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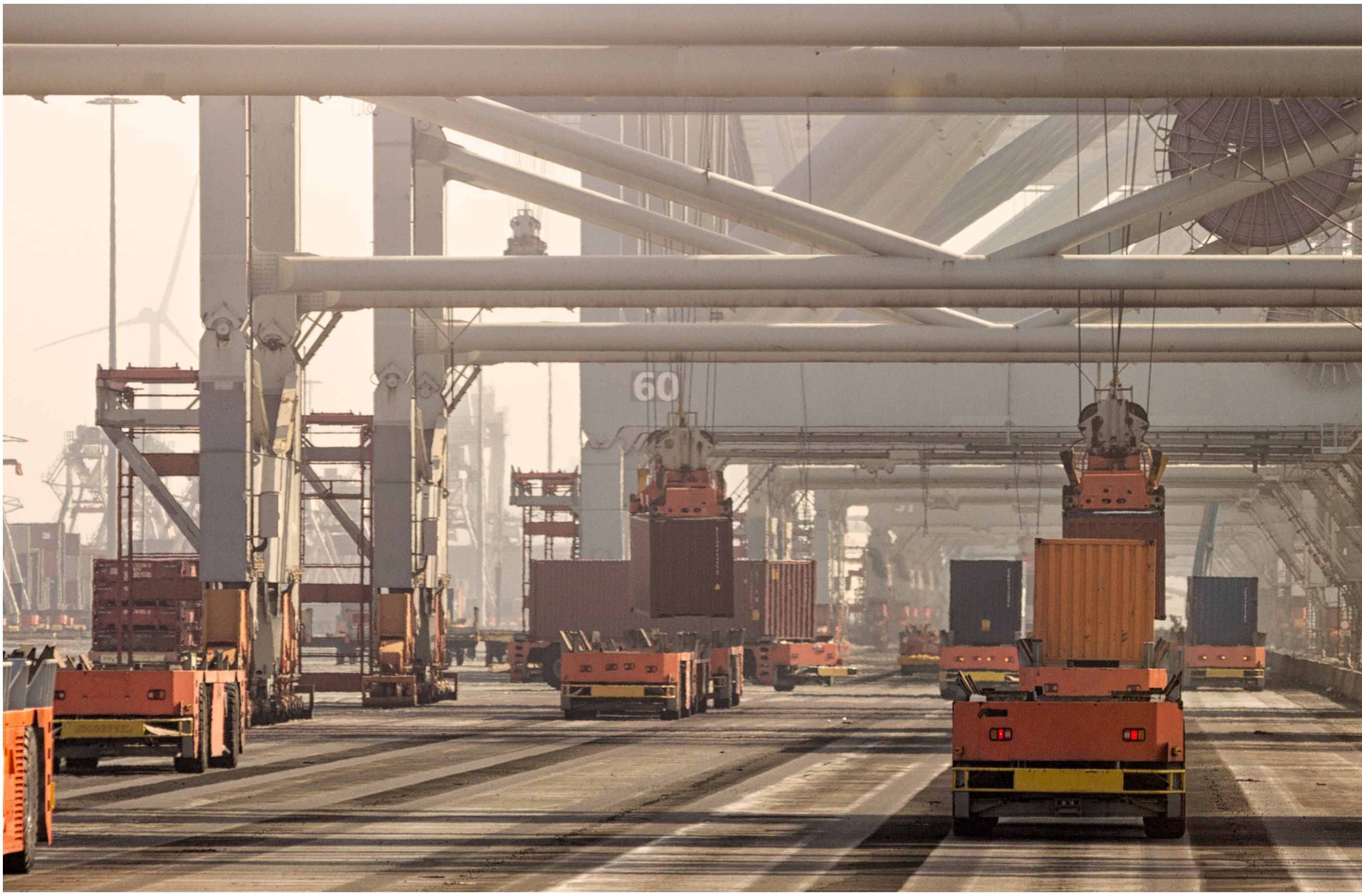
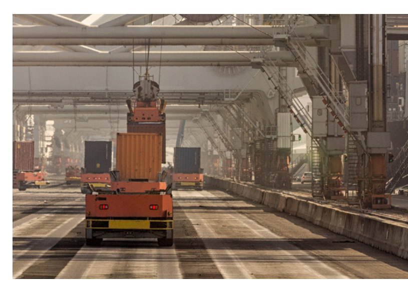


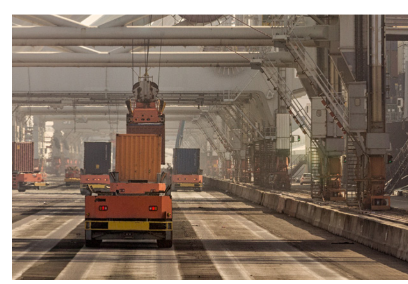
Container Port Automation
Impacts and Implications



Case-Specific Policy Analysis

Container Port Automation

Impacts and Implications



Case-Specific Policy Analysis

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Executive summary

What we did

This report provides an overview of the current state of container terminal automation in ports. It shows which terminal activities have been automated in different ports and which additional activities might be automated in the future. It assesses the effects of automation on port performance, handling costs and safety, and the extent to which automation projects have achieved their objectives. Finally, the report identifies policy issues related to container terminal automation. The report benefits from interviews with relevant stakeholders and data collected from port authorities.

What we found

Fully automated container terminals do not yet exist. Across the world, 53 container terminals are now automated to a certain degree. This represents around 4% of global container terminal capacity. Most automated systems are deployed in the container yard. Only a few terminals have automated the transport between quay and yard. No terminal has completely automated quay cranes.

Automated ports are generally not more productive than their conventional counterparts. Port organisation and specialisation, geographical location and port size are more important determinants of port performance than automation. This explains the limited automation of container ports to date.

Comparatively, high handling costs also make the case for automation not entirely convincing. Although automation of container terminals reduces labour costs, capital costs are higher as automated equipment is more expensive than manually operated equipment. Whether or not automation has led to lower overall handling costs is place-specific. It depends significantly on local labour costs and on the degree to which machines replace port labour.

Finally, it is often assumed that automation improves the safety and health of terminal workers. Whilst automating processes that expose workers to risk is clearly beneficial, there is so far little robust empirical data to demonstrate significant overall improvement in outcomes in practice.

A few container terminals have recently introduced remote quay-crane operations. Instead of operating from a cabin on the crane, the operator works from a distance in an operations centre on the port premises. This innovation has yielded mixed results so far in terms of productivity.

Automated systems for inter-terminal transport have been discussed but have not been implemented because of their limited feasibility. The port of Rotterdam sought to introduce an automated system for inter-terminal transfers but finally decided against it because of the costs and financial risks.

Container terminal automation appears to offer benefits only under certain conditions and thus for a limited group of terminals. Container terminals that face a relatively stable market with guaranteed throughput are more suitable for high levels of automation because of their regular cargo flows. In contrast, terminals with fluctuating throughput are better served by less automation as this maintains greater flexibility. Container volumes are more volatile in transhipment terminals, so more flexibility and low levels of automation are advantageous. Gateway terminals, by contrast, generally have a certain level of captive container volumes, so they tend to be more suitable for automation.

Consolidation of carriers, the market power of alliances and the rise of mega-ships have increased peak loads, volatility of cargo flows, and transhipment. These developments require terminals to be more flexible to assure ship-to-ship connections. They make the case for automation less convincing and flexible arrangements for port labour more appropriate, provided enough labour is available. Yet these factors are sometimes absent from policy considerations.

The costs and benefits of port automation projects are rarely spelt out. Automation projects can deliver clear benefits under some assumptions but not under others. No clarity on assumptions means that stakeholders will not be able to assess the merits of automation projects. Bigger ships do not necessarily need automation, and automation is not required to reduce emissions. Evaluations of port automation projects are not commonly made public and policy making internationally would benefit if more were released.

Port automation projects are regularly the subject of social conflict in ports. When the benefits of automation are ambiguous, some stakeholders will interpret any push for it as an attempt to diminish dockworkers' unions. Polarisation between the positions of employers and employees has resulted in cases of automation in the face of opposition from port workers but also attempts by legislators to restrict automation. At the same time, there are instances of unions, port authorities and terminal operators cooperating constructively to introduce automation under conditions considered appropriate by all involved. Various port automation projects have shared the benefits of automation with port workers. This has taken the form of wage increases, early retirement programmes for older workers or other benefits, often part of a package negotiated with the introduction of automation. When labour is locally scarce, workers displaced by automation are likely to be rapidly re-employed elsewhere in the economy.

The social costs of port automation are not usually quantified in port investment strategies. Costs such as social security expenditures (in case of redundancies) and tax revenues foregone (when machines replace port workers that cannot be reintegrated into the labour market), which are passed on to other parts of the public sector, are naturally disregarded by most port stakeholders, but they do need to be taken into account by government.

What we recommend

Put more focus on flexible labour arrangements

The current situation in container shipping requires flexibility to deal with peaks and troughs related to larger ships and increased volatility of container flows. With present technology, automated terminals are not particularly well suited to deal with these requirements. Flexible labour arrangements, such as port labour pools, make it possible to vary labour inputs depending on the container volumes to be handled at any given moment. Governments should consider how such flexible port labour arrangements can be facilitated.

Better identify the costs and benefits of port automation projects

Terminal operators, trade unions and governments should have access to assessments of costs and benefits of port automation project proposals and their underlying assumptions. This knowledge guarantees that all stakeholders can assess the merits of the automation project based on the same evidence. Any evaluations of port automation projects should be made public. Findings will help policy makers to identify under which conditions automation could be effective.

Stimulate social dialogue and co-operation between employers and workers on port automation

Co-operation between port stakeholders implies a social dialogue between employers, workers, and government representatives on the economics of cargo handling in ports. This should cover wider developments in container shipping that affect the desirability of automation, such as industry consolidation and ever-larger ships, as well as automation itself. Agreements to share productivity gains with workers can also facilitate the introduction of automation.

Address social costs of automation

Analyses of port automation projects should include estimations of societal costs, including impacts on local employment and tax revenues. Governments need this information even if issues related to automation are much broader than the port sector and subject to economy-wide policies on the balance between the taxation of capital and labour.

Introduction

This report explores automation in container terminals. Containerisation has rationalised cargo handling and has been credited with large increases in global trade, but it was at its outset vehemently opposed by trade unions because it would make many dockworkers redundant (Levinson, 2006). Already at an early stage, containerisation was linked to automation: in 1967, when just a few ports had started to adapt to containerisation, management consultancy McKinsey predicted that most container ports would become automated (Mc Kinsey and Company, 1967). For some actors this was highly desirable, as it would limit the labour conflicts that were considered particularly high within seaports; for others, it was not.

More than six decades after the emergence of containerised maritime transport, it appears that containerisation has indeed drastically reduced the number of dockworkers (see for example Hall, 2004), but that automation is much less widespread than predicted. Although automation is applied in several large container terminals across the world, it is far from universal practice. In 2021, around 53 container terminals can be considered fully or partially automated, accounting for around 4% of total container terminal capacity. At the same time, it has been predicted that around 90% of current dock work might disappear by 2040 due to automation (Schröder-Hinrichs et al., 2019).

This study reviews the possibilities for container terminal automation and the extent to which automation has taken place in container ports. It outlines the terminal activities that have been automated and the additional activities that might possibly be automated in the future. It also assesses the intended and unintended effects of automation, including an assessment of the effectiveness in achieving its objectives. Finally, the report identifies policy issues related to container terminal automation in relation to ensuring automation projects generate public value.

The focus of this study is on container terminals. Around the world, there is a great diversity between container terminals in the technical potential and the nature of automation in practice. In comparison, bulk terminals – in particular liquid bulk terminals – are more advanced in terms of automation (Khalili, 2020). This is reflected in the very limited effect on employment today of increasing liquid bulk cargo volumes (Bottasso et al., 2013). The experience with container terminal automation to date could also be relevant for other port terminal segments, for example, the roll-on/roll-off segment where automated equipment from container terminals could possibly be deployed (Park et al., 2021).

Categorising port automation

Port automation can be defined as the automation of a significant part of port cargo handling activities, where automation refers to processes where manual labour is fully outsourced to autonomously operating machines. There are different degrees of container port automation; in order to understand the extent to which automation has been pursued in container ports, it is necessary to understand the typical container port handling processes. This section describes these processes, the cargo handling equipment that is used during these processes and the extent to which it has been automated.

The port cargo handling process

The container port cargo handling process is the set of activities taking place in ports to transfer containers from a ship into the port area onto its next mode of transport and vice versa. Therefore, it is the processes from the moment a ship arrives in port to the moment the truck (or train, ship, barge etc.) with the container leaves the port, and vice versa. More precisely, from the moment a truck (or train, ship, barge etc.) enters the port area until the moment the container is loaded on the ship. For the purpose of this report, the current or potential forms of automation in container shipping (autonomous ships), services to guide ships to ports – such as pilotage, towage and mooring – or the automation in hinterland transport modes are not explored.

Three are three different sub-processes in port handling: quayside operations, yard operations and landside operations. Quayside operations consist of the loading and unloading of container vessels from ship to shore (or shore to ship). This process can be sub-divided into four different sub-processes: lashing, operating the quay crane, twist-lock handling, transferring from quay to yard. Yard operations consist of temporary storage of containers and assortment in areas called container yards. Landside operations consist of dispatching containers to or receiving them from truck, train, barge or ship (Table 1).

Table 1. Cargo handling sub-processes

Sub-process	Activities
Quayside operations	Lashing Quay crane operation Twist-lock handling Quay to yard transfer
Yard operations	Container stacking
Landside operations	Port gate checking

Lashing

Full container ships transport large stacks of containers: up to eleven levels on deck and up to nine levels below the deck. These stacked containers are physically connected with twist locks: twist-and-plug connectors inserted into the corner casting of a container that serves as a vertical connection between stacked containers on deck. A sufficient number of twist locks are stowed in gearbox containers aboard the ship. In addition, containers on deck are secured with lashing bars, while the cargo holds below deck are fitted with cell guides on the walls of a container ship that secure the containers against slippage (Kugler, Brandenburg and Limant, 2021).

In most container terminals, when a container ship moors at a berth, lashers come on board to manually unlock the twist locks and lashing bars between the individual container layers on deck before the unloading process can begin. The unlocking process of twist locks depends on the type of twist lock that is used. Three types can be distinguished:

- Manual twist locks, which must be manually unlocked and locked before containers can be unloaded or secured;
- Semi-automatic twist locks, which lock automatically when the container is set down on the ship but must be unlocked manually before unloading
- Fully automatic twist locks, which are automatically locked by the container's own weight and automatically unlocked by a container crane's tearing force (Bültjer and Schulze, 2013).

Securing and lashing containers on ship decks is a difficult and dangerous operation. A quayside container crane generally requires at least two stevedores for manual unlocking work (Zhang et al., 2015). According to some observers (Ma et al., 2014) fixing and removing twist locks is the most difficult process to automate in container terminal handling.

Operating quay cranes

After the twist locks are unlocked, quay cranes, also referred to as ship-to-shore cranes, transfer the container from the ship to the quay. Most container terminals use specialised container quay cranes for this operation, which consist of a supporting framework that can traverse the length of a quay on a rail track and a boom that is lifted over the ship. Container cranes are equipped with a specialised handling tool called the spreader that can be lowered on top of a container and locks onto the container's four locking points (corner castings) using the twist-lock mechanism referred to above. The quay crane is manned by an operator who sits in a cabin suspended from the trolley. The trolley runs along rails located on the top or sides of the boom and girder. The operator runs the trolley over the ship to lift the container. Once the spreader locks onto the container, the container is lifted and moved over to the dock.

Quayside operations usually involve several quay cranes at the same time. There is a physical limit to the number of quay cranes that can maximally be deployed on container ships, considering the space they take on the quayside. This physical limit acts as a constraint on quayside productivity.

There are no automated container quay cranes. Existing cranes are currently unable to autonomously lift the containers on or off the vessels due to difficulties in aligning the container spreader with the container slots. Another limitation is that vessels move slightly during container handling operations, which makes determining the exact location of the containers on the vessel a complex task. The automation of quay crane movements is possible in theory, but due to high operational complexity, quay crane automation is least developed and seldom implemented. Only selected sub-processes are automated. A few container terminals have remote crane operators, which means they no longer operate the crane in a suspended cabin on top of the crane, but in a separate operations centre elsewhere in the port area.

Twist-lock handling

When the container is lifted from the ship, the unlocked twist locks are still connected to the upper container and remain in its lower corner castings. Before onward transport of containers takes place, the twist locks must be removed from the container and returned to the ship after completion of cargo operations. The container is picked up by the quay crane, lifted from the ship, lowered over the pier and held approximately 1.5 meters above the ground so that lashers can remove the twist locks from the container and temporarily store them nearby. After that operation, the container is put down on the ground, picked up by yard vehicles and transported to the container yard.

Some container terminals have container cranes that separate the collection of twist locks and the transportation to the container yard. These cranes are so-called double-trolley quay cranes that have a lashing platform where a container can be placed for twist-lock handling. In such systems, the first trolley – the main trolley – transports the container from the ship to the lashing platform where twist locks are removed or inserted by lashers and the second trolley – the so-called portal trolley that runs on the portal beams – transports the container between the lashing platform and the yard vehicles. Since both trolleys operate independently from each other and from the twist-lock handling process, the twist locks can be inserted on or removed from the lashing platform independently of the trolley movement. Thus, the lashing platform eliminates the process of holding the container above the ground (Kugler, Brandenburg and Limant, 2021). The main trolley is manned, with the operator performing the set-down or pick-up on the ship. The rest of the cycle – from above the safe height over the ship to set-down or pick-up on land – can be fully automatic. A portal trolley is generally unmanned and fully automatic (Christerson, 2008).

In case of loading, the container is positioned below the quay crane, lifted and held above the ground so that lashers can insert the twist locks into the corner castings. When double-trolley quay cranes are in use, the twist locks are inserted at the lashing platform. On board, the twist locks are locked and after securing the containers with lashing bars, the ship is eventually ready for departure.

Moving containers from quay to yard

So-called horizontal transport vehicles perform the transportation of containers between quayside and container yards. These horizontal transport vehicles can be classified as self-lifting or non-lifting (Table 2). Non-lifting vehicles require external material handling equipment to load or unload a container; these include yard trucks and automated guided vehicles (AGVs). Self-lifting vehicles are able to lift containers from the ground, either manually or autonomously; this category of vehicles includes straddle carriers and automated lifting vehicles (ALVs).

Table 2. Vehicles for transfer from quay to yard

Category	Vehicles
Non-lifting	Yard trucks Automated guided vehicles (AGVs)
Self-lifting	Straddle carriers Automated lifting vehicles (ALVs)

The main vehicles for quay-to-yard transfer are described below:

- **Yard trucks** are the most commonly used transfer vehicles in large container terminals, given their comparatively low investment cost and large capacity. Yard trucks simply haul containers placed over a chassis. Yard trucks require a human driver; the engagement of the yard truck with the chassis can be done without human intervention, but the release of the chassis requires human intervention.

- Similar activities are carried out by **automated guided vehicles**, characterised by the fact that they are completely automated and controlled by a central computer that decides on the dispatching and movement of each vehicle.
- **Automated lifting vehicles** are similar to AGVs but, in addition, have the ability to self-lift containers.
- **Straddle carriers** are capable of stacking containers up to several levels high, so not only are they used to transfer containers from the quay to the yard, but also to use them for stacking purposes in the container yard. Most straddle carriers are operated by dockworkers, but there are also automated straddle carriers.

Most Automated Guided Vehicles (AGVs) travel on a fixed path guided by markers, wires, lasers, or computer vision. A new generation of "intelligent" AGVs do not follow a fixed path and are monitored by GPS, allowing more freedom of movement but resulting in more complicated traffic management. The travel paths of AGVs are typically divided into zones; they must request permission before moving into another zone to avoid potential collisions, congestion and deadlocks. Such deadlocks are usually managed by two strategies: deadlock prevention and deadlock resolution. Deadlock prevention strategies typically limit access to zones to prevent deadlocks. Deadlock resolution instead detects and resolves deadlocks as soon as they become possible (Lehmann et al., 2006). Deadlock prevention and resolution are commonly used together.

Yard operations

In some terminals, containers can be moved directly from the quayside to the port terminal gates to be forwarded directly to their final destinations. However, in most cases, they spend time in container stacks at the stacking area before being moved. Prior to a ship's arrival, a pre-stowage is made at the terminal, i.e. containers to be loaded are brought into the area of the berth for faster cargo operations. Currently, three main stacking solutions can be distinguished, using:

- Straddle carriers or reach stackers are transport vehicles with the capacity to lift one (and in some cases more than one) container. Straddle carriers can move between rows of containers and can stack them up to four tiers. Reach stackers usually stack not more than two deep and three or four high. Straddle carriers are more efficient for large operations than reach stackers and are faster (Vis and Roodbergen, 2009; Wiese et al., 2013). Straddle carriers and reach stackers are mostly used in non-automated terminals.
- Rail-mounted gantry (RMG) cranes are specialised yard handling equipment that run on rail tracks; they can lift containers by a spreader attached to cables. Stacking operations using RMGs decouple the seaside and landside operations. RMGs are used to stack containers in container blocks – also known as stacks – with multiple tiers, rows, and bays. Container stacks are typically oriented perpendicular to the quay. RMGs are often automated, in which case they are also called automated stacking cranes (ASCs).
- Rubber-tired gantry (RTG) cranes are gantry cranes running on rubber tyres so that rail tracks are not needed. RTGs, like RMGs, are capable of lifting fully loaded containers to great heights. RTGs are often used to streamline the movement of containers from one ship to another by orienting containers stacked parallel to the quay, a design more common in transhipment terminals. In

such terminals, RTG cranes are used to stack containers one behind the other (Gharehgozli, Zaerpour and de Koster, 2019).

Landside operations

Landside operations in a port cover the transport of a container from the container yard to its next transport mode beyond the port gate and vice versa. Moving containers from stacks to trucks and trains is generally done with the yard equipment described above. An essential activity of landside operations is checking the containers and trucks entering (and leaving) the port.

This check of containers and trucks is carried out at the port gate. The essential data to be identified, checked and transmitted are data such as container number, type, size, condition, weight, owner and voyage-related information. Not only must the container be identified but also the driver's information and the license number of the truck and chassis that need to be linked with the container.

Many container ports have automated a significant part of these gate operations. In many advanced terminals equipped with specially devised devices, truck drivers can swipe their driver licenses through the window without getting out of the cabin. Therefore, the driver information can be verified and recorded efficiently (Chao and Lin, 2017). In order to identify containers and the license plate numbers of trucks and chassis, two main technologies are used:

- Radio-frequency identification (RFID) systems need every object to be tracked to be identified with a "tag" or transponder and use radio waves to transmit data. The main advantages of this technology are the longer read distance and the large number of assets that RFID is able to identify and locate at the same time: an RFID tag on a container or truck can be read from almost a kilometre away in some cases.
- Optical character recognition (OCR) systems capture images from the top, both sides and the back of a container and then recognise container numbers from these images. OCR is used for the recognition and identification of equipment markings, such as the container number, truck and trailer license plates, and to record the condition of the equipment itself. The main benefit of OCR technology is the fact that it provides a reliable method of identification without any need to apply a dedicated tag or device to the asset.

Fully and semi-automated terminals

Quayside operations have so far been automated to only a limited extent, with limited potential for automation; yard operations and port gate operations can be automated to a large extent, as implemented by a considerable number of container ports (Table 3).

Generally, there is consensus that "automated container terminal" usually refers to automated container handling in the yard, in particular use of AGVs, autonomous straddle carriers or autonomous stacking cranes (ASC) (Gupta et al., 2017; Kumawat and Roy, 2021 Vis et al., 2001). However, the difference between a fully and semi-automated terminal has not been defined in similar ways and depends on whether sub-processes or entire process chains are automated (Martín-Soberón et al., 2014), whether both yard cranes and horizontal transport have been automated or only one of those activities (Pamungkas and Saut Gurning, 2020) and whether all or only one or two of the three main port handling operations (quayside, yard and landside) are automated (Wang, Mileski and Zeng, 2019). For this reason, the terminology of fully- or semi-automated terminals is avoided in this report to avoid misunderstanding.

Table 3. Feasibility of automation of container handling activities

Sub-process	Activities	Automation feasibility
Quayside operations	Lashing	Low
	Quay crane operation	Low
	Twist-lock handling	Low
	Quay to yard transfer	High
Yard operations	Container stacking	High
Landside operations	Port gate checking	High

Drivers of port automation

Container terminal operators are the main driving force for terminal automation projects. These are the companies in charge of container handling in ports, a right granted to them by port authorities, often via concession or lease agreements. Under such agreements, terminal operators commit to exploit port berths and make the necessary investments in terminal handling equipment, such as quay and yard cranes. In most parts of the world, terminal operators also employ and/or pay port workers so they can deal with trade-offs between labour costs and automation costs.

The main motivations for terminal operators to automate are related to productivity gains and lower handling costs. The extent to which these ambitions have been realised is assessed later in this report. The major terminal operators have terminals throughout the world, which allows them to duplicate good practices from one terminal into other terminals, but there is still a large variety in automation levels in container terminals, even between those of the same company. The reason is that terminal automation attractiveness depends on the local labour costs and the terminal profile. In countries with low labour costs for dockworkers, terminal operators have less financial incentives to automate, considering that prices for automated equipment are set globally. The rationale for automation also differs according to the terminal profile. Terminals that face a relatively stable market with guaranteed throughput volume are more suitable for high levels of automation because of their regular cargo flows, whereas terminals with high throughput uncertainty are better served with low levels of automation because it can provide more flexibility. As container volumes are more volatile in transhipment terminals, these require more flexibility and thus are better served with low levels of automation. Gateway terminals generally have more captive container volumes – implying less throughput uncertainty – so they tend to be relatively more suitable for automation (Wang, Mileski and Zeng, 2019).

Concerns about security and congestion have driven many port gate automation projects by port authorities. The 9/11 terrorist attacks increased the requirements for container security in ports throughout the world. Time-intensive checks at the port entrance easily congest port cities; automation at the port gate can speed up information exchange and control and thus help avoid such congestion.

Some port authorities also stimulate automation projects by terminal operators, e.g. via granting of concessions to automated terminals and promoting port digitalisation projects. Port authorities promote their businesses as the "smartest of the smart ports" and automation projects feature heavily in such smart port programmes.

Container shipping companies request their ships to be loaded and unloaded in the fastest possible times in order to minimise the costly time ships spend in port and to keep vessels on tight schedules while operating at lower, more fuel-efficient ship speeds (Stahlbock and Voss, 2008). The introduction of mega-ships has increased the pressure on terminal operators and port authorities to improve terminal productivity, with container carriers suggesting this might need to be provided by more terminal automation. Many of the largest container lines have integrated terminal companies, some of which operate automated terminals.

The position of trade unions for dockworkers towards automation projects has ranged from outright negative to constructive, depending on the possibility to negotiate package deals favourable to existing or new dockworkers. Trade unions in several ports have been engaged in implementing port automation projects, whereas discussions in other ports have been highly confrontational, often fuelled by the suspicion of unions that port automation projects are primarily motivated by employers' desire to minimise union power.

Governments have taken divergent positions on port automation. Several governments have formulated strategies on maritime innovation or maritime clusters, in which port automation forms a part. For example, the 2030 Port Policy and Implementation Strategy of the South Korean government focuses on the establishment of a smart logistics system, which includes port automation. China's 13th five-year plan (2016-2020) promotes the development of smart ports, which includes automation to improve productivity. For some governments, the focus is the safety of workers. In most cases, government strategies and the preferences of port authorities are aligned. Some governments, however, are more concerned about possible job losses related to port automation, which has resulted in legislative action to restrict port automation projects in some US states (see Box 3 further on in this report).

Port automation across the world

Across the world, there are around 53 automated container terminals (Table 4), representing around 4% of the total global container terminal capacity. Most of these automated terminals have emerged since the 2010s, after very gradual uptake in the 1990s and 2000s. Most of the automated container terminals are in Europe (28%), Asia (32%), Oceania (13%) and the United States (11%). The majority of the automated terminals are new terminals (greenfield); only a few of them existed as manual terminals that were turned into automated terminals (brownfield).

Table 4. Automated container terminals throughout the world

Terminal	Port	Since	Quay cranes	Transfer	Yard
ECT Delta	Rotterdam	1993		AGV	ARMG
Pasir Panjang	Singapore	1997			
APMT-R	Rotterdam	2000		AGV	AMRG
Thamesport	London	2000			ARMG
Altenwerder	Hamburg	2001	DTQC	AGV	ARMG
Fishermans Island	Brisbane	2002		Auto SC	Auto SC
Wai Hai	Tokyo	2003			ARMG
Evergreen Marine	Kaoshiung	2005			ARMG
DPW Gateway	Antwerp	2007			ARMG
Virginia International	Portsmouth	2007			ARMG
Korean Express Busan	Busan	2007			ARMG
Euromax	Rotterdam	2008		AGV	ARMG
Tobishima Pier South	Nagoya	2008		AGV	ARTG
Newport (Hanjin, HMM)	Busan	2009			ARMG
Newport (DPW)	Busan	2009			ARMG
Isla Verde	Algeciras	2010			ARMG
Taipei Port CT	Taipei	2010			ARMG
Kao Ming	Kaoshiung	2010			ARMG
Burchardkai	Hamburg	2010			ARMG
Khalifa CT	Abu Dhabi	2012			ARMG
BEST	Barcelona	2012			ARMG
London Gateway	London	2013		ALV	ARMG
Global Terminal	New York/New Jersey	2014			ARMG
TraPac	Los Angeles	2014		Auto-SC	ASC
SSA Manzanillo Int.	Colon	2014			ARMG

Yuan Hai	Xiamen	2014		AGV	ARMG
DP World	Brisbane	2014			ARMG
HPH Brisbane	Brisbane	2014			ARMG
SICT-HPH	Sydney	2014			ARMG
Lamong Bay	Surabaya	2014			ARMG + ARTG
Jebel Ali 3	Dubai	2014			ARMG
APMT-MV2	Rotterdam	2015	Remote	Lift AGV	ARMG
Rotterdam World Gateway	Rotterdam	2015	Remote	AGV	ARMG
Patrick Stevedoring	Sydney	2015		Auto SC	Auto SC
PPT	Singapore	2015			ARMG
Middle Harbor	Long Beach	2016			ARMG
Tuxpan Port Terminal	Tuxpan	2016			ASC
Hanjin Incheon CT	Incheon	2016			ARMG
APMT	Lazaro Cardenas	2016			ARMG
Liverpool 2	Liverpool	2016			ARMG
Victoria International CT	Melbourne	2016		Auto ShC	ARMG
Yangshan Phase 4	Shanghai	2017	Remote	AGV	ARMG
Qianwai CT	Qingdao	2018	Remote	AGV	ARMG
AMPT	Vado Ligure	2019			ARMG
Tanger Med 2	Tanger	2019			ARMG
Ferguson Terminal	Auckland	2019		Auto SC	
Belfast Container Terminal	Belfast	2019			ATRG
Vizhinjam Port	India	2019			
Tianjin FICT	China	2019			
Norfolk International Terminal	Virginia	2021			ASC
Haifa Bay Terminal	Haifa	2021			
Long Beach CT	Long Beach	2021			
APMT	Los Angeles	2021		Auto-SC	Auto-SC

Notes: ARMG (Automated Rail Mounted Gantry), ASC (Automated Stacking Crane), ARTG (Automated Rubber Trued Gantry Crane), AGV (Automated Guide Vehicle), Auto SC (Automated Straddle Carrier), DTQC (Double-Trolley Quay Crane). The column on quay cranes also mentions when quay cranes are remotely operated.

Source: PEMA (2016), PEMA (2020) and data collection of the author.

The first automated container terminal was the ECT Delta terminal in Rotterdam that started its automation in 1993. It used automated stacking cranes (ASCs) in the container yard and automated guided vehicles (AGVs) for the transfer of containers between quay and yard, setting the standard for subsequent automation of container terminals. Another milestone in the history of automated container terminals was the automation of the Altenwerder terminal in Hamburg in 2001, consisting not only of ASCs and AGVs but also of double trolley quay cranes. A further innovation was implemented at the Maasvlakte 2-terminals

(APMT-MV2 and Rotterdam Gateway) in Rotterdam in 2015 that introduced remote quay crane drivers, deployed by some other terminals after that as well.

All of the automated container terminals identified have automated their yard operations, using automated RMGs or RTGs or other ASCs. Around a-third of the automated terminals use automated transfers from the quayside to the yard, either via AGVs, automated straddle carriers, or other automated transfer equipment. None of the automated container terminals has completely automated quay cranes, but some have remote crane drivers and some have double trolley quay cranes.

Effects of port automation

Container terminal automation has undoubtedly resulted in job losses for dockworkers. According to Prism Economics and Analysis (2019), labour reductions at various terminals that were automated amounted to 40-50% at the TraPac terminal in Los Angeles, 50% at Patrick's terminal in Sydney and up to 85% at the automated terminal in Qingdao. The effects of port automation in this report focus on the most frequently cited objectives for port automation: port performance (productivity and efficiency), handling costs and safety. The societal costs of automation relevant to trade unions and governments are also explored.

Port performance

It is often assumed that automated ports are more **productive**. In manually operated terminals, it has been argued; there is a reduced production during shift changes, which is no concern at an automated terminal. Another argument is that the performance of automated equipment remains constant, unlike the performance of manually operated terminals (Jole, 2014). Many of these assumptions on the productivity of port automation are based on modelling and simulation exercises. For example, simulation experiments based upon real-life yard operational data from Norfolk (United States) show that the performance of a non-automated terminal could be substantially improved by automation using AGVs (Liu et al., 2004).

However, in practice, automated ports are generally less productive than their conventional counterparts. A McKinsey survey in 2017 indicated that the productivity of automated ports is 7-15% lower than non-automated ports. According to the same survey, in order to justify the high capital investments related to port automation, the operating expenses of an automated green field terminal would have to be 25% lower than those of a conventional one, or productivity would have to rise by 30% in case operating expenses fall by only 10% (Chu et al., 2018).

The effects of automation on port **efficiency** – a slightly different concept than port productivity – are also ambiguous. Port efficiency is here defined as the ratio between sets of inputs and outputs into ports. Although there are many studies on port efficiency, few of those actually look into the effect of automation on port efficiency. A notable exception is a recent article by Ghiara and Tei (2021) that considers not only the status of automation (fully-automated, semi-automated or non-automated) but also indicators such as port size, specialisation and localisation. Both size and specialisation seem to be important factors for increasing efficiency, while automation and location seem to have a reduced impact on the overall productivity value. They conclude that automation alone cannot be considered to have a highly significant impact on port terminal performance but should always be linked to the general port context to achieve real benefits. Port organisation and specialisation, as well as the geographical location and port size, are factors that impact more on the performance of analysed ports rather than simply technology.

Another assumption of automatising ports is that it would increase **reliability**, as automated terminals would be able to work constantly, without interruption, even when it is dark. This argument has also increased in relevance recently when port workers in several ports contracted the coronavirus, which reduced the labour capacity of certain ports. On the other hand, various automated container terminals have witnessed challenges with malfunctioning automated equipment, resulting in breakdowns, accidents or irrational routing that slowed down operations. Automation provides less **flexibility** to deal with unexpected circumstances, such as peaks and troughs related to ever-larger container ships.

Handling costs

The automation of container terminals generally results in lower labour costs and higher capital costs, as automated equipment is more expensive than equipment that is manually operated. The question of whether automation has resulted in lower handling costs is place-specific and depends, to a significant extent, on the local labour costs and the extent to which port labour is reduced due to automation. The higher the local labour costs, the higher the potential savings from automation, provided that automation actually replaces workers. This is one of the reasons why most of the port automation projects have been implemented in high-wage countries: in low-wage countries, automation projects simply make less sense in terms of cost savings. Reduction of labour costs only takes place insofar as automation actually reduces the workforce. This might seem trivial, but automation projects can be overly optimistic about this.

Although terminal operators might realise reductions in handling costs, these are likely to be lower than expected, as pointed out in Oliveira and Varela (2017). In their study, they assess the claims of equipment manufacturers on the labour cost reductions that can be realised due to automation. While ABB, a leading crane manufacturer, has advertised a 45% to 55% reduction of labour time per crane due to automation, Oliveira and Varela show the labour cost savings to be 33%, more than 10 percentage points lower than ABB's advertised savings.

Automated processes need to be designed, supervised and managed, for which staff is still needed, often at the same cost as dockworkers. The existing workforce often is not qualified to perform the tasks associated with an automated terminal. According to Gekara and Nguyen (2018) in their study on human resources management at Australian ports following terminal automation, this leads to additional hiring costs. Whereas recruitment at the port is typically conducted internally, such that lower-level workers are retrained to occupy more highly skilled positions, automation has seen an increase in external recruitment from the open labour market, as the appropriate skills can no longer be harnessed from within.

Considerations on handling costs need to be placed in the current context of liner shipping: a highly consolidated industry operating with mega-ships that generate significant peaks and troughs in ports where these ships operate. Consolidation in liner shipping has resulted in a highly concentrated liner shipping industry, further highlighted by their co-operation in alliances and consortia. This has created huge market power in relation to ports, resulting in more volatility of port cargo due to carriers shifting cargo from one port to another depending on the advantages they can receive there (ITF, 2018). The introduction of mega-ships on various trade corridors, notably the Asia-Europe corridor, has resulted in more cargo peaks and troughs within the ports along these corridors. Automated ports could make sense in ports with a regular and steady flow of containers, but this is much less the case in ports with volatile and peak-and-trough cargo flows. In those situations relying on dock labour is actually more cost-effective, as labour can be organised more flexibly to meet the irregularity of port cargo flows, especially in ports that have labour pools.

Safety and labour conditions

It is often assumed that the safety and health of terminal workers have been improved by automation. However, there is little robust empirical data to support this assumption. One of the rare studies that try to quantify potential reductions of injury rates, in support of US West Coast ports turning to automation, bases its main assumptions on anecdotal evidence (Sisson, 2012). Company data suggest reduced accidents in many container terminals over time. However, such high-level data do not distinguish between improvements in operational practices and the extent to which reductions are the result of fewer dockworkers being exposed to risk as a consequence of reduced employment in operational tasks. Moreover, the comparability and quality of company data are severely limited by variations in reporting practices from terminals in different parts of the world (Walters, Wandsworth, Bhattacharya, 2020).

Automation in container terminals could reduce human errors, but automation is also likely to require greater operation competencies and unlearning of old routines and may even lead to new kinds of human errors (Walters and Wadsworth, 2021). Several automated ports have been confronted with accidents related to automated equipment. Two such incidents prompted the port authority of Auckland in New Zealand to temporarily halt the usage of automated straddle carriers in 2021 out of safety concerns (Ports of Auckland, 2021).

One of the most dangerous parts of the container handling process relates to lashing on board ships and twist-lock handling at the quay. Dual trolley quay cranes – as implemented at Hamburg's Altenwerder terminal – have a lashing platform that makes twist-lock handling considerably safer (Kugler, Brandenburg and Limant, 2021). Yet, this has rarely been introduced in other container ports. A significant number of lashing incidents relate to self-handling, that is, lashing activities carried out by seafarers rather than by dockers that have much more experience in these activities. So another way to reduce lashing accidents would be to ban self-handling, or at the least, to stop subsidising self-handling activities. Several highly favourable tax schemes for shipping companies – tonnage tax schemes – cover self-handling, which means that profits related to these activities are subject to effective tax rates of 0.5-2.5% instead of the regular corporate income tax rate that applies to terminal operations (ITF, 2019).

Externalities

Researchers interested in port innovation usually approach port automation from the angle of port competitiveness, taking the automation trend for granted, without challenging the externalities related to it, as has been rightly observed by Bottalico (2019). One of the relevant negative externalities to be mentioned here is offloading the costs of redundant workers on public unemployment or social security schemes, together with tax revenues from employment foregone.

Reduction of dock work also runs counter to an often-implicit social deal: that elderly workers can do less intensive work after having done years of hazardous and dangerous work. Automation of this less intensive work, e.g. driving yard trucks, undermines this inter-generational solidarity.

Quantifications of social effects for redundant workers are rare. A study on the potential effects of a greenfield automation container terminal project in the Canadian province of British Columbia estimated a net reduction in tax revenue of around CAD 100 million, most of which are federal tax revenues foregone (Prism Economics and Analysis, 2019).

Possible positive externalities are sometimes included in assessments of automation projects. Some reports cite lower air emissions and smaller spatial footprints. As automated equipment is powered either by electricity or battery power, the introduction of automation could reduce terminal emissions. Moody's (2019) observed that Long Beach Container Terminal (LBCT) is already almost fully compliant with the goal of zero-emission cargo-handling equipment by 2030 stipulated in the Los Angeles-Long Beach Clean Air Action Plan (CAAP). In contrast, the ten non-automated terminals would need to invest considerable sums in equipment replacement in order to comply with the CAAP. A similar claim is made with regard to the land productivity of automated equipment. As automated stacking cranes can stack containers densely, semi-automated terminals would be able to achieve high throughput per acre of port land. Moody estimates that conversion to a semi-automated system at Norfolk International Terminal South would increase capacity by 47% on the same footprint (Moody's, 2019).

It is, however, electrification, not automation, that reduces air pollutant emissions and it is perfectly possible to electrify manually operated terminal equipment. This is happening in various container terminals (ITF, 2021). As for the spatial footprint, the relevant comparison is not between automated stacking cranes with straddle carriers; the relevant comparison would be to compare automated stacking cranes with non-automated stacking cranes or automated straddle carriers with non-automated straddle carriers. Such comparisons would result in similar spatial footprints between automated and non-automated terminals.

New automation frontiers for ports?

It is generally accepted that automation of yard functions and horizontal transport (between quay and yard) could be appropriate functions for automation, provided that certain conditions are fulfilled (terminal size and captive cargo). One could expect that an increasing number of terminals will deploy these automated systems in the future. What is much less certain is whether additional terminal activities will get automated. This section focuses on remote quay crane operations and inter-terminal transfers as areas for automation and the barriers to both.

Remote quay crane operations

In almost all container terminals, quay cranes are operated by a crane driver who sits in a cabin suspended from a trolley that runs along rails located on the top or sides of the boom and girder. The driver runs the trolley along the boom over the ship to lift the container. A few container terminals have recently introduced remote quay crane operations: instead of operating the crane in a cabin on the crane, the operator is in an operations centre on the port premises, working the crane from a distance. Even though discussed here, it cannot actually be considered automation: it does not result in a reduction of port workers, each quay crane still needs an operator, and there is no way in which one remote crane operator could operate two or more cranes at the same time.

Remote quay crane operations were introduced in the Maasvlakte 2-terminals in Rotterdam in 2015 (APMT-MV2 and Rotterdam Gateway). They have since been deployed in a few other terminals as well, including in Dubai’s Jebel Ali 4-terminal, Melbourne’s Victoria International Container Terminal, Shanghai’s Yangshan Phase 4-terminal and Qingdao’s Qianwan Container Terminal.

Remote quay cranes have shown mixed results so far. One could wonder if remote operations actually improve productivity. The productivity of the APMT-Maasvlakte 2 terminal cranes has lagged the rates of those in other container terminals in Rotterdam. During 2019-21, the average number of moves per crane per hour amounts to 25 moves per hour; there was hardly any week in which the rate exceeded 30 moves per hour. However, experiences appear to be different in Qingdao, where average crane productivity rates reached 43 moves per crane per hour in January 2020 (Baptista, 2020). Disappointing crane productivity of remote operations could be explained by the fact that remote drivers have difficulties gauging the effect of wind on the container, considering that they do not feel the wind, which they do in their cabin on top of the crane. Some consider these more comfortable labour conditions an advantage of remote operations, but a certain number of workers report remote operations as diminishing their work satisfaction.

Several stakeholders consider that remote operations are only at their first stage. Trade unions worry that quay crane operations might be outsourced to low-wage countries. For example, the Australian Maritime Union warned that the terminal operator International Container Terminal Services International (ICSTI), who operates the automated Victoria International Container Terminal (VICT) terminal in Melbourne, might outsource their quay crane operations to the Philippines, where ICTSI is headquartered (Prism Economics and Analysis, 2019). Following the slowdown of port work in Californian ports due to coronavirus-infected port workers, it has been suggested that the work of remote crane drivers currently done at centralised control centres could be moved out of offices and directly into worker’s homes (Watkins, 2020).

Inter-terminal transfers

Most of the world's principal container ports have multiple terminals. Considerable flows of containers move between these terminals in each port. There are various reasons for these inter-terminal transfers (ITT). Transhipment is the main reason: most maritime transport involves several sea legs, with cargo being transhipped from one ship to another ship in transhipment ports. For example, cargo being transferred from a ship operating a route between Jakarta and Singapore to another ship operating a Singapore to Rotterdam route at a transhipment port in Singapore. Most ships generally get loaded and unloaded in one terminal per port, as it takes time, money and the co-operation of various port actors – such as harbour pilots, tug boats and mooring operators – to get a ship berthed. This means that the container that arrives from one ship (coming from Jakarta) will not necessarily be unloaded in the same terminal where the next ship (to Rotterdam) will be departing. Hence, an inter-terminal move of this container is needed. There are other reasons for such moves. When vessels arrive late, they might need to berth in other terminals than the ones previously assigned to them. This could mean that containers that need to be loaded on that ship are stacked in another terminal, so would need to get transferred to the right terminal. Inter-terminal transfers are also needed when a container has been delivered to the wrong terminal.

Inter-terminal transfers can be numerous, especially in pure transhipment ports. These are ports that function as nodes that bring together container ships of different sizes, operated by a range of different operators on a huge variety of different routes. Container ships operating on regional feeder markets are usually much smaller than those on inter-continental routes. Using the quay cranes that are used for mega-ships for feeder ships will be inefficient, as they are not adapted to handle smaller ships and will block slot space for the mega-ships.

Therefore, transhipment that involves ships with largely different sizes will likely result in inter-terminal moves, as most terminals are designed to host similar-sized container ships and various ports have separate terminals for short sea shipping. Shipping companies have contracts with certain terminal operators; transhipment often involves two different shipping companies that have not contracted the same terminal operators. In gateway ports – where containers do not have an additional sea leg but are directly transported to their hinterlands by truck, train and barge – there will generally be fewer inter-terminal moves. However, in such ports, not all terminals have direct access to trains or barges, so inter-terminal moves might be needed for the transfer to the multi-modal terminal.

Inter-terminal transfers have more negative impacts in ports where terminals are located far away from each other. In most global container ports, distances between terminals are less than 10 km. These accounted for 27 out of 37 global ports covered in Nellen et al. (2020); in that survey, seven ports had terminals with distances of more than 10 km and three ports with inter-terminal distances of more than 25 km. Large distances between terminals are frequent in expanding ports. There is a tendency for expanding container ports to move towards the sea and away from city centres in order to accommodate larger ships, which require deeper and larger terminals (Merk, 2018). This often leads to a division of work where the newest terminals deal with the biggest ships, whereas the older terminals host the smaller ships, operating on regional trades or short sea shipping. Container transfers between terminals can lead to negative traffic impacts in port cities. In Busan, for example, inter-terminal transport has to cross the city centre (OECD, 2014).

There are surprisingly few quantitative data on such inter-terminal moves. Many ports do not collect data on this. While this might make sense for pure gateway ports – like Los Angeles and Long Beach – where inter-terminal moves are marginal, it is more surprising for ports that also have transhipment cargo. In some cases, it is terminal operators that collect these data, but not all terminal operators have been willing to share these data for reasons of confidentiality.

There is considerable variety in inter-terminal transport moves, even when comparing container ports with similar transhipment rates (Table 5). The ITT moves, as a share of total container volume handled, represents between 2% and 13% in the data available for this study. The relatively high share in Busan could be explained by the high number (eight) of different container terminals there, which obviously increases the need for inter-terminal moves.

Table 5. Inter-terminal transfers in selected world container ports

Port	Inter-terminal transfer moves per year	% Inter-terminal transfer /total containers	Number of terminals	Transhipment rate
Busan	1 863 500	13.4%	8	54%
Shenzhen West	92 635	n/a	3	n/a
Valencia	68 696	2.2%	3	55%
Bremerhaven	109 904	3.9%	2	55%

Notes: Data in this table provide the yearly average, based on calculations over 2019 and 2020.
Source: Based on data received from Busan Port Authority, CM Ports, Valencia Port Authority and North Sea Terminal Bremerhaven.

Trucks carry out most of the inter-terminal transport. In some cases the inter-terminal moves are subsidised: e.g. in Busan Port Authority provided a USD 5 million subsidy to the transhipment trucking shuttle between Busan New Port and Busan North Port. Where terminals are located next to each other, ITT is carried out by the terminal equipment, e.g. straddle carriers in Bremerhaven. Some ports also use barges and trains for ITT. In Busan, two barges with 150 TEU capacity each were used a decade ago for ITT, but these operations turned out to be twice as expensive as trucking, vulnerable to adverse weather conditions, and less reliable for time-sensitive cargo. In Shenzhen west port, around 48% of the ITT moves is carried out by barge, the rest by truck. In Rotterdam, a large share of the inter-terminal transport currently takes place via barge, with trucks as a solution for last-minute changes.

A common strategy of carriers to avoid excessive ITT moves is to have a ship call at several container terminals in the same port. It is mostly the feeder ships that do multi-terminal port calls, e.g. almost all feeder ships in Rotterdam and Bremerhaven. In Busan, carriers apply this strategy more to avoid ITT between the two main port sites (New Port and North Port), rather than avoiding ITTs within each port site: port calls to both North Port and New Port represent 95% of the multi-terminal calls. Ports generally charge ships only once for port fees in case of multi-terminal calls.

Table 6. Multi-terminal port calls selected world container ports

Port	Number of multi-terminal calls	% multi-terminal call/total container ship calls
Busan	1 893	14%
Shenzhen West	64	n/a
Valencia	674	23%
Bremerhaven	1 300	55%

Notes: Data in this table provide the yearly average, based on calculations over 2019 and 2020.
Source: Based on data received from Busan Port Authority, CM Ports, Valencia Port Authority and North Sea Terminal Bremerhaven.

Container shipping developments of recent years have affected the need for inter-terminal transport ambiguously. Over the last few decades, the number of ports with intercontinental liner shipping connections has decreased and for various countries the share of indirect connections – so, transhipment – has increased. This has likely increased the need for inter-terminal transport in various large container ports. At the same time, liner shipping companies have consolidated, perfected their co-operation in alliances and consortia and have vertically integrated with terminal operating companies (ITF, 2018; ITF, 2019). As a result, most liner companies now have a services network with global coverage. One would expect that this effect reduces the need for inter-terminal transport.

Inter-terminal transport is a significant challenge for large port areas or geographically separated terminals within a port area. Longer distances make it more difficult to plan for container transport by truck, which is the dominant mode of inter-terminal transport. Longer distances also increase the risk of delays. One way to improve planning reliability and minimise the risk of delays is to use dedicated infrastructure for container transports in the port. Of the 37 ports reviewed in Nellen et al. (2020), 28 use public roads for inter-terminal transport. Only nine ports have dedicated infrastructure for inter-terminal transport, four of which are located in Europe. One of these is the Container Exchange Route in Rotterdam discussed in Box 1.

Automated systems could be used for inter-terminal transfers. Especially where ports have container terminals that are lined up or adjoined. Container terminals that are lined up consist of a continuous row of terminals, which means that there are no clear lines between the terminals, so that the terminals appear as one large terminal, even if individual terminals can have different operators and have several entrances and exits. Adjoined terminals are connected terminals, which means that they are located at very close linear distance to each other (less than 1 km). Lined-up and adjoined terminals are considered to be the most appropriate for a connection through a dedicated infrastructure using autonomous vehicles. Autonomous systems usually mean structural challenges for the port and terminals, especially in the case of long distances between terminals (Nellen et al., 2020).

Automated systems for inter-terminal transport have not been deployed in ports with spread-out container terminals. Various studies have looked into such possibilities (e.g. Duinkerken et al., 2006; Schroër et al., 2014; Spruijt, van Duin and Rieck, 2017). Analytical models that are used in the research on inter-terminal transport most often are mathematical programming models, branch and bound models, queuing models, network models and simulation models that have limited applicability given the dynamic nature of the terminal handling industry and process (Edirisooriya and Bandara, 2017). The port authority of Rotterdam sought to introduce an automated system for inter-terminal transfers but decided against it because of the costs and financial risks (Box 1).

Box 1. Autonomous inter-terminal transfers in the port of Rotterdam

The port authority of Rotterdam has invested in a dedicated road, the Container Exchange Route (CER), to facilitate inter-terminal transfers between the different container terminals, an empty container depot, multimodal terminals and customs facilities. The construction of the 17 km connection started in 2019 and was achieved through an investment of the port authority of EUR 175 million. The objective was to speed up the transfer of containers between terminals (facilitating smoother transhipment) and the transfer of containers to customs and intermodal facilities (facilitating smoother inland transport).

Although originally planned as a connection to be used by manned vehicles, the port authority changed course in 2020 and decided to have the CER used by autonomous vehicles instead. The motivation was that an autonomous CER would be able to provide transfers at a lower cost, an estimated EUR 10 per TEU against more than EUR 20 using manned multi-trailer systems (Port of Rotterdam, 2020a). The autonomous CER was also seen as a good demonstration project for the ambition of the port authority to be “the smartest port” (Port of Rotterdam, 2020b). The assumption underlying the proposal was that the container volumes transported via the autonomous CER would amount to 350 000 TEUs at the outset, growing to 1 million TEUs in the future (with no specific date).

To implement the autonomous CER, the port authority launched a tender in April 2020. The tender document stated that the port authority was looking for an operator for transport services on the Container Exchange Route. In press communications, the port director explained to be looking for “an innovative type of AGV” that would ideally have double-stack capabilities and a higher travel speed than the current speed of AGVs at container terminals (Wilt, 2020). The plan was for the selection of the contractor in the fourth quarter of 2020, tests in the first quarter of 2021 and full commercial operation in the fourth quarter of 2021.

The trade union for dockworkers, FNV Havens, is opposed to the autonomous CER as it would contradict an earlier agreement with the port authority and terminal operators that included manning the CER with dockworkers from three specified container terminals covered by a collective labour agreement (Werkzekerheidsakkoord, 2016). A manned CER would require 70-80 workers; an automated CER would not be able to accommodate these workers, which could mean they would become redundant. Terminal operators were concerned about the interfaces between the autonomous CER and the transport within their own terminals, as the landside terminal areas lack automated vehicle guidance infrastructure as they are designed for access by container haulage trucks. In the initial period for the operation of the autonomous CER, terminal operators would pick up the container with their own drivers as soon as it arrived at the terminal. There were doubts as to whether the project would represent a viable market for vehicle manufacturers, as not many ports were expected to deploy similar technologies (Wilt, 2020).

In May 2021, the port authority announced that it would withdraw its proposals for an autonomous CER and would aim for a version with manned vehicles instead. This decision was taken because there were “too many risks and uncertainties” and because the desired automation solution was not available. The limited potential return on the contract for basically a one-off project may have deterred the market (Wilt, 2021). The port authority does not exclude that an autonomous CER might become a reality in a few years and is now looking into different modalities for a manned CER.

The original business case for the autonomous CER is not available to the public. As such, it is not clear whether a rigorous cost-benefit analysis was carried out for this project, and relevant stakeholders to the process have not been able to provide more clarity on the assumptions for the project. This lack of transparency on the business case of a significant investment by a public authority like the port of Rotterdam could be considered problematic. Concerns could arise on the assumptions made in four different areas: the expected volume, the costs of the different options, estimated benefits and the social costs.

According to the port authority, the volumes to be transported via the CER are 350 000 TEUs from the outset and 1 million TEUs in the future. Public information on current moves between the container terminals are not available, but estimations from stakeholders range between 100 000 to 200 000 container moves, which would represent between 170 000 TEUs and 340 000 TEU. So the higher estimate would be in line with the estimations for the CER project. It is unclear what the timeframe is for the expected 1 million TEUs. If we assume that this is the volume that is reached at the end of the depreciation period of the autonomous vehicles, the business case might have been based on 1 million TEUs volume by 2030, assuming an average depreciation period of autonomous vehicles of nine years. If the growth rates of the terminals connected to the CER over 2020-30 were in line with the TEU growth rates of the port of Rotterdam over 2010-20 (29%), it would mean that 450 000 TEUs would be transferred between terminals in 2030. In order to reach 1 million TEUs of inter-terminal moves in 2030, the share of inter-terminal moves (as % of total TEUs handled) would need to double from 2020 to 2030. It is not clear whether the assumption of such a drastic increase is realistic: the transhipment share in the port of Rotterdam might increase slightly, but the upwards effect from this on inter-terminal moves could be outweighed by the downwards effect from increased integration of global liner networks. This discussion on estimated transport volumes is relevant because the fixed capital costs need justification in terms of high volumes, not necessary for the more flexible costs of manned transport.

The assumptions of EUR 10 per transferred container for the automated option could not be verified. The main reason for not pursuing the automated option was that the market could not supply the vehicles at the price set.

One of the intended benefits of the automated CER in comparison with the manned CER was superior speed. Apart from doubts over operating speed in practice (considering that the interface between CER and landside part of terminals would require a driver, which would interrupt the smoothness of the process), one could also wonder what value of time was used to capture the benefits of gained time. Especially in the context of transhipment, where most boxes remain days in the port before being transhipped.

In terms of the social costs of the automated option, these would consist of costs to the Dutch public budget in the case that 80 workers became redundant and unable to find employment elsewhere. It is an open question if the cost estimations of the project took social costs into account.

Sources: Wilt (2020), Wilt (2021), Port of Rotterdam (2020a, 2020b).

Policy implications

There is no automatic success formula for container terminal automation. This has important implications for policy makers: their considerations on port automation should be based on a clear identification of costs, benefits and alternatives, facilitated by constructive social relations, and grounded in a clear understanding of ways to deal with the societal costs of automation. Fully automated container terminals do not actually exist, contrary to what common port automation terminology would suggest. Most automated systems are deployed in the container yard, only a few terminals have automated the transport between quay and yard, and no terminal has automated quay cranes. The reason for gradual uptake of port automation is that container terminal automation makes economic, financial and business sense only for a limited number of terminals and only under certain conditions.

Identification of costs, benefits and alternatives

The costs and benefits of port automation projects are rarely spelt out explicitly. Automation projects can make sense under some assumptions but not under others. Quite often, assumptions underlying assessments are misleading, e.g. that bigger ships need automation or that automation is necessary to reduce emissions. To build consensus around port automation projects it is therefore crucial that a broad set of stakeholders, including trade unions and governments, have access to the assumptions underlying proposals prepared by operators. Similarly, potential job losses and potential external costs need to be made explicit.

A lack of publicly available cost-benefit analyses makes it difficult to evaluate the effects of automation projects. Ex-post evaluations of port automation projects are practically not available. Terminal operators are likely to have carried out such evaluations, but none seem to be available in the public domain. Instead, what is amply available are academic modelling exercises. However, it is a mistake to take model outcomes for evidence of the effectiveness of port automation projects in practice. Some academic studies confuse the two. For example, Kon et al. (2020) reviewed existing academic studies on container terminal automation, observing positive outcomes but failing to mention that none of the evaluation studies reviewed was of actual port automation projects.

Shipping developments will affect the potential of investments in automation to generate returns and should be considered when discussing port automation projects. Developments in shipping markets (consolidation, concentration of market power, introduction of mega-ships) have increased peak loads, volatility of container flows and transhipment volumes. This all requires more operational flexibility to deal with peaks and troughs resulting from larger ships and increased volatility of container flows. This makes the case for automation with current technologies less convincing and flexible port labour arrangements – as described in Box 2 – more appropriate. These factors often appear to be overlooked in policy making related to ports. For example, in relation to port labour pools, the European Commission’s focus has been perceived anti-competitive effects, requesting Belgium and Spain to reform their port labour systems without identifying alternative tools that could help ports to be adaptive and flexible in the context of peak loads generated by mega-ships and consolidation.

Box 2. Port labour pools in EU countries

The general idea of dock labour pools is to share available dock labour among different terminals in the same port so that workers can be deployed from the pool depending on demand. This increases efficiency as it allows terminals to deploy more workers if there is peak demand and fewer workers if there is little demand. Employers and employees generally work together to define the working conditions (e.g. number of workers per operation), which in turn determine the overall labour supply that is needed in the port to meet current and future traffic needs. That way, they guarantee flexibility in labour quantity. The dockworkers that are part of the pool need to be officially registered or licensed dock workers. Registered workers are not employed at a particular terminal operator or stevedoring company but hired through a central pool or hiring hall.

Fifteen out of twenty-two EU member states have some kind of port labour pool system. In eleven of these systems, pool workers have preferential rights, which means that they will get priority for assignments (Van Hooydonk, 2013). There are large differences in the use of labour pools within countries.

The extent to which dock labour pools are used depends on whether such use is mandatory or voluntary. In Germany and the Netherlands, employers can hire permanent company employees directly from the external labour market but any additional (casual) labour must be hired from a regulated labour pool (Notteboom, 2018).

The advantage of labour pools for workers is that they are no longer employed by the day but guaranteed a quasi-permanent contract within the pool. This means they get paid even if they are left idle due to a shortage of ship arrivals during a particular day, week or month. They are paid either by the pool that provides them with a minimum monthly salary or by the pool in combination with unemployment benefits paid by the state. Dock labour pools can be funded by special funds to which port employers contribute. For example, the labour pool in Hamburg, called Gesamt Hafenbetriebs Gesellschaft (GHBG), pays pool workers through a Fund financed by port operators (based on their turnover) and port customers, via a mark-up on the price of stevedoring services.

Some pool workers are employed on a semi-permanent basis by port employers. In these cases, dock labour pool schemes often include a “continuity rule”, which means that a docker hired on a particular day can be re-hired for the next day or days without having to be rehired every day by the central hiring place; so there often is automatic “repeat hiring” (Notteboom, 2018). Workers in dock labour pools are usually covered by collective bargaining agreements. In some systems, surplus workers from terminal operators can be offered to the labour pool. This is the case in Hamburg, where the dock labour pool functions as a transfer point for surplus dock workers. Terminal operators can offer excess capacity to the pool, but the pool is not obliged to take it (Notteboom, 2018).

Source: OECD (2021).

Social relations

Port automation projects regularly provoke significant social conflict within ports. In the United States and Australia, announcements of port automation have resulted in opposition from trade unions, blockages, or strikes include ports. In many cases, these social conflicts are related to the unclear articulation of costs and benefits described above.

This could be particularly problematic in periods of low growth of cargo volumes. In the case of negative or moderate growth, a new terminal is most likely going to attract cargo that previously went to other terminals in the port. If a newly automated terminal does this, it is likely going to mean net job losses within a port. The situation is different in the case of strong cargo growth: a new terminal can benefit from strong growth without taking cargo from other terminals and will thereby create jobs, considering that fully-automated terminals also need workers, albeit fewer than a non-automated terminal would have created. This cyclical effect is a double-edged sword: periods of slow cargo growth are generally economic downturns in which unemployment rates rise; therefore, regional job losses are all the less desirable. The 2016 port strike in Rotterdam can be explained in these terms: automation of the two automated container terminals of Maasvlakte 2 would have passed more easily if they had started in a strong growth period, as opposed to a turbulent market.

When the benefits of automation are ambiguous, some stakeholders will interpret pushing for automation as a way to diminish dockworker unions (Oliveira and Varela, 2017). Paradoxically, strong union pushback – and strikes – seem to act as a confirmation for employers that they are right to automate: they will then use strikes as an argument for automation. As such, the case for automation could then become a self-fulfilling prophecy: automation would reduce labour conflicts, but there would be less labour conflict if the prospect of automation was not raised.

Polarisation between employers and employees has resulted in cases of forced automation or automation projects where worker concerns were not considered but also in attempts of legislators to restrict port automation (Box 3). Governments often need to approve automation projects or have possibilities to hamper them, so they are in a position to arbitrate between divergent positions on port automation.

Box 3. Regulatory approaches on port automation in the United States

Various state legislatures in the United States have been discussing restricting port automation in different ways. In February 2021, the Senate of the State of Washington adopted a new law, Engrossed Senate Bill 5026, stating that: "moneys available to a port district or a port development authority shall not be used to purchase fully automated marine container cargo handling equipment." While the new law eliminates purchases of automated equipment by a "port district or a port development authority", that does not necessarily prevent purchases by port tenants such as the operator of a terminal. So the Bill does not target banning port automation but intends to make sure that port automation projects are not facilitated by federal or state subsidies. The Bill expires in 2031.

In 2019, lawmakers in California discussed a proposal for legislation titled AB 1321, aimed at creating a new state-wide oversight body that would be empowered to approve or deny automation projects at state seaports. The proposed legislation would remove decisions concerning automation in California's ports from local harbour commissioners and place them under state-wide control through a three-member committee comprised of the state's lieutenant governor, controller, and director of finance. Following pushback from the Pacific Maritime Association, the proposal was amended. Instead of approving or denying automation projects, the committee would hold a series of meetings to consider the impacts of automated technology at California's ports and to report to the Legislature. In 2020, the proposed Bill "died" in the Senate inactive file.

Sources: Senate of State of Washington (2021), California Legislature (2019), Watkins (2019).

There are instances where unions, port authorities and terminal operators have constructively co-operated to introduce forms of automation considered appropriate by all parties. Strong unions can help to advance automation and avoid deadlocks in port automation projects. In such cases, unions have often not only been seen as legitimate partners because they represent a large share of the workers but have also been recognised institutionally, for example, via tri-partite governance structures with co-responsibility for decision-making. Essentially, meaningful social dialogue between representatives of employers, employees and governments is needed. Regulators need to be coherent in their approaches as well, for example, taking similar lines in the way competition regulation is applied to port labour pools and to the container shipping market.

In a good number of port automation projects, the benefits of automation have been shared with workers. This can take the form of wage increases, early retirement programmes for elderly workers or other benefits that are often part of a package negotiated with the introduction of automation. For example, in the 1990s, port automation in Rotterdam came with an agreement on better pay and early retirement programmes for existing workers. Automation is much more attractive to workers if they get a share in its productivity gains. This has been done very directly at the Container Terminal Altenwerder in Hamburg, where worker pay is linked to the overall productivity gains from automation as well as individual productivity. Staff training is also part of the package required to ensure productivity gains actually materialise.

Social costs of automation

The social costs of port automation are often ignored. These include social security expenses (in case of redundancies) and tax revenues foregone (when port workers are replaced by machines). Most people get income from work and personal income tax revenues are generally higher than corporate tax revenues. Therefore the personal tax income lost due to the replacement of a worker by a machine is in many cases not compensated by higher corporate tax revenues. There can be additional tax income related to the profits that the manufacturing of automated equipment generates, but these are generated in the countries where the equipment is manufactured, which is often not where the worker is replaced by the machine. The social costs of automation will naturally be disregarded by the stakeholders that benefit but should be taken into account by governments in their decisions on port automation. This would be facilitated by making sure that ex-ante assessments of port automation projects always take these social costs into account. Discussing societal costs as a standard part of the political discussion on port automation should become the default.

When labour is scarce, automation can increase the number of workers that can be employed elsewhere. In those situations, automation could provide social opportunities if wage and working conditions of the new jobs are better than in their previous jobs.

Dealing with the societal costs of port automation is linked to wider tax considerations and the balance between taxation on capital and labour (generally higher taxation of labour). In this context, there have been calls for taxation of automation in many parts of the economy with a “robot tax”. Leaders from various dockworker unions across the world, including in Canada and the Netherlands, have supported the call for the introduction of robot taxes (McKeen, 2019; Visscher, 2017), although, for the reasons outlined in this report, ports are unlikely to be one of the sectors most affected by automation in the medium term.

Conclusions

Port automation is not a magic bullet for more efficient port operations. Especially not for ports that are confronted with huge workload peaks and troughs related to larger ships. Very few container ports have introduced extensive automation, probably because there is limited evidence that automation increases productivity or reduces handling costs in practice in ports subject to fluctuating workload. In specific circumstances – such as large terminals with highly captive and regular container flows – terminal automation can be a cost-effective measure. It may also be cost-effective where there are labour shortages. Consolidation in container shipping and the intensive co-operation between container lines via alliances and consortia have increased the bargaining power of container shipping companies over ports. This consolidated bargaining strength has made container flows to most ports less captive and terminals less likely to benefit from automation. The introduction of automation often results in social conflicts. Especially when there is little dialogue between representatives of employers and employees or when costs and benefits of automation projects are not clearly spelt out. These factors lead to the following recommendations for policy makers.

First, generally focus more on flexible labour arrangements. The current container shipping environment requires flexibility to deal with peaks and troughs related to larger ships and increased volatility of container flows. Automated terminals are not particularly well suited to deal with these requirements. Port labour is. Flexible port labour arrangements, like worker pools, make it possible to vary operational inputs depending on the container volumes to be handled at any given moment. Governments should consider how such flexible port labour arrangements can be best facilitated.

Second, better identify the costs and benefits of port automation projects. It is crucial that not only operators themselves but also the wider set of stakeholders, including trade unions and governments, have access to the estimations of costs and benefits of port automation project proposals and the assumptions underlying the proposals. This will facilitate informed debate and improve consensus building. Evaluations of port automation projects need to be made public to facilitate this wider access to information. This will help policy makers to identify under which conditions automation can be most effective.

Third, stimulate co-operation between employers and workers. Co-operation implies a meaningful social dialogue between representatives of employers, workers and government that can facilitate discussions on cargo handing in ports. As well as automation itself, such social dialogue should discuss developments in container shipping that have an impact on the desirability of automation, such as industry consolidation and ever-larger ships. Co-operation between employers and workers has been particularly effective in automation projects that share productivity gains with workers.

Finally, address the social costs of automation. Analyses of port automation projects should include estimations of costs to society. Impacts on local employment and tax revenues should be considered in the context of national policy towards automation.

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Container Port Automation

This report provides an overview of the current state of automation in container ports. It shows which terminal activities have been automated in different ports and which additional activities might be automated in the future. It assesses if automation projects have achieved their objectives and identifies policy issues related to container terminal automation.

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