The future of automated ports

The challenges are significant, but careful planning and implementation can surmount them.

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Executive summary

Although ports have adopted automation more slowly than comparable sectors, notably mining and warehousing, the pace is now starting to accelerate. Automated ports are safer than conventional ones. The number of human-related disruptions falls, and performance becomes more predictable. Yet the up-front capital expenditures are quite high, and the operational challenges—a shortage of capabilities, poor data, siloed operations, and difficulty handling exceptions—are very significant. A McKinsey survey indicates that while operating expenses decline, so does productivity, and the returns on invested capital are currently lower than the industry norm.

Nonetheless, successful automated ports show that careful planning and management can surmount these difficulties: operating expenses could fall by 25 to 55 percent and productivity could rise by 10 to 35 percent. And in the long run, these investments will lead the way toward a new paradigm—call it Port 4.0—the shift from asset operator to service orchestrator, part of a larger transition to Industry 4.0, or digitally enabled efficiency gains throughout the world economy. Port 4.0 will generate more value for port operators, suppliers, and customers alike, but that value isn't proportionally distributed across ports and their ecosystems. Innovative business models and forms of collaboration will be required to realize this vision.

The difficult economics of port automation

The first automated container port was developed in Europe in the early 1990s. Since then, many ports—more than 20 in the past six years—have installed equipment to automate at least some of the processes in their terminals (see sidebar, "What is port automation?"). Almost 40 partly or fully automated ports now do business in various parts of the world, and the best estimates suggest that at least $10 billion has been invested in such projects.[1] The momentum will probably accelerate: an additional $10 billion to $15 billion is expected over the next five years.

On the face of it, container ports seem ideal places to automate. The physical environment is structured and predictable. Many activities are repetitive and straightforward. They generate vast amounts of readily collected and processed data.[2] Better still, the value from automation includes not only cost savings but also performance and safety gains for ports and the companies that do business there.

Nonetheless, ports are moving more slowly than sectors with comparable complexities (Exhibit 1), in part because the economics of automating them haven't lived up to expectations. In the mining sector, which is also process driven and asset intensive, some early movers in automation have improved costs and productivity by 20 to 40 percent. In the warehousing business, the improvements have been estimated at 10 to 30 percent. Manufacturers of cars and trucks have also successfully automated complex processes, and some of the equipment they use, such as automated guided vehicles and materials-handling robots, are highly relevant for ports.

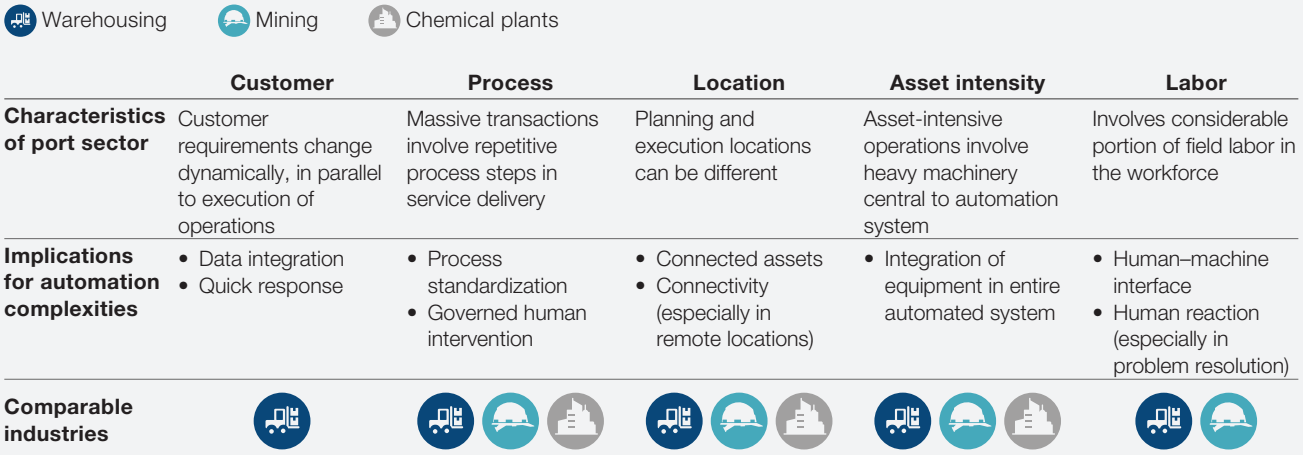
Yet our recent survey of industry leaders indicates that the real-world performance of most automated ports doesn't increase sufficiently in every material way. Safety improves, the number of human-related disruptions (such as shift changes) falls significantly, and performance becomes more predictable. But practitioners responding to the survey think that these ports, especially fully automated ones, are generally less productive than their conventional counterparts. The return on invested capital of assets at some automated ports is falling short by up to one percentage point from the industry norm of about 8 percent.

What the research shows

To determine the current status and future outlook of container-terminal automation in the port sector, McKinsey hosted a forum together with the Shanghai International Port Group and conducted a survey in 2017, just before the Port of Shanghai

Exhibit 1

Container ports face complexities comparable to those of other industries that have already begun to automate.



rolled out a fully automated terminal. We collected the responses of more than 40 participants from leading practitioners in the top ports of China, Europe, the Middle East, Singapore, and the United States; global suppliers of automation equipment and software; and experts from academia, port asset-management firms, and shipping companies. More than three-quarters of the participants were senior executives or high-level managers.

The survey clearly showed that automation has become a trend. Eighty percent of the respondents expect that in the next five years, at least half of all greenfield port projects will be semi- or fully automated. Thirty-five percent believe that the proportion of automated ports will rise above seven in ten.[3] Brownfield projects—the total or partial conversion of existing conventional ports—will probably gain momentum soon: more than half of the participants expect at least 50 percent of the top 50 ports to initiate retrofitting plans or to add automated equipment during the next five years.

But the survey also clearly showed that the return on investment from port automation demands attention from port operators and investors alike. Up-front capital outlays are high. We estimate that to justify these investments, the operating expenses of an automated greenfield terminal would have to be 25 percent lower than those of a conventional one or productivity would have to rise by 30 percent while operating expenses fell by 10 percent.[4]

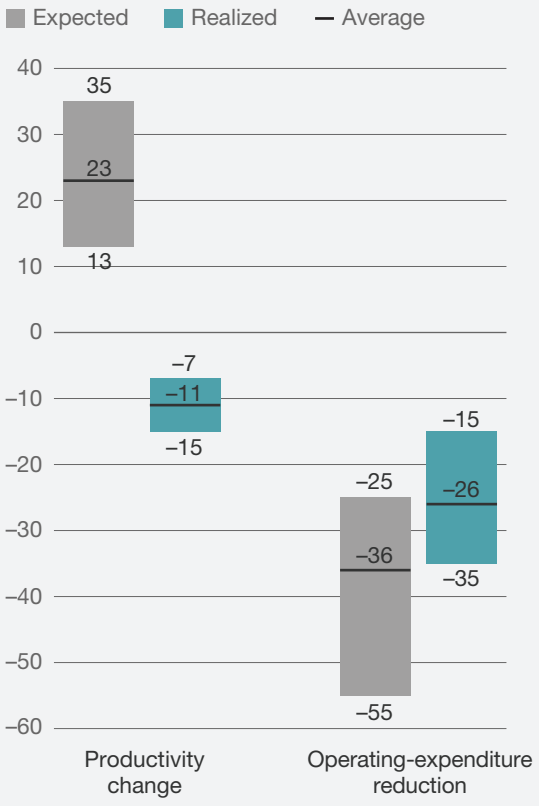
The respondents to McKinsey's survey expect automation to cut operating expenses by 25 to 55 percent and to raise productivity by 10 to 35 percent, in line with our estimates of what might be possible. But today these expectations generally aren't realized, especially in fully automated projects.[5] Our survey indicates that operating expenses at automated ports do indeed fall, but only by 15 to 35 percent (Exhibit 2). Worse, productivity actually falls, by 7 to 15 percent. An executive of a global port operator told us, for example, that at fully automated terminals,

the average number of gross moves per hour for quay cranes—a key indicator of productivity—is in the low 20s. At many conventional terminals, it is in the high 30s. With numbers like these, automation can't overcome the burden of the up-front capital expenditures.

Exhibit 2

Automation currently may not reduce operating expenses or increase productivity as much as expected.

Impact comparison of fully automated greenfield terminal vs conventional terminal, %



Source: Expert interviews; McKinsey Container Terminal Automation Survey, 2017

Barriers and solutions

Responses to our survey suggest that the major barriers (in descending order of importance) are capabilities, data quality, siloed operations, and the handling of exceptions.

A shortage of capabilities

Respondents who had previous experience with automation say that the top problem is filling the specialized technical positions it requires (Exhibit 3); they add that even experienced engineers can take as long as five years to train. Many ports have apparently underestimated the challenge of acquiring the needed capabilities, especially in planning and implementation. Port and terminal operators must therefore step up their efforts to acquire talent and build these capabilities.

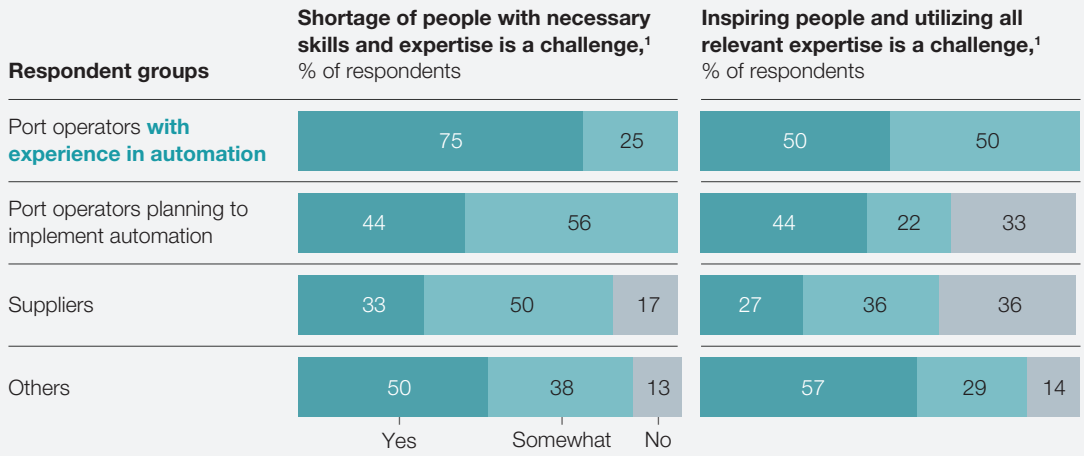
Poor data quality

Like organizations in other sectors, ports find that data silos and a lack of data standards are basic problems in automation. Many interviews with managers of port operations indicate clearly that the quality of data and the data analytics isn't sufficiently strong to run automated ports efficiently.

Why? The first reason is that the lack of a structured, transparent data pool makes it hard to monitor and diagnose the operations and performance of equipment quickly. Second, the standards, formats, and structures of the data may be misaligned or even wholly absent, so ports can't collect and exchange data efficiently.

Data-infrastructure applications have huge potential. They can help to predict and forecast demand and the arrival-and-departure patterns of container ships. They can schedule the maintenance of equipment for optimal availability, allocate equipment and frontline staff, and adjust the allocation in real time. They can also use machine intelligence to make plans ever more accurate. Standardizing data so that they can be used in

Exhibit 3 **A shortage of talent for specialized technical positions is a common issue.**



[1] Figures may not sum to 100%, because of rounding.

Source: Expert interviews; McKinsey Container Terminal Automation Survey, 2017

these ways will help to make ports and terminals more efficient. Ports are not only becoming more aware of this reality but are also starting to upgrade and harmonize their terminal operating systems. Nonetheless, the IT setups of most terminal operators remain fragmented.

Siloed operations

Breaking down silos between functions is always a challenge, but it is especially difficult for ports: the basic principle of automation is process orientation, which requires integration across the end-to-end terminal process chain and important interfaces. Automated ports, unlike conventional ones, can't contain problems at individual functions or process steps. They must therefore ensure close collaboration among activities ranging from marine operations to crane movements to the control of yards and gates.

Handling exceptions

Many ports find that exceptions are the greatest single challenge for raising productivity. More than 60 percent of the operators in our survey agree that when ports have large numbers of exceptions, the likely culprit is a mistaken approach to automating manual processes. Such ports skip an important step: simplifying processes before automating them. These processes therefore remain cumbersome even after they are configured by automated systems.

The way forward

No one route will take all ports to the automated future, but our knowledge of the leading automated ports has revealed general principles that others might consider.

1. *Build automation-ready capabilities.* As we have already noted, port automation shouldn't merely run old processes with new automated equipment. The first step is to redesign the operating model. Port operators should start with a blank slate as they think through every process from beginning to end, across functional silos. The redesigned processes will suggest

the necessary organizational structure and capabilities, including data, the human–machine interface, and the technical infrastructure.

2. *Set up a strong project-governance and communication plan—and execute with discipline.* Automation projects require a wide variety of capabilities in areas such as terminal operations, technical engineering, software engineering, and systems integration. A collaborative project environment is essential, and so is early input from stakeholders such as customers, shareholders, labor representatives, operations leaders, the technical team, vendors, and external experts.

   Make sure to leave enough time for testing, dry runs of operations, and production trials. A normal project cycle could involve 3,000 to 5,000 incident logs that users of the terminal and the port must handle collectively, as well as months of stabilization efforts. Throughout the journey, the case for change should be communicated thoroughly, and stakeholders must be carefully managed. Remember too that the capital intensity of port automation has implications for the economics of projects and for the ongoing cost of implementation, maintenance, and operations. It therefore calls for an awareness of the total cost of ownership and for disciplined execution.

3. *Define a road map to realize value from automation.* Port concessions have timelines, so realizing the benefits of automation at a reasonable pace is important. Port executives should develop the business case for investments and support it with solid productivity, cost, and implementation targets. Then they should monitor performance to track the capture of value. A step-by-step approach will probably work better than a "big bang" push for a total transformation in one mighty blow.

4. *Build and continually refresh your technology ecosystem.* Technical functions not only support automated ports but also control the effort to improve their productivity and asset turnarounds. An appropriate portfolio of in-house and third-party technology providers balances strategic control of important competitive advantages against the need to keep up with the latest developments. The choice of technologies should reflect the business needs of the port and its customers, not the intellectual curiosity of the technical staff.

5. *Incorporate external data into your automation system.* One key benefit of automation is consistent, predictable performance. In a perfect world, machines would execute nothing except instructions. But operational variables beyond terminals—for instance, the arrival of trucks, feeders, and ships—are also important elements of performance; ships, for example, may arrive or depart significantly earlier or later than planned. An advanced automated port should factor these variables (typically available through external data) into its automation systems so it can be flexible enough to cope with changes from customers and unlock the potential of its investment in automation.

Beyond automated machinery

Over the years, ports have evolved through several basic models of operation. In what we call Port 1.0 ("management by hero"), they adopt individual pieces of machinery, such as yard cranes, while workers link individual process steps and direct yard operations. The process-driven operations that define Port 2.0 ("management by process") demand a process-oriented approach: ports govern the steps of these processes through a terminal operating system, while operators make most decisions in the central control tower. Port 3.0 ("management by exception") is a progression from Port 2.0: automated equipment and algorithms

What is port automation?

Automation has five components in ports. They can create value by implementing each component individually but will unlock the full benefit only if all five are integrated and coordinated.

1. *Automated equipment.* Typically, automation requires large up-front capital investments across functions such as ship to shore, yard operations, ground transportation, and gate automation. The technology is relatively stable and mature for many solutions, and we have seen them implemented successfully. This kind of equipment makes operations run more consistently and without downtime. Ports are starting to recognize the importance of such benefits even where low factor costs seemingly make automation hard to justify.

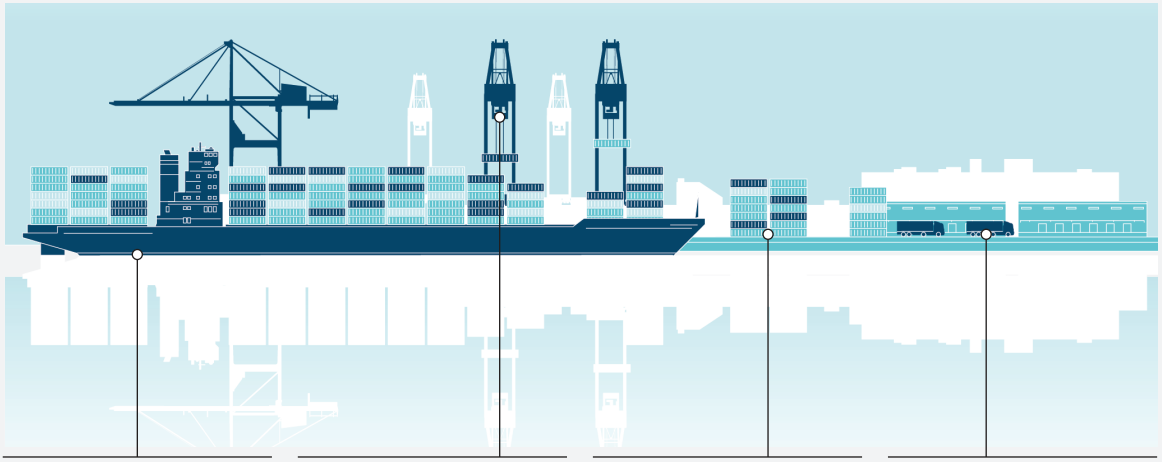
2. *Equipment-control systems.* The essential systems and processes that control machines and equipment make operations smoother and provide more information for decision making. Although integrating many systems and interfaces is hard, and the lack of standardization adds complexity, many ports have begun to use such applications: ports have integrated gate-operating software with advanced optical-character-recognition and camera technology, for example, to automate gate operations and to identify and route containers and trucks automatically.

3. *Terminal control tower.* The "brain" of an automated terminal comprises the terminal operating system, decision-making tools, advanced analytics, the digital platform, and interfaces to the port community and customers. The control tower coordinates and optimizes the management of the entire port; handles demand forecasting, workflow management, scheduling, optimization, monitoring, and control; gives working instructions to the equipment controls; and receives real-time feedback from them. Advanced analytics and machine learning, which can improve the performance of ports by generating better demand forecasts and optimizing operations, will enable these benefits.

4. *Human–machine interactions.* The increasing use of robots and other automated equipment makes interactions between them and humans increasingly important in ports. These interactions take many forms; technologies like augmented reality and virtual reality, for example, direct robots and automated guided vehicles. Augmented reality can also speed up complex tasks such as maintenance. Humans will soon be able to program their own experiences and judgment into these systems.

5. *Interactions with the port community.* A more seamless exchange of data and connectivity along the wider value chain—both sea side and land side—makes the system more efficient. Digitization and real-time connectivity are important for collaboration among the key stakeholders (including liners, logistics service providers, consignees, and customs officials) and for interactions with the wider port ecosystem.

Exhibit 4 **Port 4.0 will be powered by artificial intelligence, optimization through advanced analytics, and dynamic scheduling.**



Real-time berth planning
Berthing slots and labor can be better used by forecasting ships' arrival times more accurately, resulting in up to 8 percentage points of EBITDA[1] potential for terminals

Predictive maintenance for key assets
Predictive and remote crane and vehicle maintenance can lead to a 30–50% reduction of total machine downtime, increasing the availability of critical port assets, such as STS[2] and RTG[3] cranes

Automated yard planning
Advanced analytics and modeling make it possible to swap assets, reroute containers dynamically, and adjust routing and speed in real time

Demand planning at gate
More accurate predictions of consumer and production behavior can help terminals better estimate demand for gate arrivals

[1] Earnings before interest, taxes, depreciation, and amortization.
[2] Ship to shore.
[3] Rubber-tired gantry.

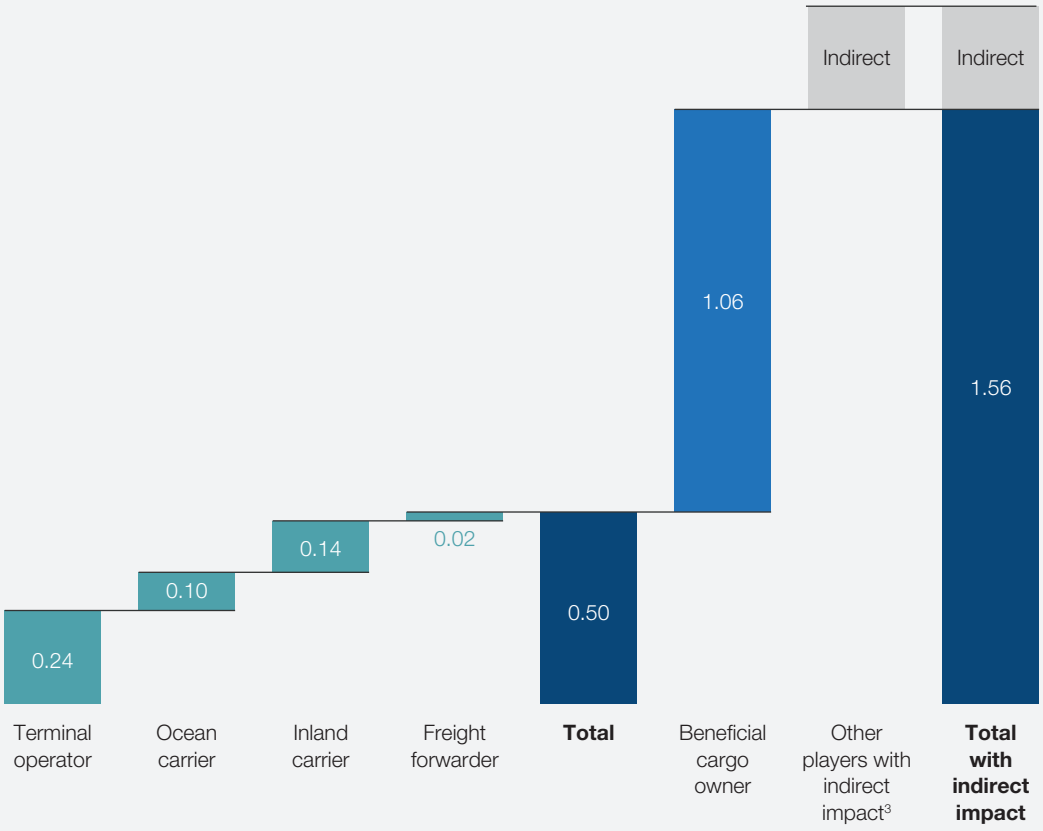
run and optimize processes, leaving humans to dispose of exceptions.

But Port 3.0 isn't the end of the story. In the model of the future, Port 4.0 ("from manage to orchestrate"), ports will enlarge their role by orchestrating physical and information flows inside and outside terminals to enhance the port ecosystem's broader, systemwide efficiency (Exhibit 4). Forward-looking ports will push toward this next horizon, beyond automation, in the coming Port 4.0 era. Every player—terminal operators, trucking companies, railroads, shippers, logistics companies, and freight forwarders—will be connected to optimize not just the port itself but also its entire ecosystem.

The cornerstone of Port 4.0 will be automation, which—if implemented and configured appropriately—can transform ports into highly reliable and flexible logistics hubs that direct predictable physical flows and use extensive data and advanced analytics to buffer the many variables in transportation networks. Ports, now often seen as constraints in transportation networks, could then actively resolve problems in other parts of the value chain.

Exhibit 5 **Port 4.0 could create more than $1.5 billion in value for an average port and could have an impact of some $70 billion to $80 billion on a global scale.**

Example of value creation[1] for 1 medium-size port,[2] by stakeholder, $ billion



[1] Sum of revenue and cost absolute impact, rounded numbers.
[2] Assuming ~$1 billion in revenues for container port, 6 million–8 million twenty-foot equivalent units of import/export generated, and ~$2 trillion trade value per annum.
[3] Sum of revenue and cost absolute impact, rounded numbers. The indirect impact includes customs, port authority, towage, and pilotage.

This journey from Port 1.0 to Port 3.0 has been evolutionary, but Port 4.0 requires a leap into the future and bold changes in the operating model. We estimate that for a six- to eight-million TEU[6] port that handles both imports and exports, the value at stake from Port 4.0 might be more than $1.5 billion a year for the port community, including terminal operators, shipping companies, intermodal operators, freight forwarders, shippers, and consignees. Terminal operators might capture less than 20 percent of the value pool directly, and other parties in the ecosystem would claim the rest (Exhibit 5).

The sectorwide gain in efficiency is obvious. But the ports' traditional investment model, which

requires terminal operators to front-load investments, doesn't align with the distribution of value in Port 4.0. It will be essential to involve the relevant stakeholders and to develop, together with them, a new business and governance model for collaboration—a model that ties investments to the redistribution of value. Only then will Port 4.0 unlock its full potential.

The value at stake from Port 4.0 is large but not proportionally distributed across ports and their ecosystems. Realizing that value will require innovative business models and new collaboration frameworks. They won't come easily. Yet this is surely a future worth striving for.

[1] Port-automation investments include basic infrastructure and automation equipment.

[2] For more, see "Harnessing automation for a future that works," McKinsey Global Institute, January 2017, on McKinsey.com.

[3] The percentage could vary by region. In any case, the trend toward automation is consistent, particularly for high-capacity greenfield projects, which are mostly major gateway ports and transshipment hubs that must provide consistent, reliable, and uninterrupted service for large vessels.

[4] We derived these estimates from interviews with experts and industry executives, as well as our own estimates and analysis.

[5] Integrated quayside–yard–gate automated terminals.

[6] Twenty-foot equivalent unit.

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