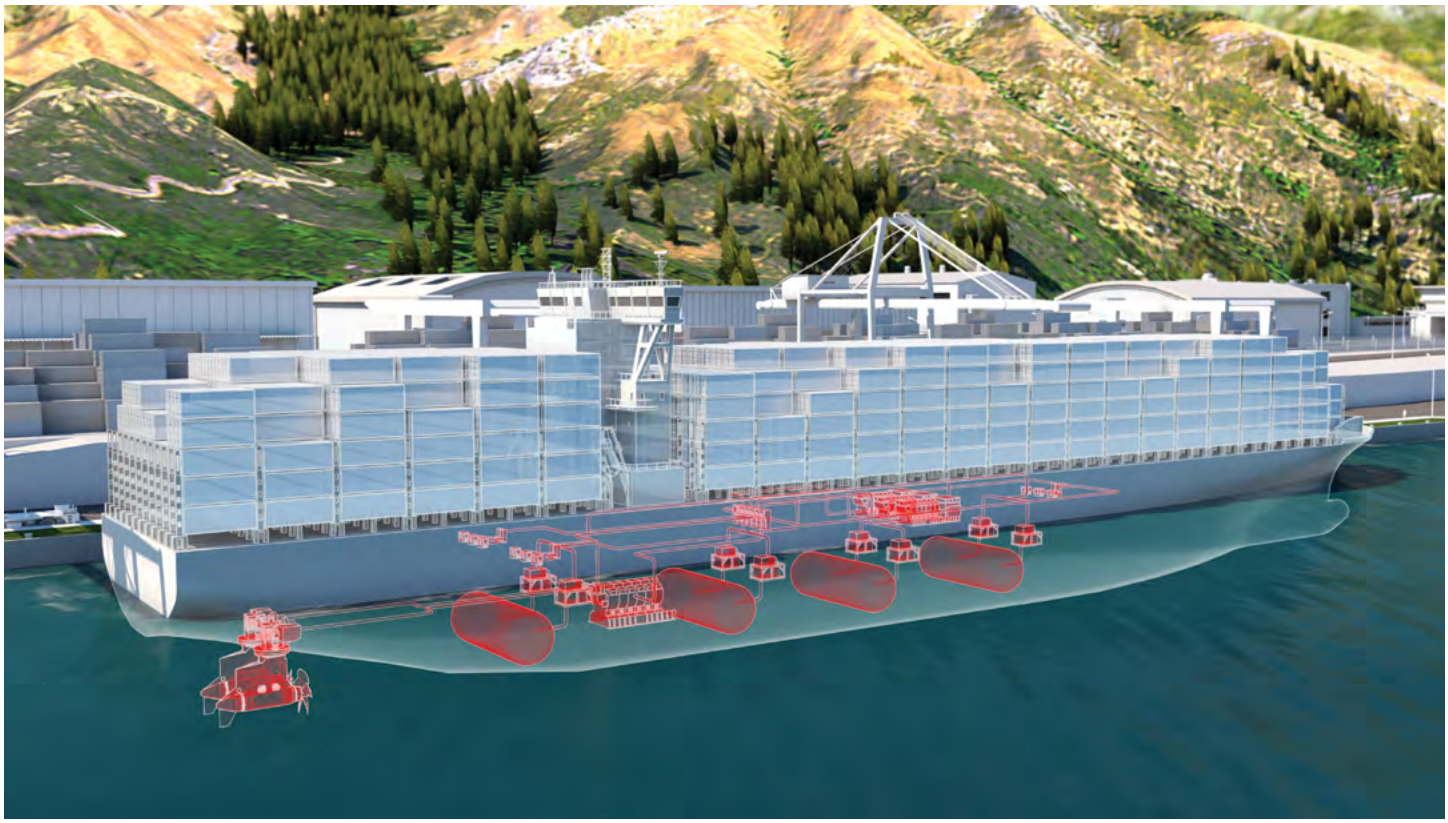


Image: ABB

This concept illustration shows a large vessel powered by hydrogen fuel cells, which is in development by manufacturing and automation company ABB and Hydrogène de France. Research into advanced fuels and alternative power designs are under way for low- or zero-carbon marine transportation.

consider long distances between fueling, structural requirements, and space limitations for power systems.

Key criteria for oceangoing vessels and vessel-assist harbor craft will continue to be the power-to-size and power-to-weight ratios. Today, cargo payload design requirements are matched with engine room and fuel storage needs for traditional marine propulsion and petroleum fuels. If renewable or low-GHG fuels are less energy-dense, then energy and power choices may reduce cargo capacity and may require adjustments to vessel design characteristics, voyage routing and ranges, transshipment combinations, and other factors.

Transportation research is accelerating to define new pathways that engage all parts of the marine transportation system and supporting energy and fuels infrastructure. Vessel-focused research is exploring cleaner fuels, advanced fuels, alternative power designs, and efficient hull designs, as well as the economics and required land-based infrastructure to make these feasible.

In the intermediate and long term, there will likely be more than one winner in the race to develop fuels and energy systems for zero-carbon shipping. Active assessments are now under way on additional biofuels, alcohols, alcohol–lignin blends, and ammonia (Table 1, page 10).

Each of these approaches presents advantages and challenges. Supply of the various "E-" fuels will require electricity production that uses renewable energy sources. The transition will require methodologies and metrics to define how to address current electricity generation portfolios as they become higher in renewable energy sources and lower in GHG in coming decades.

Standards, Metrics, and Policies

Beyond the cost of the transformation, the thorniest issues in the global adoption of net-zero energy technologies for shipping may not lie in engineering, naval architecture, or fuels production and infrastructure. Global alignment of technical, regulatory, and operational standards and financial incentive structures is essential to ensure these tools progress at the required pace and that reductions are properly allocated to the nations and companies in ways that enable rapid decarbonization with minimal false starts or dead ends. These standards and incentives include a focus on

- Regulatory frameworks and goals;
- Fuel and engine/fuel system safety engineering and certification standards, which are critical to success;

TABLE 1 Readiness and Research Needs for Vessel Energy Decarbonization Approaches

TECHNOLOGY	CURRENT KNOWLEDGE AND RESEARCH NEEDS
Battery	Viable for short-sea shipping and harbor craft, but not presently for deep-sea shipping. Could be used for peak shaving or as a hybrid option.
Nuclear	Thorium technology is under development, but public concerns may limit adoption.
On Board Carbon Capture	At concept stage only—space requirements have serious impacts on cargo-carrying capacity.
Fuel Cells	Strong potential as a technology disruptive to combustion engines in the future, but too expensive for shipping at present. Cost reduction is a research need.
Biofuels and Biodiesel	• Biodiesels now are in limited blended marine use. Concerns include feedstocks, scaling, and competition with other modes. • Synthetic biofuels (biomass-to-liquid) and advanced biofuels are at the development stage and will expand available options. Scalability is a research priority.
Biomethane	• Scalability of production is a concern. • May not be net-zero because of methane emissions during production and combustion, so there is uncertainty on whether this can be a route towards net-zero GHG emissions.
Hydrogen	• Currently not feasible for deep-sea shipping because of range (storage space requirements and availability), but very important as a feedstock. • Safety is a concern and is ripe for research efforts.
Alcohols	• Methanol is technically feasible today, but green methanol production is not yet available at scale. • Only second-generation ethanol is acceptable, and it is more expensive than methanol.
Lignin Alcohols	Development is still at early research stages, with high potential.
Ammonia	• Green ammonia offers zero-emissions potential in both tank-to-wake (TTW) and well-to-wake (WTW). • Production not yet available at scale. Engine and safety developments are ongoing. There are technical and regulatory barriers to the use of toxic fuels. • Research opportunities include safety throughout production, use of green production methods, other environmental impacts, and TTW/WTW analysis standards.

- Economic structures to direct and accelerate change, support research and development, finance new vessel designs, and build new fueling infrastructures; and
- Methodologies and metrics to define and compare the life cycle impacts of new energy and fuel alternatives and set and track global goals and progress.

Consistent life cycle assessment (LCA) standards based on the full GHG suite (CO_2e, especially including methane and NO_x) are essential to understanding and prioritizing the options and developing consistent global strategies and regulations. Although it is more challenging, only a full well-to-wake life cycle analysis can provide the information needed for good investment decisions and practical GHG reduction strategies, and changes in land use or other extended results must also be considered in consistent ways.

The regulatory aspects of such a major transformation must be addressed in a timely way to avoid regulatory fragmentation and establish clear metrics and goals. This is uncharted territory, and the process cannot rely on business-as-usual approaches. Action is needed on a grand and transformative scale. Funding for research and innovations, as well as other economic mechanisms, must be fully considered. Regulatory mechanisms also must be based on data and fleets, reward first movers, and encourage laggards to invest sooner. Enforcement is essential and cannot be an afterthought.

Implementation of any energy and materials transformation will face unintended consequences. Identification of potential safety, environmental, health, and economic consequences and mitigations must be incorporated into research

plans and expectations, along with a full cradle-to-grave life cycle approach.

Decarbonizing marine energy systems must also consider other environmental performance requirements to avoid unintended trade-offs. Supplies of biofuels, for example, may be limited by food and feed demand or land-use constraints. Moreover, broader efforts to decarbonize multimodal transportation (road and rail) could present competition for the most flexible energy solutions, leading to shortages and price volatility.

View of the Future

What does our crystal ball show? There will be more than one winner, and innovation must occur concurrently on many fronts. The best outcomes will require contributions by global stakeholders and innovators, especially the diverse talents and skills of the transportation research community.

Short-sea shipping and ferries are already demonstrating successful implementation of electrical power and some fuel cell technologies. Some global companies have committed to the LNG pathway, which can lead to equipment and practice improvements for other gaseous fuels. The transportation and logistics company CMA CGM is expanding LNG services to the United States; Maersk has stated publicly that it is focusing on biofuel-based services available today, followed by alcohols, alcohol–lignin blends, and ammonia.

Photo: Reading Tom, Flickr

The diesel–electric hybrid ferry MV *Lochinvar*, shown at the Mallaig transportation hub in Scotland, entered service in 2014. Electric power has already been implemented in short-sea and ferry applications.

Combinations of approaches, such as a hybrid of electric and diesel, will extend ranges and broaden applicability. Finally, the role of those involved in defining metrics and LCA processes cannot be understated in terms of criticality in the smooth transition to low- or zero-carbon shipping.

As public policy priorities set timelines to decarbonize shipping within the next two to three decades, some major fleet operators and cargo owners are already working toward new net-zero GHG targets, partly to address corporate and customer sustainability goals.

Corporations and governing bodies seek research insights in transportation systems and climate science, including contributions by the Transportation Research Board. This presents real opportunities for transportation research professionals to help shape the future.

VOLUNTEER VOICES

"I want to work toward a world in which all people—regardless of circumstances—have equal access to opportunities and a high quality of life. I see transportation as the cornerstone of that vision, as so much of the determinants of health, safety, and success are rooted in transportation access. The Transportation Research Board provides the research, tools, and access to excellent practitioners who enable me and my organization to take baby steps toward that vision every day.

—IAN DETAMORE
Program Manager
Pennsylvania Department of Transportation, Harrisburg

Importance of the Marine Transportation System to the United States

PAUL BINGHAM

The author is Director, Transportation Consulting, for IHS Markit in Los Angeles, California.

The marine transportation system (MTS) is a crucial part of the U.S. economy. The magnitude and value of MTS infrastructure are enormous, comprising more than 300 seaports and river ports and their marine terminals; shipyards, navigation channels, locks, and dams; and the networks that keep the infrastructure operating.

Most overseas exports and imports—and significant domestic goods movements—rely on an effective MTS. The importance of the MTS to the country was emphasized in 2020, when maritime imports of essential medical supplies and equipment saved lives during the COVID-19 pandemic. The economic role of the MTS is extensive and includes the value and operations of cargo vessels, ferries, cruise ships, fishing vessels, and recreational boats, as well as the infrastructure and workers that support them. The MTS also provides invaluable national security support to the military.

According to the U.S. Maritime Administration, MTS waterborne cargo movement and associated activity contributes more than $500 billion to the U.S. gross domestic product and sustains more than 10 million jobs in the economy (*1*). This activity is mostly in the private sector, and it generates more than $200 billion annually in taxes that support the budgets of all levels of government.

Photo: Corey Templeton, Flickr

Fishing vessels on the Portland, Maine, waterfront take part in the city's historically marine-based economy. The Portland waterfront is undergoing a revival, with a mix of freight, industrial, tourist, and nonmarine uses, as well as traditional fishing and passenger marine travel. With its network of industries, the MTS is central to the U.S. economy.

The U.S. economy depends on an efficient and reliable MTS to enable other sectors of the economy to operate. The MTS moves agricultural, manufactured, and resource commodities in a competitive global market. Since the country's founding, the MTS has contributed to the growth of the economy and is essential to the United States as a maritime nation.

MTS assets require maintenance and investment to continue supporting the economy. If aging MTS infrastructure is not adequately maintained, the consequences of lower reliability, higher costs, and greater environmental impacts will be

Photo: Steve Walser, Flickr

Upstream of the Clearwater River Bridge (*pictured*), Idaho's only seaport allows inland wheat farmers to transport their crops inexpensively down the Snake and Columbia rivers. The MTS includes not only international routes but also the inland waterways that are so vital to U.S. agriculture.

significant. These impacts became apparent during the pandemic when capacity for handling the trade surge was strained, resulting in delays and higher costs for shippers, impeding U.S. exports, and disrupting business inventories.

Reduced effective MTS capacity can lead to higher costs for other modes, decreased producer profitability, and higher prices for imports, risking lower overall economic activity. A healthy MTS can sustain or improve the competitiveness of U.S. businesses while reducing transportation-related environmental impacts and supporting well-paying jobs throughout the country. Substituted for truck or rail transport, maritime transportation can reduce unit shipping costs and reduce emissions per ton-mile (*2–3*).

The MTS comprises businesses and workers in many industry sectors—from marine ports and terminals to shipyards to cargo vessels, cruise ships, and ferries—and the manufacturers and service providers who support those maritime sectors. MTS businesses and workers are located in every coastal state and in the 38 states directly served by inland waterway transportation.

Businesses and workers in every state depend on the MTS for transportation of the energy, mining, agricultural, manufacturing, and retail goods they produce and consume. Even as globalization patterns shift, key supply chains depend on the MTS to keep the economy functioning and support future growth.

More than $1.5 trillion in U.S. international trade was handled by the MTS in 2020, according to the U.S. Census Bureau (*4*). This is more than 40 percent of all U.S. merchandise trade, including $997 billion in imports and $516 billion in exports. MTS cargoes include bulk commodity transport, the largest volumes comprising the energy and agriculture goods fundamental to the economy. Dry bulk vessels, tanker vessels, and barges carry the majority of these commodities; container ships and vehicle carriers move valuable manufactured goods such as electronics and vehicles through the MTS.

Looking to the future, the ability for the MTS to support the economy faces such challenges as aging infrastructure, sea level rise, weather extremes, and changes in workforce and technology. Investments in the MTS will be required to address impacts of global warming. Expenditures on digitalization, as well as other MTS technology developments such as automation, will affect MTS productivity and employment. Demands on the MTS from other parts of the economy are likely to grow, increasing its importance to the country.

Increasing demand will come from underlying economic growth, as well as from the desired substitution of maritime transport for other, less efficient modes of transport. An improved and increasingly important MTS can benefit the entire economy as more efficient marine transport reduces overall transportation-related environmental costs and enhances economic competitiveness.

REFERENCES

1. Maritime Transportation System. Maritime Administration, U.S. Department of Transportation. www.maritime.dot.gov/outreach/maritime-transportation-system-mts/maritime-transportation-system-mts. Accessed April 30, 2021.
2. National Transportation Statistics Table 3–21. U.S. Department of Transportation Bureau of Transportation Statistics. www.bts.gov/content/average-freight-revenue-ton-mile. Accessed April 30, 2021.
3. *Port Emissions Inventory Guidance: Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emissions.* U.S. Environmental Protection Agency. Report EPA-420-B-20-046, Sept. 2020. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10102U0.pdf.
4. FT-920 US Merchandise Trade: Selected Highlights December 2020. U.S. Census Bureau, Foreign Trade Division. Feb. 5, 2021.

AUTONOMOUS VESSELS IN U.S. SHIPPING

Following the Northern European Lead

Image: videotrinkets, Shutterstock

SEAN T. PRIBYL

The author is an international trade, maritime, and business attorney in Washington, D.C. He also is a Marine Board member.

Above: Setting sail into the not-too-distant future, AI-controlled ships are poised to move freight around the world.

The transportation sector is currently undergoing an evolution with the increasing development of highly automated autonomous vessels (AVs), which, loosely defined, can augment onboard navigation decision-making or perform a set of specific operations without direct intervention from a crew.[1] Such technologies bring a new set of challenges, as innovation will affect regulatory compliance, design, operations, safety, security, training, and the workforce.

Modernizing the historically conservative marine industry with advanced autonomy presents a marked transformation, as AVs may offer more sustainable solutions related to economics, environmental impact, and societal benefits. Also, there is increasing public demand for a more flexible and cost-effective way to enable a more sustainable shipping sector. Proponents suggest that AVs can achieve economies of scale, improve safety, increase efficiency, relieve humans from repetitive tasks, and reduce crew and auxiliary costs.

These are important considerations, since human error is estimated to contribute to anywhere from 75 percent to 96 percent of marine accidents (*1*). Thus, incorporating advanced decision-making aids and augmented situational awareness on vessels could conceivably lead to fewer accidents attributable to human factors or, at least, could be as safe as conventional means. In addition, AVs may improve traffic management through more efficient route optimization and data exchange while offering more sustainable environmental solutions.

The Northern European Approach

The advent of AVs is not an entirely novel concept; in 1898, Nikola Tesla demonstrated a remote-control vessel. Now,

[1] Other terms include maritime autonomous surface ships (MASS), autonomous surface vehicles, and autonomous ship systems, although a universal definition or term has not been developed. For purposes of this article, the term AV is used.

Image: Yara/Kongsberg

A 120-TEU (20-foot equivalent units) open-top container ship due to launch in 2022, Norway's *Yara Birkeland* will be the world's first fully electric, autonomous, zero-emissions container ship. The vessel is designed to move cargo equivalent to 40,000 annual truck journeys along waterways instead of roads.

northern European countries—including Norway, Denmark, Finland, Belgium, and the Netherlands—are moving from theory to practice and pioneering new approaches to increase their competitiveness based on perceived benefits of improving safety and lowering operational costs. Moreover, AV development abroad is spurred by cultural acceptance, national interests, collaboration, and investment with an emphasis on commercial applications. Finnish company Wärtsilä suggests four areas where autonomy could add value over time: increased safety, fuel and operational expenditure savings, low crew requirements, and efficient ship design (*2*).

Some northern European countries are aggressively supporting the development of advanced autonomy in the shipping sector on the basis that such innovation could bring economic incentives by reducing the high cost of labor. Such endeavors also are based on sustainable solutions to environmental challenges, such as lowering greenhouse gas emissions. These countries generally propose that maritime innovation of this kind could also offer new employment and training opportunities as a means to attract and retain new talent with future hybrid skill sets.

To that end, governments are subsidizing various commercial projects. For example, Norway has built upon its long maritime history and launched an ambitious, integrated, ecosystem-based ocean strategy involving incentives for innovative maritime technology to support domestic job creation, encourage industry collaboration, and support the United Nations Sustainable Development Goals. The Norwegian government has backed the development of the *Yara Birkeland,* a battery-operated, zero-emissions, autonomous container vessel preparing for uncrewed operations by 2022 and designed to replace 40,000 annual truck journeys by moving that same cargo through waterways instead.

ASKO Maritime is constructing vessels to operate on Norwegian waters with reduced crew before implementing fully autonomous voyages, and Zeabuz is building self-driving electric ferries near Trondheim. In support, Norway is reportedly updating national legislation to accommodate technological advances in autonomous shipping by exempting pilot requirements while examining new artificial intelligence (AI) monitoring tools for vessel traffic services.

However, Norway is not alone. In 2018, the *Falco* ferry made an autonomous voyage in Finland. Svitzer, Kongsberg Maritime, and American Bureau of Shipping are developing RECOTUG in Denmark as a fully operational and remote-controlled tugboat. In Belgium, a remote-controlled barge has taken boxes from Zeebrugge to Antwerp. And ZULU Associates—with operational company Anglo Belgian Shipping Company—is developing the ZULU MASS vessel intended to operate uncrewed and to evolve into zero-emissions propulsion. Damen Shipyards in the Netherlands is incorporating autonomous and wireless-helm systems as standard new-build features. The Baltic and International Maritime Council is drafting AUTOSHIPMAN as the first standard contract for autonomous ship operations.

Consequently, northern European countries are emerging as global leaders

Image: ZULU Associates

Following a tradition of innovation, ZULU Associates—with subsidiary Anglo Belgian Shipping Company—is developing a MASS vessel that is designed to operate without a crew and will evolve into zero-emissions propulsion.

in innovative maritime autonomy and are developing lessons learned through projects such as Horizon Europe 2020, Marlab (UK), Autoship (EU), AEGIS (Norway and Finland), ONE Sea and Rethinking Autonomy and Safety Ecosystem (Finland), and the Norwegian Forum for Autonomous Ships. Some of these projects are receiving tens of millions of euros in investment to develop short-sea shipping and inland waterways scenarios. The major container ports of Rotterdam, Antwerp, and Hamburg also are integrating digital solutions.

Timelines

Increased automation is starting within domestic waters under varying degrees of autonomy and with a human onboard; notably, AV business cases do not always envisage removing crew. The short-term focus contemplates a limited number of vessel types (e.g., survey vehicles, ferries, tugs, support vessels, and inland barges), semiautomated bridges, shore-based remote navigation, and use of an onboard technical crew.

Midterm expectations call for increased automation on expanding vessel types and new builds, as well as a gradual reduction of technical crew. In the long term, completely uncrewed vessels engaged in international trade remain an aspirational goal. Timelines for AVs in northern Europe are more ambitious and supported by direct financial justification, customer benefit, and reduced risk profiles.[2] For example, in 2017 the Finnish company Digital, Internet, Materials & Engineering Co-Creation predicted commercial autonomous traffic to develop by 2025, as shown in Figure 1.

Although there is movement with inland and near-coastal operations, fully autonomous oceangoing vessels in regular international service—once thought entirely elusive—remain seemingly feasible and within reach technically, save for regulatory hurdles.

[2] Japan, Singapore, China, and South Korea are also developing comprehensive AV timelines.

Degrees of Autonomy

Degree 1: Ship with automated processes and decision support
Degree 2: Remote-controlled ship with seafarers on board
Degree 3: Remote-controlled ship without seafarers on board
Degree 4: Fully autonomous ship

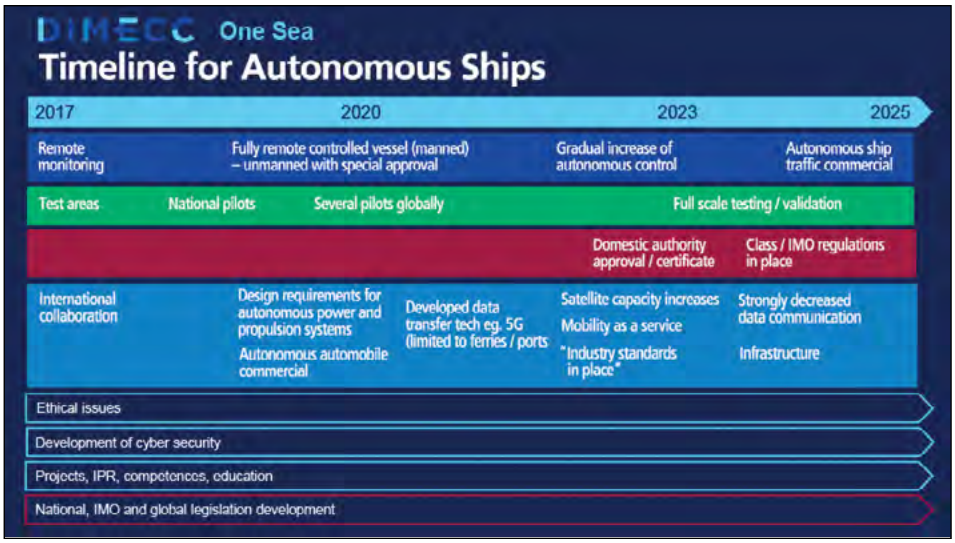


FIGURE 1 Predicted promulgation of northern Europe's necessary MASS regulations. (Source: Digital, Internet, Materials & Engineering Co-Creation.)

Where the United States Stands

Historically, the United States has been a leader in technological innovation. However, by all accounts, it is lagging behind its counterparts in the development of commercial AVs since the United States has generally deferred to the private market. Limited commercial use cases are developing on certain vessel types under varying degrees of automation, including augmented bridge navigation, remote-control operations, and AI decision-making.

More specifically, companies like Buffalo Automation are developing augmented navigation support technology for varying degrees of autonomy. Sea Machines Robotics and First Harvest Navigation have collaborated to upgrade short-sea operations with remote crew-assist technology that includes autonomous command and remote helm control systems. SailPlan is developing intelligent navigation platforms for ships that enable operators to increase safety, reduce operational costs, and increase schedule integrity.

Unlike Europe, the focus of U.S. AV development has been in the defense and government sectors and, thus, no large-scale commercial AV projects are comparable to European counterparts. The U.S. Navy has overseen voyages under advanced autonomy between California and Hawaii and from Alabama to California via the Panama Canal, operating autonomously 98 percent of the time under the latter. The National Oceanic and Atmospheric Administration has been operating uncrewed surface survey vehicles for ocean data gathering.

Both institutions have committed to long-term investment of uncrewed vessels with strategic plans, and their use of autonomous navigation is important in supporting the ongoing question of whether advanced automation can comply with navigational rules. At the urging of the U.S. House Committee on Transportation and Infrastructure, U.S. Coast Guard (USCG) Commandant Admiral Karl L. Schultz has started to implement recommendations from the Transportation Research Board's *Special Report 335: Leveraging Unmanned Systems for Coast Guard Missions—A Strategic Imperative* "to realign plans, operations, budgets, and policies to enable the USCG to capitalize on unmanned systems through purposeful strategic action" (*3*).

Although future U.S. markets depend on the ability to offer sustainable solutions, maintain a strong industrial base, and develop innovations that allow the nation to be an independent and competitive leader, no timelines for full-scale implementation of AVs exist. Stakeholders in the United States generally lack practical experience in navigating the myriad national regulations related to AVs, and the United States has a dearth of meaningful industry and domestic best practices.

If more formal policy is developed, such endeavors would support presidential executive orders and U.S. Department of Transportation initiatives on ensuring that American leadership in AI and USCG strategies focused on promoting maritime commerce and emerging technologies. To gain ground on international counterparts, the U.S. industry needs more investment, more collaboration, and a holistic view of the entire marine transportation system (MTS).

AV Governance

AV governance falls under a regulatory framework at the international level, such as the International Maritime Organization (IMO), regional or district level (EU), and national regulations. These regulations must provide assurances of transparency, validation, and traceability of autonomous systems. Other elements include adoption of universally accepted definitions, accountability, and rights and responsibilities of traditional roles (e.g., captain). In addition, governance must support third-party validation, certification, and oversight of risk by appropriate approval authorities with an overarching safety theme.

Photo: Gard

Magne Nilssen (*at right*), Gard Insurance's chief operating officer in London, was part of the Norwegian delegation presenting the *Yara Birkeland* project to members of the IMO at the 99th session of the Marine Safety Committee on May 21, 2018. The committee addresses all matters pertaining to maritime safety and security, including insurance policies and regulations.

In May 2021, the IMO Marine Safety Committee (MSC) completed a regulatory scoping exercise that analyzed relevant IMO treaty instruments in order to assess how AVs—the IMO uses the term MASS—could be regulated. The committee recommended that the best way to address MASS in the IMO regulatory framework is preferably through the development of a goal-based instrument, or MASS Code. The MSC invited member states to submit proposals on how to achieve the best way forward and will continue to engage with IMO's Legal and Facilitation committees before the 104th MSC session in October 2021. If a MASS Code is the preferred way forward, industry should not expect a final version until around 2028 to 2030.

In the interim, governance is expected to follow "soft law" that looks for compliance under existing domestic regulations through equivalencies, exceptions, authorizations, or waivers with a holistic approach involving safe and smart measures, best practices, and legal interpretations. IMO's *Interim Guidelines for MASS Trials* also serves as a vital guidance document for AV testing. Policy labs and consortiums could offer useful input on barriers to implementation, and measures may be pursued at the national, bilateral, regional, and global level. Building public and industry trust will be at the core of governance.

In the United States, AV governance will be guided by defense use cases and the domestic legal framework, the most prevalent being those related to carrying crew onboard and navigational rules compliance. In terms of oversight, the USCG serves as lead regulator for safety and security of AV operations, and the Maritime Administration is tasked with supporting the development of the commercial AV sector balanced with developing the U.S. mariner workforce.

To that end, USCG—as a technology user and regulator—has begun to explore how to integrate AV and these evolving technologies into the MTS. At this time, USCG's stated strategy is to manage early adoption by establishing a governance approach that leverages existing authorities under legal interpretations and equivalencies. In 2020, USCG published a Request for Information on the integration of automated and autonomous commercial vessels and vessel technologies into the MTS and has established the Blue Technology Center of Expertise, which serves as a facilitator for commercial development. Industry should expect USCG to continue an active role in IMO to help shape AV international oversight.

Validation and Testing

Put simply, the United States is not there yet. It lacks a validation process and designated AV testing areas while novel technology and nontraditional stakeholders are driving development. Industry needs standardization and interoperability for intelligence and autonomy as it focuses on scale, continuity, and resilience. Shipping can learn from and develop examples of how other industries can transform and overcome challenges using AI, edge computing, and innovative cloud architecture.

The key to meaningful progress with maritime autonomy is to continue developing data sets that evaluate whether the technology will decrease costs, increase safety, and comply with all regulations. Overall, the focus should be on developing a framework of standards to assure the safety of advanced autonomy navigation systems, including their sensors and components.

Who will be involved in developing those standards? Look for classification societies, including Det Norske Veritas and the American Bureau of Shipping, to become involved with emerging standards. The International Association of Classification Societies is also developing a new standard for ships and marine technology terminology related to automation of AVs. The International Standards Organization has been addressing technological developments with autonomous shipping.

Given the novel technologies, achieving these standards will require new competencies at USCG, although interagency and cross-sector applications with lessons learned from automated road and aerial vehicles may prove useful. Finally, academia could continue to offer invaluable research and develop curricula to meet the demands of the marine workforce.

Points of Pain

The complexities of the development of AVs should not be underestimated. The main points of pain in the United States primarily relate to the lack of adequate funding. Governments in the EU are investing, but U.S. markets rely on venture capital. High initial capital costs are creating challenges, and markets still seem somewhat unconvinced of the promise. Most important is determining whether the technology fits within the existing legal framework.

Full operations at the national and international levels will require permanent solutions with potential amendments to governing instruments to develop a feasible regulatory framework for validating autonomous navigation collision avoidance systems, decision-making, and communication links. Near-term solutions to these issues still require a human in the loop.

The typical assumption is that operator error is the cause of most incidents and accidents, although these views are confounded by the lack of relevant data. Thus, more data are crucial, as is direction from the IMO with a forward-looking, goal-based perspective on terminology and legal interpretations on matters related to compliance with bridge lookout and crewing requirements, remote operations, and algorithm-based decision-making.

Infrastructure in the United States also will need to develop and improve to allow for advanced automation in the transportation sector. Federal regulators should oversee the critical infrastructure resiliency of assets, networks, and systems in the MTS, including modernizing waterways, vessel traffic services, aids to navigation, and ports. This should mitigate risks to critical infrastructure and enhance unity of effort in MTS to optimize maritime planning. To that end, industry needs to gain the acceptance of advanced automation from marine pilots and shore-based labor unions because they are entry points for adoption of a digital ecosystem.

Impact on Labor

Innovation with AVs can transform the marine workforce in a positive manner, and "autonomous" does not always equate to "uncrewed." As shown in Figure 2, shrinking ship crew sizes are nothing new and, although technological progress may make it possible to reduce the number of persons on board to zero, it is not realistic that oceangoing vessels will go uncrewed overnight. Views differ on the future labor force with AVs, although more data are required to fully appreciate the gaps and perceived benefits. As a consequence, the World Maritime University has been developing workforce data in its publication *Transport 2040: Automation Technology Employment—The Future of Work* (*4*).

Proponents prioritize the benefits of AVs, suggesting this will sharpen high-tech service competencies and support the talent equation transformation and continuous learning. Some suggest that AVs are creating new skill sets, although acquiring those skills may require nonlinear approaches. The advent of remote operations keeps humans in the loop and purports to

Image: Crowley Engineering Services

Crowley's electric tugboat requires no exhaust stack, provides a 360-degree view from the pilot's stations, produces zero emissions, and has been designed for future autonomous operation, including integrated automation and control systems. The intelligent maneuvering and control system offers more efficient vessel operations and allows masters to focus on the overall control and position of the vessel.

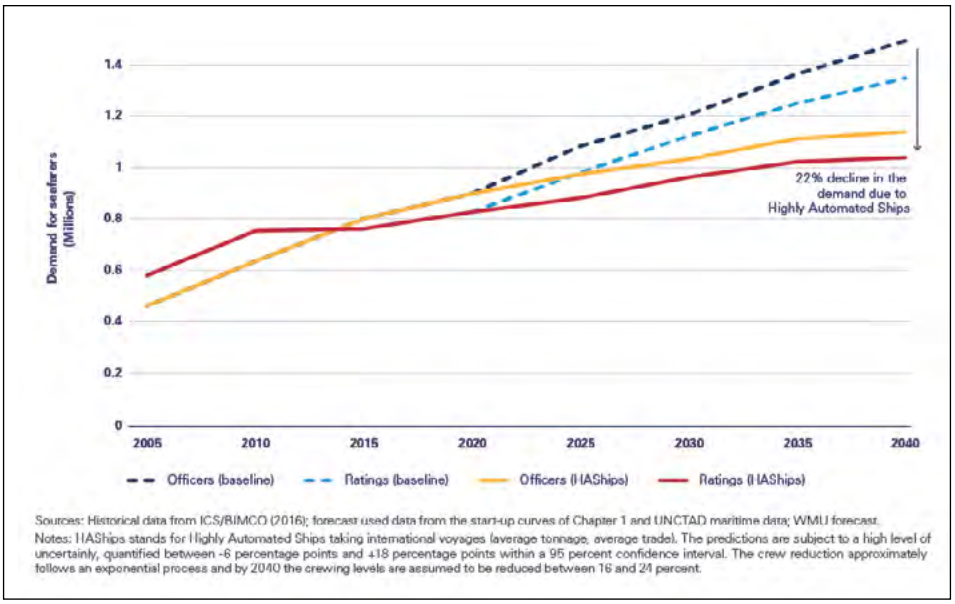


FIGURE 2 **Reduction of crew size on highly automated ships over the next couple of decades (*4*).**

cater to those who want a maritime career but not to be away from home, concepts already being developed by European companies Massterly and SEAFAR.

Wärtsilä is seeking markets for combining smart technology with support from the labor side through projects like EU SkillSea, which aims to ensure that Europe's maritime professionals possess future skills needed to adapt to a rapidly changing maritime labor market. AVs could also create new opportunities for naval architects and shipyards to design and build novel vessels. In order to develop a futureproof workforce, industry will still require competencies, licenses, and a viable support network.

Highly automated vessels present challenges to maritime education and training. Academia will be integral to the successful integration of new technology, and new programs are being developed at some maritime schools. New curricula and training will need to fit within the global training and education regime currently in place. Also, this will require a new class of academics and trainers who are capable of training the future marine workforce. Overall, new positions will need to leverage effective oversight of third parties and build capacities and partnerships.

Photo: Massterly

Highly skilled operators will take the helm at the Massterly Remote Operations Centre in Lysaker, Norway. The remote-control system can be used to monitor a crewed vessel, or—for uncrewed journeys—plan cargo and voyages, maneuver through dynamic positioning, go to safe harbor, and drop anchor.

Conclusion

The United States has fallen behind in maritime innovation. Global trade technology and innovation are moving quickly, and disruptive technologies create an opportunity for the United States to take a position as global leader by pioneering new approaches through collaboration.

In some respects, the United States is at a pivot point. America can seize the moment as markets are developing and stimulate a more sustainable U.S. maritime industry—albeit with a more complicated public acceptance process—or continue down a path of lagging behind the European lead. Northern Europe seems to have dispelled the view that this innovation is mere hype. To the maritime industry there, it is reality. Emerging business cases will evaluate legal compliance and the return on investment but, in the interim, industry should think outside traditional approaches to solutions. These inflection points now can build emerging technology into sustainable solutions while being active in shaping the compliance framework.

REFERENCES

1. *Safety and Shipping Review 2020*. Allianz Global Corporate & Specialty, 2020. https://www.agcs.allianz.com/news-and-insights/reports/shipping-safety.html. Accessed March 29, 2021.
2. Huntly-Playle, I., H. Bußhoff, and H. Quraish. *The Future of Smart Autonomy Is Here*. Wärtsilä, 2021. https://www.wartsila.com/insights/whitepaper/the-future-of-smart-autonomy-is-here. Accessed March 29, 2021.
3. *Special Report 335: Leveraging Unmanned Systems for Coast Guard Missions: A Strategic Imperative*. Transportation Research Board, Washington, D.C., 2020. https://doi.org/10.17226/25987. Accessed March 29, 2021.
4. *Transport 2040: Automation, Technology, Employment—The Future of Work*. World Maritime University, Malmö, Sweden, 2019. http://dx.doi.org/10.21677/itf.20190104. Accessed March 29, 2021.

Automation in Container Port Systems and Management

Photo: Jean-Paul Rodrigue

JEAN-PAUL RODRIGUE AND THEO NOTTEBOOM

Rodrigue is a professor in the Department of Global Studies and Geography at Hofstra University in New York. Notteboom is a professor in the Maritime Institute at Ghent University and at Antwerp Maritime Academy at the University of Antwerp in Belgium.

Above: Trucks line up for loading under an automated stacking crane at Long Beach Container Terminal in California. Containers are automatically retrieved from the stacking pile and loaded onto the chassis while the driver waits in the protected truck cabin.

Terminal automation is a full or partial substitution of terminal operations through automated equipment and processes. Depending on how automation is defined, it is already present in many terminals, at least in its simplest form using information technologies (ITs) to manage terminal assets and supplement human activity.

Automation processes often result in two major types of automated terminals. A fully automated terminal uses a computer–IT-led system to handle a container from dockside to the pickup area through remotely operated ship-to-shore cranes, automated stacking cranes in the yard, and automated horizontal transfer vehicles. By contrast, a semiautomated terminal involves just the automated stacking of equipment in the yard.

The number of fully or semiautomated terminals remains relatively small compared with the scale of the global container terminal business (Figure 1). Although the information is likely to be partial and incomplete, 55 container terminals worldwide were either fully or partially automated as of late 2020, and eight were in the planning stage. Considering that there are about 750 container terminals, this represents 7.3 percent of all main container terminals but 12.2 percent of the total global footprint in terms of hectares. Although the average container terminal size was 51.7 hectares, it was 85.5 hectares for fully automated terminals and 69.9 hectares for semiautomated terminals, underlining the scale propensity for automation.

Though terminal automation has not yet become mainstream, it is more likely to occur in three main contexts. The first is when an existing terminal facility has a footprint that is difficult to expand, often due to the lack of land and spatial planning regulations. Automation becomes a strategy to increase throughput, cope with escalating operating costs, and remain competitive while keeping a similar terminal footprint. The second context is when a terminal acts as a major transshipment hub, a facility mainly handling

Photo: Theo Notteboom

Moving parts capture the curiosity of onlookers at the Deurganckdok complex, located at the Port of Antwerp in Belgium. Opened in 2005, the complex represents a massive undertaking to expand terminal capacity. The Antwerp Gateway Terminal (*at right*)—operated by Dubai Ports World—is semiautomated.

ship-to-ship traffic that is typically operated by a carrier-owned terminal operator. Automation becomes a strategy to allow for the fast turnaround times expected in a transshipment hub, particularly in view of larger ships expecting similar turnaround times. The third context is when a new terminal facility is developed. Automation becomes a strategy to attract customers in a competitive environment, while reducing the necessity to train a port terminal workforce.

Leveraging Automation Technologies

Automation can be achieved in any or all of the four main functional areas of a container terminal:

- *Vessel to quay* (*ship-to-shore movement*): The use of remotely operated ship-to-shore cranes, such as in China's YSH4 Terminal near Shanghai and at Qingdao New Qianwan Container Terminal.
- *Quay to stack* (*horizontal transfer system*): Automation in this area includes the use of uncrewed automated terminal tractors, automated guided vehicles (AGVs), or runners (low-straddle carriers). In 1993, the ECT Delta SeaLand Terminal in Rotterdam, Netherlands, became the first terminal in the world to use AGVs. In the meantime, quite a few terminals use automated horizontal transfer systems. The latest generation of AGVs is guided by GPS technology and is battery powered (instead of diesel–hydraulic powered), resulting in zero carbon dioxide emissions and in noise reduction. Some terminals, such as APM Terminals in Rotterdam, are using lift AGVs that can lift and stack a container.
- *Yard-stacking system*: Automated stacking cranes (ASCs) are automated rail-mounted gantry cranes used for stacking operations. In some cases, such as at the Alterwerder Terminal in Hamburg, Germany, two ASCs with different dimensions (allowing one to pass under the other) work together on the same stack. Less common are automated straddle carriers (AutoStrad), uncrewed straddle carriers used for quay-to-stack operations and stack-to-truck loading operations. Examples include Brisbane AutoStrad

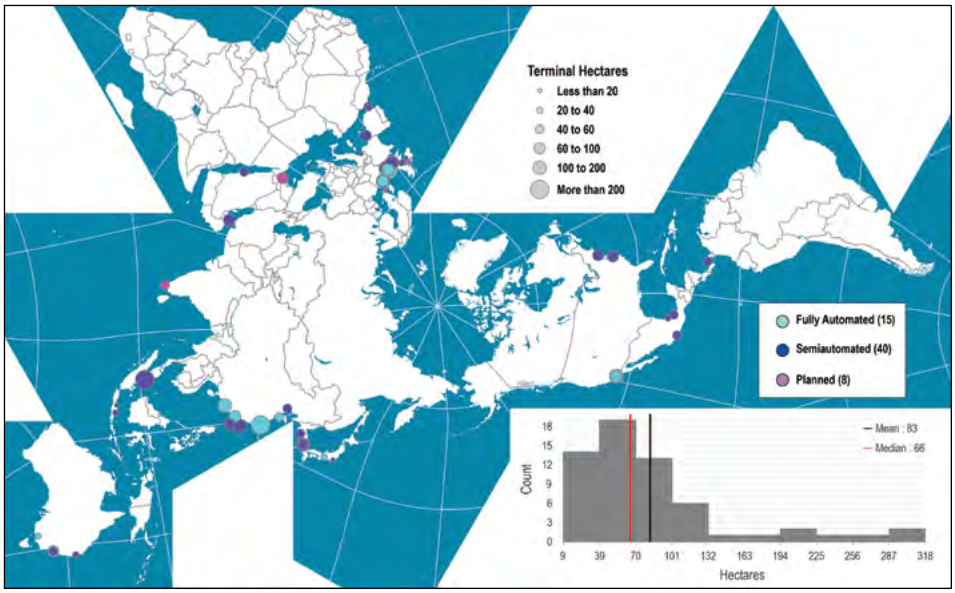


FIGURE 1 Map of fully automated, semiautomated, and planned terminals worldwide.

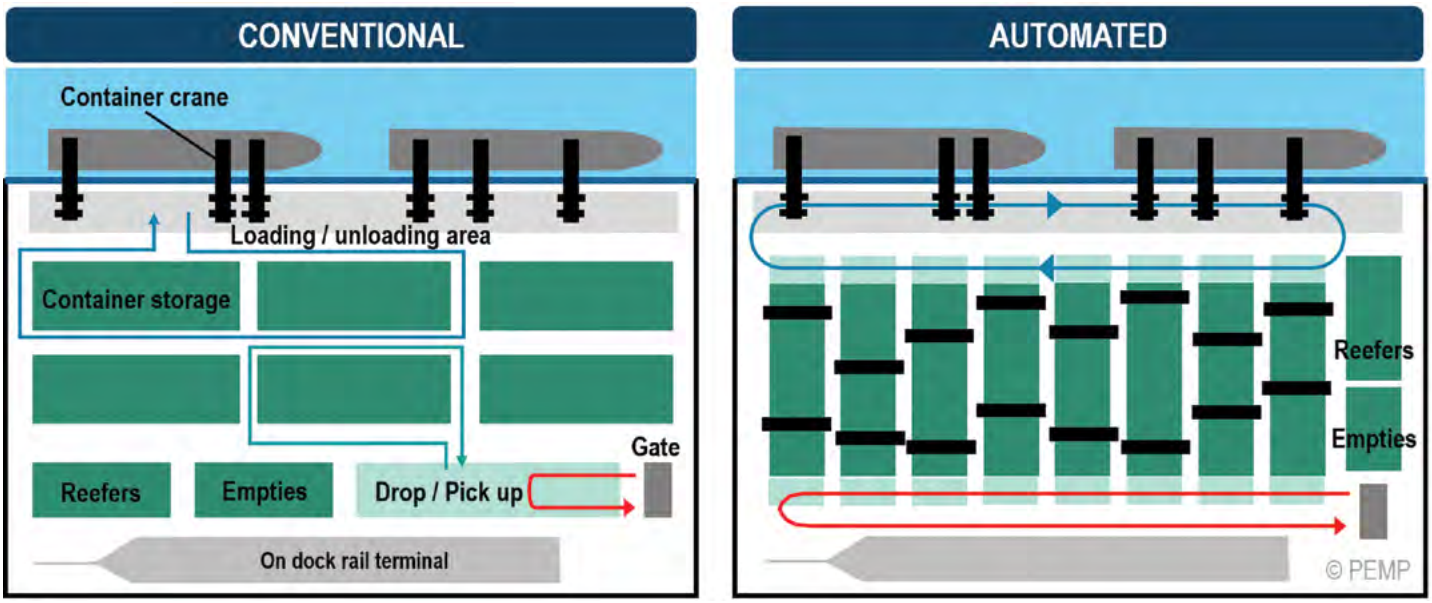


FIGURE 2 Conventional versus automated container terminals (*1*).

Terminal and Sydney AutoStrad Terminal, both operated by Patrick Terminals in Australia. Among the latest innovations are the vertical storage yards or high-bay storage systems such as BOXBAY, developed by a joint venture of DP World and the SMS Group.

- *In–out gate function:* Automation in this area primarily concerns automated truck gates.

A common automated container terminal configuration relies on block layouts perpendicular to the piers, thereby reducing horizontal ground movements (Figure 2). These stacking blocks are serviced by ASCs, allowing for quick storage and retrieval. On the gate side, stacks are serviced by trucks that have their containers picked up by an ASC. On the pier side, containers are retrieved by straddle carriers or AGVs and brought to the end of a stack.

The six automated or semiautomated terminals in the United States primarily rely on ASC technology for yard operations (Figure 3). In 2007, APM Terminals inaugurated the first semiautomated yard in Norfolk, Virginia, relying on ASC technology. TraPac Terminal, inaugurated in 2012 at the Port of Los Angeles, was the first automated terminal on the West Coast. It relies on a combination of AutoStrads to carry containers between the apron and ASCs for yard management. Long Beach Container Terminal, automated in 2016, also relies on ASC but on AGV for movements between the yard and the apron. AutoStrads are an emerging automation technology for terminals on the West Coast, as—in addition to TraPac—APM Terminals Pier 400 in Los Angeles is in the process of automating with AutoStrads.

The decision to automate usually is the outcome of a complex interplay between multiple motivations, such as the following:

- *Increase operational efficiency*. There is an increased interest in terminal automation to improve quayside and land productivity in view of dealing

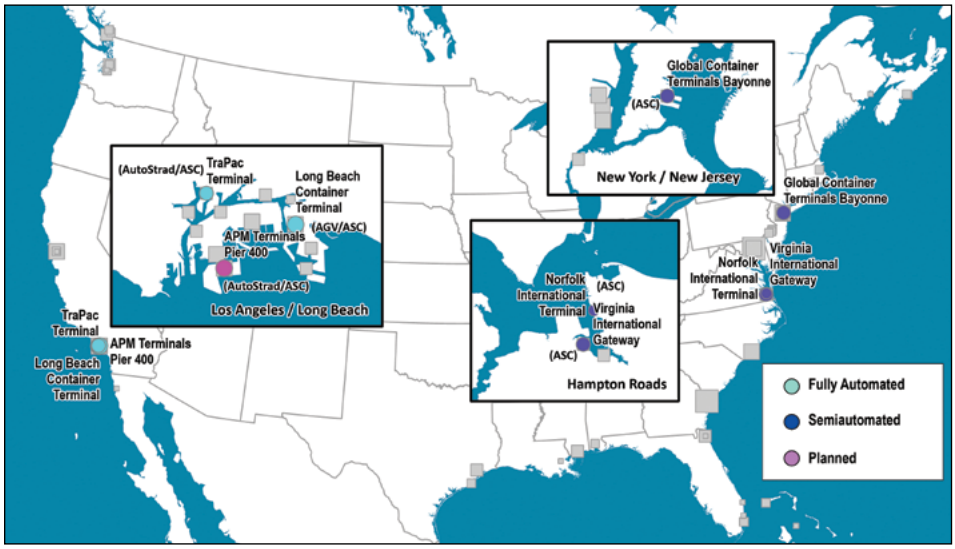


FIGURE 3 Map of fully automated, semiautomated, and planned terminals in the United States.

Photo: Theo Notteboom

A large container ship docks at the Port of Algeciras, Spain. Located in the province of Cádiz within the autonomous community—or region—of Andalusia, the port is one of the largest commercial terminals in the Mediterranean. For more than two decades, economies of scale—the idea that larger ships and ports result in cost savings—have been prevalent in maritime shipping and prompted the move toward terminal automation.

with the scale increases in container vessel size and increased container volumes. Although automation might present much better terminal productivity figures than manual terminals, in other cases, traditional terminals still outperform automated terminals in net crane productivity. The real operational efficiency gains of automation do not lie in the field of faster handling. They are more about achieving stability, predictability, and consistency of operational performance, which reduces downtime that is due to external factors (e.g., weather conditions) and allows continuous operations. Such operational conditions are easier to achieve when the cargo demand at the given terminal is consistent throughout the year and only standardized boxes are used (thus, no open-top containers or oversized cargo units). When no ship is berthed at the terminal, the equipment can be used for other activities, such as reshuffling and restacking containers or loading and discharging inland transport modes.

- *Lower the unit cost of container handling*. Automation is often aimed at reducing generalized costs of terminal operations per unit handled. A study by McKinsey & Company concluded that automation could cut operating expenses by 25 percent to 55 percent while raising productivity by 10 percent to 35 percent (*2*). According to a survey by Navis, a leading company in terminal operating systems, most terminal operators expect productivity increases between 25 percent and 50 percent when opting for automation (*3*). However, not all automation projects realize savings in overall costs. If a high degree of repetition and predictability and low volatility in cargo volumes cannot be achieved, the cargo handling cost per unit increases above conventional container terminals.
- *Shift from labor to capital costs*. Automation shifts the cost structure toward capital costs, reducing labor costs and the uncertainty that manual labor can bring. Risks such as strikes, labor regulations concerning work hours and overtime, and the availability of longshore workers are common. An uncrewed terminal also avoids idle time caused by breaks and shift changes.
- *Improve land productivity*. Commonly used semiautomation configurations result in denser yard stacking. Terminals facing severe land availability issues thus show a higher willingness to consider automation.
- *Improve safety, security, and environmental sustainability*. Automation can help improve safety, security, and environmental sustainability as well as reduce land use, particularly if automation results in increased quayside and yard density and productivity. Investments in automation often go hand in hand with full integration with security systems. Improving the safety and security profile of a terminal has positive financial effects, such as lower insurance premiums. Automation also offers possibilities to reduce the environmental footprint of the terminal by reducing energy consumption. Energy savings are typically achieved by optimizing container moves and horizontal transfers, thereby reducing crane time per unit handled and distance covered or by transitioning to electric or hybrid power sources.
- *Showcase technological innovation*. Several terminal automation projects have been realized in countries or regions that wanted to demonstrate their technological know-how. For example, the pioneering Delta SeaLand Terminal in Rotterdam was developed in cooperation with the nearby Delft University of Technology, a leading technical and engineering university. YSH4 Terminal complex in Shanghai can be viewed as a demonstration project by Shanghai International Port Group and Shanghai-based leading equipment manufacturer ZPMC. Such technological showcases are real-life testbeds and learning opportunities for developing next-generation automation solutions.

The core driver for terminal automation in North America is growing vessel sizes

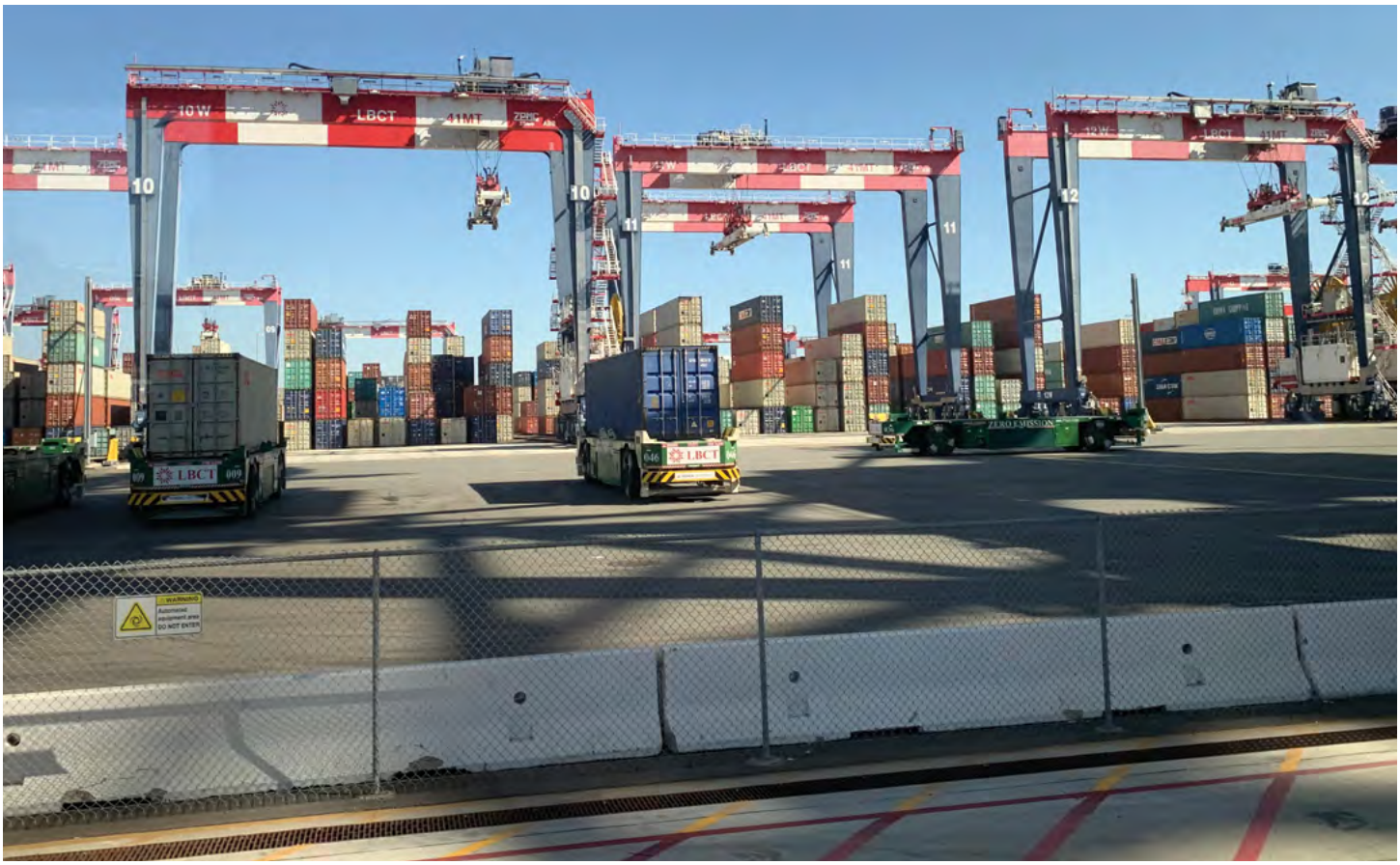


Photo: Jean-Paul Rodrigue

One of only two fully automated terminals in North America, Long Beach Container Terminal also uses AGVs to provide lateral container moves between dockside and the container yard.

and the associated port call volumes. This points to the ports of Los Angeles (e.g., TraPac, of which only a portion of the terminal yard is automated) and Long Beach Container Terminal, which are the only two fully automated terminals in North America. The fact that West Coast terminals tend to be operated by the terminal operating branches of ocean carriers implies that the containers handled come from a few shipping lines within the same alliance. This also implies simpler yard sorting operations, as large blocs of containers can belong to the same cargo owner. Therefore, full automation is less complex to implement. East Coast terminals tend to be called on by numerous ocean carriers, resulting in more complex yard sorting operations that are not as well-suited to the use of AGV or AutoStrad. Complex yard sorting operations thus lend themselves to semiautomated terminals as the preferred design. Environmental regulations, which are more stringent on the West Coast, are also a key driver for the automation of horizontal movements. Converting to AGV and even retrofitting diesel straddle carriers to electric-powered AutoStrads allows for potentially reaping the benefits of automation while lowering emissions.

Terminal Automation in Practice

Despite the previously mentioned economic, technical, environmental, and energy-related factors that drive automation, several terminal operators are reluctant to automate, adopting a wait-and-see approach. In some cases, terminal automation plans were canceled or delayed. The main reasons for such behavior are high irreversible investment costs of automation, unavailable skills and resources, governance issues, and implementation time.

AUTOMATION POSES A COST–BENEFIT RISK

Automation requires high upfront capital investments in rather new technologies and involves large, customized terminal capacities that lack flexibility. Once fixed, the layout is difficult to change. Automated terminals carry greater risks and are harder to implement compared with traditional container terminals, which have been tested and improved over many decades (see sidebar, page 26).

Automation requires full synchronization and integration of hardware and software in all aspects of terminal operations. Purchasing automation components and equipment from different suppliers can result in expensive and lengthy integration processes and cost overruns.

Furthermore, the implementation period for an automated terminal is typically longer than for conventional terminals. Terminal operators must invest large sums of money for longer time periods before any return on investment can be achieved. The long implementation time is caused by a prolonged terminal construction period and an extended test period. Upgrading a fully operational terminal to an automated facility can be quite painstaking, as the operator must temporarily give up some terminal capacity and will be faced with running two systems (automated and non-automated) concurrently in the transition period. Automation costs are being driven down as more knowledge and expertise become available, which reduces risks and increases benefits.

CASE-SPECIFIC SUITABILITY

Next to the factors discussed in the previous section, automation projects also need to consider the demand characteristics for container handling, including volatility of cargo volumes, mix of import–export and transshipment containers, and mix of vessel sizes. The governance and user profile of the terminal and the availability of funding also are at play. Combining these factors might promote automation in one location but undermine any automation project in another.

RISK OF DISTURBING LABOR RELATIONS

Automation can generate disruptions in existing labor relations and working practices. Automation typically demands a specialized and multiskilled workforce that requires an adaptation process for existing port labor systems. Terminal operators who opt for automation may find themselves in the middle of a war for talent with firms from other industries when attracting people with a strong technical, IT, or engineering background.

In some cases, local regulation and labor union governance practices complicate the automation path to such an extent that a risk-averse terminal operator instead opts for the status quo. For example, International Longshoremen's Association labor contracts on the U.S. East Coast prohibit full automation.

RISK OF NOT ACHIEVING LABOR COST SAVINGS

The willingness of terminal operating companies to invest in automation is partly related to the perceived cost savings at the dock labor level. If automation allows reducing dock labor (or, in the case of full automation, even eliminating it), then the terminal operator will only benefit from the labor cost savings if staff are indeed reduced in size. If such a reduction in labor is not possible within the contours of the dock labor employment system, then the stevedoring company will be far less eager to introduce technological innovations.

The trade-offs when introducing new automated cargo-handling technology surfaced in a dispute between labor unions and terminal operator APM Terminals in the Port of Rotterdam. Opened in 2015, their newest terminal features remotely controlled ship-to-shore cranes. The company believed automation can take out much of the human disruption on reliable terminal productivity linked to the handling of ever larger container vessels. However, the new terminal development faced strong opposition from labor unions, who feared a possible loss of jobs and lower wages, given the shift from traditional crane drivers to remote operators of automated cranes.

Evolution or Revolution?

Container terminal automation in the U.S. port system has mainly occurred in large-scale import terminals, usually by carrier-owned terminal operators. Decisions to automate have been supported by the availability of capital investments (including support of public entities) and expected productivity improvements. In this context, automation is an evolution to catch up with the increase in vessel and call sizes, as well as spatial and environmental constraints faced by U.S. ports. The latter are compressing terminal operations and placing pressures on the terminal footprint.

Compared with other regions in the world, terminal developments in the United States are relying more on retrofitting existing facilities instead of on new, large-scale, greenfield projects, developed on land that is reclaimed from the sea or rivers or that was formerly an agricultural or natural setting. This observation, in combination with the absence of a transshipment market and the realities of the U.S. dock labor systems, make the large-scale adoption of automated terminals less likely than in other regions, particularly in developing countries.

Further growth in the scale of import–export cargo flows is likely to extend the automation evolution to landside operations through the automation of intermodal transport systems and a further synchronization and integration with transport chains down to the last mile (e.g., city logistics). For this to happen, automation will need to benefit from further standardization, which has been an ongoing process since containerization began. Automation will need to further encourage distribution systems to implement technological solutions that can eventually lead to fully or partially automated supply chains.

REFERENCES

1. Notteboom, T., A. Pallis, and J.-P. Rodrigue. *Port Economics, Management and Policy*. Routledge, New York, 2021.
2. Chu, F., S. Gailus, L. Liu, and L. Ni. The Future of Automated Ports. McKinsey & Company, 2018. https://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/the-future-of-automated-ports#.
3. Port Technology International. Navis Survey: Terminal Automation Critical to Survival. 2018. https://tinyurl.com/3a6pe2a6.

SUGGESTED READINGS

Davidson, N. Retrofit Terminal Automation Measuring the Market. *Port Technology International*, 2018, Vol. 77, pp.1–3.

Moody's Investor Service. Automated Terminals Offer Competitive Advantages, But Implementation Challenges May Limit Penetration. June 24, 2019.

Martín-Soberón, A. M., A. Monfort, R. Sapiña, N. Monterde, and D. Calduch. Automation in Port Container Terminals. *Procedia Social and Behavioral Sciences*, 2014, Vol. 160, pp.195–204.

Yang, Y. C., and K. Y. Shen. Comparison of the Operating Performance of Automated and Traditional Container Terminals. *International Journal of Logistics Research and Applications*, 2013, Vol. 16, No. 2, pp.158–173.

Capital Intensiveness Risks of Automation

JEAN-PAUL RODRIGUE AND THEO NOTTEBOOM

Rodrigue is a professor in the Department of Global Studies and Geography at Hofstra University in New York. Notteboom is a professor in the Maritime Institute at Ghent University and at Antwerp Maritime Academy at the University of Antwerp in Belgium.

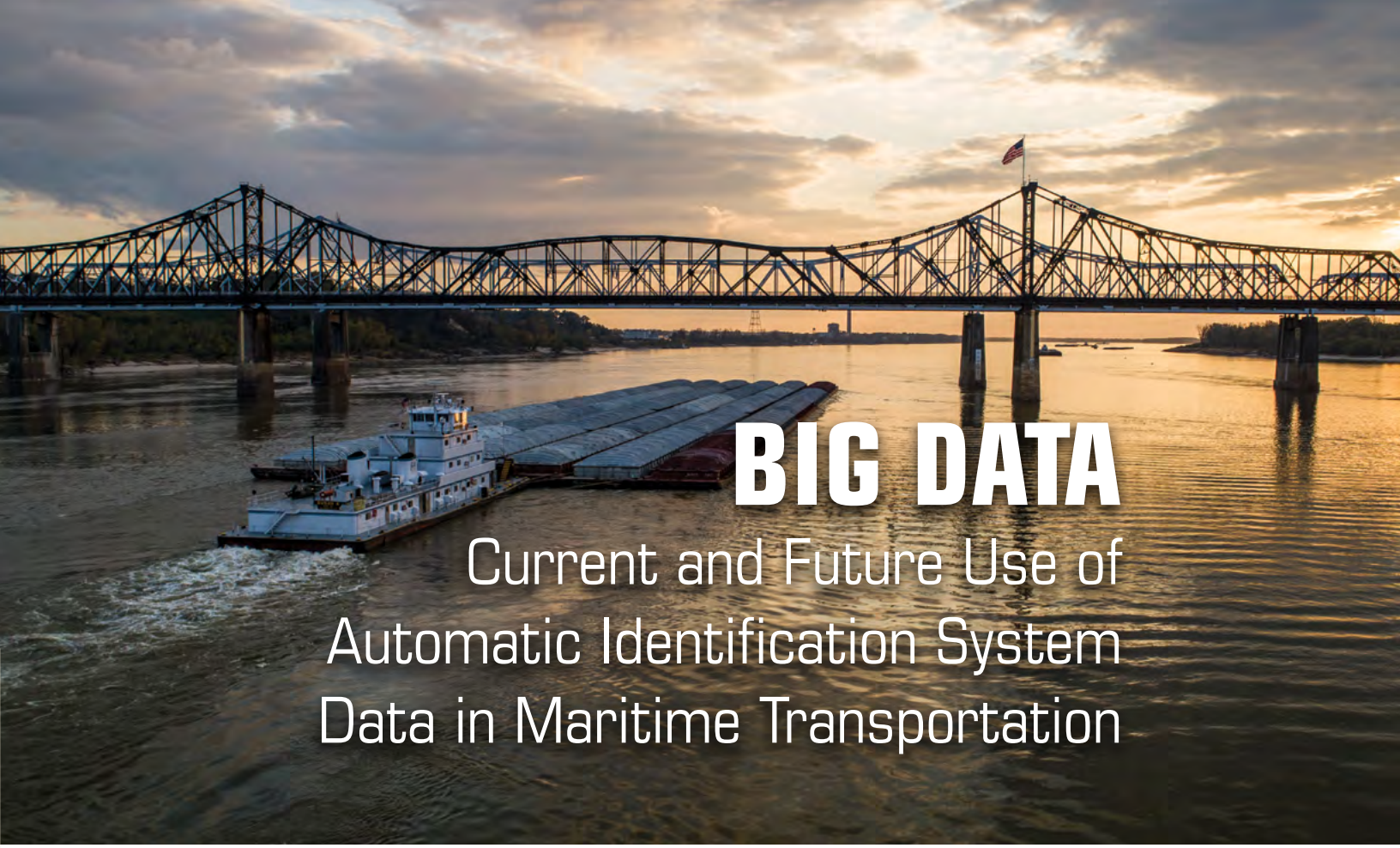
Virginia International Gateway in Portsmouth was opened in 2007 and operated by APM Terminals as a semiautomated terminal. The privately owned terminal required capital investments of $500 million. However, just three years later, APM Terminals leased the facility to the Virginia Port Authority, which took control of operations. The onset of the financial crisis of 2008–2009 spurred APM Terminals to divest from an entirely new facility, despite the apparent benefits of automation.

In 2014, Alinda Capital (a financial company) acquired the terminal for an undisclosed amount in an agreement in which Virginia Port Authority remained the operator. The terminal undertook a second wave of automation that was completed in 2019, doubling its capacity to 1.2 million TEUs, or 20-foot equivalent units, at the cost of $312 million.

On the West Coast, the automation of Long Beach Container Terminal cost around $1.4 billion in capital investments with an associated capacity of 3.3 million TEUs. TraPac, the other fully automated terminal, has an annual capacity of 2 million TEUs. With an apparent automation threshold of about 1.5 million TEUs per terminal, few container terminals in the United States are in a position to upgrade and derive clear financial benefits. Outside of very large terminal facilities with stable volumes, capital intensiveness remains a high risk. As automation technology matures, a higher number of terminals may become suitable. But this could take several years.

Photo: National Renewable Energy Lab, Flickr

Vessels like the OOCL *Luxembourg* are loaded and unloaded with shore power at the Long Beach Container Terminal in California. Fully automated in 2010, the port features electrified handling equipment, electric stacking cranes, solar panels, and LEED-certified buildings.



BIG DATA

Current and Future Use of Automatic Identification System Data in Maritime Transportation

Photo: Justin Wilkens

BRIAN TETREAULT AND NED MITCHELL

Tetreault is a navigation systems specialist based in Baltimore, Maryland, and Mitchell is a research civil engineer based in Vicksburg, Mississippi. Both are with the Coastal and Hydraulics Laboratory, U.S. Army Engineer Research and Development Center.

Above: The pushboat M/V *Susan K* moves a load of barges down the Mississippi River in Louisiana. In recent years, AIS technology has entered widespread use. AIS technology facilitates real-time, automatic communication of navigation and voyage information and, when integrated with the capabilities of big data, offers many possibilities for vessel and waterway operation, management, and analysis.

Every transportation mode requires a way to monitor its system components, as well as the ways users interact with each other and with the system itself. For centuries, monitoring maritime transport was particularly difficult because of long offshore distances traveled and the remote, often harsh, maritime environment.

Over the past two decades, automatic identification system (AIS) technology has been developed and now is used widely. AIS facilitates the automatic communication of navigation information to and from vessels in real time and allows vessels to communicate their position, identification, and other voyage-related information to other vessels and shore-based authorities.

This article offers background on the AIS technology, explores how it can be used in support of maritime and intermodal transportation operations, and projects how the use of AIS may evolve.

AIS Technology

AIS is a maritime digital communications system that operates in the very high frequency (VHF) radio spectrum (*1*). AIS equipment aboard a vessel receives input from ship navigation sensors—GPS, speed logs, and heading sensors—and transmits the vessel's position, course, and speed every two to 10 seconds, depending on the vessel's speed and rate of turn. Vessel identification, characteristics, and other information also are transmitted every five to six minutes.

Other vessels can receive these transmissions and display them on shipboard navigation systems for situational awareness and collision avoidance. AIS transmissions are self-organized so that many vessels can use the same frequency without interfering with each other. The AIS transceivers autonomously determine when to transmit to avoid interfering with transmissions from other stations, working in a "cell" made up of nearby transceivers.

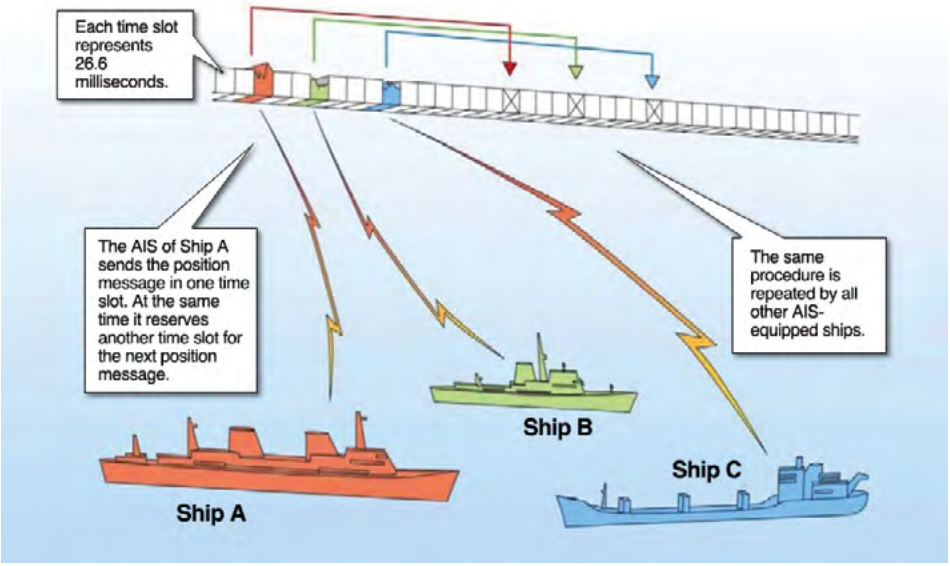


Image: IALA-AISM

AIS stations communicate using a time-division multiple access, or TDMA, communications scheme in which the data link used is divided into equal time slots that hold a set amount of data and are synchronized using GPS time.

The transmissions from vessels can also be received by shore-based AIS stations and by AIS receivers on satellites. Once the transmissions are received by shore or satellite stations, they can be displayed on tactical systems, and the data is stored in a database for future retrieval and analysis.

In the United States, the U.S. Coast Guard (USCG), U.S. Army Corps of Engineers (USACE), and Great Lakes–St. Lawrence Seaway operate shore-based AIS transceiver networks. The data they collect are stored in a database hosted by USCG and can be accessed by other government agencies and researchers (*2*). Commercial providers of AIS data also operate their own AIS networks, satellite receivers, or both; they also provide AIS data and analysis for purchase.

Because the VHF radio spectrum generally allows line-of-sight communications, AIS transmissions may be blocked by terrain, buildings, and the natural curvature of the Earth. In general, a higher receiver antenna will provide greater coverage, but when AIS is received from high altitudes—such as from an aircraft or satellite—transmissions from multiple cells also are received, resulting in interference between transmissions. This is particularly a problem in areas with large concentrations of vessels, such as the Gulf of Mexico, Southeast Asia, or the Dover Strait.

In general, commercial vessels of more than 20 meters in length are required to carry and operate AIS. Other vessels may voluntarily carry AIS, but not all do, particularly smaller or private (recreational) vessels (*3*). Some vessels may turn off their AIS transceivers for legitimate purposes—such as to avoid detection by pirates—or may turn off AIS deceptively or provide incorrect information to conceal illegal activities. Problems related to the physical installation of AIS equipment on vessels include loose antenna cable connections or parts of the vessel blocking AIS transmissions, resulting in reduced ability to track these vessels.

Shore-based and other transceivers also may transmit such information as navigation safety reports, like notices to mariners of uncharted waterway hazards; the locations of buoys and other aids to navigation (AtoN); and meteorological and hydrological observations like wind speed and direction and water levels.

In addition to their use for real-time situational awareness and vessel tracking, AIS data can be collected and used in conjunction with other information to provide in-depth analysis of waterway operations and performance.

Supporting Navigation Operations

The use of AIS in support of maritime transportation (navigation) operations can be characterized in three ways:

- **Tactical Navigation.** This is what AIS was originally developed for and includes use by individual vessels for situational awareness and collision avoidance and by shore authorities like USCG for monitoring the locations of vessels in real time for safety, security, and law enforcement (*4–5*). Operation of waterway infrastructure also is facilitated by the ability of lock and bridge operators to "see" a vessel approaching from many miles away and determine its estimated arrival time. AIS also is used to measure lock performance and has automated the collection of lock usage statistics, which previously had to be done manually.
- **Operational Navigation.** This includes the use of AIS capabilities to support fleet voyage planning by shipping companies, adaptive waterway management by waterway authorities on real-time vessel information (e.g., the implementation of one-way traffic areas), waterway infrastructure operations (e.g., the operation of locks or drawbridges), and incident response.
- **Strategic Navigation.** This includes the use of historical AIS data for use in waterways infrastructure planning, regulatory development, operations and maintenance, incident investigation, port performance monitoring, and freight system tracking (*6*). AIS can be used for "hot spot"–type analyses to identify choke points in the navigation channel and to gauge relative performance or delays across portfolios of navigation channels (*7*).

AIS can support regulatory actions tactically, operationally, or strategically. Flag states can monitor the locations and operations of vessels carrying their flag to ensure regulatory compliance and the vessel's security. Port states can use AIS data from

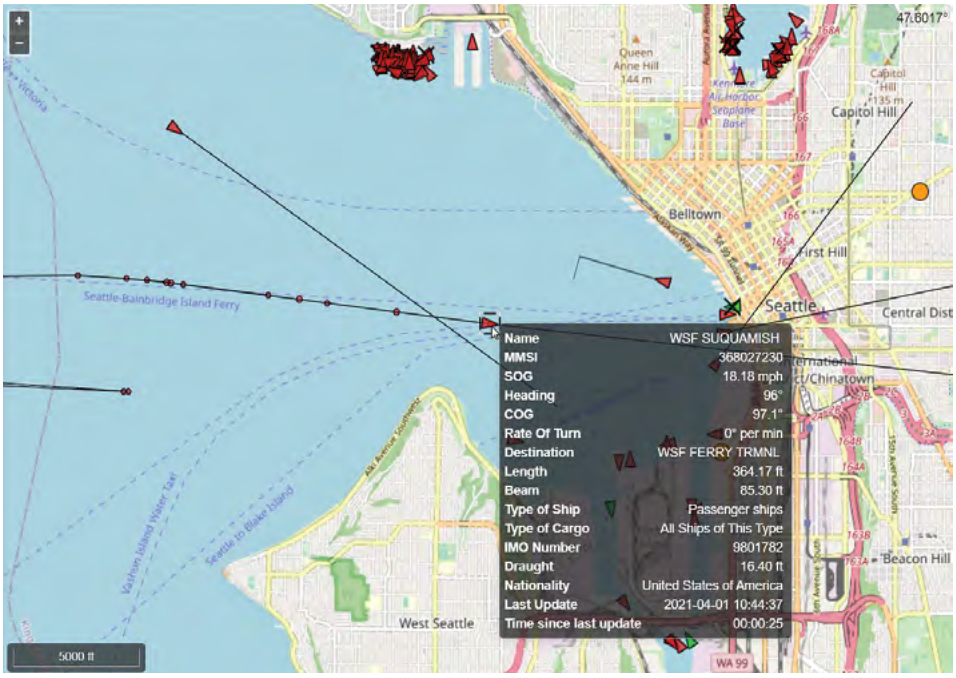


Image courtesy Brian Tetreault and Ned Mitchell

Developed by the U.S. Army Engineer Research and Development Center, the Lock Operations Management Application uses AIS technology to provide real-time information about inland waterways and port activity, helping lock and vessel operators access better information as they make crucial decisions.

Improving Strategic Waterways Management

Historical AIS data provide a rich digital record of vessel traffic utilization patterns within maintained ports and waterways. The research literature from recent years contains many examples where AIS data are used to characterize and to quantify baseline conditions, marine traffic densities, and associated temporal trends.

Within the United States, USACE has investigated ways to inform waterway management decisions within federally authorized projects, particularly in relation to the regular maintenance dredging required to remove accumulated sediment and ensure that navigation channel depths are sufficient to accommodate the sailing drafts of prevailing marine traffic. Historical AIS data have been used to estimate the wave energy generated by passing ships arriving vessels to verify required vessel reporting, such as notices of arrivals, movement of dangerous goods, and collection of taxes and fees. The data also can be used to ensure compliance with environmental regulations (e.g., International Maritime Organization [IMO]–mandated traffic routing measures and protection of IMO-identified Particularly Sensitive Sea Areas). In the United States, the National Oceanic and Atmospheric Administration has used AIS data to monitor vessel speed reductions aimed at protecting endangered right whales, and the U.S. Environmental Protection Agency has used AIS data to monitor and calculate the emissions of vessels traveling near the U.S. coastline (*8*).

Historical AIS data can be used for the strategic implementation or modification of regulations. An example of this is the permitting and placement of offshore energy installations like wind farms. By analyzing historical vessel traffic through an area in which such an installation is being considered, regulatory agencies can use modeling to determine the impact on navigation, develop mitigation or safety measures, and assess different scenarios of installation layout and regulatory actions.

Photo: Larry Koester, Flickr

By allowing flag states to monitor vessel locations, AIS can help ensure compliance with environmental regulations (e.g., controlling maritime activities to protect IMO-designated Particularly Sensitive Sea Areas like Australia's Great Barrier Reef).

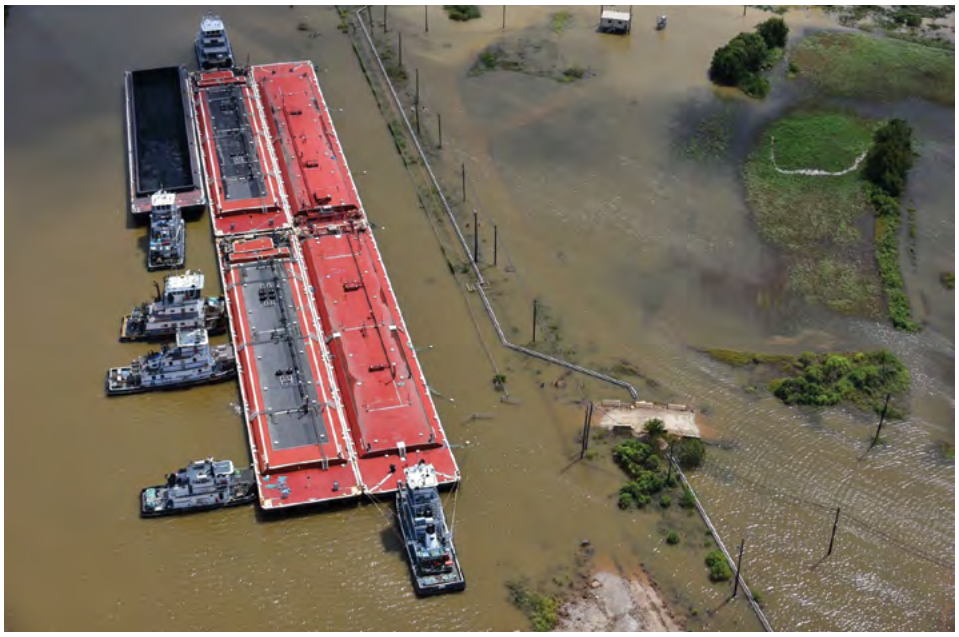


Photo: Patrick Kelley, USCG

After Hurricane Harvey in 2017, USCG aircrews conducted port assessments in the Texas cities of Houston, Texas City, Freeport, and Galveston. Ports can use AIS data to assess disruptions to operations from extreme weather events.

and the potential to exacerbate shoreline erosion issues.

For tracking navigation channel conditions, USACE maintains a similarly data-rich repository of hydrographic surveys known as eHydro that—when combined with historical AIS records of transiting vessel drafts, dimensions, and trip counts—provides a robust, objective framework for evaluating dredging needs in terms of observed underkeel clearances (*9*). The AIS records also enable analysis of vessel traffic patterns before and after dredge events, thereby improving the understanding of and ability to quantify the benefits of regular waterway maintenance dredging to vessel operators. From a tactical perspective, AIS also provides a real-time capability to improve the efficiency and safety of dredging operations by showing the locations of approaching ships.

The research literature also contains many examples of historical AIS data informing port resiliency questions on several spatial and temporal scales. Of particular note, AIS data have been used to quantify and compare the severity and duration of hurricane-induced disruptions to port operations, offering valuable insights into best practices for improving port system resiliency (*10–11*).

The National Weather Service uses AIS data to evaluate the response of vessels to the weather warnings they provide, especially storm and hurricane warnings. By observing which vessels maneuver to avoid heavy weather, they can evaluate the timeliness and effectiveness of the warnings and make modifications to future weather forecast products, making sure to reach potentially affected vessels in time for them to make safe navigation decisions.

Communicating Navigation Safety Information

Shore-based AIS stations can transmit information to augment physical AtoN, such as buoys and lights, and the information available on nautical charts. AIS AtoNs can be transmitted quickly to mark changed waterways conditions or navigation hazards. AIS also can be used to transmit weather or hydrological observations, real-time infrastructure status (e.g., a lock queue or whether a drawbridge is open or closed), and safety zones that can be displayed on a vessel's electronic charting system (*12*).

In combination with appropriate onboard sounding equipment and accurate vessel dimension and sailing draft values, AIS can communicate critical channel depth and width information to waterway users. Such information is particularly valuable in high-density, shoaling-prone waterways where aggressive sedimentation patterns can quickly alter navigable conditions.

This also provides an unprecedented spatial data set of navigation channel conditions through time, creating a robust capability for directing limited waterway maintenance funds to areas with the greatest need.

New and Innovative Uses of AIS

In addition to directly supporting vessel navigation, AIS also is used in innovative ways to support maritime transportation. One such use is crowd-sourcing. Because AIS is installed aboard thousands of vessels around the world—often in locations where other sensors are not available—it can be used as an ad hoc means of communicating many small pieces of information.

One such effort uses automatic weather sensors aboard commercial vessels to collect weather observations (*13*). These observations can be converted into messages that are transmitted by the ship's AIS equipment in addition to its regular position reports. The received observation messages can then be parsed and provided to the global telecommunications system, a worldwide collection of meteorological observations in which the data can be used in weather models to improve weather forecasts, particularly in places with no fixed sensors.

Another use of crowd-sourced AIS data is to use the information from vessels that have already transited a channel to share channel conditions with other vessels wanting to navigate the same waterway. AIS data can indicate a successful, safe transit of a narrow or changing waterway. If the draft of the vessel that successfully transited is known, it can indicate that vessels with the same or shallower draft can also safely pass within a reasonable amount of time afterward.

It is also possible to take the information from a vessel's depth sounder and include it in AIS transmissions, potentially providing crowd-sourced bathymetry. Although the quality of this information likely would not be adequate to use for charting purposes, it could provide early warning of shoaling and could help waterways authorities prioritize survey and channel maintenance efforts.

AIS and Intermodalism

Maritime vessels are a significant part of the overall intermodal transport network,[1] and AIS can help harmonize the operations of various modes (*14*). The most obvious contribution is providing increased visibility into the maritime sector, facilitating the coordination of arriving vessels with shore transport like rail or trucks. Knowing the actual position of a vessel—and being able to calculate and monitor its transit time easily—can increase efficiency of dockside operations and lessen the impact of delays on other transport modes.

An emerging concept in intermodal transport is synchromodality: optimal mix of transport modes, facilitated by close monitoring and communication of each mode's state and performance and flexibly selecting the right mode or combination of modes to move cargo or passengers most efficiently.

Key to achieving synchromodality is knowing the location of transport elements and accurately predicting their future location. AIS can already do this for vessels and can facilitate communication among users of the system. Additional factors—waterway capacity, bottlenecks, and the capabilities of system components—can be determined by real-time analysis of AIS data. Information on waterway infrastructure also may be derived via monitoring AIS data and using it in conjunction with other information such as hydrographic surveys, water and weather sensors, and cargo movement input.

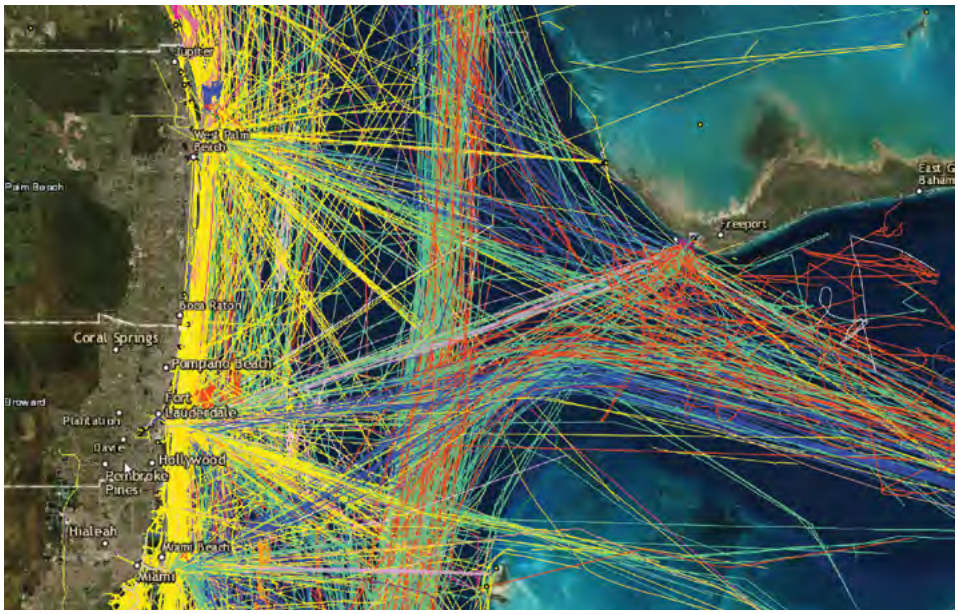


Image courtesy Brian Tetreault and Ned Mitchell

The web-based AIS Analysis Package tool allows users to analyze and visualize archived and near-real-time vessel data from USCG: vessel position, as well as time, speed over ground, direction, vessel draft, beam, length, and vessel type. This visualization shows vessels off the coasts of south Florida and the Bahamas.

Evolving the Use of AIS Data

Historical and real-time AIS data—in conjunction with information on environmental conditions and baseline waterway traffic patterns—can be used to predict vessel transit times and estimated arrival times at critical locations. Analysis of AIS data to monitor vessel fleet activity can also provide an indication of the overall performance of a waterway (i.e., once a travel time baseline is established for a section of waterway). Variances in the real-time speed of vessels can provide an indicator of waterway performance, like slower vessel speeds that are due to waterway restrictions or environmental conditions such as low visibility or ice.

Prediction of vessel movements can also help forecast congestion at locations like locks, one-way traffic areas, and coastal ports. The processing power provided by modern cloud computing platforms enables machine learning algorithms to be trained against large historical AIS data sets to better predict waterway congestion events, which can delay vessels for days or even weeks. Better predictions with improved lead times then can be used to plan vessel operations or alter voyage plans to minimize delay.

Although the AIS data are valuable, they typically must be used in combination with other data sources to provide true value beyond their original intended purpose of collision avoidance and waterway monitoring. Information such as channel bathymetry, tidal elevations, wind and wave conditions, and other environmental conditions, when combined with AIS data, offer new insights into how maritime operations are influenced by the natural environment.

AIS data can be correlated with vessel movement records—required reporting of cargo movements, customs records, and vessel arrival and departure reports—to validate those records and augment them with additional details and resolution. For example, a customs notice may provide information on a vessel arrival and the cargo it carried, but its actual movements within the port can be observed using AIS.

[1] As used in this article, "intermodalism" means "the organization of a sequence of modes between an origin and destination, including the transfer between the modes. Its main goal is to connect transportation systems that could not be connected otherwise because they are not servicing the same market areas due to their technical characteristics." See Rodrigue, J.-P. Intermodalism, Multimodalism, and Transmodalism. In *The Geography of Transport Systems,* Fifth Edition, Routledge, New York, 2020.

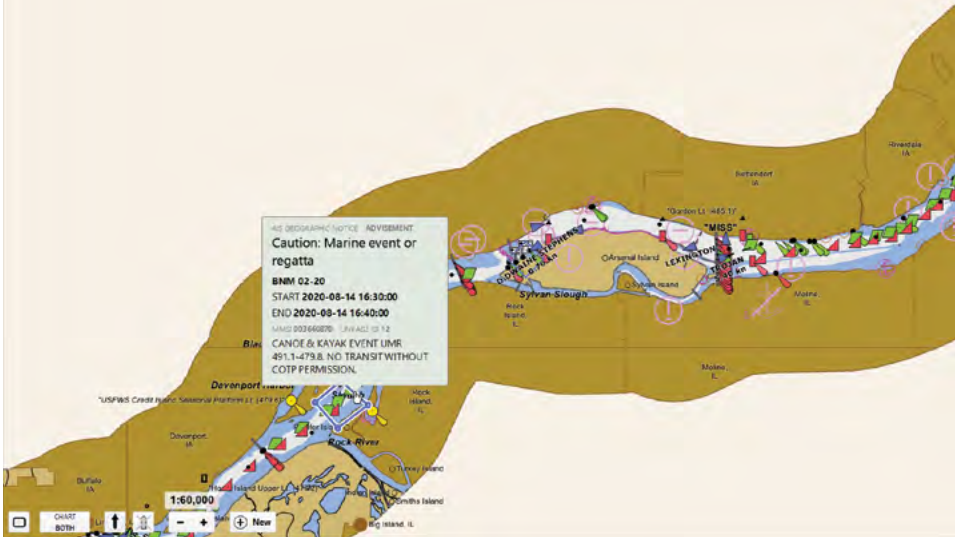


Image courtesy Brian Tetreault and Ned Mitchell

A Rose Point ECS software screen view shows vessel movement and marine events near the Rock Island Arsenal in the Mississippi River between Illinois and Iowa. The ability to predict vessel movements can help forecast congestion at various waterway locations, allowing vessel operators to plan their movements to minimize delays.

By coupling with similarly structured GPS truck probe data, AIS can be used to form a more complete understanding of port terminal throughput trends and capacities, particularly as they relate to any constraints posed by nearby roadway congestion (*15*). This intermodal view of the overall freight system—not simply piecemeal views of the respective modes—helps capture the end-to-end fluidity required for an efficient and reliable transportation network and inform infrastructure investment decisions.

Since its development and widespread use over the past two decades, AIS has had an enormous impact on navigation operations and waterways management. It has provided expected benefits in improved navigation safety and the ability of authorities to monitor coastal vessel traffic, but there have also been huge benefits in the use of AIS capabilities and data in ways beyond its original conception as a collision avoidance tool.

The collection and analysis of AIS data using emerging "big data" tools and techniques have vastly increased the visibility into the workings of the marine transportation system and have provided valuable tools for waterways users and managers to operate, manage, and maintain waterways safely and efficiently as part of the global transportation system.

REFERENCES

1. International Telecommunications Union (ITU). *Technical Characteristics for an Automatic Identification System Using Time-Division Multiple Access in the VHF Maritime Mobile Band.* ITU-R M.1371-5. ITU, Geneva, Switzerland, 2014.
2. U.S. Coast Guard Navigation Center. Automatic Identification System Overview. U.S. Coast Guard, Washington, D.C. https://www.navcen.uscg.gov/?pageName=AISmain. Accessed March 30, 2021.
3. Automatic Identification System. 33 C.F.R. 164.46 (2015–20).
4. Recommendation on Performance Standards for a Universal Shipborne Automatic Identification System (AIS). In *Resolution MSC.74(69): Adoption of New and Amended Performance Standards*, International Maritime Organization, London, 1998.
5. Tetreault, B. Use of the Automatic Identification System (AIS) for Maritime Domain Awareness (MDA). In *Proceedings of OCEANS 2005 MTS/IEEE*, Vol. 2, Institute of Electrical and Electronics Engineers, Washington, D.C., 2005, pp. 1590–94. http://dx.doi.org/10.1109/OCEANS.2005.1639983.
6. Mitchell, K. N., and B. Scully. Waterway Performance Monitoring with Automatic Identification System Data. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2426, 2014, pp. 20–26. http://dx.doi.org/10.3141/2426-03.
7. Kress, M. M., B. Tetreault, K. N. Mitchell, M. Balazik, and M. C. Booton. *AIS Data: Real-Time Operation Support, Incident Investigations, and Waterway Use Analysis.* Technical Note ERDC/CHL CHETN-I X-53. U.S. Army Engineer Research and Development Center, Vicksburg, Miss., 2019. http://dx.doi.org/10.21079/11681/36395.
8. Robards, M. D., G. K. Silber, J. D. Adams, J. Arroyo, and D. Lorenzini et al. Conservation Science and Policy Applications of the Marine Vessel Automatic Identification System (AIS): A Review. *Bulletin of Marine Science.* University of Miami Rosenstiel School of Marine and Atmospheric Science, 2016. http://dx.doi.org/10.5343/bms.2015.1034.
9. Scully, B. and D. Young. Evaluating the Underkeel Clearance of Historic Vessel Transits in the Southwest Pass of the Mississippi River. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, Vol. 147, No. 5, 2021. https://ascelibrary.org/doi/full/10.1061/%28ASCE%29WW.1943-5460.0000655.
10. *2017 Hurricane Season: Recommendations for a Resilient Path Forward for the Marine Transportation System.* U.S. Committee on the Marine Transportation System, Washington, D.C., 2018.
11. Touzinsky, K., B. Scully, K. N. Mitchell, and M. Kress. Using Empirical Data to Quantify Port Resilience: Hurricane Matthew and the Southeastern Seaboard. *ASCE Journal of Waterway, Port, Coastal, and Ocean Engineering*, Vol. 144, No. 4, 2018. http://dx.doi.org/10.1061/(ASCE)WW.1943-5460.0000446.
12. Johnson, G., B. Tetreault, and I. Gonin. Development of an AIS Transmit Architecture to Support the Dissemination of Electronic Marine Safety Information (eMSI). Presented at European Navigation Conference (ENC14), Rotterdam, Netherlands, 2014.
13. Tetreault, B., and G. W. Johnson. Sharing Ships' Weather Data via AIS. *TransNav: International Journal on Marine Navigation and Safety of Sea Transportation*, Vol. 14, No. 1, 2020. http://dx.doi.org/10.12716/1001.14.01.17.
14. DiJoseph, P., K. N. Mitchell, B. Tetreault, and J. Marshall. *Inland Marine Transportation System Travel Time Atlas via Automatic Identification System (AIS) Data: Ohio River, Upper Mississippi River, and Illinois River.* Technical Report ERDC/CHL TR-19-15. U.S. Army Engineer Research and Development Center, Vicksburg, Miss., 2019. http://dx.doi.org/10.21079/11681/34083.
15. Asborno, M. I., S. Hernandez, and M. Yves. GIS-based Identification and Visualization of Multimodal Freight Transportation Catchment Areas. *Transportation*, 2021. http://dx.doi.org/10.1007/s11116-020-10155-3.

Innovations That Increase Maritime Resilience

Photo: U.S. Coast Guard

REAR ADMIRAL RICHARD V. TIMME

The author is the Assistant Commandant for Prevention Policy for the U.S. Coast Guard in Washington, D.C. He is responsible for the development of national policy, standards, and programs promoting marine safety, security, and environmental stewardship.

Above: Making its way across calm seas, a U.S. Coast Guard unmanned surface vehicle prototype goes through its paces during a 30-day test off the coast of Oahu, Hawai'i. The test was to determine how current and emerging technologies can enhance maritime domain awareness in remote regions.

As a maritime nation, America's past, present, and future economic prosperity, national security, and global influence are inextricably tied to the marine transportation system (MTS). With more than 90 percent of global trade transiting ocean routes, a functional MTS is the backbone of thriving international trade and the global economy (*1*).

The United States relies on the MTS to deliver medical supplies, food, clothes, oil, and manufactured goods, among other commodities. MTS resiliency is the cornerstone of America's supply chain that makes the availability of raw materials and finished components possible. It enables new cars, trucks, and sports utility vehicles to roll off the assembly line and onto driveways, fresh bread to reach the stores, and the newest smart TVs to be available in time for the big game.

The maritime industry is facing new demands, pushing the limits of existing infrastructure and driving growth of the MTS capacity through innovations in marine design, operations, and resource efficiencies. Dramatic increases in U.S. energy production and continuing demand require enhanced efficiency and increased commercial vessel sizes in order to meet just-in-time delivery. These changes—along with an increase in the number of commercial and recreational vessels and users in traditional shipping channels that is due to growing waterborne tourism—have greatly increased the complexity of the maritime planning necessary to ensure safe navigation.

Public expectations for sustainability and environmental stewardship encompass factors such as critical habitats, coastal zone management, public utility use, commercial and recreational waste streams, and changing climate conditions that include sea level rise and storm intensity, all of which affect the MTS. Although these expectations have environmental benefits, incorporation of new operational practices, innovative design thresholds, and additional engineering equipment also have created challenges in understanding new advanced marine systems.

Photo: U.S. Geological Survey

At 7,800 square miles, Florida's Everglades National Park—a UNESCO World Heritage Site—is the United States' largest subtropical wilderness and home to rare and endangered species such as the American crocodile, the Florida panther, and the manatee. With environmental sustainability in mind, the Coast Guard focuses on practices and technology that allow it to perform its duties along Florida's waterways while protecting the delicate ecosystem.

Ready, Resilient, and Relevant

For more than 230 years, the U.S. Coast Guard has been facilitating maritime safety and security, protecting national economic and security interests, assisting global and domestic trade, and providing for safe travel and recreation on America's waterways. To remain ready, resilient, and relevant, the Coast Guard has implemented the Maritime Commerce Strategic Outlook (MCSO).

The MCSO serves as a guide to maintaining the resilience of the MTS and its impact on the nation's economic prosperity. Three lines of effort are critical to the success of the Coast Guard:

1. Facilitating lawful trade and travel on a secure MTS,
2. Modernizing aids to navigation and mariner information systems, and
3. Transforming workforce capacity and partnerships to meet the increasingly complex operating environment within the MTS.

Accounting for $5.4 trillion in economic activity, the MTS is connected to and impacts every segment of the U.S. economy. The MTS also enables critical national security sealift and supply capabilities that support U.S. Armed Forces' logistical requirements around the globe. Any significant disruption to the MTS—whether natural phenomena or human-caused—can lead to cascading and devastating impacts on the domestic and global supply chain and, consequently, on the United States' economy and national security. Recently, global supply chains were affected when the Evergreen *Ever Given*—one of the largest container ships in the world—inadvertently blocked the Suez Canal for six days, bringing maritime transportation between Asia, Europe, and North America to a halt. The overall economic consequences from this event are still being determined. The Coast Guard's mission enhances the safety of the MTS so that the nation has uninterrupted access to the global supply chain.

The Coast Guard's broad authorities make it well-positioned to coordinate short- and long-term recoveries aimed at restoring the flow of commerce and other critical port activities. It leads the responses to major disruptions in the MTS under the auspices of the National Response Framework: a strategy that is designed to ensure resiliency following a disturbance, such as a casualty or extreme weather event (Figure 1).

Cultivating resilient maritime communities requires deliberate and coordinated crisis and surge incident planning with maritime partners. The Coast Guard does this by using lessons learned from previous events, enhancing planning and evaluation of preparedness, and implementing

Photo: U.S. Coast Guard

In 1944, at the height of U.S. involvement in World War II, U.S. Coast Guard Cutter *Eastwind* patrolled the waters around Greenland to stop teams of German scientists and military personnel from establishing weather stations on remote parts of the island. The Coast Guard was founded in 1790, primarily to enforce tariff and trade laws and to disrupt smuggling.

realistic interagency management exercises that incorporate future and emerging challenges.

The Coast Guard is expanding and evolving required incident command system training to prepare for increased MTS activities. The year 2020 saw a complete update of performance qualification standards for personnel who will serve in positions within the incident command system structure. The year 2021 has included completion of the first ever national course for Marine Transportation System Recovery Unit (MTSRU) personnel. These teams respond whenever there is a disruption to a waterway. MTSRU members stand ready to coordinate with maritime partners for the rapid and expedient mobilization of resources to ensure resumption of regular activity on the waterway. This coordination is accelerated through the use of the Common Assessment Reporting Tool (CART), a unique online tool that allows vital port status information to be accessed by Coast Guard leadership at every level the instant it is entered. These teams and their use of the CART system were vital to reopening ports after the devastating effects of major Hurricanes Harvey, Irma, and Maria in 2017.[1]

The COVID-19 pandemic revealed stressors in the U.S. supply chain. In the spring of 2020, as people were encouraged to remain at home in an effort to slow the spread of the coronavirus, consumers experienced shortages of cleaning supplies, medical supplies, and basic necessities. Newsfeeds were filled with images of empty airports, employees transitioning to work from home, and food and toiletries vanishing off store shelves. In March 2020, the first MTSRU support cell was established at Coast Guard headquarters in Washington, D.C., and proved to be invaluable in evaluating and mitigating the immediate effects of the COVID-19 pandemic on the national MTS.

During that time, the Coast Guard collaborated with federal partners at the Centers for Disease Control and Prevention (CDC) to follow the spread of COVID-19 among cruise ships within or bound for U.S. waters, as well as those carrying U.S. citizens aboard globally. The Coast Guard worked with the CDC to issue concrete guidance to ship operators and stood watch at ports across the nation. These swift actions ensured the safe disembarkation of more than 250,000 cruise ship passengers and 90,000 crew members from 125 vessels. As pandemic impacts rapidly spread, the Coast Guard promulgated policy aimed at keeping maritime workers at work. These actions had an immediate effect, but more study needs to be dedicated to evaluating the long-term effects on the maritime industry and the U.S. economy.

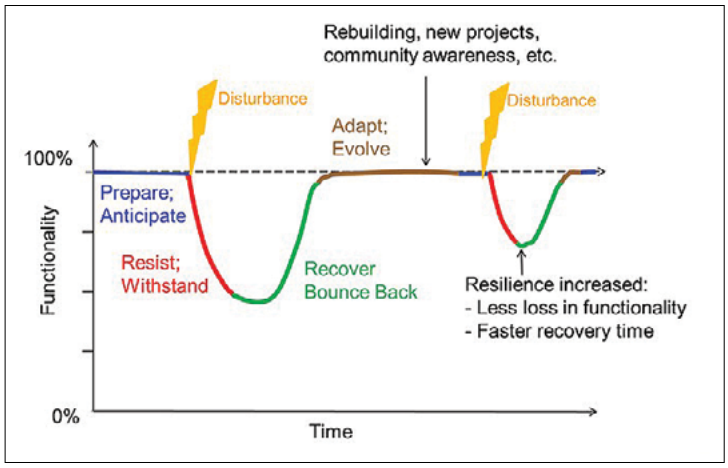


FIGURE 1 **This resilience timeline represents a wide variety of specific activities that are catalyzed by a disturbance and lead to the next key action (*2*).**

Photo: U.S. Coast Guard

Responding with strength and strategy, a Coast Guard team airlifts a survivor of Hurricane Harvey's devastating floods away from Houston, Texas. The Coast Guard coordinates closely with federal, state, and local emergency operations to manage search and rescues from incident command posts.

Marine Planning

The drive for alternative energy production has resulted in large wind farms expanding into the maritime domain and

[1] See *TR News 331* January–February 2021: "Strengthening Post-Hurricane Supply Chain Resilience: Observations from Hurricanes Harvey, Irma, and Maria." http://www.trb.org/Publications/Blurbs/182128.aspx.

Photo: Bill Ingalls, NASA

Curious spectators gather as the SpaceX Crew Dragon *Endeavor* commercial spacecraft is lifted onto the SpaceX GO *Navigator* recovery ship after reentry off the coast of Pensacola, Florida. But are these onlookers too close for comfort? The Coast Guard is working with NASA, the FAA Office of Commercial Space Transportation, the U.S. Air Force, and the U.S. Space Force to establish policies and protocols that mitigate navigation risks and that maintain public safety—offshore and onshore.

challenging existing waterways usage. Adroit marine planning is crucial for rapid construction of offshore wind farms. Offshore wind development has expanded globally for the past two decades and is now expanding along U.S. coasts. Within the United States, the high demand for electricity in coastal states is a catalyst in the surge of offshore wind development.

Marine planning is integral to managing the already crowded maritime domain. As new wind farm locations are proposed, potential conflict between current users and stakeholders who transit in this space—such as fishermen and tug and barge operators—must be resolved. This requires extensive stakeholder engagement with state and local governments, marine industry, and the public. Whatever policy is developed affects the system's future usage by the entire maritime community.

The emerging commercial space industry also overlaps with aspects of the MTS and may present risks to navigation and public safety. A recent Coast Guard instruction provides guidance to operational commanders for space launch and reentry activities affecting the MTS. This instruction outlines Coast Guard responsibilities for mitigating and responding to the navigation risks posed by testing, launching, and reentry of space vehicles. The Coast Guard is working toward establishing policies, procedures, agreements, and communications with the Federal Aviation Administration Office of Commercial Space Transportation, NASA, U.S. Air Force, and the U.S. Space Force (*3*). Through these partnerships, the Coast Guard can effectively advise on navigation safety and public safety risks, provide patrol assets, supplement first responder capabilities, and create safety and security zones to protect the public or keep them out of an area with national security implications.

Accelerating the Pace of Innovation

Thirty years ago, autonomous technology only existed in television, movies, and science fiction novels. Autonomously operated systems are increasingly becoming technically and economically feasible for waterways users. Today, the United States is planning for the arrival of the *Mayflower*, a 15-meter-long, self-propelled trimaran, in Cape Cod, Massachusetts (see page 53). This modern craft is equipped with state-of-the-art technology to enable it to navigate around buoys, cargo ships, and other ocean hazards.

Technical innovation and the constant drive toward economies of scale fuel MTS users' development of novel technology and adaptations to existing methods. These developments occur within the shared marine environment. Specifically, the development and deployment of artificial intelligence and other autonomous systems, which operate vessels and serve distinct functions at waterfront facilities, have become a new reality over the last decade. As the International Maritime Organization (IMO) and stakeholder nations discuss methods of governance related to these systems, the pace of technical advancements continually shifts the goal line. Concurrently, developers and waterway users continue to seek ways to test prototypes in real-world scenarios as proofs of concept.

These technological advancements, such as autonomous and robotic systems and new propulsion methods, are altering the character of maritime operations and placing greater demands on the MTS. The pace of innovation is creating additional challenges: Advanced technologies create new regulatory, legal, and operational challenges. Staying abreast of changing technology is an increasing demand across all Coast Guard workforce components, stressing existing resources, and challenging effective leadership. As the introduction of new technology increases risks that could result in injury, death, harm to the marine environment, or disruption of vital trade activity, the Coast Guard has an obligation to understand emerging autonomous technologies and clear a path toward sensible, prudent regulations ahead of global adoption.

Coast Guard captains of the port and their waterway managers have many objectives when considering stakeholders' uses of U.S. waterways. Foremost, they must ensure the safety, security, and environmental stewardship of their waterway. Simultaneously, because U.S. innovation and economic advancement are matters of national security and core objectives for other federal agencies, they strive to facilitate the United States' efforts to promote the MTS to remain globally competitive. However, ports and harbors

carry different risks than those of open oceans. To fulfill their objectives, captains of the port and waterway managers must have a unified vision and strategy specific to how autonomously operated systems may safely and securely operate alongside traditional waterway users. Conducting a navigation safety risk assessment, a key component of a port and waterway safety assessment, is critical to promoting these strategies and to recognizing and mitigating the overall risks.

As the MTS evolves, increasing demand for waterway access; growing size and complexity of vessels, facilities, and port operations; and the pressing need to protect the maritime environment present a triple threat to the Coast Guard's prevention mission. The pace of innovation, emerging technologies, and expansion of natural resource exploration, production, and transportation is driving the demand for capacity, complexity, and capability in the MTS, as well as creating new risks. The next evolution in MTS operations may involve autonomously augmented shipping and facilities. To continue safeguarding the MTS, the Coast Guard must assess and improve its readiness. In order to do this, the development of national standards for these autonomous systems—which set expectations for safe, secure, and sustainable operations—must be a priority. This includes verifying compliance with these standards and assessing feedback to drive recommendations for improvement that complete the continuous cycle of seeking to reduce risk in the MTS.

While technologies increase the complexity of the operating environment, they also present great opportunities for improved safety and efficiency. The Coast Guard's ability to set and enforce effective standards that advance maritime safety and environmental stewardship must keep pace with rapid technology application in the afloat, ashore, and cyber-related elements of the MTS. There is no simple solution to the challenges presented by autonomy. In many instances, this technology is advancing faster than the regulations and infrastructure required to support these endeavors. Success can be achieved when the Coast Guard works together with industry and regulatory partners, leveraging data to optimize resources and capturing lessons learned as new technology comes to fruition. Participating in venues where all parties can engage in robust dialogue and share best practices remains a pillar of the Coast Guard's approach.

Photo: U.S. Coast Guard

A U.S. Coast Guard Academy team participates in the National Security Agency's 20th Annual Cyber Exercise, a virtual competition that assesses offensive and defensive cybersecurity skills. As part of the Coast Guard's efforts to address cyberthreats in an advancing technological maritime environment, the Academy recently instituted a degree in cyber systems.

Cybersecurity: Risks, Culture, and Resilience

The MTS faces increased risk of cyber-related vulnerabilities. Vessel and facility operators alike are increasingly dependent on emergent and modernized technologies for navigation, communications, engineering, cargo handling, and numerous other critical operational applications. These technologies enable the MTS to operate with a strong record of reliability at a capacity that supports the United States' place in the global economy, as well as national defense. However, exploitation of and malicious activities in these systems by a cyberintrusion can significantly disrupt vital trade activities, causing environmental harm and personnel injury.

These risks drive the need for cyber-focused operational policy, requirements, and training initiatives to enhance the capability to protect MTS operations and infrastructure. The Coast Guard has embraced cyberspace as an operational domain, facilitating a focus on strategic priorities and supporting initiatives in these areas. In 2020, a Coast Guard Cyber Command established the Maritime Cyber Readiness Branch to track, investigate, and analyze all reported cyberincidents in the MTS. This team maintains the big picture, correlates disparate incidents, and helps produce information-sharing products for government and industry partners to assist in mitigating cyberthreats. Additionally, establishing deployable cyberprotection teams provides tactical support during incidents. They are specially trained to hunt and clear malicious actors from systems and networks supporting the MTS, assess the cybersecurity response and risk

posture of port stakeholders, and provide technical expertise to support the hardening of stakeholders' cybersecurity defenses against future attacks.

A Ready Coast Guard

Operational success in the maritime domain is supported by the Coast Guard's ability to leverage a capable workforce; smartly manage risk and information; and maintain strong, collaborative partnerships.

In responding to the nation's expectations for the Coast Guard to meet competing and increasing demands throughout the MTS, the Coast Guard MCSO has prioritized recruiting, training, supporting, and retaining a mission-ready total workforce. These personnel are empowered with the information, knowledge, skills, equipment, and support systems needed to excel across the full spectrum of Coast Guard operations. Along with modernized training, Coast Guard personnel will leverage new technologies to enhance operational decision-making and employ mitigation strategies to reduce enterprise risks. These lines of effort provide a path for improving program readiness with enhanced proficiency, technology, and governance to achieve mission excellence.

The Coast Guard also must remain focused on leveraging its unique authorities, broad mission suite, and trusted partnerships to promote unity of effort among maritime stakeholders. Through these partnerships, the Coast Guard will facilitate the evolution of appropriate maritime standards and practices to efficiently and specifically address risks in the MTS. Only through a shared commitment to a culture of innovation and cooperation will success be reached in identifying, preventing, and responding to challenges that threaten the safety and security of maritime commerce. Anticipating changing needs within the MTS will require robust engagement with port and maritime industry decision-makers; federal, state, local, and tribal government entities; and the spectrum of MTS stakeholders, including vessel and facility owners and operators, port authorities, maritime trade associations, other government agencies, foreign governments, and international organizations (e.g., IMO). The Coast Guard will continue to modernize its customer service exchanges, strengthen its relationships, increase unity of effort, and enhance its oversight capabilities.

Coast Guard missions, at home and abroad, ensure the resiliency of the MTS via mitigation of risk to critical infrastructure and support the uninterrupted flow of cargo between ports around the globe. Persevering through the challenges of the COVID-19 pandemic and the record-breaking 2020 hurricane season, the Coast Guard—with the support of committed partners—continues to ensure that the nation's ports and waterways remain open. The Coast Guard remains *Semper Paratus*—Always Ready—to meet and respond to future challenges and protect the MTS.

REFERENCES

1. U.S. Coast Guard. *Coast Guard Maritime Commerce Strategic Outlook*, October 2018, Washington, D.C.
2. Schultz, M. T., S. K. McKay, and L. Z. Hales. *The Quantification and Evolution of Resilience in Integrated Coastal Systems*. U.S. Army Corps of Engineers, ERDC TR-12-7. 2012. https://hdl.handle.net/11681/8513.
3. U.S. Coast Guard. *Coast Guard Strategic Plan, 2018–2022*, Washington, D.C., 2018.

VOLUNTEER VOICES

"Most impactful solutions to the real and complex transportation challenges our world faces today necessitate finding solutions in a diverse and inclusive setting, where top researchers collaborate through open dialogue. Over the past 100 years, the Transportation Research Board has consistently provided such an environment, conducive to the free exchange of ideas among all transportation professionals. As a part of the freight community and the chair of the Standing Committee on Freight Transportation Planning and Logistics, I intend to encourage that open collaboration and advance TRB's agenda to provide implementable engineering solutions that not only positively impact the transportation space but benefit our society as a whole.

—SUSHANT SHARMA
Associate Research Scientist
Texas A&M Transportation Institute, Euless, Texas

Leveraging Unmanned Systems for U.S. Coast Guard Missions

Photo: Sara Muir, U.S. Coast Guard

HEIDI PERRY AND MONICA STARNES

Perry is the assistant head of the Air, Missile, and Maritime Defense Technology Division at the Massachusetts Institute of Technology Lincoln Laboratory in Lexington and chair of the study committee. Starnes is a senior program officer with the Consensus and Advisory Studies Division, Transportation Research Board, National Academies of Sciences, Engineering, and Medicine in Washington, D.C., and the study director.

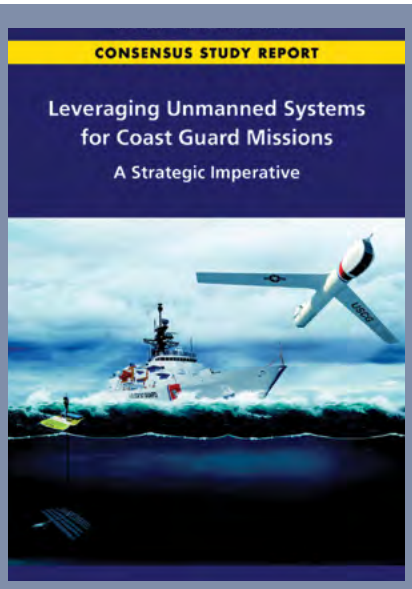
Above: Site lead Mike McCord and technician Dwight Smith recover the small unmanned aerial system ScanEagle aboard the USCGC *Stratton*. The drone was deployed for reconnaissance during national security operations in the Pacific in 2019.

As one of the six military services of the United States and its prime maritime law enforcement service, first responder, and maritime regulator, as well as a member of the intelligence community, the U.S. Coast Guard (USCG) is responsible for defending the nation's maritime territory and laws.

Although it is a relatively small service, USCG has a large scope of responsibilities spread over 11 statutory missions to ensure the country's maritime security, safety, and economic and environmental stewardship. The Coast Guard fulfills these diverse missions in a vast maritime domain that encompasses more than 100,000 miles of coastline and inland waterways and the largest exclusive economic zone in the world, approximately 4.5 million square miles of sea from Puerto Rico to Guam and from the Arctic Circle to American Samoa south of the equator. The broad set of responsibilities in such extensive maritime domain requires versatility for USCG personnel, assets, and concepts of operations.

Apart from a small number of unmanned aerial systems mainly used to expand the surveillance range of some of its cutters, all USCG's vessels and aircraft are manned. In the past few years, the USCG has carried out multiple initiatives to assess the applicability of unmanned systems (UxS) for its operations. The adoption of these systems has been slow and ad hoc, however; this has opened untapped opportunities for USCG to deploy UxS, adding new capabilities and strengthening existing ones with less risk to personnel and traditional assets.

The Frank LoBiondo Coast Guard Authorization Act of 2018 called for a National Academies of Sciences, Engineering, and Medicine study of how USCG uses UxS to enable its critical and unique missions and the ways it can expand this usage. In response to this request from Congress, the Transportation Research Board convened a committee of experts (see box, page 40) to evaluate current and emerging capabilities of aerial, surface, and underwater systems—with



For more information and to download a copy of *Leveraging Unmanned Systems for Coast Guard Missions*, visit https://doi.org/10.17226/25987.

various levels of autonomy—and intelligent decision aids that can integrate data from unmanned vehicles and payloads. Also examined were any realignments in USCG policies, procedures, and protocols that may be necessary to exploit UxS more fully and effectively.

In addressing the charge, the committee took several key positions. First, committee members agreed that the potential use of aerial, surface, and underwater UxS must be considered in a broader context across all Coast Guard missions—especially since USCG places strong emphasis on versatile assets that can be used in diverse operations.

Second, given the accelerated rate of technological advancement in UxS, the committee chose to consider the broad aspects of these technologies—(e.g., their key attributes and functionality)—instead of evaluating specific vehicles or systems that could rapidly become obsolete or profoundly transformed.

Finally, for USCG, exploiting the promise of unmanned systems is less of a technology issue than an institutional one. Even though USCG has multiple initiatives past and present to explore the applicability of UxS for its operations, it lacks a formal means for identifying, investigating, and integrating UxS into its force structure.

Many agencies and organizations that have leveraged unmanned systems successfully into their operations have been guided by a strategic vision and deliberate plan for making the necessary changes in culture, processes, and investments in personnel and other resources. For instance, other military services such as the U.S. Navy and other federal agencies—most recently, the National Oceanic and Atmospheric Administration—have articulated strategies and established the appropriate organizational structure, recognizing that ad hoc and piecemeal efforts to investigate and introduce UxS can lead to fragmented and unrealized benefits.

Similar to other military services and federal agencies, USCG needs strategic planning for how it can optimize the use of manned and unmanned systems in the field, the scale at which to leverage UxS, and how UxS affects its general operations.

Strategic Approach

USCG has persuasive reasons and growing opportunities to advance in leveraging UxS more strategically, deliberately, and rapidly for its operations. Indeed, the committee concluded that to remain responsive and fully relevant to its many missions, the Coast Guard must take a more strategic and accelerated approach to exploit the capabilities of existing and future UxS.

Through its ongoing exploratory initiatives and recent acquisitions, USCG has demonstrated interest in using UxS for more missions. That interest is not complemented by a funding commitment, however, including essential funding for research and development (R&D). The committee concluded that USCG's small current budget for UxS R&D and incremental applications is not sufficient to meet the UxS imperative.

It also is unlikely, the committee concluded, that the required funding to identify and integrate UxS into the force structure will be met with a simple reallocation of traditional USCG appropriations. The USCG budget will need to grow

Committee on Coast Guard Maritime Domain Awareness

Heidi Perry, MIT Lincoln Laboratory, Lexington, Massachusetts, *Chair*

Rear Admiral Thomas J. Eccles (National Academy of Engineering; U.S. Navy, retired), Trident Maritime Systems, Arlington, Virginia

Jaye Falls, U.S. Naval Academy, Annapolis, Maryland

Barry M. Horowitz (National Academy of Engineering), University of Virginia, Charlottesville

Lauren J. Kessler, Draper Laboratory, Cambridge, Massachusetts

Annette J. Krygiel, Independent Consultant, Great Falls, Virginia

Vice Admiral Fred M. Midgette (U.S. Coast Guard, retired), Westlake, Ohio

Commander Matthew Pickett (National Oceanic and Atmospheric Administration, retired), Oceans Unmanned, Santa Barbara, California

Sean T. Pribyl, Gard AS, Arendal, Norway

Charles E. Thorpe, Clarkson University, Potsdam, New York

Photo: U.S. Coast Guard

One USCG research and development project tested small quadcopters and fixed-wing unmanned vehicles—like the Puma All-Endurance by AeroVironment, shown here—in different geographic areas and on every class of Coast Guard vessel. These systems can assist in a variety of missions, from drug interdiction to protection of living marine resources.

to enable larger-scale acquisitions and investments. Although the Coast Guard is responsible for building a compelling case for substantial additional funding, the committee believes the findings and recommendations in this report warrant the attention of Congress and the U.S. Department of Homeland Security (DHS), whose support will be vital.

Recommendations

USCG leadership, DHS, and Congress face the question of realigning plans, operations, policies, and budgets to enable the Coast Guard to embrace and capitalize on UxS. Informed by the findings and conclusions from the study, the committee recommends the following five key actions:

- The Coast Guard Commandant should issue a high-level UxS strategy that articulates a compelling rationale for UxS, sets forth agency-critical goals advanced by these systems, and outlines USCG's approach for achieving them.
- The Commandant should designate a top Coast Guard official—at the flag officer or senior executive service levels—to advocate for and advance the service's UxS strategy. This top official should be responsible for identifying, promoting, coordinating, and facilitating the changes that will be needed across the organization to further the Commandant's strategic goals and objectives for UxS.
- The Commandant should establish a UxS program office that will work with the top official charged with advancing USCG's UxS strategy to plan, coordinate, assess, and promote UxS activities across the service and to leverage relevant activities and capabilities from outside USCG. An early initiative of the program office should be to develop a road map that translates the high-level UxS strategic goals and objectives into an actionable plan that lays out pathways to accomplishment, including outlining specific tasks that need priority attention, setting time frames for completing them, and establishing performance milestones and measures.
- To build upon and reinforce its naturally innovative culture, USCG should expand and normalize efforts to ensure ample and systematic operations-related experimentation with low-cost UxS, including potentially designating field units specifically for experimentation and rapid transitioning of systems into operations. Encouraging experimentation with low-cost UxS technologies will not only lead to the identification of beneficial uses, but nurture a technologically curious and proficient workforce across the ranks.
- To ascertain the magnitude of investments that will be required, the Commandant should commission an internal study of the multiyear spending required for research, assets, integration, personnel, and the like that will enable full and sustained implementation of a UxS strategy. The committee also highlights that the budget estimates should be developed with a realistic expectation that investments in UxS may not be accompanied by opportunities for significantly reducing spending on manned assets and operations, but they will nevertheless be vital for much more efficient and capable hybrid operations to fulfill USCG's critical missions.

Susan J. Binder

Principal, Cambridge Systematics, Inc.

Susan J. Binder began her career with a University of Maryland bachelor of science in consumer economics. An internship revealed her passion for transportation, and a master's degree in business administration in transportation from George Washington University in Washington, D.C., followed. Recognizing that "to understand the policy, you have to follow the money," she specialized in funding and financing.

Wherever she worked in transportation, Binder brought her interdisciplinary perspective—supported by facts and an understanding that people make it real. During nearly four decades in federal positions at the U.S. Department of Transportation (DOT), Federal Highway Administration (FHWA), and the Office of Management and Budget, as well as authorizing committees for the U.S. House and Senate, she became known as a strategic thinker and planner. She earned the respect of political leaders, civil servants, and engineers while championing a results-based agenda. She also gained critical insights into the political environment. Along the way, she broke the glass ceiling, but acknowledges that women are not yet on equal footing: "I still have a lot to do on that score."

Binder has spent 10 years in the private sector at Cambridge Systematics in Bethesda, Maryland. "We relish solving difficult problems for our clients, bringing together a wide range of technical, analytical, and management skills," she notes. She guides a diverse group of national, state, and local clients through a broad range of policy issues that have and will continue to influence the United States, its communities, and the transportation services that "help glue them together." As a principal, she serves as the program manager for the FHWA policy indefinite delivery/indefinite quantity procurement vehicle for Cambridge Systematics and its teaming partners. She also is the company's client relationship manager for U.S. DOT. Her understanding of surface transportation's complex modal issues and the nuances of intergovernmental relations is critical to her role.

"When you are directly involved in research, it helps you separate fact from opinion—the wheat from the chaff."

During her years of public service, she has been at the forefront of the modern evolution of federal transportation investment programs and partnership relationships with state and local governments, as well as with other stakeholders. She helped develop and implement federal surface transportation legislation over more than 10 reauthorization cycles.

Binder champions investment in research as a catalyst in continuous improvement by the transportation community, as a whole and for individual professionals. "Rigorous research and critical thinking aren't just academic exercises," she explains. "They stimulate growth in skills, broaden our horizons and options, and contribute to practical problem solving." Through experience working with executive policy and in legislative environments, she understands the importance of developing research skills and insights throughout one's career. "When you are directly involved in research, it helps you separate fact from opinion—the wheat from the chaff," she adds.

Binder has been an active member of many National Cooperative Highway Research Program (NCHRP) panels and Transportation Research Board (TRB) committees, including the Standing Subcommittee on Transportation History, as well as standing committees on Strategic Management and on Economics and Finance. Since 1976, she has not missed a TRB Annual Meeting, and she has presented on numerous topics. "It's like attending a full curriculum of a transportation university crammed into one week," she asserts. "TRB has created a space in concert with government, industry, and academia that fosters growth and innovation."

In encouraging younger colleagues, Binder advises them to "look at opportunities to manage research efforts as continuing education—a way to keep expertise up to date and expand their horizons." She further advises them to get involved with panels and committees, especially in leadership roles, where opportunities to practice management skills abound. "People often don't realize how unique and valuable the collaborative culture fostered by TRB, NCHRP, and the other Cooperative Research Programs is when compared with other sectors."

Binder has served on the Foundation Board of the Women's Transportation Seminar, is the executive and public relations vice president of the Transportation Research Forum, and sits on the Advisory Board of the Mileage-Based User Fee Alliance. In 1994, when she was appointed FHWA's division administrator for the state of Maryland, she became the first woman and the second non-engineer in the country to serve in that capacity. She has received the Presidential Rank Award for Meritorious Executive, several secretary's and administrator's awards, and the 2005 Lester P. Lamm Award for Outstanding Public Servants. "Les was a guiding star in my early years at FHWA, so this is personal," she remarks. "He was a visionary leader who understood the need for diverse groups to work together." Working across disciplinary boundaries is Binder's core strength and her legacy—the ability to bring disparate groups together to foresee needs and agree on how to build the future.

Vice Admiral James C. Card

Maritime Consultant

Vice Admiral James C. (Jim) Card has more than 50 years of experience in maritime transportation safety, security, and environmental protection, leading research programs with the U.S. Coast Guard and the American Bureau of Shipping (ABS).

As senior vice president and chief technology officer at ABS, Card was responsible for overall management of global technology, research, and rule development for ships and offshore facilities. A particularly rewarding project involved leading a group of 75 engineers and scientists in developing a strategic plan for the company. The team outlined five-year projects to advance ABS's mission to promote the security of life, property, and the natural environment.

Anywhere from 60 to 75 projects were under development at any one time at ABS, on topics that ranged from improving predictions of loads on ship structures to applying life cycle risk management concepts for machinery and electrical systems to developing tools to plan, assess, and audit the role of the human element in shipboard design and operation.

"Projects were chosen based on customer needs, field engineers' inputs, and opportunities offered by changing technology," Card recalls. "We were a dynamic group."

Before joining ABS, Card served in the U.S. Coast Guard for 36 years. He was Vice Commandant from 1998 to 2000; before that he served as Commander of the Pacific Area and Assistant Commandant for Marine Safety, Security, and Environmental Protection. As the leader of the nation's marine safety, maritime security, and environmental protection programs, Card carefully balanced national needs and priorities with those of maritime commerce. He also led many United States delegations to the International Maritime Organization. As a primary customer of Coast Guard Research and Development, he and his team clearly defined the needs for products and systems to improve marine safety and environmental protection operations and worked closely on those projects.

In the 1990s, Card served as chair of the Ship Structure Committee (SSC), an interagency group addressing research in advanced concepts and long-range planning, as well as in technology areas of materials criteria, loads and response, design methods, fabrication and maintenance, and reliability. The Marine Board's Committee on Marine Structures advised the SSC on a ship structure research program. In 1995, the National Research Council published *Marine Structures Research Recommendations: Recommendations for the Interagency Ship Structure Committee's FY 1996–97 and Later-Years Research Program.*

"Projects were chosen based on customer needs, field engineers' input, and opportunities offered by changing technology."

"We developed a very clear process, which identified projects to be funded by the contributions from the many agencies in the SSC that included the Coast Guard, the Navy, the Maritime Administration, and the Society of Naval Architects and Marine Engineers," he notes.

Card is a graduate of the U.S. Coast Guard Academy; the Massachusetts Institute of Technology, with master's degrees in naval architecture, marine engineering, and mechanical engineering; and the Industrial College of the Armed Forces.

He is the chair of the board of directors of the energy logistics company AET Offshore. He recently served on the National Academies Resilient America Roundtable and is a National Associate of the National Research Council. Card joined the Marine Board in 2008 and served as its chair from 2014 to 2016. As Marine Board Chair, he was a member of the TRB Executive Committee, where he led a special committee to define research needs for resilience in transportation.

As chair of the Committee on Offshore Wind Farm Worker Safety, Card led a study requested by the U.S. Department of the Interior's Bureau of Ocean Energy Management that assessed the agency's approach for regulating the health and safety of wind farm workers on the outer continental shelf. The committee identified hazards and recognized existing regulations, standards, and best practices that could address each hazard, presented in *Special Report 310: Worker Health and Safety on Offshore Wind Farms.* Card also served on the Committee to Review Implementation of the United States Flag Registry and the Committee on U.S. Coast Guard Oversight of Recognized Organizations.

Honors include the Rear Admiral Halert C. Shepheard Award for achievement in merchant marine safety from the Chamber of Shipping of America; the Vice Admiral Emory S. "Jerry" Land Medal for outstanding accomplishment in the marine field from the Society of Naval Architects and Marine Engineers; the Roy Wilkins Renown Service Award from the NAACP; and many military awards, including the U.S. Department of Transportation Distinguished Service Medal and the Coast Guard Distinguished Service Medal.

Card has authored many papers on marine safety, environmental protection, and concepts for tankers and human factors in marine operations.

TRANSPORTATION INFLUENCER

Jhony Habbouche

Jhony Habbouche is a research scientist at the Virginia Transportation Research Council of the Virginia Department of Transportation. He is a member of the Standing Committee on Binders for Flexible Pavement, the Standing Committee on Design and Rehabilitation of Asphalt Pavements, the Young Members Coordinating Council, the Transportation Infrastructure Group Young Member Subcommittee, and a friend to many more committees and groups. He also is an editor for the Transportation Research Record: Journal of the Transportation Research Board (TRB) *and serves as an advisor and a technical expert for several National Cooperative Highway Research Program IDEA projects.*

How did you first hear about and become involved in TRB?

When I was a graduate student in the pavement engineering and science program at the University of Nevada, Reno, I was fortunate to be mentored by Professor Elie Y. Hajj, a great contributor to TRB activities. From 2016 to 2019, I and several of my colleagues traveled with him to Washington, D.C., to attend the TRB Annual Meeting, where we gave presentations, participated in various meetings, met new people, widened our network, made valuable connections, and simply learned. I am so grateful for that!

How has TRB influenced your career so far?

Attending TRB Annual Meetings gave me a strong start to my career, especially in my research work at a state department of transportation. Understanding the key components that go into the agency–industry–academia triangle remains challenging, but TRB helped me better understand this relationship and its importance. That was a big deal! TRB also helped me establish strong connections with fellow professionals—inside and outside of the pavement domain—that continue to lead to great collaborative efforts that will benefit the pavement and transportation sectors.

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

Since 2017, I have helped lead the "3-Minute Thesis Competition" at the TRB Annual Meetings. This workshop invites young TRB volunteers to present their research in a way that attendees can absorb the key objectives and components in three minutes. As a result of the consistent work and contributions of all of the young professionals—including me—throughout the years, in 2020 the Young Members Coordinating Council of what is now the Safety and Operations Group—as well as the Young Members Subcommittee of what is now the Highway Maintenance Section—received the Blue Ribbon Award, highly regarded by transportation institutions and organizations. I will never forget those moments!

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

VOLUNTEER VOICES

"The world should welcome more ideas from nontechnical transportation professionals who can communicate innovations in transportation more visually and less technically. I hope to refresh in everyone's mind that transportation safety is not only engineering business; it is everybody's business. The Transportation Research Board (TRB) has provided me with research-based tools and peer-to-peer learning, not to mention the knowledge I've gained during the four times I've attended the TRB Annual Meeting in Washington, D.C., over the last decade. I have been given many opportunities to connect with experts in the field, as well as an avenue to publish valuable technical reports. I will value and utilize those opportunities regardless of where my career takes me.

—RUDYNAH CAPONE
Innovation and Technology Transfer Manager
Louisiana Transportation Research Center, Baton Rouge

Bill Rogers, senior program officer at TRB, retired on July 2, 2021, after 14 years.

Eileen Delaney, director of publications and publications senior advisor for TRB's Cooperative Research Programs, retired July 14, 2021, after 30 years.

Ray Derr, senior program officer at TRB, retired August 13, 2021, after 27 years.

Sharon Lamberton, an editor for TRB's Cooperative Research Programs, retired on August 31, 2021, after 9 years.

Sharon Feigon, founder in residence at Shared-Use Mobility Center in Chicago, Illinois, has retired. She has been an active member of the Standing Committee on Innovative Public Transportation Services and Technology.

Yu Zhang, former associate professor of civil and environmental engineering at the University of South Florida in Tampa, has been promoted to professor. She is the chair of the Standing Committee on Airfield and Airspace Performance, a member of the Aviation Group, and a panel member on NCHRP Project 20-113, "Research Roadmap: Transformational Technologies (other than CV/AV)."

Let's Hear From You!

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

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

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

That's it!

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

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

What is the most memorable experience you've had on public transit?

Snapshot of Essential Research

2022 TRB MINORITY STUDENT FELLOWS PROGRAM

KAREN FEBEY

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

Photos: Mona Arora and Ladd Keith, University of Arizona

TRB Minority Student Fellow Ash Avila (*right, main photo*) and mentor Nicole Iroz-Elardo set up their data collection equipment at an Arizona vaccination site in April. (*Inset*) A thermal camera image of the inside of a large vaccination tent at the site shows the effects of vehicle heat, a topic of study for Avila.

The 13th cohort of TRB's Minority Student Fellows Program will be comprised of student participants from 14 minority-serving institutions across the United States, which include historically Black colleges and universities, Hispanic-serving institutions, and American Indian/Alaska Native–serving institutions. From these 14 institutions, 25 student Fellows will participate, ranging in academic levels from those seeking bachelor's degrees to those working on PhDs.

Although most of the students are studying civil engineering, other students' degree programs include sustainable built environments, mechanical engineering, Earth science, electrical engineering, construction engineering, urban and regional planning, and industrial and systems engineering.

One major change to the Minority Student Fellows Program involves the Fellows' presentation of their research. Previously, Fellows presented their research in a session organized by the standing committee that reviewed their paper. This year, for the first time and on a pilot basis, Fellows will have a group poster session during which they will present their research together. With this change, Fellows and mentors will be able to interact better and learn about one another's research. The separate session also will provide a better forum to showcase the program and the Fellows' research while drawing more foot traffic from TRB Annual Meeting participants to their presentations.

This article provides mini profiles of the varied research interests and backgrounds of four of the student Fellows.

MIRIAM ALABI, NORTH CAROLINA A&T UNIVERSITY

Miriam Alabi is a doctoral candidate in industrial and systems engineering at North Carolina A&T University in Greensboro, North Carolina. Alabi came to the United States as an immigrant from Ghana, where she earned a bachelor's degree in geomatic engineering from Kwame Nkrumah University of Science and Technology in Kumasi, Ghana. She also worked at the Department of National Service's Ministry of Roads and Highways in Accra.

Alabi's research focuses on how intelligent transportation systems can play a role in mass emergency evacuations by characterizing people's decision-making behavior during an emergency evacuation. Specifically, she seeks to understand how individuals make decisions in an uncertain, time-constrained environment. In learning how decisions are made, Alabi hopes to be able to predict behavior with machine-learning algorithms. Her goal is to contribute to disaster management literature by providing data-supported models to guide decision-making when there is limited information.

Alabi's research has been informed by her work with her advisor, Professor of Industrial and Systems Engineering Younho Seong. Throughout her doctorate studies, Alabi noted that her research interests are in the areas of human factors, simulation, visualization, machine learning, and data analytics to improve human-related systems in the transportation sector. But her work as a graduate research assistant at the Center for Advanced Transportation Mobility (CATM) sparked her interest in transportation-related research.

At CATM, she was exposed to methods of inquiry that identify safe, reliable transportation solutions that can increase and improve mobility of vulnerable road users and can understand human behavior during emergency evacuations. At the Annual Meeting, Alabi hopes to build her career network and to be exposed to a range of diversified theories and concepts in her field.

ASH AVILA, UNIVERSITY OF ARIZONA

Ash Avila is a junior at the University of Arizona majoring in sustainable built environments, with a focus on sustainable communities and urban planning. For nearly two years, Avila has worked as an undergraduate research assistant at the University of Arizona's Smart Transportation Lab. There, she has worked on research such as the City of Tucson signal retiming project, which involved collecting and analyzing data to create time series diagrams and to analyze signal timing effectiveness.

Under the guidance of her advisor, Nicole Iroz-Elardo, assistant research professor in the School of Landscape Architecture and Planning, Avila will study the role of the built environment and the presence of vehicles on ambient air temperatures, radiant surface temperatures, and human thermal comfort at outdoor COVID-19 vaccination sites in Tucson. Specifically, her research will build on an ongoing project requested by the Pima County Office of Emergency Management aimed at evaluating microclimate heat risk. She will study the ambient air temperature; radiant surface temperature; and thermal comfort impacts on staff, volunteers, and clients attributable to vehicles at those sites.

Avila will focus on the effects linked directly to vehicles that likely increase heat risk through two mechanisms: emitting heat from the engine and exhaust and emitting heat from the shell of a vehicle (particularly those dark in color), which increases surface temperatures.

Avila recalls an anecdotal finding that the presence of idling vehicles may substantially increase the risk of heat effects during the 15-minute post-vaccination observation period as well as heat exposure of staff and volunteers. Her goal is to develop a study design that takes advantage of natural experimental conditions while isolating the effects of idling vehicle heat at the micro-scale, using ambient air temperature and thermal comfort measurements. Avila comments that her work applies to people in other situations related to vehicle heat, such as pedestrians near international border crossings as well as cyclists and pedestrians at busy intersections.

Avila looks forward to meeting people from various backgrounds in transportation to expand her professional network at the TRB Annual Meeting and to being exposed to research she hopes will inspire her as she begins her transportation career and her goal of pursuing a master's degree in urban planning.

NOREL McADOO, TENNESSEE STATE UNIVERSITY

Hailing from Little Rock, Arkansas, Norel McAdoo is beginning his senior year as a civil engineering student at Tennessee State University in Nashville. McAdoo was drawn to the transportation field because he believes it offers the opportunity to directly affect the safety of communities by reducing the number of crashes.

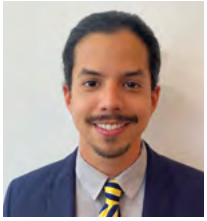
In the summer of 2019, McAdoo developed his research skills at the University of Nebraska–Lincoln's National Science Foundation–funded Research Experiences for Undergraduates when he worked on rural infrastructure sustainability projects using lidar and drone equipment to test the effectiveness of the resulting data near bodies of water.

McAdoo is an engineering intern at the Arkansas Department of Transportation, where he is working on identifying the best times for construction work to take place at various sites based on traffic volumes and lane capacities. He also participated in the I-40 Memphis Bridge Closure Project, collaborating with advanced engineers to evaluate new traffic trends and detour routes. Drawing on his work experiences and coursework in areas such as computer engineering graphics analysis, statics, soil mechanics, environmental engineering, and hydraulic engineering, McAdoo ultimately wants to work on transportation projects that improve communities.

At the TRB Annual Meeting, McAdoo will present research guided by his faculty mentor, Professor of Civil Engineering Deo Chimba. This research models secondary crashes in areas of the highway where scheduled or unscheduled roadwork was taking place. McAdoo explains that these crashes have been of great concern to transportation management authorities and can be related to factors such as traffic, environmental conditions, and roadway characteristics. He observes that not all primary incidents result in the occurrence of secondary crashes, so modeling secondary crashes can be challenging in terms of finding the appropriate model to evaluate the impact of dependent variables.

At the TRB Annual Meeting, McAdoo hopes to learn more about transportation issues related to his research and ultimately to be more prepared for a career as a transportation professional after graduation.

JESUS MOLINA, FLORIDA INTERNATIONAL UNIVERSITY



Jesus Molina is beginning his senior year as a civil engineering student at Florida International University in Miami. Focusing on transportation, Molina has acquired expertise through coursework in traffic engineering and highway geometric design. Under the guidance of his faculty mentor, Associate Professor of Civil and Environmental Engineering Priyanka Alluri, Molina is studying possible short-term effects on traffic crash frequencies in the week before and the week after the beginning and end of daylight savings time. Molina will examine Florida state crash data between

the years of 1983 to 2019 by using statistical tests to compare any difference in crash frequency.

An immigrant from Venezuela, Molina comments that his interest in transportation was sparked during his first trip to the United States when he observed how efficient the transportation infrastructure seemed. Since beginning his studies at Miami Dade College, where he obtained his associate's degree, he has acquired expertise in computer-aided design, working for two companies on architectural design drawings. When he graduates with his bachelor's degree in April 2022, Molina would like to secure a position as an entry-level engineer. He is particularly excited to attend the TRB Annual Meeting so that he can begin to put into practice what he has learned about transportation and other topics.

Photo: Patrick Lu, Flickr

Plaza Saltillo, a Capital Metropolitan Transportation Authority commuter rail station and living and working complex in Austin, Texas, is an example of a mixed-use joint development on transit authority land, also known as "on-site" joint development.

TCRP RESEARCH REPORT 224

Guide to Joint Development for Public Transportation Agencies

ALDEN S. RAINE

The author is National Practice Leader in Transit-Oriented Development with AECOM in Boston, Massachusetts.

Transit-oriented development (TOD) is at the center of virtually every discussion about smart growth, equitable development, and climate change. In that light, it's no surprise that joint development—that is, TOD in which a transit agency is a participant—is a topic of growing interest not only to transit agencies themselves but also to developers, local governments, and community stakeholders.

Some U.S. transit agencies have been in the joint development business for decades, with a portfolio of projects and experience under their belts; some have completed a project or two; and others have not yet ventured into joint development and are unsure whether or how they might proceed.

In 2018, the Transportation Research Board, through the Transit Cooperative Research Program (TCRP) and with the support of the Federal Transit Administration (FTA), launched an effort to create a practical, experience-based guidebook. The team, led by the author and including a broad array of the nation's top TOD experts, was supported by a project panel of senior consultants, practitioners, and agency officials. *TCRP Research Report 224: Guide to Joint Development for Public Transportation Agencies* (the Guide) was published earlier this year.

For more information and to download a copy of *TCRP Research Report 224: Guide to Joint Development for Public Transportation Agencies*, visit https://doi.org/10.17226/26045.

DEVELOPING THE GUIDE

Underlying the Guide was a months-long research program in which the team conducted structured, in-depth interviews with 32 transit agencies, 18 local or regional government agencies, and 17 private developers and investors. The interviewees were chosen to represent regional diversity; the full range of transit markets by size, complexity, service modes, and extent of TOD or joint development experience; different types of local government entities; and, on the private side, for-profit and nonprofit corporations from the affordable housing, market-rate housing, commercial, and mixed-use sectors.

The Guide consists of two main sections. The first is a set of chapters that takes the reader through the joint development process in a series of sequential steps—from organizing the program to planning a specific project, selecting a developer, negotiating the agreement, closing on the real estate transaction, and seeing it through construction, occupancy, and beyond.

The second section addresses strategic issues that cut across the sequential process. These key issues include the role of FTA; the economics of a joint development project, with emphasis on parking and affordable housing as important deal-drivers encouraged by public policy; and the variety of business models emerging at the cutting edge of joint development practice.

A volume of nine technical appendices presents the research results and accompanying literature review in detail.

KEY FINDINGS

Among the Guide's key findings and recommendations, several stand out:

- The opportunity for joint development is widely available. It is not limited to transit agency land or to large agencies with rail systems. It can also occur with or without the involvement of FTA, which, although potentially very helpful, arises only in certain circumstances.
- Transit agencies undertake joint development for three main reasons: to monetize a real estate asset, enhance ridership, and influence land use in their station areas and corridors. Agencies must decide—with buy-in from transit agency board members and senior executives—how to prioritize these goals and translate them into program and project-level decisions.
- Organization matters. An agency should empower a TOD or joint development director, visible to senior leadership, who can recruit the necessary staff and consultant skills, coordinate proactively with internal and external stakeholders, and see an opportunity through the eyes of developers and local officials.
- Increasingly, views on joint development are converging among transit agencies, TOD developers, and local officials. Although this consensus is hardly universal, the opposing beliefs—that "TOD is illegal" (under typical zoning) or that "developers and transit agencies are from different planets," or that transit agencies are in the mobility business and "don't do land use"—are being eclipsed by aligned interests and shared experiences among agencies and developers.
- In dealing with developers, it is essential for transit agencies to understand existing market demand as it affects property use and disposition. Closely related is the concept of residual land value and the trade-offs between simple land price and other desired benefits, as these conditions have a major impact on private-sector interest and support in any development project.
- Local government agencies may be regulators, development partners, major sources of financing, or stakeholder managers. There is no substitute for coordinating with local agencies early and often—especially if a zoning change or some form of regulatory relief is required to make a project work.
- Agencies should publish explicit policies for two everyday stewardship issues: their procedure with respect to unsolicited proposals and their preferred method of conveying development rights. Many agencies prefer long-term lease or partnership arrangements rather than outright sales of land.
- Developer selection, although critical, is the tip of the iceberg. Presolicitation planning and "test-fitting" almost always pay dividends. Nor does implementation end when a developer agreement is signed. Implementation requires the capacity to oversee design and construction; manage future phases, if applicable; and enforce the negotiated terms.

Joint development does not end up transit-oriented by accident. In forming projects, agencies must be explicit, creative, and intentional in their approach to land use, development density, parking, housing affordability, and urban design. When these projects succeed, they help create a built environment that is sustainable, equitable, productive, and community-based.

State of Research on Automated Vehicles and Shared Mobility

TOPICAL PAPERS FROM A TRANSPORTATION RESEARCH BOARD FORUM

KATHERINE KORTUM

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

For those wanting to better understand the state of research on automated vehicles and shared mobility, the National Academies–TRB Forum on Preparing for Automated Vehicles and Shared Mobility (the Forum) can help. The Forum brings together public, private, and research organizations to share perspectives, identify and facilitate research, and inform policy on critical issues for deploying automated vehicles (AVs) and shared mobility.[1]

In coordination with the National Cooperative Highway Research Program (NCHRP) and engineering services company Stantec, the Forum has developed nine papers summarizing each of its most critical research issues: data, safety, infrastructure, social impacts, equity, freight, transit, planning and modeling, and land use. (More details about each paper follow.)

Each paper includes a description of the issues; key findings; research completed, under way, and planned; and remaining research gaps. More specifically, the goal of each paper is to provide a snapshot of all research on that specific topic that was completed as of September 2020. Collectively, these papers establish a foundation for further development and comprehensive research that tracks the identified research gaps.

[1] More information is available at https://trb.org/AVSMForum.

Graphic: Stantec

Critical issues that surround AVs and shared mobility were the focus of representatives from public, private, and research organizations at the National Academies–TRB Forum on Preparing for Automated Vehicles and Shared Mobility.

Following are key findings from each of the nine papers, presented along with links to the documents themselves.

MODELS FOR DATA SHARING AND GOVERNANCE

For more, visit http://onlinepubs.trb.org/onlinepubs/AVSMForum/products/1-NCHRP_Data_Sharing_and_Governance_Final_10-28-20v2.pdf.

- The discussion around data sharing and AVs needs to be narrowed around anticipated use cases.
- Regulations implemented for new mobility are being developed in isolation from data standards.
- New privacy laws may affect the government's ability to collect data for safe operations.
- Consumer interests around privacy and data security will likely play a role in the public adoption of AVs and the continued use of shared mobility.
- Consistent frameworks are needed for navigating open records requests and law enforcement requests for data.

SAFETY SCENARIOS AND ENGAGEMENT DURING TRANSITION TO HIGHLY AUTOMATED VEHICLES

For more, visit http://onlinepubs.trb.org/onlinepubs/AVSMForum/products/2-NCHRP_Safety_Paper_Final_10-28-20v2.pdf.

- Safety scenarios are a core building block in most alternative approaches to ensuring the safety of highly automated vehicles (HAVs).
- Most research on testing remains proprietary.
- The roles and responsibilities in creating, adopting, and enforcing regulatory safety standards follow traditional federal, state, and local allocation of responsibility.
- Exclusively relying on test tracks and road testing will delay research.
- New safety methods under development include such approaches as third-party validation or performance-based standards.
- Demonstration programs can provide meaningful lessons and the opportunity to evaluate safety assurance programs in a constrained environment with a single modal vehicle type.

INFRASTRUCTURE ENABLERS FOR AVs AND SHARED MOBILITY

For more, visit http://onlinepubs.trb.org/onlinepubs/AVSMForum/products/3-NCHRP_Infrastructure_Final_10-28-20v2.pdf.

- Understandably, the current infrastructure is designed for human drivers.
- Lane markings, traffic signals, and road signs should be readable by AVs.
- Vehicle-to-infrastructure technology will play an important role in the future and will require government investment.
- Long-term impacts of AVs and shared mobility on physical infrastructure remain unknown.
- Increased investment in traveler assistance services—including mounted variable messaging, 511 systems, and traffic management—may be unnecessary or redundant over time.
- Research has shown the largest impacts in the following areas: setting regulatory policy, encouraging pilot developments, identifying work zones, and managing data frameworks.

MAXIMIZING POSITIVE SOCIAL IMPACTS OF AUTOMATED VEHICLE DEPLOYMENT AND SHARED MOBILITY

For more, visit http://onlinepubs.trb.org/onlinepubs/AVSMForum/products/4-NCHRP_Paper_Social_Impacts_Final_10-28-20v2.pdf.

- AVs powered by electricity and deployed in shared-use models offer social benefits.
- Concerns about the impacts of AVs on jobs is a topic to address.
- Policy frameworks should be aligned around measurable goals with respect to decreased vehicle miles traveled, electrification, and shared use, as well as equity outcomes.

Graphic: Stantec

Of particular importance are the effects of AVs on vulnerable and marginalized communities. Although these vehicles can increase access to transportation, at present they do not meet the needs of all users. It is crucial to address barriers to equitable and accessible deployment of AVs.

- Public engagement is a key in maximizing adoption and promoting positive outcomes.

PRIORITIZING EQUITY, ACCESSIBILITY AND INCLUSION AROUND THE DEPLOYMENT OF AUTOMATED VEHICLES

For more, visit http://onlinepubs.trb.org/onlinepubs/AVSMForum/products/5-NCHRP_Paper_Equity_Final_10-28-20v2.pdf.

- AVs can increase access to transportation.
- Barriers to equitable and accessible deployment must be addressed.
- To date, AVs on the road do not meet the needs of all users.
- The potential use of artificial intelligence combined with the expected increased reliance on digital applications raises new issues around potential discrimination.

POTENTIAL FOR IMPACTS OF HIGHLY AUTOMATED VEHICLES AND SHARED MOBILITY ON THE MOVEMENT OF GOODS AND PEOPLE

For more, visit http://onlinepubs.trb.org/onlinepubs/AVSMForum/products/6-NCHRP_Freight_Final_10-28-20v2.pdf.

- Freight applications of HAV technology are among the most active.
- HAVs for freight encompass a broad range of use cases and operating environments.
- Job loss related to highly automated trucking is an important topic in current research.
- Automated heavy-duty trucks offer significant fuel savings compared with traditional trucks.
- Automated transportation for people and goods increases challenges in managing competing curb uses.

IMPACTS OF AUTOMATED VEHICLES AND SHARED MOBILITY ON TRANSIT AND PARTNERSHIP OPPORTUNITIES

For more, visit http://onlinepubs.trb.org/onlinepubs/AVSMForum/products/7-NCHRP_Transit_Final_10-28-20v2.pdf.

- Partnerships with AV and other smart mobility service providers can increase shared mobility options and, perhaps, transit connections.
- Early planning for mobility hubs at transit stations and centers includes provisions to support shared and individually owned AVs.
- "Public transportation" definitions in federal, state, and local law and regulations require updating to account for new partnership models and on-demand services.
- Use cases for shared AV services include first–last mile, fixed-route, paratransit, and circulator services, each of which could expand the impact of transit and expand mobility in areas not served by transit.
- AV partnerships also present opportunities to connect on the first and last 50 miles of a journey, with a particular focus on rural service.
- Once they are deployed in large numbers, HAVs will reduce the number of driver positions.

IMPLICATIONS FOR PLANNING AND MODELING

For more, visit http://onlinepubs.trb.org/onlinepubs/AVSMForum/products/8-NCHRP_Paper_Planning_Final_10-28-20v2.pdf.

- It is not yet the norm to include AV and shared mobility in long-range transportation plans, but these discussions are increasing dramatically.
- Planning for uncertainty is an area that remains under development.
- Modeling for "Zero Occupancy" or other characteristics for AVs needs emphasis.
- Market acceptance remains the critical unknown force for modeling and planning.
- Incorporating new modes into traditional models remains a challenge.
- Demonstration programs provide meaningful lessons, but the knowledge transfer elements of these demonstrations are burdened by the substantial evolution of services and technologies.

IMPACTS AND OPPORTUNITIES AROUND LAND USE AND AUTOMATED VEHICLES AND SHARED MOBILITY

For more, visit http://onlinepubs.trb.org/onlinepubs/AVSMForum/products/9-NCHRP_Final_Draft_Land_Use_Final_10-28-20v2.pdf.

- Shifts to HAVs and greater shared-mobility strategies will affect land use patterns, particularly in the urban environment.
- Management of the public right-of-way in an era of increased AVs can lead to greater shared mobility, equity, and accessibility.
- 5G telecommunications may require up to five times the number of small cells as 4G, leading to more land use conflicts in urban areas, heavy investment requirements in rural communities, and a much higher level of regulatory involvement.

TRR Journal

THE CARRIER FOR FREIGHT RESEARCH

TRR Focus Issue on Freight Transportation Automation, Logistics, and Supply Chains, submission deadline November 30, 2021.

As growth in e-commerce has demonstrated the importance of freight to regional economies, the COVID-19 pandemic has underscored how freight movement affects everyone. Researchers and practitioners solving critical freight problems across the globe have had few options for publishing their findings in a quality journal with a good reputation and turnaround time. So the *Transportation Research Record* (*TRR*), TRB's flagship journal, has stepped in to put freight and marine research front and center by providing a dedicated space for publishing theory and practice-ready research.

To show its commitment toward freight and marine research, *TRR* is publishing a Focus Issue on the broad theme of freight and intermodal transportation automation, logistics, and supply chains, covering the private and public sectors.

Sushant Sharma, chair of the Standing Committee on Freight Transportation Planning and Logistics, is the issue's lead editor, supported by well-known national and international freight experts as guest editors.

Of particular interest are papers advancing state-of-the-art theories, design practices, or operations; exploring the role of automation in the freight industry and freight planning, including information technologies, new modeling tools, and data-sharing paradigms; and addressing the impacts on logistics and supply chains, international trade, multimodal infrastructure, equity, and environmental sustainability. Papers are welcome on urban or rural, mode-specific or intermodal, public or private, and regional or global freight topics.

Paper submissions are open through November 2021. The first review and decision will be provided within three months, and the papers will be made freely available via an open-access link.

Please note that the papers in this Focus Issue are for publication in the *TRR* only. Paper submission for the 2022 TRB Annual Meeting will be conducted under a separate and distinct process.

For more information, visit https://trb.secure-platform.com/a/page/trrfreight.

VOLUNTEER VOICES

"Transportation is meaningful across all societies for many different reasons. I chose a career that connected me to things that matter to all of us. I stay in this industry because of the variety of people and projects that I get to work with every day. There is always a new challenge to overcome or skill set to learn.

—SUSAN HEAP
Director, Asset Management Business Advisory, Central Region
WSP, Austin, Texas

What's in Your Tank?

Drive along any U.S. highway and you'll notice there are a lot of electric vehicles (EVs). With advances that allow EVs to go farther per charge, rising gasoline prices, and even a shaken sense of consumer confidence after the Colonial Pipeline disruption, it makes sense that EVs will increase in popularity.

Photo: Michael Fousert, Unsplash

A yellow cord is a visual giveaway that this vehicle is powered by electricity. Says Radboud University Nijmegen's Florian Knobloch, lead study researcher: "The idea that electric vehicles could increase CO_2 emissions is essentially a myth."

Whatever the reason for this surge in replacing older, gas-powered cars with EVs, will there be a visible decrease in global carbon dioxide (CO_2) emissions? The answer—in part—requires knowing the source of the electricity that powers EVs.

Electricity throughout the world is produced by different means—from high CO_2-producing methods like burning coal to zero-emission renewables.

Research from Radboud University Nijmegen in the Netherlands and the universities of Exeter and Cambridge in England concluded that in 95 percent of the world, driving an electric car is better for the climate than a conventional gas-engine car. The same study looked at a scenario in which half of all cars in use are electric—something researchers project will happen by 2050.

For more information on electric vehicles and CO_2 emissions, visit https://www.sciencedaily.com/releases/2020/03/200323125602.htm.

INTERNATIONAL

The New *Mayflower* Aims to Make History

With no passengers and crew, the *Mayflower Autonomous Ship*, or MAS, will make history while retracing the Pilgrims' 1620 *Mayflower* transatlantic journey from Plymouth, England, to what the Pilgrims named Plymouth, near present-day Cape Cod, Massachusetts. Speeches, naming, and the ceremonial pouring of a bottle of Plymouth Gin on the high-tech ship were part of the official launch in the UK on September 16, 2020, exactly 400 years after the original *Mayflower*.

The fully autonomous marine research vessel's journey began June 15, 2021, after a delay from the pandemic. However, at this writing, MAS is back at its UK base after stopping and reporting a malfunction three days into the trip. A fractured coupling between the ship's generator and exhaust system caused the problem. MAS's solar panels may have produced enough power to propel the vessel, but the weather was bad. These setbacks are an eerie echo of the delays that forced the original *Mayflower* to leave later than planned in the rough seas of September instead of in July. When the journey restarts, the trip should take MAS about three weeks—roughly one-third the time of the 1620 *Mayflower* voyage. When MAS retraces the original route, it will make history as the world's largest autonomous ship to cross the Atlantic.

The cloud-based artificial intelligence (AI) Captain, which enables this sleek trimaran vessel to sense, think, and make decisions, conveyed the malfunction via Twitter. Machine learning and automation software ensure that its decisions are safe and follow collision regulations throughout the more than 3,000-mile trip.

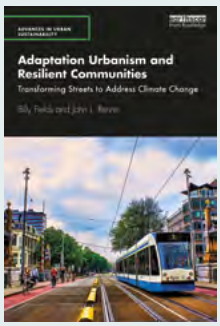
The AI Captain is supported by onboard systems that report back like a traditional ship's crew. MAS's radar detects hazards within 2.5 nautical miles, and onboard cameras send visual data to a computer vision system to identify those hazards. An automatic identification system reports nearby ship particulars, such as class, weight, speed, and cargo. The AI Captain gets weather updates and can even "taste" the ocean salt with an AI-assisted electronic tongue called Hypertaste that enables fast onboard analysis of ocean chemistry.

Photo: IBM Newsroom

Slicing through the water during a sea trial, the *Mayflower Autonomous Ship* showcases advanced maritime technology. But that's only part of the story. Events surrounding the commemoration of the historic voyage focus on inclusion and take a contemporary look at the consequences of contact for the UK, the Netherlands, the United States, and the people of the Wampanoag Nation.

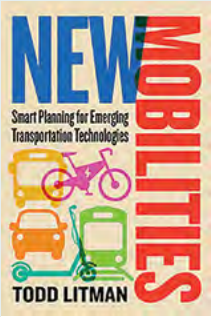
Experiments and data collection will focus on gaining a better understanding of the ocean, marine mammals, and tides. For example, MAS's high-definition video and accelerometers will calculate the enormous power of waves in the open ocean. Imagine if scientists could harness that wave energy. This data-intensive research may lead to a new source of sustainable, renewable energy.

Learn more at https://mas400.com.



Adaptation Urbanism and Resilient Communities: Transforming Streets to Address Climate Change
Billy Fields and John L. Renne. Routledge, 2021, 264 pp., $44.95, 978-1-642-83145-0.

Via a series of case studies, the authors outline and explain adaptation urbanism as a theoretical framework for understanding and evaluating resilience projects in cities and relate it to pressing contemporary policy issues akin to urban climate change mitigation and adaptation.



New Mobilities: Smart Planning for Emerging Transportation Technologies
Todd Litman. Island Press, 2021, 208 pp., $35, 978-0-367-13495-2.

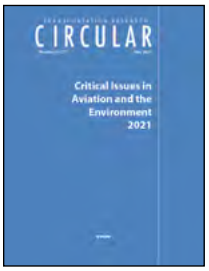
The author examines emerging transportation technologies and services, including public transit innovations, bike sharing, teleworking, ride-hailing, and autonomous vehicles, and evaluates them according to such factors as the current status of the technology, user experience, economic opportunity and fairness, and benefits versus costs.

Automated People Mover Standards
American Society of Civil Engineers, 2021, 114 pp., $150, 978-0-784-41557-3.

This standard, ANSI/ASCE/T&DI 21-21, establishes the minimum requirements necessary to achieve an acceptable level of safety and performance for an automated people mover (APM) system, or a fully automated guided transit mode featuring vehicles that operate on guideways with exclusive right-of-way. This standard covers the design, construction, operation, and maintenance of APM systems.

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

TRB PUBLICATIONS



Critical Issues in Aviation and the Environment 2021
Transportation Research Circular E-C271

The aviation industry and federal government are investing significant resources into understanding and minimizing aviation-related environmental impacts, but in some cases, environmental concerns constrain aviation system capacity. This volume summarizes the progress made to date and offers recommendations for additional research to help achieve and mitigate environmental impacts.

For more information, visit www.trb.org/Main/Blurbs/182198.aspx.

Transportation Research Record 2675
Issue 2

Authors present research on the influence of lane width on bus crashes, user experiences with two new wheelchair securement systems in large accessible transit vehicles, and overcoming challenges of distributed fiber-optic sensing for highway traffic monitoring.

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

Transportation Research Record 2675
Issue 3

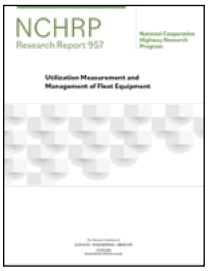
Featured in this issue is an evaluation of in-vehicle sound and vibration during incursions on sinusoidal rumble strips. Authors also examine integrated overnight train scheduling and maintenance planning for high-speed railway lines and develop citywide hurricane impact maps using real-life data on infrastructure, vegetation, and weather.

2021; 404 pp. For more information, visit http://journals.sagepub.com/home/trr.

Transportation Research Record 2675 Issue 4

Among the topics examined in this volume are a simulation model of crowd evacuation navigation in a multiobstacle environment, the role of urban big data in travel behavior research, and an evaluation of network-level data collection variability and its influence on pavement evaluation utilizing the random forest method.

2021; 405 pp. For more information, visit http://journals.sagepub.com/home/trr.



Utilization Measurement and Management of Fleet Equipment
NCHRP Research Report 957

This report is both a handbook on equipment utilization concepts and a guide for making cost-effective equipment utilization decisions. Included is utilization prediction and management software, which allows users to estimate equipment utilization and manage the fleet at a regional level.

2021; 82 pp.; TRB affiliates, $55.50; TRB nonaffiliates, $74. Subscriber categories: maintenance and preservation, vehicles and equipment.

Electrochemical Test Methods to Evaluate the Corrosion Potential of Earthen Materials
NCHRP Research Report 958

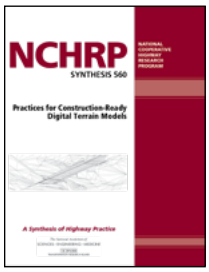
This report presents a protocol for evaluating the corrosion potential of earthen materials in contact with steel highway structures.

2021; 78 pp.; TRB affiliates, $55.50; nonaffiliates, $74. Subscriber categories: construction, geotechnology, materials.

Diverging Diamond Interchange Informational Guide, Second Edition
NCHRP Research Report 959

This report presents a comprehensive guide to the design and operation of diverging diamond interchanges and updates material found in the Federal Highway Administration's *Diverging Diamond Interchange Informational Guide*. Also available are videos from the workshop, as well as a workshop summary.

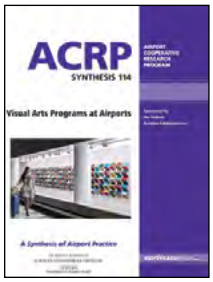
2021; 238 pp.; TRB affiliates, $74.25; nonaffiliates, $99. Subscriber categories: design, highways, operations and traffic management.



Practices for Construction-Ready Digital Terrain Models
NCHRP Synthesis 560

This synthesis documents processes and strategies used by state departments of transportation for the use and transfer of digital terrain models from design into the construction phase of highway projects.

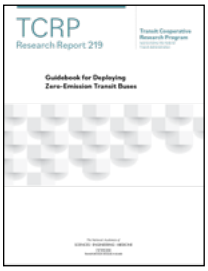
2021; 96 pp.; TRB affiliates, $55.50; nonaffiliates, $74. Subscriber categories: highways, data and information technology, design.



Visual Arts Programs at Airports
ACRP Synthesis 114

This synthesis is an initial compilation of practices used by airport arts professionals for understanding the operations, management, and benefits of temporary visual arts programs at their airports. Every airport that aspires to high ratings must offer an engaging arts program, as these yield many additional benefits for airports, passengers, and surrounding communities.

2020; 50 pp.; TRB affiliates, $44.25; nonaffiliates, $59. Subscriber category: aviation.



Guidebook for Deploying Zero-Emission Transit Buses
TCRP Research Report 219

This report provides transit agencies with information on current best practices for zero-emission bus deployments and lessons learned from previous deployments, industry experts, and available industry resources.

2021; 170 pp; TRB affiliates, $70.50; nonaffiliates, $94. Subscriber categories: public transportation, vehicles and equipment.

Low-Speed Automated Vehicles (LSAVs) in Public Transportation
TCRP Research Report 220

This report presents current use cases for LSAVs and provides a practitioner guide for planning and implementing LSAV services as a new public transportation service.

2021; 120 pp.; TRB affiliates, $59.25; nonaffiliates, $79. Subscriber categories: public transportation, passenger transportation, planning and forecasting.

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

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.

MEETINGS, WEBINARS, AND WORKSHOPS

August

24–27 Highway Capacity and Quality of Service
Online
For more information, contact Richard Cunard, TRB, 202-334-2963, RCunard@nas.edu.

25 TRB Webinar: Evaluating and Rating Unsurfaced Roads
For more information, contact Elaine Ferrell, TRB, 202-334-2399, TRBwebinar@nas.edu.

26 TRB Webinar: Use and Design of Low-Density Cellular Concrete
Online
For more information, contact, Elaine Ferrell, TRB, 202-334-2399, TRBwebinar@nas.edu.

30 TRB Webinar: Fixing the Bump at the End of the Bridge
For more information, contact Elaine Ferrell, TRB, 202-334-2399, TRBwebinar@nas.edu.

31 International Workshop on Structural Health Monitoring*
Online
For more information, contact Stephen Maher, TRB, 202-334-2955, SMaher@nas.edu.

31 TRB Webinar: LED Roadway Lighting's Effect on Driver Sleep Health and Alertness
For more information, contact Elaine Ferrell, TRB, 202-334-2399, TRBwebinar@nas.edu.

September

2–3 International Workshop on Structural Health Monitoring*
Online
For more information, contact Stephen Maher, TRB, 202-334-2955, SMaher@nas.edu.

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."

9–14 Conference on Advancing Transportation Equity
Online
For more information, contact Gary Jenkins, TRB, 202-334-2311, GJenkins@nas.edu, or visit https://trb.secure-platform.com/a/page/transportationequity.

13–15 60th Annual Workshop on Transportation Law
For more information, contact Robert Shea, TRB, 202-334-3209, RShea@nas.edu.

*TRB is cosponsor of the meeting.

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.

In Memoriam

Terrence McCleary, owner of and chief geotechnical engineer at McCleary Engineering in Peru, Illinois, died May 14, 2020. He was a knowledgeable and active panel member on NCHRP Project 24-48, "Develop a Formula for Determining Scour Depth Around Structures in Gravel-Bed Rivers."

Barbara Donovan, retired public transit program manager at the Vermont Agency of Transportation, died December 20, 2020. She was a panel member on NCHRP Project 23-04, "Statewide Insurance Pooling for Public Transit."

INFORMATION FOR CONTRIBUTORS TO **TR NEWS**

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

ARTICLES

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

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

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

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

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

OTHER CONTENT

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

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

SUBMISSION REQUIREMENTS:

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

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

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