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

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.

Photo: Theo Notteboom

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

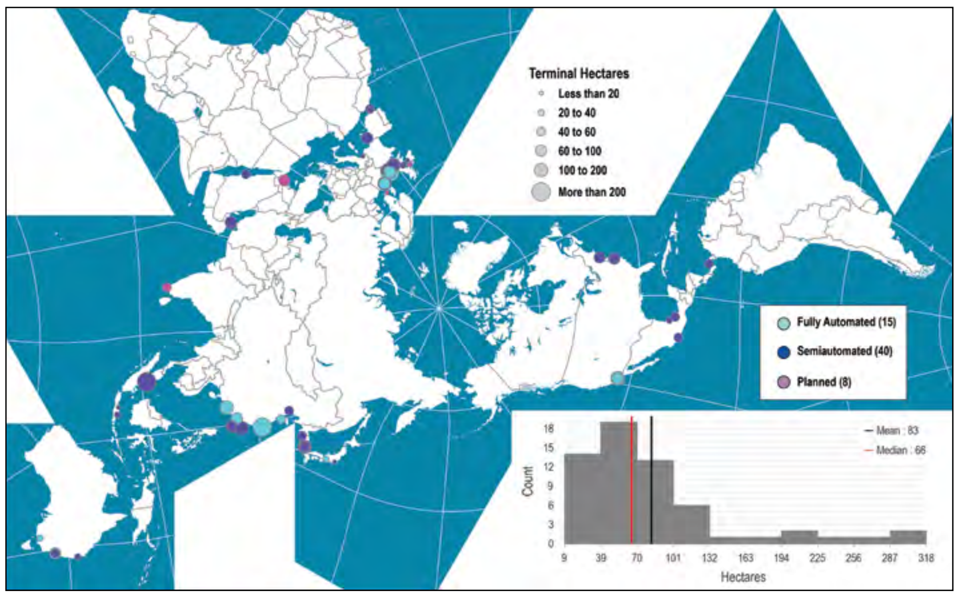

FIGURE 1 **Map of fully automated, semiautomated, and planned terminals worldwide.**

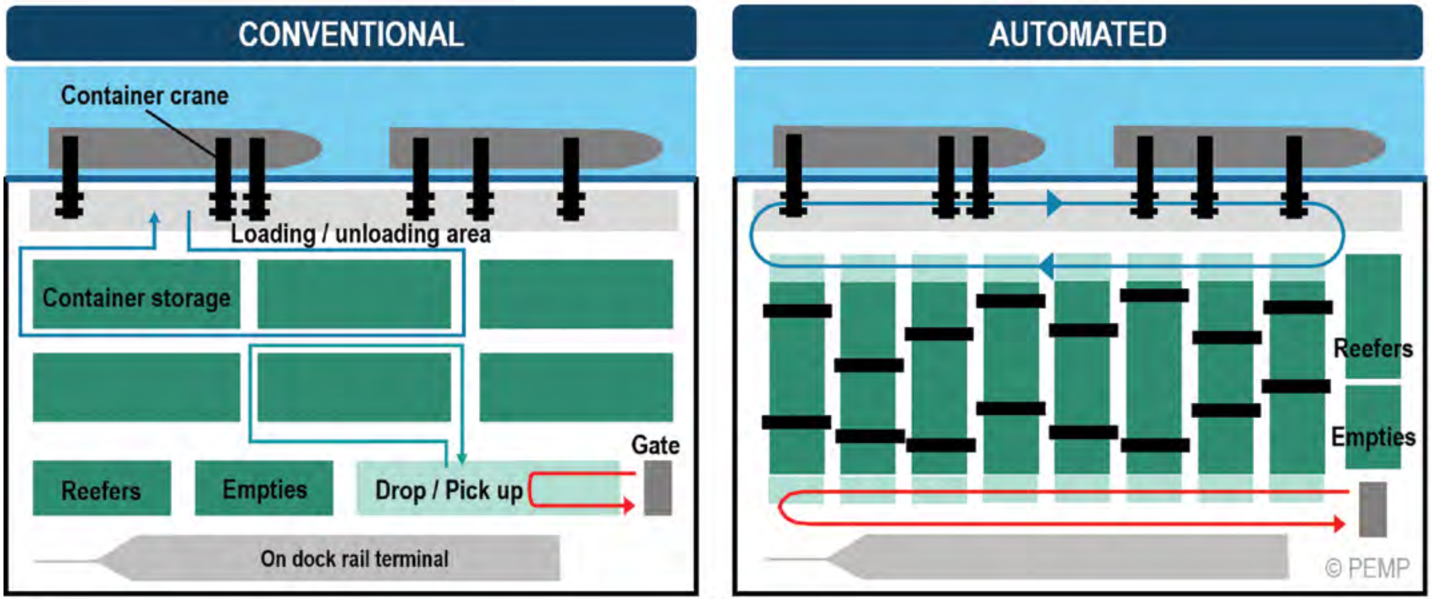

FIGURE 2 Conventional versus automated container terminals (*1*).

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

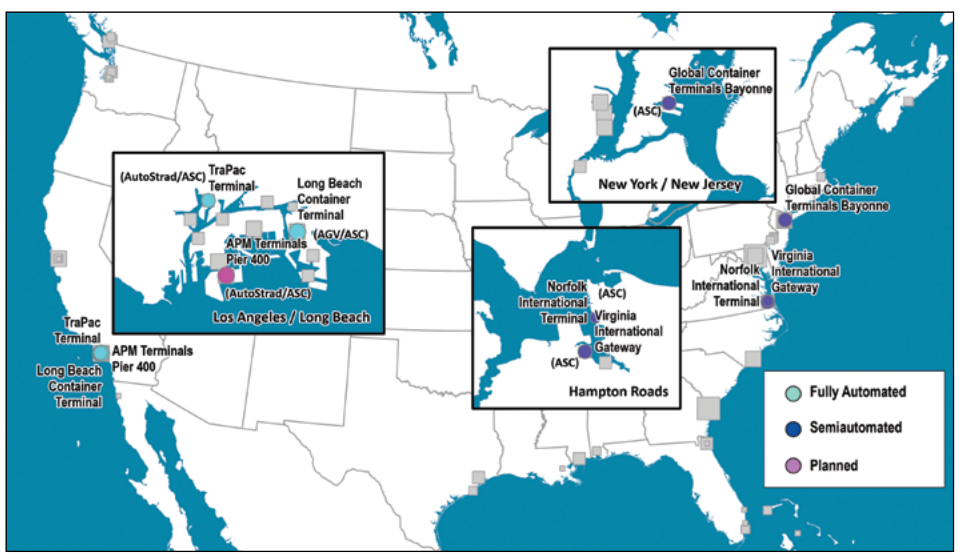

FIGURE 3 Map of fully automated, semiautomated, and planned terminals in the United States.

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

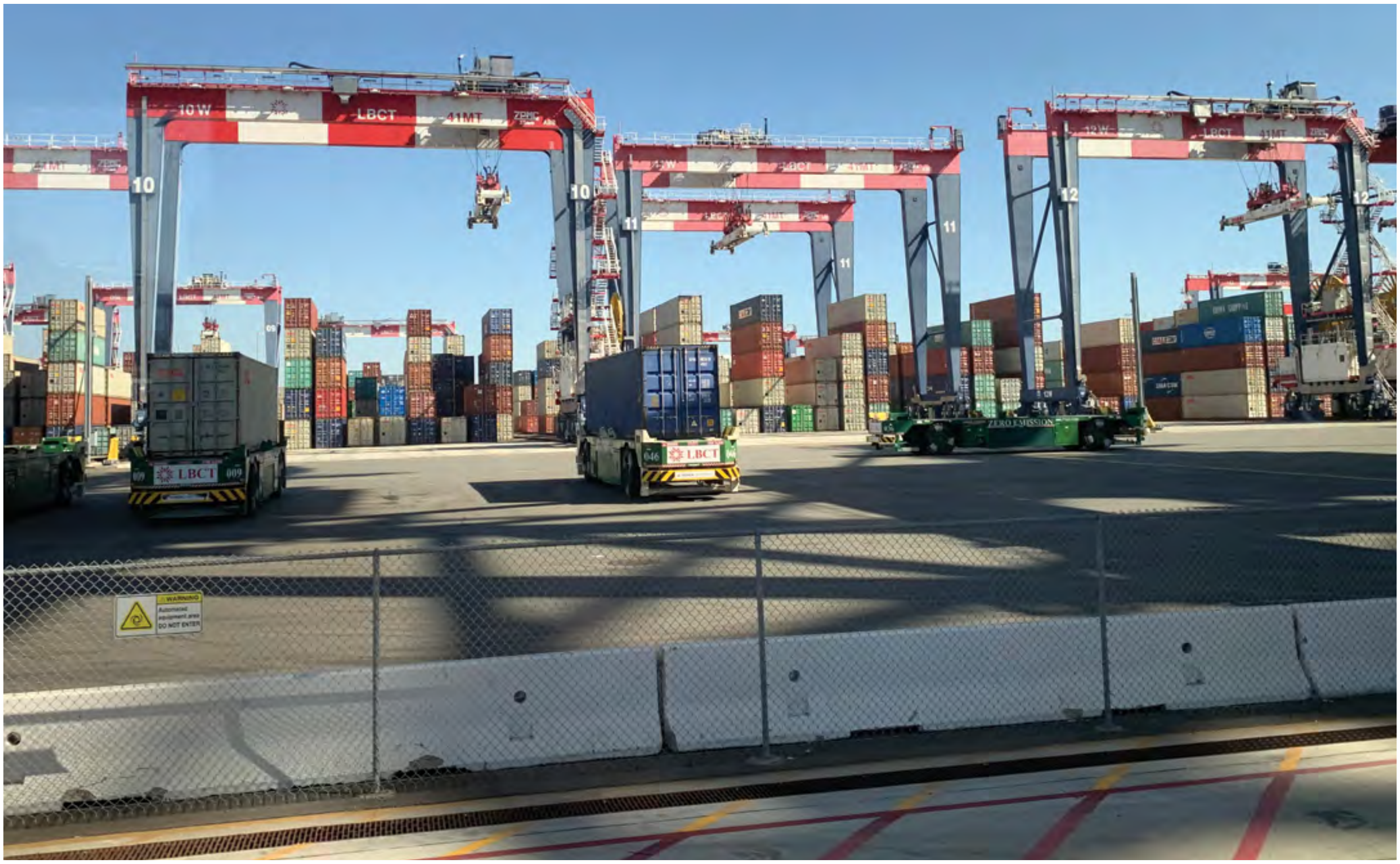

Photo: Jean-Paul Rodrigue

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.