



March 2024

PORT INFRASTRUCTURE

U.S. Ports Have Adopted Some Automation Technologies and Report Varied Effects

GAO Highlights

Highlights of [GAO-24-106498](#), a report to congressional committees

Why GAO Did This Study

U.S. ports' ability to efficiently move containers into and out of terminals is crucial for the U.S. economy. In 2020, coastal ports handled cargo that accounted for nearly half of U.S. trade. Faced with increased container volumes and supply chain challenges, some ports in the U.S. and abroad have adopted automation technologies to improve performance and increase capacity.

The Ocean Shipping Reform Act of 2022 included a provision for GAO to describe the adoption of technologies at U.S. ports as compared to foreign ports. This report describes: (1) the adoption of automation technologies by selected U.S. container ports and similarities to technologies adopted by selected foreign container ports; (2) the reported effects of port automation technologies; (3) how U.S. terminal operators consider these effects and other factors when deciding whether to adopt automation technologies; and (4) federal activities related to the development or adoption of port automation technologies.

GAO analyzed information from equipment manufacturers, ports, and terminal operators. These ports included the 10 largest U.S. container ports by volume and 10 foreign ports selected for factors such as volume and location. GAO visited U.S. and foreign ports and interviewed port and terminal operator officials at these ports, as well as nine other industry stakeholders, including two labor unions. GAO also reviewed federal documents and interviewed officials from six federal entities.

View [GAO-24-106498](#). For more information, contact Andrew Von Ah at (202) 512-2834 or vonaha@gao.gov.

March 2024

PORT INFRASTRUCTURE

U.S. Ports Have Adopted Some Automation Technologies and Report Varied Effects

What GAO Found

Automation technology at ports reduces human involvement in processing and handling cargo. All of the 10 largest U.S. container ports have adopted automation technology to varying degrees. At least one terminal at each of these ports uses process automation technology to optimize, track, or communicate container movements (e.g., automated gate systems). Four also use automated cargo handling equipment to load, unload, and move containers. Selected foreign ports generally adopted more automation technologies than U.S. ports due to factors such as larger container volumes and variations in labor availability.

Automated Cargo Handling Equipment at TraPac Los Angeles Terminal



Source: GAO (photo). | GAO-24-106498

U.S. and international port stakeholders agreed that automation technologies can improve worker safety by separating humans from machines and can reduce emissions by improving efficiency. However, they reported mixed effects on the workforce, security, and performance. For example, a few terminal operators said automated equipment could stack containers more densely than conventional equipment, increasing capacity; others said this equipment moved containers more slowly than conventional equipment, reducing performance. Similarly, a few stakeholders said automation can reduce jobs; others said automation can create more comfortable work environments and new, higher-skilled positions.

Officials from U.S. ports and terminal operators said operators consider factors such as labor, costs, priorities, and operations when deciding whether to automate. The relative importance of these factors varies based on the unique circumstances of each port and terminal.

The Department of Transportation, the Environmental Protection Agency, and the Federal Maritime Commission conduct some activities that are related to port automation, though few of these activities are explicitly focused on port automation. For instance, GAO identified eight discretionary grant programs which do not explicitly support port automation, but which ports could use to acquire certain automation technologies.

Contents

Letter		1
	Background	4
	Selected U.S. and Foreign Ports Have Adopted Some Similar Technologies, but Automation is More Prevalent at Selected Foreign Ports	9
	Port Stakeholders Reported Mixed Effects of Port Automation Technologies	13
	U.S. Terminal Operators Consider Various Factors Based on Their Unique Circumstances When Deciding Whether to Automate	19
	Few Federal Activities Focus Exclusively on the Development and Adoption of Port Automation Technologies	23
	Agency Comments	31
Appendix I	Selected Port Stakeholders Interviewed	33
Appendix II	GAO Contact and Staff Acknowledgments	35
Tables		
	Table 1: Potential Effects of Port Automation Technologies Identified by Selected Stakeholders	14
	Table 2: Department of Transportation (DOT) Discretionary Grant Programs For Which Port Automation Technology Costs May Be Eligible	26
	Table 3: Environmental Protection Agency (EPA) Programs and Discretionary Grant Funding Related to Port Automation Technologies	28
	Table 4: List of Entities Interviewed	33
Figures		
	Figure 1: Examples of Process Automation Technologies in Marine Container Terminals	7
	Figure 2: Examples of Port Automation Technology in Marine Container Terminals	8
	Figure 3: Use of Automation Technology at 10 Largest U.S. Container Ports by Volume and Selected Foreign Container Ports as of June 2023	10

Figure 4: Use of Automated Cargo Handling Equipment and Annual Cargo Volume in Marine Container Terminals at Selected U.S. and Foreign Ports, as of 2019	12
Figure 5: Semi-automated Double Trolley Ship-to-shore Cranes and Automated Guided Vehicles	15
Figure 6: Automated Rail-mounted Gantry Cranes	18
Figure 7: Radio Frequency Identification (RFID) and Optical Character Recognition (OCR) Technologies	21

Abbreviations

AI	Artificial Intelligence
CMTS	Committee on the Marine Transportation System
DOT	Department of Transportation
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
FLOW	Freight Logistics Optimization Works program
FMC	Federal Maritime Commission
INFRA	Infrastructure for Rebuilding America program
ITS	Intelligent Transportation Systems
MARAD	Maritime Administration
MTDI	Maritime Transportation Data Initiative
OCR	Optical Character Recognition
RAISE	Rebuilding American Infrastructure with Sustainability and Equity program
RFID	Radiofrequency identification
TEU	Twenty-foot equivalent unit

This is a work of the U.S. government and is not subject to copyright protection in the United States. The published product may be reproduced and distributed in its entirety without further permission from GAO. However, because this work may contain copyrighted images or other material, permission from the copyright holder may be necessary if you wish to reproduce this material separately.



March 19, 2024

Congressional Committees

U.S. ports' ability to efficiently move containers into and out of terminals is crucial for the U.S. economy. In 2020, coastal ports handled nearly all container cargo coming into and leaving the U.S., which accounted for about \$1.5 trillion—or 40 percent—of U.S. trade, according to the U.S. Department of Transportation (DOT). According to DOT, container volumes have steadily increased in recent years. Moreover, U.S. ports and other parts of the global supply chain experienced unprecedented shifts in supply and demand during the COVID-19 pandemic. Faced with these higher volumes and other pandemic supply chain issues, such as equipment shortages, many ports in the U.S. and abroad have sought opportunities to increase their efficiency and capacity.¹

Some terminal operators are turning to automation—technology that can reduce human involvement—to increase the volume of containers they can move through terminals. For instance, many ports have installed hardware and software to coordinate the arrival of trucks with container availability and automate their entry and exit through terminal gates rather than relying on workers to manually check and record truck information. Other ports have introduced software platforms called port community systems that automatically share data on container movements with key stakeholders.

About half a dozen federal agencies and entities are involved in the oversight and modernization of port infrastructure, such as DOT and the Federal Maritime Commission (FMC). DOT, which also oversees the U.S. freight network, has identified the implementation of advanced transportation technologies—including at ports—as a policy goal for improving the performance and resilience of supply chains and facilitating freight movement.² Such technologies include some automation technologies like port community systems.

¹In this report, we define efficiency as performing the work with the fewest resources and productivity as the amount of work performed.

²DOT, *Supply Chain Assessment of the Transportation Industrial Base: Freight and Logistics* (Washington, D.C.: February 2022).

The Ocean Shipping Reform Act of 2022 included a provision for GAO to describe the adoption of technologies at U.S. ports as compared to foreign ports.³ In this report, we: (1) describe the adoption of automation technologies by selected U.S. container ports and similarities to technologies adopted by selected foreign container ports, (2) identify reported effects of port automation technologies, (3) describe how U.S. terminal operators consider these effects and other factors when deciding whether to adopt automation technologies, and (4) describe federal activities related to the development or adoption of port automation technologies.

To identify the types of technologies within our scope for all four objectives, we reviewed available literature and information from equipment manufacturers, and interviewed industry stakeholders. To obtain perspectives on all four objectives, we interviewed officials at U.S. ports and container terminals and foreign ports. We selected the 10 U.S. ports that had the greatest annual container volume in 2020—the most recent year for which data were available.⁴ We selected two container terminals at each of the six “landlord” ports (i.e., ports for which the port authority leases terminals to private terminal operators) for interviews based on factors such as the quantity and types of automation technologies used, and modernization efforts.⁵ We also selected 10 foreign ports from among the top 21 ports, measured by the greatest annual container volume in 2019, which is the most recent year for which data were available. We selected the 10 foreign ports for variation in

³Pub. L. No. 117-146, § 25, 136 Stat. 1272, 1286. Under the provision, GAO is to submit a report to Congress within 1 year of enactment. In response to this provision, we provided a briefing on preliminary results to appropriate congressional staff in June 2023.

⁴The 10 U.S. ports in our review were the ports of Los Angeles (CA), Long Beach (CA), New York and New Jersey (NY and NJ), Savannah (GA), Houston (TX), Virginia (VA), Oakland (CA), Charleston (SC), Tacoma (WA), and Seattle (WA). Because 2020 was an atypical year due to the COVID-19 pandemic, we also reviewed container volume data for 2019 to ensure that the 2020 data were not outliers and determined that the top 10 U.S. container ports by volume were the same in 2019 and 2020.

⁵Our U.S. port selection included five landlord port authorities (container operations at the ports of Seattle and Tacoma are overseen by the Northwest Seaport Alliance). The port authorities for the remaining four ports own and operate the container terminals.

annual container volume, location, and performance as measured by ship time in port.⁶

We conducted semi-structured interviews with port authority officials for all 10 selected U.S. ports, terminal operators for nine of the 12 selected U.S. container terminals, and port authority or terminal operator officials at four of the 10 selected foreign ports.⁷ In addition, we conducted semi-structured interviews with nine industry stakeholders, including four technology or equipment vendors, two industry organizations that we identified through interviews and a literature search, two unions, and one global shipping company. For more information on the stakeholders we interviewed, see appendix I.

To obtain information about the adoption of automation technologies by selected U.S. and foreign container ports, we reviewed public information on the types of automation technologies being used. This included information from port authority, terminal operator, and technology and equipment vendor websites and news and journal articles.⁸ In addition, we visited three ports and six terminals in the U.S. and two ports and three terminals in Belgium and the Netherlands.⁹ During these visits, we met with the respective port authorities to view equipment and interviewed terminal and port authority officials. We conducted two of the port authority interviews by phone.

To identify the effects of port automation technologies, we conducted a literature search for studies that analyzed the effects of port automation technologies at ports where such technologies had been implemented. We searched for relevant scholarly studies, conference papers, government reports, association/nonprofit publications, and trade/industry articles across multiple databases, including ProQuest, EBSCO, and SCOPUS. We performed these searches in June 2023 and included

⁶The 10 foreign ports in our review were the ports of Antwerp-Bruges (Belgium), Busan (South Korea), Guangzhou (China), Laem Chabang (Thailand), Dubai (United Arab Emirates), Qingdao (China), Rotterdam (Netherlands), Shanghai (China), Singapore (Singapore), and Tanjung Pelepas (Malaysia).

⁷We contacted representatives for the remaining three terminals for interviews and representatives either declined to be interviewed or did not respond.

⁸A terminal operator may be a private company or a port authority. We obtained similar information from ports during our interviews.

⁹We conducted site visits to terminals at the Ports of Los Angeles, Long Beach, and New York in the U.S. and terminals at the Ports of Antwerp-Bruges and Rotterdam abroad.

literature published since 2018. We did not identify sufficient literature to draw broad conclusions about the effects of port automation technology. We also sought data on the effects of automation technologies, but such data were not available.

To describe how U.S. terminal operators consider these effects and other factors when deciding whether to adopt automation technologies, we analyzed the information we collected through interviews with the selected U.S. port authorities and terminal operators described above. We analyzed this information to identify common themes and factors.

To identify federal activities related to port automation, we reviewed federal documents such as the Committee on the Marine Transportation System's (CMTS) *Comprehensive Matrix of Federal Roles in the Marine Transportation System* and asked selected port authorities, terminal operators, and industry stakeholders about the agencies they work with.¹⁰ We also interviewed officials from DOT, Maritime Administration (MARAD), Federal Highway Administration (FHWA), FMC, Environmental Protection Agency (EPA), and CMTS, and reviewed strategic plans for fiscal years 2017 through 2023, program documents, and discretionary grant information, such as Notices of Funding Opportunities.

We conducted this performance audit from January 2023 to March 2024 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

Container terminals are facilities at ports where cargo containers are transferred between different modes of transportation. For instance, a container may be transferred from a ship to a train or a truck for transport. Terminal operation at ports can be complex and involves a wide range of public and private sector actors. There are multiple federal agencies involved in various aspects of ports, including facilitating international

¹⁰CMTS's *Comprehensive Matrix of Federal Roles in the Marine Transportation System* details the roles and responsibilities of federal agencies across the marine transportation system. We focused on agencies that played a role in port infrastructure to identify agencies that may have activities related to port automation technologies. We excluded agencies and programs focused on security as we did not consider security technologies in our review.

trade, maintaining navigable waterways, modernizing port infrastructure, and ensuring port security. For example, DOT provides a variety of funding opportunities to ports to pursue activities, including construction, repair, and modernization of waterside port infrastructure such as bridges and docks, and landside infrastructure such as on-dock rail and roadways. Federal agencies, including DOT and others, also play a role in overseeing the commercial supply chain, in which marine container terminals serve as a key node.

In general, federal agencies do not have a role in port ownership and operation; rather, port facilities in the U.S. are generally owned by a port authority, which is a state or local government entity. Terminal operators may be a private company that leases out the terminal from the port authority (i.e., a landlord model), or the port authority itself (i.e., an operational model). Some private companies operate multiple terminals within the U.S. and around the world. Globally, private companies or government agencies may operate ports. Container terminal operations require coordination between ports and terminal operators, ocean carriers, shippers, beneficial cargo owners, railroads, and motor carriers to efficiently move containers from vessels to ground transport for distribution.¹¹

Container terminals use a variety of heavy equipment and technologies to support their operations and over the past 20 years have increasingly incorporated automation. Automation is technology that modifies physical or cognitive processes to make them more automatic by reducing human involvement.¹² Port automation technology varies in the degree to which it requires human operation. For example, some technologies require a human operator located either within the cabin on the equipment or in a remote location to guide containers for the final inches of movement (i.e., semi-automated) and others require no human intervention (i.e., fully-automated).

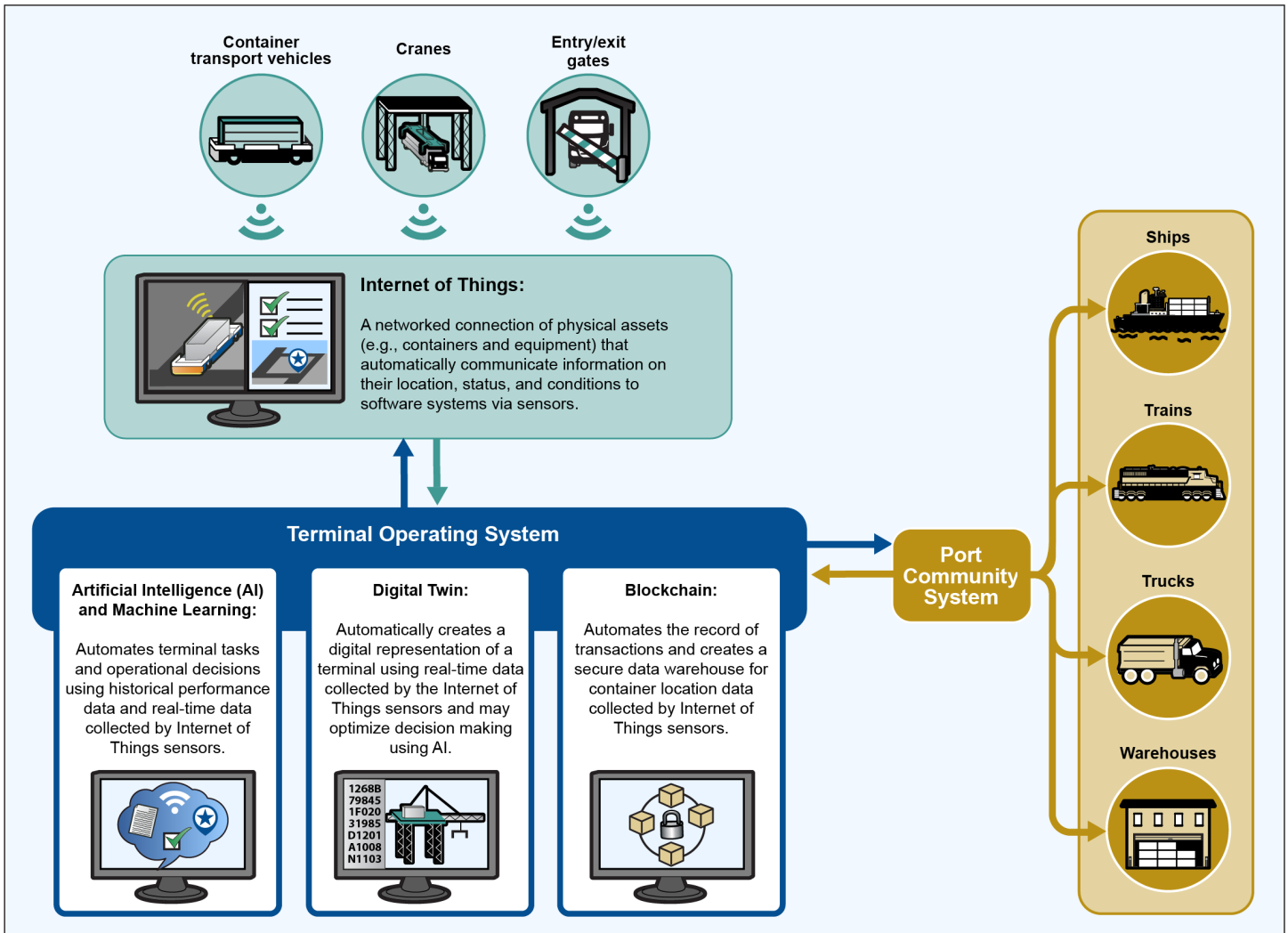
¹¹Shippers are the entities that supply or own the cargo being transported. Carriers are the companies that transport the cargo. Beneficial cargo owners are the importers that take possession of the cargo being shipped.

¹²See GAO, *Workforce Automation: Insights into Skills and Training Programs for Impacted Workers*, [GAO-22-105159](#) (Washington, D.C.: Aug. 17, 2022) and GAO, *Workforce Automation: Better Data Needed to Assess and Plan for Effects of Advanced Technologies on Jobs*, [GAO-19-257](#) (Washington, D.C.: Mar. 7, 2019).

In container terminals, automation technology includes process automation technologies and automated cargo handling equipment:

Process automation technologies reduce human involvement in optimizing, tracking, or communicating container movements. For example, an automated gate system uses sensors to collect information from trucks and containers that pass through a port's gates. These technologies can either replace or reduce the number of workers that are manually checking and recording this information. Many process automation technologies use software to perform tasks traditionally performed by workers. For example, digital ledgers can be used to record transactions and provide real-time monitoring of container location instead of a worker manually recording this information into a physical ledger. See figure 1 for examples of process automation technologies used at ports.

Figure 1: Examples of Process Automation Technologies in Marine Container Terminals

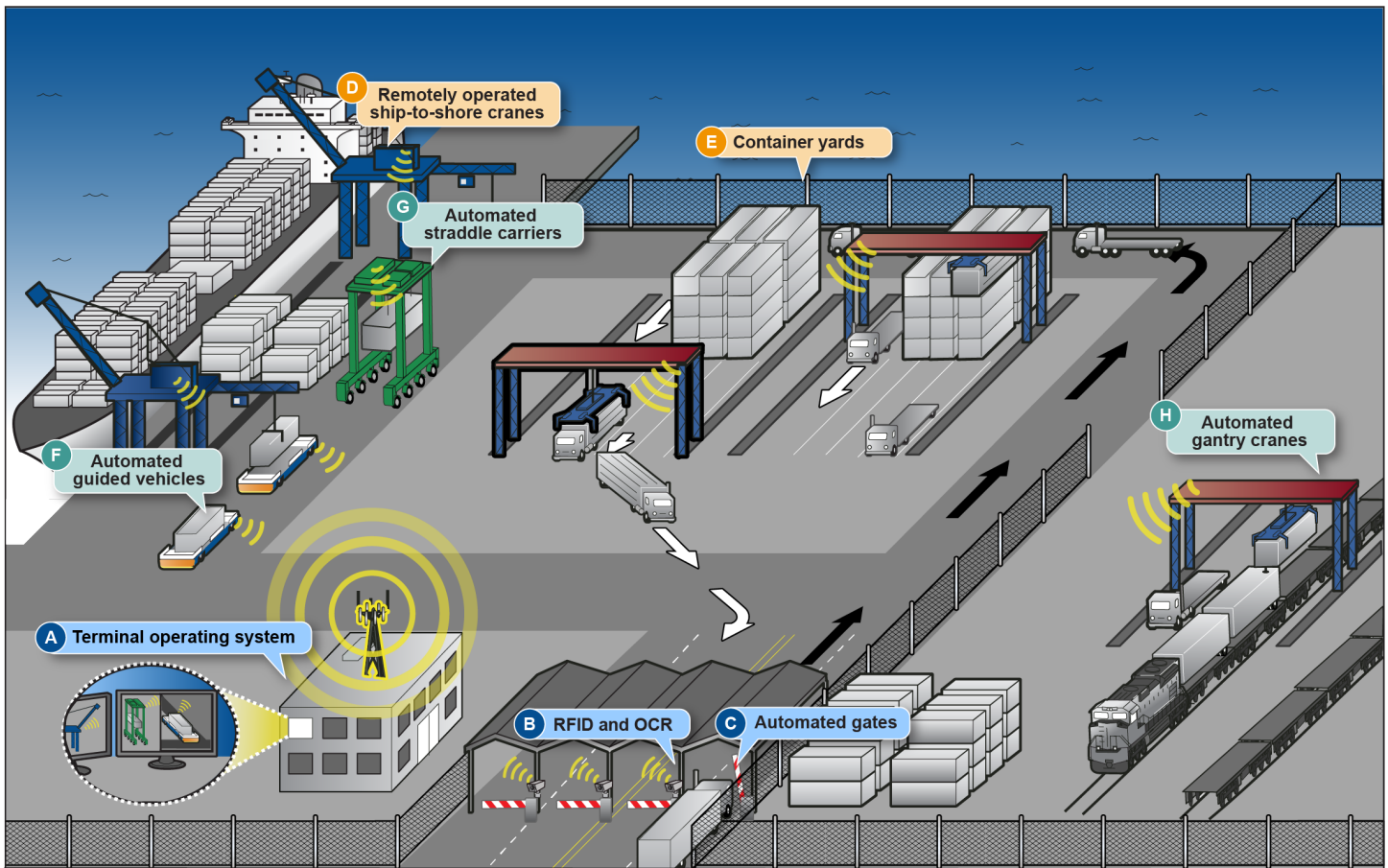


Source: GAO analysis of publicly available information and information provided by port officials and GAO (illustrations). | GAO-24-106498

Automated cargo handling equipment reduce human involvement in the loading, unloading, or movement of containers within the terminal. For example, an automated gantry crane stacks or transports containers to a truck or train. Automated gantry cranes can either be operated by software or by a worker located in a remote location to guide containers onto a truck chassis or train. This contrasts with conventional equipment that relies on an operator on the crane to move containers. See figure 2

for an illustration of automated cargo handling equipment that may be deployed in container terminals.

Figure 2: Examples of Port Automation Technology in Marine Container Terminals



- A Terminal operating system:** Software platform that communicates with all equipment and containers in the terminal and tracks and directs their movements based on the information from sensors and cameras.
- B RFID and OCR:** Radio frequency identification (RFID) sensors and optical character recognition (OCR) software in cameras collect, verify, and transmit data on the location of all equipment, vehicles, and containers entering, exiting, and waiting in the terminal.

- C Automated entry/exit gates:** Allows trucks to enter and exit without delay using RFID, OCR, and software.
- D Remotely operated ship-to-shore cranes:** A remotely located worker moves containers onto and off of vessels.
- E Container yards:** Containers wait for pickup with their location tracked by RFID and OCR.

- F Automated guided vehicles:** Move containers from the shipside to the yard without human intervention using sensors and software.
- G Automated straddle carriers:** Move containers from the shipside to the yard, or onto trucks, with little or no human intervention using sensors, cameras, and software.
- H Automated gantry cranes:** Stack or transport containers to trucks or trains with little or no human intervention using sensors, cameras, and software.

Source: GAO analysis of publicly available information and information provided by port officials and GAO (illustrations). | GAO-24-106498

Terminals do not typically adopt all port automation technologies at once.¹³ Terminals generally adopt simple process automation technologies, such as automated gates, first. These types of process automation technologies are easier to implement because they may use existing infrastructure and typically do not require large capital investments. Terminals then typically adopt automated cargo handling equipment, such as automated gantry cranes, which can be more complicated to implement because such equipment is costly and may require infrastructure changes. Lastly, terminals adopt more advanced process technologies, such as artificial intelligence and digital twins, to optimize port operations.¹⁴

Selected U.S. and Foreign Ports Have Adopted Some Similar Technologies, but Automation is More Prevalent at Selected Foreign Ports

The 10 largest U.S. container ports have all adopted some form of automation technology, but to varying degrees. All 10 U.S. ports that we included in our review have at least one terminal that has adopted one or more automation technologies we evaluated.¹⁵ More of these U.S. ports have adopted process automation technologies than automated cargo handling equipment. Terminals at all 10 ports use at least one type of process automation technology and terminals at four use at least one type of automated cargo handling equipment. The use of each technology within these ports varies by terminal. For example, at the Port of Long Beach, which has five container terminals, two of the terminals have adopted four or more types of automation technologies. In contrast, the other three terminals have three or fewer of the automation technologies we evaluated.

The foreign ports we reviewed have generally adopted more automation technologies than the 10 largest U.S. container ports and are more likely to use automated cargo handling equipment. All 10 of the selected foreign container ports have at least one terminal that has adopted a process automation technology; nine have at least one terminal that has adopted an automated cargo handling technology. See figure 3 below for more information about the adoption of each technology at selected U.S. and foreign ports.

¹³See for example, Theo Notteboom, Athanasios Pallis and Jean-Paul Rodrigue. *Port Economics, Management and Policy*, (New York: Routledge, 2022).

¹⁴A digital twin is a digital representation or “twin” of a physical object that allows for continuous monitoring, predictive analysis, and autonomous decision-making.

¹⁵The U.S. ports included in our review had between two and seven container terminals.

Figure 3: Use of Automation Technology at 10 Largest U.S. Container Ports by Volume and Selected Foreign Container Ports as of June 2023

Technology	Top 10 U.S. Container Ports ^a	Selected Foreign Container Ports ^b
Process Automation Data Systems and Technologies		
Automated Gate Systems Systems that use a combination of hardware, such as Radio Frequency Identification (RFID) tags and high-definition cameras, and software such as Optical Character Recognition, to allow trucks and containers to seamlessly enter and exit the terminal with no or limited human interaction.	1 2 3 4 5 6 7 8 9 10 	1 2 3 4 5 6 7 8 9 10
Port Community Systems Neutral and open electronic platforms that automatically exchange data between port stakeholders and optimize, manage, and automate logistics and supply chain processes through a single data access point.		
Artificial Intelligence (AI) and Machine Learning Systems AI software mimics and goes beyond human intelligence to automate tasks and decisions. Machine learning is a subset of AI that enables systems to identify patterns, make decisions, and improve themselves through experience and data without human intervention. Ports and terminals can incorporate AI and machine learning systems into their terminal operating systems to optimize scheduling and resource use.		
Digital Twin Technologies A digital representation or "twin" of a physical object that allows for continuous monitoring, predictive analysis, and autonomous decision-making. Ports can create their own digital twins to test new processes without affecting ongoing port operations.		
Blockchain Automated digital ledger technology that provides a trusted, tamper resistant record of transactions and can serve as an autonomous data clearinghouse when paired with the Internet of Things. Blockchain verifies transactions and prevents data modification by sharing cargo transaction details with all users participating in the transaction.		
Internet of Things Systems A networked connection of physical assets (e.g., cargo handling equipment and containers) to software via sensors like RFID, GPS, and cameras to enable automated tracking, optimization, and management of automated equipment and complex systems.		
Automated Cargo Handling Equipment		
Automated Gantry Cranes Heavy machinery on tires or rails that lifts and stacks containers without human intervention or through control of a worker in a different location.		
Automated Guided Vehicles Driverless vehicles or chassis that transport containers from one area of the terminal to another.		
Remotely-operated Ship-to-Shore Cranes Dockside stationary cranes controlled by a worker in a different location that load and unload containers from vessels.		
Automated Straddle Carriers Large container-handlers on tires that can both lift and stack containers and transport them from one area of the terminal to another without human intervention or through control of a worker in a different location.		

Source: GAO analysis of publicly available information and information provided by port officials. | GAO-24-106498

Note: A port is counted as having a technology if at least one terminal at the port has adopted the technology.

^aWe selected the 10 U.S. ports that had the greatest annual container volume in 2019 and 2020, which were the ports of Los Angeles (CA), Long Beach (CA), New York and New Jersey (NY and

NJ), Savannah (GA), Houston (TX), Virginia (VA), Oakland (CA), Charleston (SC), Tacoma (WA), and Seattle (WA).

^bWe selected 10 foreign ports out of the top 21 ports that had the greatest annual container volume in 2019. We selected these ports for variation in terms of annual container volume, location, and performance as measured by ship time in port. The ports include the ports of Antwerp-Bruges (Belgium), Busan (South Korea), Guangzhou (China), Laem Chabang (Thailand), Dubai (United Arab Emirates), Qingdao (China), Rotterdam (Netherlands), Shanghai (China), Singapore (Singapore), and Tanjung Pelepas (Malaysia).

Foreign ports also tend to use more advanced technologies, such as digital twin technologies and blockchain, which have not been widely adopted in the U.S. In general, foreign ports we spoke with have a longer history with automation technologies and have been able to implement more of these technologies. For example, some terminals at the Port of Rotterdam are among the earliest adopters of automation technologies, one beginning in the early 1990s, and are considered to be highly automated, while U.S. ports that use automation have generally started doing so during the last decade.

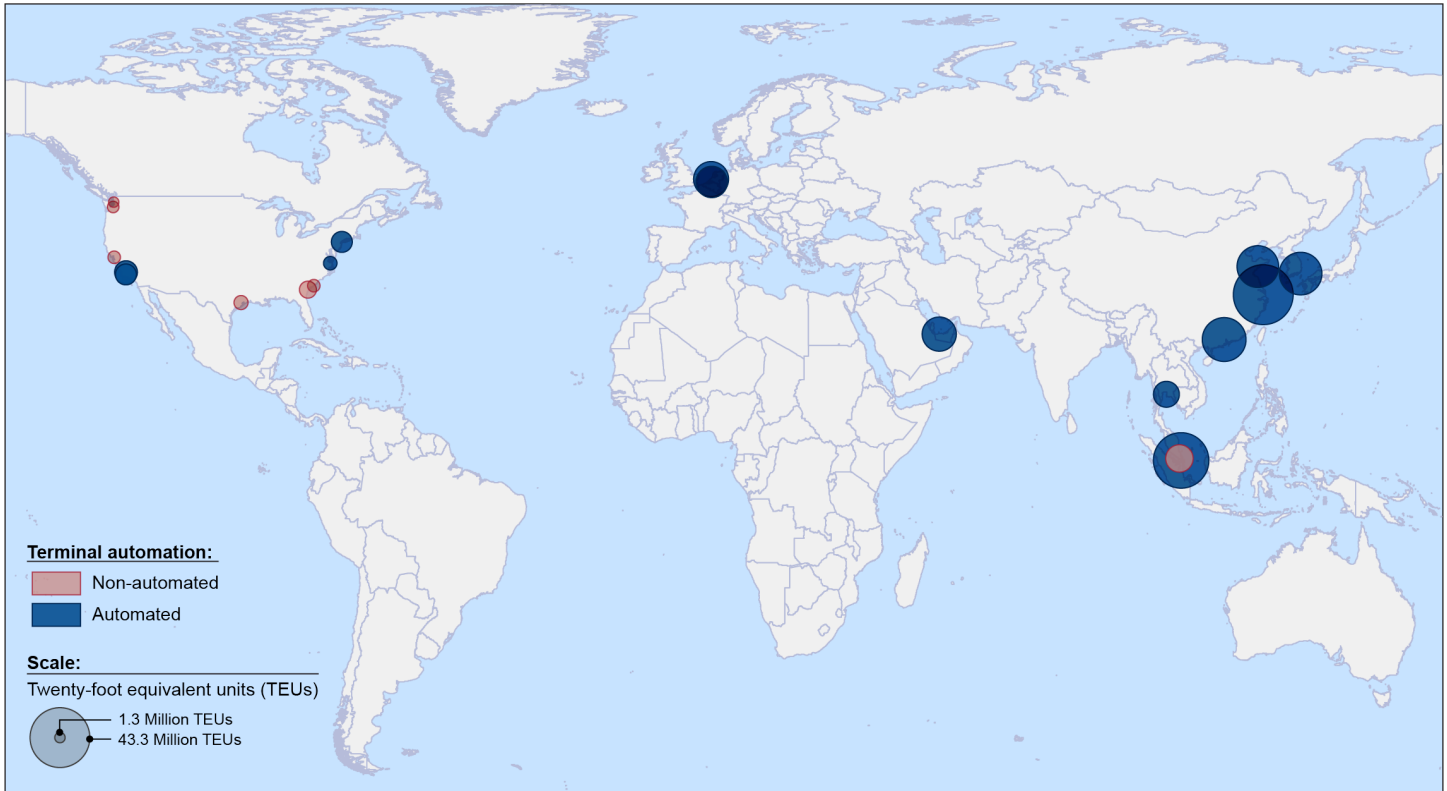
According to U.S. and international port authorities, terminal operators, and other industry stakeholders (“port stakeholders”) we interviewed, some factors contribute to more widespread adoption of automation technologies by foreign ports as compared to U.S. ports:¹⁶

- **Port size:** Our selected foreign ports handle higher volumes of cargo than U.S. ports, and the additional cargo they handle helps to justify the investment in automation technologies. Automation technologies, especially automated cargo handling equipment, generally require a significant capital investment. A few stakeholders told us that a terminal would need to surpass a minimum amount of cargo—one stakeholder estimated at least 2.5 to 3 million twenty-foot equivalent units (TEU)—to realize a potential return on the investment.¹⁷ Most U.S. container ports handle less than this amount of cargo, and therefore, may not have adopted as many automation technologies as foreign ports. As shown in figure 4 below, as of 2019, selected ports with higher cargo volumes were more likely to have adopted automated cargo handling equipment.

¹⁶We interviewed 34 port stakeholders. In this section, to summarize port stakeholders’ statements we use “many or most” to refer to 23-34 stakeholders; “some” to refer to 12-22 stakeholders; and “a few” to refer to 3-11 stakeholders. Of these 34 stakeholders, 25 were ports and terminal operators.

¹⁷A TEU, or twenty-foot equivalent unit, is a measure of cargo capacity that is often used for container ships and container ports.

Figure 4: Use of Automated Cargo Handling Equipment and Annual Cargo Volume in Marine Container Terminals at Selected U.S. and Foreign Ports, as of 2019



Source: GAO representation of information collected by the Organization for Economic Cooperation and Development's (OECD) International Transport Forum, Department of Transportation Bureau of Transportation Statistics information, and MapResource. | GAO-24-106498

Note: We designated ports as automated based on information collected by OECD's International Transport Forum indicating that these ports use automated cargo handling equipment. See OECD International Transport Forum Policy Papers, *Container Port Automation: Impacts and Implications*, No. 96 (Paris: OECD Publishing, 2021). This does not reflect the use of process automation technologies. The circle size represents the volume of cargo.

- Labor:** According to some port stakeholders we interviewed, existing labor agreements in the U.S. can make it more difficult for U.S. ports to adopt automation technologies than foreign ports because the use of certain types of automation technologies may require a change to current labor agreements. For example, according to a few U.S. ports and terminal operators, some labor agreements specify that union employees must carry out certain job functions. As a result, the ports may face union resistance if they want to use automation technologies to perform those functions. Further, labor supply may vary in other parts of the world. For example, one international industry stakeholder

told us that automation is viewed as a necessity in some European countries due to labor shortages.

- **Types of shipments:** Foreign ports tend to have more transshipments—meaning that containers are moved from one ship to another ship rather than to trucks or rail—than U.S. ports. Ports with a large percentage of cargo moved through transshipment lend themselves to the use of automation technologies. For example, one stakeholder said transshipment ports may be more conducive to automation because operations are less complex when moving containers from one ship to another ship as opposed to moving them from a ship to another mode of transportation that carries the containers inland. Terminal operators at large transshipment ports may use automation to increase container throughput from one ship to another rather than looking for ways to improve the movement of goods in and out of the port on other modes of transportation. Officials from the Port of Singapore—a port with a large percentage of transshipments—told us this was a key consideration in their decision to automate.

Port Stakeholders Reported Mixed Effects of Port Automation Technologies

Port stakeholders we interviewed told us that port automation technologies can have a range of potential effects on port outcomes.¹⁸ These port stakeholders generally agreed that automation technologies can potentially improve worker safety and reduce emissions but reported mixed potential effects on security, the workforce, and port performance (see table 1).

¹⁸We interviewed 34 port stakeholders. In this section, to summarize port stakeholders' statements we use "most" to refer to 23-34 stakeholders; "some" to refer to 12-22 stakeholders; and "a few" to refer to 3-11 stakeholders. Of these 34 stakeholders, 25 were ports and terminal operators.

Table 1: Potential Effects of Port Automation Technologies Identified by Selected Stakeholders

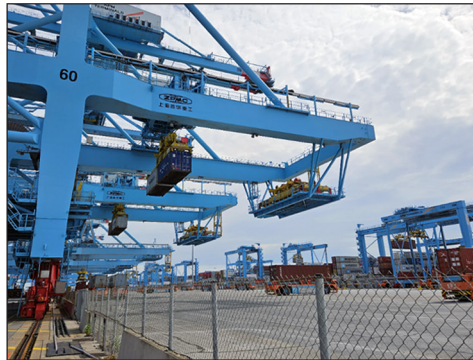
Outcome	Examples of potential effects of port automation technologies
Safety	<ul style="list-style-type: none"> Decreased human interaction with heavy equipment can lower the risk of accidents.
Security	<ul style="list-style-type: none"> Increased visibility of personnel, containers, and trucks can lower the risk of illicit activities. Increased number of systems connected to the internet can heighten vulnerability to cyber threats.
Emissions	<ul style="list-style-type: none"> Increased efficiency of container movements can reduce emissions. Increased visibility of container availability and faster gate times can reduce truck idling. Increased use of automated equipment, which is often electric, can reduce emissions.
Workforce	<ul style="list-style-type: none"> Increased terminal capacity and throughput can lead to more jobs. Decreased manual labor, simplified tasks, and safer environment can make jobs easier and improve working conditions. Increased use of automated equipment that replaces manual labor can lead to fewer jobs. Increased use of automated equipment that changes the types of skills required can lead to more higher-skilled positions.
Performance	<ul style="list-style-type: none"> Increased visibility into operations and ability to identify issues can lead to greater efficiency. Increased efficiency can lead to higher terminal capacity and throughput. Increased operations, such as operating 24 hours a day, 7 days a week, can lead to higher productivity. Decreased ability to operate in adverse weather conditions and respond to exceptions can lead to reduced efficiency and productivity. Increased frequency of equipment maintenance issues can lead to reduced efficiency and productivity.

Source: GAO interviews with port authorities, private marine terminal operators, and industry stakeholders. | GAO-24-106498

Safety

Some port stakeholders we interviewed said that automation technologies can improve the safety of ports. According to some port stakeholders, automation technologies can lower the risk of accidents because the technologies reduce or eliminate human interaction with heavy, dangerous equipment. For example, one terminal operator told us that before automation, their terminal had two or three injuries per month, and that some past injuries had been fatal. In the months since adopting automated gantry cranes, the operator reported that the terminal has had no injuries.

Figure 5: Semi-automated Double Trolley Ship-to-shore Cranes and Automated Guided Vehicles



Semi-automated double trolley ship-to-shore cranes load containers onto automated guided vehicles that are unloaded by the automated rail-mounted gantry cranes.



The automated area of the terminal (the yard) is fenced off from areas with workers, reducing the potential for injuries.

Source: GAO (photos). | GAO-24-106498

Security

A few port stakeholders we interviewed told us that automation technologies can improve port security. A few of the port stakeholders said that having fewer workers on the terminal combined with other process automation technologies can improve visibility of personnel, containers, and trucks moving through the terminal, which can increase security and lower the risk of illicit activities. For example, one industry stakeholder told us that radio frequency identification (RFID) technology ensures that only authorized trucks can enter the terminal. It also enables tracking of trucks within the terminal to ensure that they are only going to their designated locations. A few port stakeholders noted that having more equipment and systems connected to the internet can increase vulnerability to cyber-attacks; however, a few of the port stakeholders said that automation technologies may not be any more susceptible to cyber-attacks than their existing internet-connected systems.

Emissions

Some of the port stakeholders we interviewed said that automation technologies can help reduce emissions. A few port stakeholders said that process automation technologies like artificial intelligence, optical character recognition (OCR), and port community systems can help coordinate truck pickups, reducing their wait times. These faster turnaround times can reduce emissions from truck idling. For example, according to an analysis performed by the Port of Virginia, it reduced truck turnaround times by introducing automated gate technologies and a truck reservation system. According to the analysis, this helped lower

emissions by at least 20 percent between 2017 and 2022.¹⁹ In addition, a few port stakeholders said automated cargo handling equipment can reduce emissions because it has the potential to move containers more efficiently than conventional equipment and because it is often electric, compared to conventional cargo handling equipment which is diesel-powered.

Workforce

Remotely operated cranes

Remotely operated cranes use cameras, sensors, and other technologies to move containers onto or off ships, trucks, trains, and within yard container stacks.

- A few stakeholders said that remote operations offer a more comfortable and safer working environment for the operators, although some operators may still prefer to be in the crane.
- Reported effects of remote operations on performance were mixed, with a few port stakeholders saying they are more productive and others saying they are less productive.

Pictured below is a remote rail-mounted gantry crane operator at the former GCT Bayonne terminal in the Port of New York and New Jersey.



Source: GAO (Photo). | GAO-24-106498

Port stakeholders we interviewed reported that automation technologies can have varied effects on the size and skills of the workforce. A few of the port stakeholders we interviewed said that adoption of automation technologies can reduce the size of the port workforce. Some automation technologies, such as automated guided vehicles or fully automated gates, can independently perform tasks traditionally performed by humans and therefore could replace these workers. For example, a few port stakeholders we interviewed said that the number of job positions at terminal gates was significantly reduced after the introduction of automated gate technologies.

However, a few port stakeholders said that automation technologies can be adopted without replacing the workforce. For example, a few port stakeholders we interviewed said that prior to having automated gates, terminals had clerks who collected the truck and container information by hand. With an automated gate system, the terminal operators still have gate clerks, but the information is automatically captured and sent electronically to a gate clerk who manually verifies it. A few port stakeholders said that adoption of port automation technologies allowed them to expand their operations, which required an equal or greater number of workers.

Aside from reducing the port workforce, some port stakeholders we interviewed said that automation technologies transform the nature of port jobs. For example, a few port stakeholders said that moving to semi-automated remote cranes or automated gate operations transformed difficult, dangerous, and physically demanding positions to more safe and comfortable office jobs within a central office. For example, one terminal operator said that their previously manual gate operations created a hazardous environment for the gate clerks who had to interact directly with nearly 5,000 trucks per day. After implementation of automated gates, this stakeholder said that the gate clerks work remotely, away from

¹⁹The Port of Virginia, *2021 Environmental Sustainability Report* (Norfolk: Virginia Port Authority, n.d.).

the trucks and natural elements, and have better ability to interact with their coworkers. Another terminal operator we interviewed switched to remote gantry crane operations, and now the operators sit together inside the main office in a temperature-controlled room, away from dangerous equipment and are more easily able to take breaks.

Some port stakeholders also told us that automation technologies change the types of jobs available and the skills required to perform them.²⁰ For example, a few port stakeholders noted that terminals with automation technology require a higher-skilled workforce knowledgeable in information technology and mechanics. A few port stakeholders said that they are working to “upskill” or train their existing workforce to fill these positions. For instance, officials at one port authority told us that they are working with federal and state governments to ensure that training is available for current and future workers to develop the skills necessary for future operations.

Performance

Port stakeholders reported a range of mixed effects that automation technologies can have on terminals’ performance. Most port stakeholders said that automation technologies can increase terminal capacity and allow for more efficient operations.²¹ For example, automated equipment can stack containers closer together than conventional equipment and, according to a few port stakeholders, can arrange containers with fewer movements (see figure 6). However, a few of the port stakeholders we interviewed said that automated equipment may not be as productive as conventional equipment. These stakeholders said that adopting automated cargo handling equipment can slow operations, as the equipment may not move containers as quickly as conventional equipment. For example, two terminal operators we interviewed (one domestic and one international) said that—contrary to their expectations—after several years of operating a terminal with automated equipment, the automated equipment was still slower and less productive than the conventional equipment.

²⁰GAO has found that employers may be unable to find enough workers with the new skills needed to perform the job in situations where automation required new skills. See GAO, *Workforce Automation: Insights into Skills and Training Programs for Impacted Workers*, [GAO-22-105159](#) (Washington, D.C.: Aug. 17, 2022).

²¹In this report, we define efficiency as performing the work with the fewest resources and we define productivity as the amount of work performed.

Figure 6: Automated Rail-mounted Gantry Cranes

Automated rail-mounted gantry cranes can stack containers at greater densities than human-operated rubber-tired gantry cranes.



Automated rail-mounted gantry cranes at Hutchison Ports ECT Euromax in Rotterdam, The Netherlands.



Automated rail-mounted gantry cranes at DP World Antwerp Gateway in Antwerp, Belgium.

Source: GAO (photos). | GAO-24-106498

A few port stakeholders said automation technologies can allow for operations 24 hours a day, 7 days a week, which can increase throughput. However, a few other port stakeholders said that extended hours of operations would not improve performance because trucks do not want to come to the port to pick up containers at all hours or because warehouses are not always open for trucks to drop off the containers.

According to a few port stakeholders, automated equipment can also decrease terminal productivity—as measured by the total number of container moves—due to the absence of a human operator. These stakeholders gave the example of automated or semi-automated remote cranes which may not be able to operate in adverse weather conditions like rain or fog that obscure sensors' or cameras' views, whereas a human operator sitting in the crane may still be able to see. In addition, a few port stakeholders noted that automated equipment cannot respond to exceptions—unexpected deviations from its programmed operations—and may have more frequent maintenance issues, both of which require human intervention and decrease productivity.

While port stakeholders provided more mixed perspectives on the effects of cargo handling equipment on terminals' performance, most port stakeholders we interviewed said that process automation technology improved terminals' performance. For example, a few port stakeholders noted that automated gate systems led to faster gate transactions and, combined with other automation technologies, have helped to decrease

the overall amount of time a truck spends in a terminal. A few others said that port community systems—which eight of the ten U.S. ports included in our review have adopted—have improved terminals’ performance through helping coordinate and organize many different parts of the supply chain.

U.S. Terminal Operators Consider Various Factors Based on Their Unique Circumstances When Deciding Whether to Automate

U.S. port authorities and terminal operators we interviewed said that terminals decide whether to adopt automation technologies based on a variety of different considerations, including labor, costs, terminal operators’ priorities, and terminal operations.²² The importance of these factors varies from port to port and even from terminal to terminal within a port, and some stakeholders told us that certain types of automation are either not possible or not suitable for all ports.

Labor

Most of the U.S. port authorities and terminal operators we interviewed said that labor factored into operators’ decisions to automate, including issues such as union opposition to automation and labor agreements. Port labor unions have expressed opposition to automation technologies and concerns that such technologies will reduce available jobs. Representatives for one union we spoke to told us that when terminals automate, they spend more money on equipment and less money on labor, with the intent to shift profits from workers to terminal operators.

On the other hand, a few terminal operators that adopted automated equipment told us that they try to maintain a good relationship with their respective unions, and they worked closely with their union to ensure the terminal could adopt these technologies without eliminating jobs. A few other terminal operators we interviewed said that they did not adopt automated equipment either because of concerns that these technologies could adversely affect their workforce or because they knew it would likely face resistance from their respective unions.

A few ports and terminal operators said that they must also abide by negotiated union agreements, some of which mandate that terminal

²²We interviewed 18 U.S. ports and terminal operators. In this section, to summarize U.S. ports’ and terminal operators’ statements we use “most” to refer to 12-18 stakeholders; “some” to refer to 6-11 stakeholders; and “a few” to refer to 3-5 stakeholders.

operators employ a minimum number of union workers or that union workers fill certain positions. A few ports and terminal operators told us that these requirements may reduce the potential beneficial effects of automation technologies, such as offsetting labor costs. However, as mentioned above, a few ports still saw potential benefits in adopting process automation technologies alongside their existing workforce. For example, one terminal operator we interviewed said that they adopted semi-automated gates where RFID and OCR technology reads truck and container information, which is electronically sent to a gate clerk to manually verify.

Cost and Return on Investment

Automation technologies are generally expensive relative to conventional port equipment, and terminal operators consider cost and return on investment when deciding whether to automate. Adoption of automation technologies, especially cargo handling equipment, typically involves high up-front costs, which some terminal operators may not have available. In addition, according to a few stakeholders, obtaining a return on investment within a reasonable time frame requires large volumes of containers moving through the terminal. For example, a few U.S. ports and terminal operators we interviewed said it could take 10 to 20 years or more to recover the costs associated with adopting automated cargo handling equipment, at which point the equipment would be reaching or exceeding its operational life expectancy.

Because consistent large volumes are important factors in realizing a return on investment, automated equipment tends to only be found in large ports, as described earlier. For smaller ports that do not process enough containers to necessitate this level of operations, these investments may not be wise or feasible. For instance, three of the four terminals with automated equipment in the U.S. are found in the three largest container ports: the Port of Los Angeles, the Port of Long Beach, and the Port of New York and New Jersey.

Terminal Operators' Priorities

Terminal operators' decisions to adopt automation technologies will vary based on their unique priorities, including environmental goals and safety. A few of the ports and terminal operators told us that they adopted automation technologies as part of broader efforts to reduce emissions. For example, according to a few ports and terminal operators we interviewed, California requires ports and terminals to meet specific emissions reduction targets. To meet these targets, a few terminal operators replaced conventional diesel-powered trucks with electric-powered equipment, such as automated guided vehicles. A few ports and terminal operators across the U.S. told us that adoption of process

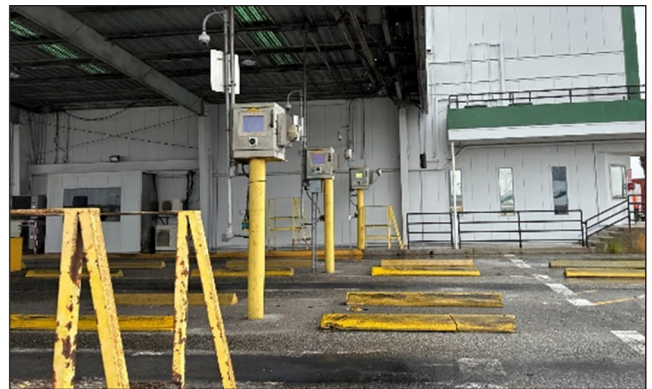
automation technologies like RFID and OCR have expedited gate transactions and lowered truck turnaround times, reducing truck idling and associated emissions (see fig. 7).

Figure 7: Radio Frequency Identification (RFID) and Optical Character Recognition (OCR) Technologies

Radio frequency identification (RFID) and optical character recognition (OCR) technologies can improve gate transaction and truck turnaround times, reducing truck idling and emissions.



RFID and OCR technologies at TraPac Los Angeles Terminal.



RFID and OCR technologies at SSA Marine Pacific Terminal in Long Beach.

Source: GAO (photos). | GAO-24-106498

Some ports and terminal operators we interviewed also said that worker safety was a company priority and improving safety was a factor in deciding to adopt automation technologies. According to most stakeholders, working at a terminal can be dangerous, for example, due to working near heavy equipment or near moving trucks at terminal gates, and injuries can be serious or fatal.

Terminal Operations

Most ports and terminal operators told us that terminal characteristics, such as location and infrastructure, and general operations were factors in deciding whether to adopt automation technologies. Two terminal operators said that it is easier to automate undeveloped or newly expanded terminals than existing terminals that may need to be retrofitted, which may pause operations and increase costs. For example, one automated terminal operator told us that they would not have automated if they had not acquired new, undeveloped land, as it would have been too costly. A few ports and terminal operators told us that terminal configuration is a factor in decisions to automate; certain types of equipment are better suited for certain layouts.

Relatedly, a few terminal operators told us that the capacity of their terminal was an important consideration in decisions to automate. Operators of a few terminals in the U.S. said they do not have room to expand; therefore, in order to increase capacity, they need to be able to stack more containers in the same footprint. To do this, operators may pursue automated equipment that can stack containers more densely than conventional equipment. One terminal operator we interviewed said that they chose to automate despite the difficulties that their small and irregular terminal layout presented for automation because they wanted to ensure that they could accommodate expected increases in future container volumes.

Two Terminals' Approaches to Automation: Expansion versus Rebuilding

One terminal operator ("Operator 1") historically operated two conventional container terminals within a single U.S. port, but when an opportunity arose to expand one of their terminals onto adjacent, undeveloped land, they decided to build an automated terminal with automated gate technologies and automated gantry cranes, among other technologies. Officials from Operator 1 said that the land itself was a particularly important factor—if they had not acquired the undeveloped land, they may not have pursued automation technologies at their existing facilities because of the associated challenges and costs of building over an existing terminal. Further, automated equipment was seen as a necessary investment because the small and narrow shape of the new site required denser stacks in order to realize a return on their investment. Officials from Operator 1 said that they considered the union's opposition in their decision making, but they worked with the union and, although the equipment required fewer workers, the increase in throughput from the expansion resulted in hundreds of new jobs and a large increase in worker safety.

A second terminal operator at a U.S. port ("Operator 2") took a different approach to building their automated terminal. Rather than expanding the footprint of its operations, Operator 2 underwent a 10-year rebuild of their existing conventional terminals, converting them into a single automated terminal with automated gantry cranes and electric automated guided vehicles, among other technologies. This required a significant investment, including shutting down the terminal for a period of time. Officials from this terminal told us that the company decided to automate to achieve several goals: increased productivity, greater density, better return on investment, improved worker safety, and reduced emissions. According to officials from Operator 2, automation has helped them achieve these goals: automation helped make the terminal the most productive in the U.S., doubled its capacity, greatly improved worker safety, and reduced emissions. These officials noted that automation reduced longshoremen jobs but created more skilled labor positions. To address this shift in the workforce, officials told us that the operator invested in on-the-job training. Moreover, officials said the terminal's labor costs increased after automation, in part because of expanded operations. While the terminal has experienced these benefits, officials also noted that automated equipment has experienced more frequent breakdowns than conventional equipment.

Source: GAO analysis of interviews. | GAO-24-106498

Some ports and terminal operators we interviewed told us that automated equipment either did not or would not fit with their operations, and a few have pursued alternatives to automated equipment. One terminal operator said that they had previously piloted remote crane operations in their yard. However, the crane operators did not like the remote operation as much and it performed more slowly, so the terminal operator reverted to the conventional equipment.

Another terminal operator told us that they did not believe it was possible to fully realize the potential productivity and safety benefits of automated equipment without first ensuring that they were operating as efficiently as possible without the automated equipment. This terminal operator said that before adopting automated equipment, they wanted to fully map out and understand their processes to identify areas that would benefit most from investment and then optimize and standardize their operating procedures. The terminal operator said that if they ever decide to automate in the future, they believe that these steps will save them time and money.

Few Federal Activities Focus Exclusively on the Development and Adoption of Port Automation Technologies

We identified three agencies with strategic goals, programs or efforts, or discretionary grant funding that related to port automation technologies in some way: DOT, EPA, and FMC.²³ Of these agencies, only DOT conducted a few activities that explicitly focused on port automation. However, the majority of the related DOT activities we identified were not explicitly focused on port automation technologies. Further, of the few related activities EPA and FMC conducted related to port automation technologies, port automation was secondary or tertiary to the activities' purposes.

The Department of Transportation Conducts Some Activities on Port Automation Technologies

DOT and its modal administrations had some strategic goals, programs or efforts, and discretionary grant funding related to port automation technologies, a few of which focused exclusively on port automation. For the most part, DOT and its modal administrations identified goals and engaged in activities that were not specific to port automation technologies, but which could be achieved through or were

²³For the purposes of our review, programs and efforts refers to activities conducted by federal agencies, except those that provide funding for port infrastructure, technology, or equipment. We reviewed programs that provide such funding to ports under the grant funding category, but only reviewed discretionary grant programs.

complementary to port automation, such as broader efforts to improve the performance of the supply chain and address freight bottlenecks.

Goals and objectives. Since 2017, DOT identified individual goals and objectives specific to port automation in five strategic documents, including DOT's and MARAD's strategic plans and DOT's freight plans and assessments. In almost all these strategic documents, DOT linked individual goals and objectives related to port automation to goals for innovation. For instance, in 2020, MARAD set a goal to drive maritime innovation by "accelerat[ing] the adoption of productivity and safety-enhancing automation for vessel and port functions."²⁴ In its *Supply Chain Assessment of the Transportation Industrial Base for Freight and Logistics*, DOT also recommended port community systems and Internet of Things systems as one of several ways to improve supply chain performance.²⁵ In addition to these goals, DOT identified several broader strategic goals for transportation automation, technology development and innovation, port performance, port modernization, and supply chain performance. Port automation technology was secondary or tertiary to these goals because they could be achieved in part or in full through development or adoption of port automation technologies, but do not specifically discuss port automation as part of the goal.

Programs and Efforts. We identified 17 DOT programs and efforts related to port automation. For nearly three-quarters of these, port automation technologies were secondary to the program's or effort's broader purposes of technology development and innovation and supply chain performance.²⁶ For instance, in 2022, DOT established the Freight Logistics Optimization Works (FLOW) program, which is an effort to improve the transparency of cargo movements through the supply chain through improved data exchange. While the purpose of FLOW is not to encourage the adoption of automation technologies, three U.S. port authorities or terminal operators we spoke to identified this program as a federal effort related to port automation. For instance, one port authority told us that the FLOW initiative relates to process automation

²⁴MARAD and DOT, *Goals and Objectives for a Stronger Maritime Nation: A Report to Congress* (February 2020).

²⁵DOT, *Supply Chain Assessment of the Transportation Industrial Base*.

²⁶The results of our analysis are not intended to represent an exhaustive list of DOT or other federal agency programs related to port automation.

technologies because it is intended to improve the transparency of cargo movements.

We identified five DOT efforts that focused more explicitly on one or more of the port automation technologies we reviewed. These efforts were all stand-alone initiatives or projects that were generally related to DOT's research and development and innovation efforts.²⁷ For example, DOT's Intelligent Transportation Systems (ITS) Joint Program Office and MARAD co-lead the ITS Maritime Administration Program, which seeks to use ITS to improve the performance of ports and terminals. Within this program, the ITS Joint Program Office and MARAD have partnered with FHWA to study truck staging and automated trucking at ports.²⁸ These studies have included port automation technologies such as terminal gate automation, automated vehicles, and port community systems. Additionally, in 2019 MARAD published a Request for Information to obtain the public's views on a range of issues related to the safety effects, opportunities, challenges, and impacts of automated transportation at ports.²⁹ MARAD officials told us that they used the information MARAD obtained to inform future research opportunities.

Discretionary Grant Funding. We identified six DOT discretionary grant programs that could be used for port automation technologies. The goals of these grant programs are complementary to, or could be achieved through, some port automation technologies although none of the programs explicitly support port automation. See table 2 for examples of how these funding programs could support port automation technologies.

²⁷DOT and FHWA, *Cooperative Driving Automation: Research into Automated Port Operations and Automated Commercial Motor Vehicle Operations: Concept of Operations for Enhanced Automated Port Drayage*, FHWA-JPO-22-925 (Washington, D.C.: March 2022). This report was sponsored by FHWA and published in coordination with the Office of the Assistant Secretary for Research and Technology, Intelligent Transportation Systems Joint Program Office.

²⁸DOT, FHWA, and MARAD *ITS MARAD Truck Staging Study: Final Report* (Washington, D.C.: May 2, 2019). DOT and FHWA, *Cooperative Driving Automation*. These reports were sponsored by FHWA and published in coordination with the Office of the Assistant Secretary for Research and Technology, Intelligent Transportation Systems Joint Program Office and MARAD. The Federal Motor Carrier Safety Administration also provided support for some of the research conducted under this program.

²⁹*Request for Information on Opportunities, Challenges and Impacts of Automated Transportation in a Port Environment*, 84 Fed. Reg. 37951 (Aug. 2, 2019).

Table 2: Department of Transportation (DOT) Discretionary Grant Programs For Which Port Automation Technology Costs May Be Eligible

Discretionary Grant Program	Description	Potential port automation technologies that could be included ^a
<i>DOT</i>		
Rebuilding American Infrastructure with Sustainability and Equity (RAISE)	Funds surface transportation infrastructure projects that improve, among other things, safety, economic competitiveness, state of good repair, and innovation.	Internet of Things technology for gate automation
National Infrastructure Project Assistance or “Megaprojects”	Funds large projects likely to generate national or regional economic, mobility, or safety benefits.	Gate automation technology
Infrastructure for Rebuilding America (INFRA) Grants	Funds multimodal freight and highway projects of national or regional significance including those that improve the safety, efficiency, and reliability of the movement of freight and people in and across rural and urban areas.	Gate automation technology
<i>Federal Highway Administration (FHWA)</i>		
Advanced Transportation Technologies and Innovative Mobility Deployment Program ^b	Funds advanced transportation technologies to improve safety, mobility, efficiency, system performance, intermodal connectivity, and infrastructure return on investment.	Gate automation technology, port community systems, and port management systems that use Artificial Intelligence
Reduction of Truck Emissions at Port Facilities ^c	Will fund projects that reduce port-related emissions from idling trucks including through, among other things, improvements in efficiency, focusing on port operations.	Gate automation technology and port community systems
<i>Maritime Administration</i>		
Port Infrastructure Development Program	Funds projects that, among other things, improve the safety, efficiency, or reliability of the loading and unloading of goods, the movement of goods, operational improvements, or environmental and emissions mitigation measures at ports.	Technology such as automated gates, sensors, freight intelligent transportation systems, and digital infrastructure ^d

Source: GAO Analysis of agency documentation. | GAO-24-106498

^aWe identified these examples through our review of past award descriptions, Notices of Funding Opportunity and interviews with DOT officials.

^bThis program was formerly called the Advanced Transportation and Congestion Management Technologies Deployment Program.

^cAs of May 2023, FHWA anticipated announcing award recipients for fiscal years 2022 and 2023 by November 2023.

^dThe Port Infrastructure Development Program Notice of Funding Opportunities for fiscal year 2023 states that recipients may not use awards to purchase fully automated cargo handling equipment if the Secretary determines that such equipment would result in a net loss of good jobs or reduction in the quality of jobs within the port or port terminal. DOT, *Notice of Funding Opportunity for the Maritime Administration’s Port Infrastructure Development Program (PIDP) under the Infrastructure Investment and Jobs Act and Consolidated Appropriations Act, 2023*. The restriction on the use of PIDP funds for fully automated cargo handling equipment was first put in place in fiscal year 2019.

Though some automation technologies could be eligible expenses, federal requirements for some of these programs may limit the extent to which recipients may use awards for port automation. For instance, the

Port Infrastructure Development Program Notice of Funding Opportunities for fiscal year 2023 states that recipients may not use awards to purchase fully automated cargo handling equipment if DOT determines such equipment would reduce the quantity or quality of jobs at the port.³⁰ However, ports and terminal operators we spoke with did not indicate that federal funding limitations have significantly affected U.S. operators' decisions to adopt automation technology. As discussed above, U.S. ports and terminal operators told us that they consider a variety of factors when deciding whether to automate and what kinds of technology to adopt, and the majority of port authorities and terminal operators we spoke with told us that they had not applied for or received federal funding for port automation technologies. Further, MARAD officials told us that they did not find any of the applications submitted between fiscal years 2019 and 2022 to be ineligible due to this restriction.³¹

Other Federal Activities Are Not Explicitly Focused on Port Automation Technologies

EPA and FMC conduct a few activities related to port automation. These activities are intended to address issues related to, but not exclusively focused on, port automation technologies.

EPA's limited activities related to port automation are tied to its efforts to reduce emissions. We did not identify any EPA strategic goals or objectives related to port automation. None of EPA's programs or grant funding are specifically intended to encourage the development or adoption of port automation technologies.

However, EPA has one program and two discretionary grant programs that relate to some port automation technologies. For example, EPA published some technical resources under its Ports Initiative that discuss port automation technologies. However, EPA officials told us that the agency is impartial regarding automation in the context of the Ports

³⁰DOT, *Notice of Funding Opportunity for the Maritime Administration's Port Infrastructure Development Program (PIDP) under the Infrastructure Investment and Jobs Act and Consolidated Appropriations Act, 2023*. The Notice of Funding Opportunity states that the use of award funds for automated cargo handling equipment is prohibited if the Secretary of DOT determines that such equipment would result in a net loss of good jobs or reduction in the quality of jobs within the port or port terminal.

³¹For PIDP grant applications, DOT has considered how the use of PIDP funds for fully automated cargo handling equipment affects net job loss and degradation of job quality since fiscal year 2019. MARAD officials told us that between fiscal years 2019 and 2022 they flagged 11 applications as potentially seeking funding for fully automated cargo handling equipment, but upon further review found that none of the 11 included fully automated cargo handling equipment as a component. MARAD awarded funds to four of the 11 projects.

Initiative which highlights technologies that may help ports reduce emissions and improve air quality. Similarly, EPA officials told us that Diesel Emissions Reduction Act grant funding is agnostic to automation and instead focuses on replacing diesel powered equipment like cargo handling equipment with less polluting equipment to reduce emissions and improve air quality. See table 3 for more information on these programs and funding.

Table 3: Environmental Protection Agency (EPA) Programs and Discretionary Grant Funding Related to Port Automation Technologies

Program	Description	Relationship to Port Automation
<i>Programs</i>		
Ports Initiative	Supports efforts to improve efficiency, enhance energy security, save costs, and reduce harmful health impacts of emissions at ports by advancing next-generation, clean air technologies and practices at ports.	Includes technical resources, such as best practices and recommended operational strategies that discuss some port automation technologies, including automated gate systems and automated cargo handling equipment.
<i>Discretionary Grant Funding</i>		
Clean Diesel Funding Assistance Program (also known as Diesel Emissions Reduction Act or DERA grants)	Funds projects that achieve significant reductions in diesel emissions through, among other things, the retrofit or replacement of cargo handling equipment or vehicles.	Automated cargo handling equipment that meets reduced emissions standards may be an eligible expense.
Clean Ports Program	Will fund zero-emission port equipment and technology.	Eligibility of specific technologies is yet to be determined by EPA. ^a

Source: GAO Analysis of agency documentation. | GAO-24-106498

^aThe Inflation Reduction Act of 2022 appropriated funds—which remain available for award until September 30, 2027—to EPA to support the reduction of air pollution at ports. EPA issued Requests for Information in November 2022 and May 2023 to solicit public comments on the design of the program. As of October 2023, EPA expected to publish a Notice of Funding Opportunity in late winter 2024.

While the EPA programs we identified are agnostic to automation, some port stakeholders told us that some federal requirements may limit ports' ability to use discretionary grant funds from EPA and elsewhere for automated cargo handling equipment.³² Specifically, representatives from one industry stakeholder, three port authorities, and one terminal operator told us that limitations on using federal grant funding to purchase foreign-

³²Because EPA has not published a Notice of Funding Opportunity for the Clean Ports Program as of October 2023, we are not able to determine the eligibility of specific technologies. However, EPA officials told us that the agency is agnostic on port automation as it relates to efforts to reduce emissions.

manufactured goods, such as the Buy America requirements, effectively prohibit operators from using federal funding for automated cargo handling equipment because almost all of this equipment is manufactured overseas.³³ EPA officials also told us that port stakeholders have communicated to EPA that they anticipate few zero-emissions technologies—automated or conventional—will meet the Buy America requirements. Officials added that EPA has provided waivers of these requirements for other programs in the past as appropriate, and that these requirements have not been a significant hindrance to the agency’s funding programs.

FMC’s limited activities related to port automation are focused on improving electronic communication of cargo status between port stakeholders. We identified one FMC initiative that relates to port automation technologies, though port automation is not a direct focus of the program or FMC’s efforts. The Maritime Transportation Data Initiative (MTDI) is an effort led by one FMC Commissioner to develop common data definitions and transmission standards in the maritime industry using input from a wide range of stakeholders.³⁴ Based on the information collected through this effort, the lead Commissioner made recommendations intended to improve communication of cargo status throughout the supply chain. One recommendation was for terminal operators to share specific cargo status data and another was that port authorities disseminate the data to all relevant stakeholders.

While the MTDI’s final report and recommendations do not specifically identify port automation technologies, several recommendations are

³³See *e.g.*, 41 U.S.C. §§ 8301-8305. Buy America(n) requirements apply to various financial assistance programs. In general, Buy America(n) requirements create a preference for the procurement and use of domestic materials funded at least in part by the federal government. Specific requirements vary depending on the agency and program and are often codified in Buy America statutes. Requirements could include, among other restrictions, the use of U.S. manufactured iron and steel. Each of the specific agency statutes outlining the relevant Buy America(n) requirements allows for waivers to be granted by the agency under specific circumstances. In its 2022 *Supply Chain Assessment of The Transportation Industrial Base*, DOT also found that there is a limited domestic supply base for specialized cargo handling equipment and gantry cranes and production is limited to a handful of foreign-owned companies.

³⁴In November 2021, the Chairman of the Commission requested one Commissioner to examine the issue of data and maritime commerce to: (1) catalogue the status quo for maritime data elements, metrics, transmission and access, and (2) identify key gaps in data definitions, classification, and utilization. See Commissioner Carl W. Bentzel, FMC, *Recommendations on the Maritime Transportation Data System Requirements* (Washington, D.C.: April 2023).

consistent with the purpose and function of port community systems, which is to digitalize and automate information-sharing regarding cargo movements. Additionally, the report discusses Internet of Things technology, such as GPS and sensors to monitor and communicate cargo location and status. Further, one port authority told us that such standardization of electronic communication could accelerate digitization, and with it, other major technological advances in the port industry. In August 2023, FMC sought additional public input and information on the issues identified through the MTDI.³⁵

Few Selected Ports Desired More Federal Activity on Port Automation Technologies, but Generally Wanted More Support on Supply Chain Issues

Fewer than half of the port authority and terminal operator representatives we spoke with told us that they interacted with federal entities regarding port automation technologies or told us they would like additional federal activity specifically on port automation. Specifically, only five port authority or terminal operator representatives told us that additional federal funding for port automation technologies would be welcome.

However, half of the port authority or terminal operator representatives we spoke to expressed interest in additional federal support on non-automation issues. Specifically, nine representatives told us that increased federal efforts to address broader challenges such as the performance of the overall supply chain, workforce training and development, and U.S. ports' access to certain port equipment would be helpful.

Further, half of port authority and terminal operator representatives we spoke to told us that broader issues with the supply chain, such as limited cargo visibility and mismatches between port, warehouse, and ground transport working hours and approaches, significantly affect terminals' ability to efficiently process containers. For instance, representatives for one port authority and one terminal operator told us that unless other parts of the supply chain—such as ground transportation and warehousing—can increase the speed and efficiency of their operations, any gains in capacity or efficiency that terminals make by adopting automated equipment or other approaches will be lost further down the chain. Another port authority representative told us that port automation would not have prevented many of the supply chain delays and disruptions that arose during the COVID-19 pandemic.

³⁵Request for Information, 88 Fed. Reg. 55697 (Aug. 16, 2023).

Some of the goals, programs, and funding related to port automation that we identified above are primarily intended to address some of these broader supply chain challenges. For example, in February 2022, DOT published an assessment of the freight and logistics supply chain in which it identified more than 60 recommendations to improve the resilience of the U.S. supply chain, including federal activities.³⁶ Additionally, FMC's MTDI seeks to make cargo movements more transparent, improving stakeholders' visibility over supply chain movements to help them better identify and address bottlenecks.

Agency Comments

We provided a draft of this report to DOT, EPA, and FMC for review and comment. FMC provided technical comments, which we incorporated, as appropriate. DOT and EPA did not have any comments on the report.

We are sending copies of this report to appropriate congressional committees, the Secretary of Transportation, the Administrator of EPA, the Chairman of the Federal Maritime Commission, and other interested parties. In addition, the report is available at no charge on the GAO website at <http://gao.gov>.

If you or your staff have any questions about this report, please contact Andrew Von Ah at (202) 512-2834 or vonaha@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in Appendix II.



Andrew Von Ah
Director, Physical Infrastructure

³⁶In November 2023, DOT announced the creation of the Office of Multimodal Freight Infrastructure and Policy within the Office of the Undersecretary of Transportation for Policy. Congress required DOT to create such an office to administer and oversee certain multimodal freight grant programs, promote and facilitate information sharing between public and private freight actors, and conduct research on freight mobility, among other things. Infrastructure Investment and Jobs Act, Pub. L. No. 117-58, § 21101, 135 Stat. 429, 652-656 (Nov. 2021) (codified at 49 U.S.C. § 118).

List of Committees

The Honorable Maria Cantwell
Chair
The Honorable Ted Cruz
Ranking Member
Committee on Commerce, Science, and Transportation
United States Senate

The Honorable Brian Schatz
Chair
The Honorable Cindy Hyde-Smith
Ranking Member
Subcommittee on Transportation, Housing and Urban
Development, and Related Agencies
Committee on Appropriations
United States Senate

The Honorable Sam Graves
Chairman
The Honorable Rick Larsen
Ranking Member
Committee on Transportation and Infrastructure
House of Representatives

The Honorable Tom Cole
Chairman
The Honorable Mike Quigley
Ranking Member
Subcommittee on Transportation, Housing and Urban
Development, and Related Agencies
Committee on Appropriations
House of Representatives

Appendix I: Selected Port Stakeholders Interviewed

Table 4: List of Entities Interviewed

Federal entities	U.S. Department of Transportation	Federal Highway Administration
		Maritime Administration
		Office of the Secretary
	U.S. Committee on the Marine Transportation System	
	U.S. Environmental Protection Agency	
	Federal Maritime Commission	
Associations	American Association of Port Authorities	
	Digital Container Shipping Association	
Technology and equipment companies	Advent eModal	
	Kaleris	
	Kalmar	
	Portbase	
Shipping companies	Hapag-Lloyd	
Labor unions	International Longshore and Warehouse Union	
	International Longshoremen's Association	
U.S. port authorities and terminal operators^a		
Charleston, South Carolina	Port of Charleston - South Carolina Ports Authority	
Houston, Texas	Port of Houston	
Long Beach, California	Port of Long Beach	
	SSA Marine Pacific Container Terminal	
	Long Beach Container Terminal	
Los Angeles, California	Port of Los Angeles	
	TraPac Los Angeles Terminal	
	APM Terminals Los Angeles Pier 400	
New York City, New York	Port of New York and New Jersey	
	APM Terminals Port Elizabeth	
	GCT Bayonne	
Seattle and Tacoma, Washington	Northwest Seaport Alliance	
	Husky Terminal	
	SSA Marine Seattle Terminal 18	
	Washington United Terminals	
Oakland, California	Port of Oakland	
Savannah, Georgia	Port of Savannah - Georgia Ports Authority	
Norfolk, Virginia	Port of Virginia	

**Appendix I: Selected Port Stakeholders
Interviewed**

International port authorities and terminal operators

Antwerp, Belgium	Port of Antwerp-Bruges
	DP World Antwerp Gateway
Rotterdam, The Netherlands	Port of Rotterdam
	APM Terminals Maasvlakte II
	Hutchison Ports ECT Euromax
Singapore, Singapore	PSA Singapore
Dubai, United Arab Emirates	DP World Jebel Ali Port

Source: GAO. | GAO-24-106498

^aOur U.S. port selection included five landlord port authorities (Northwest Seaport Alliance oversees container operations at the ports of Seattle and Tacoma). The port authorities for the remaining four ports own and operate the container terminals.

Appendix II: GAO Contact and Staff Acknowledgments

GAO Contact

Andrew Von Ah, (202) 512-2834 or vonaha@gao.gov

Staff

Acknowledgments

In addition to the contact above, Nancy Lueke (Assistant Director); Stephanie Purcell (Analyst-In-Charge); Kate Raymond (Analyst-in-Charge); Lilia Chaidez; Michelle Everett; John Mingus; Malika Rice; Matt Rowen; Kelly Rubin; Pamela Snedden; Tasha Straszewski; Mary Turgeon; Michelle Weathers; and Alicia Wilson made key contributions to this report.

GAO's Mission

The Government Accountability Office, the audit, evaluation, and investigative arm of Congress, exists to support Congress in meeting its constitutional responsibilities and to help improve the performance and accountability of the federal government for the American people. GAO examines the use of public funds; evaluates federal programs and policies; and provides analyses, recommendations, and other assistance to help Congress make informed oversight, policy, and funding decisions. GAO's commitment to good government is reflected in its core values of accountability, integrity, and reliability.

Obtaining Copies of GAO Reports and Testimony

The fastest and easiest way to obtain copies of GAO documents at no cost is through our website. Each weekday afternoon, GAO posts on its [website](#) newly released reports, testimony, and correspondence. You can also [subscribe](#) to GAO's email updates to receive notification of newly posted products.

Order by Phone

The price of each GAO publication reflects GAO's actual cost of production and distribution and depends on the number of pages in the publication and whether the publication is printed in color or black and white. Pricing and ordering information is posted on GAO's website, <https://www.gao.gov/ordering.htm>.

Place orders by calling (202) 512-6000, toll free (866) 801-7077, or TDD (202) 512-2537.

Orders may be paid for using American Express, Discover Card, MasterCard, Visa, check, or money order. Call for additional information.

Connect with GAO

Connect with GAO on [Facebook](#), [Flickr](#), [Twitter](#), and [YouTube](#).
Subscribe to our [RSS Feeds](#) or [Email Updates](#). Listen to our [Podcasts](#).
Visit GAO on the web at <https://www.gao.gov>.

To Report Fraud, Waste, and Abuse in Federal Programs

Contact FraudNet:

Website: <https://www.gao.gov/about/what-gao-does/fraudnet>

Automated answering system: (800) 424-5454 or (202) 512-7700

Congressional Relations

A. Nicole Clowers, Managing Director, ClowersA@gao.gov, (202) 512-4400, U.S. Government Accountability Office, 441 G Street NW, Room 7125, Washington, DC 20548

Public Affairs

Chuck Young, Managing Director, youngc1@gao.gov, (202) 512-4800
U.S. Government Accountability Office, 441 G Street NW, Room 7149
Washington, DC 20548

Strategic Planning and External Liaison

Stephen J. Sanford, Managing Director, spel@gao.gov, (202) 512-4707
U.S. Government Accountability Office, 441 G Street NW, Room 7814,
Washington, DC 20548

