Container Terminal Automation

A global analysis and survey on decision-making drivers, benefits realized, and stakeholder support

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Container Terminal Automation

A global analysis and survey on decision-making drivers, benefits realized, and stakeholder support

Abstract

This study focuses on the automation of terminal equipment used to handle containers. A distinction is made between *semi-automated terminals,* which have manned vehicles to move the containers from the berth to the yard with automated stacking equipment in the yard, and *fully-automated terminals* where both the horizontal movement of containers from the berth to the yard and the vertical movement of containers in the yard is automated (unmanned). This study provides an in-depth analysis of the drivers of automation, the realized benefits, stakeholders' attitudes towards automation, and specific implementation and investment considerations. A dataset was compiled covering all 63 automated container terminals, their organizational features, technical dimensions, and the maritime and urban markets they serve. The first layer analysis focuses on where, when, under which conditions, and to what extent container terminals have been automated, and who is responsible for implementing terminal automation.

The second part of the analysis relies on a unique survey-based approach targeting senior representatives of terminal operating entities in charge of the fully and semi-automated container terminals. Thirty-two terminals participated in the survey, representing 50.7% of all automated container terminals worldwide. Terminal operators ranked the importance of drivers influencing their decision to automate the terminals. The survey tool was also used to re-examine the initial decision-making drivers by asking the respondents to score potentially realized benefits, thus establishing how accurate terminal operators predicted the benefits of automation.

The findings show that most of the benefits assumed by an individual terminal operator materialized once the automated terminal was in operation. An analysis of the gaps between decision-making drivers and benefits realized revealed that *reduced labor costs*, *reduced air emissions*, *improved truck-turn times*, *elimination of human factors* along with terminals having *limited land for expansion* and the opportunity to *serve as a test-bed for new technologies* were all factors where benefits exceeded expectations. In the case of *reduced labor costs*, the differences between expectations and benefits realized is marginal (slightly negative for U.S. and Europe and slightly positive for Pacific Asia). The study also provides a regional comparison of the findings for three regions (i.e., North America, Europe, and Pacific Asia), aiming to understand better the sensitivity that might be produced due to local perspectives and culture. A further detailing of the regional components compared the U.S. results with those of China and compared the U.S west coast and east coast terminals. In addition, the survey examined terminal operator's perspectives of various stakeholder group positions on automation along with testing and implementation issues (such as length of the testing period and the governance of system integration) and financial/managerial issues (such as the return on investment (ROI) period) for the automation investment.

INTRODUCTION

Terminal automation is a full or partial substitution of terminal operations through automated equipment and processes. Depending on how automation is defined, it is already present in many terminals, at least in its simplest form, using information technologies to manage terminal assets and supplement human activity. For example, modern container terminals use advanced Terminal Operating Systems (TOS) to control and optimize the movement and storage of boxes in and around the terminal. Terminal operations are further facilitated by applying various technologies such as RFID, optical character recognition (OCR), and anti-sway systems in cranes. However, automation processes can also include ship-to-shore cranes, the movement of containers from the berth to the yard, and yard equipment. The focus of this study is on this type of automation.

In the past decade, container terminal automation has attracted much attention in business, policy, and, subsequently, academic circles. The progressive introduction of semi- and fully-automated terminal systems is driven, among other reasons, by the need for operations standardization, reduction in manning, and productivity improvements. Yet, container terminal automation still seems to remain the exception instead of the norm. Only certain terminals will fit the profile where unmanned automated equipment brings added value.

Automation is a capital-intensive and complex process that takes place at different scales, paces, and locations. Temporal, institutional and spatial factors are expected to play a role in the decision to automate, next to more operational and economic drivers. While previous studies have extensively reported on the global spread of terminal automation, extant literature does not provide in-depth analyses of the drivers of automation, the realized benefits, stakeholders' attitudes towards automation, and specific implementation and investment considerations. This report aims to fill this gap by addressing the following research topics.

First, this study advances a better understanding of *where*, *when*, under *which conditions*, and to *what extent* container terminals have been automated and *who* is responsible for implementing terminal automation. The report maps automated terminals around the globe and details their key features. A dataset developed by the research team explores the geography of the 62 automated container terminals in operation and the one in development, their organizational features, technical dimensions, and the maritime and urban markets they serve.

Second, this study identifies the *multi-faceted array of factors that drive the decision to automate a container terminal* and analyses the variation of the relative importance of these factors by several parameters such as terminal operator and locality. As a first step, potentially relevant drivers are shortlisted based on the literature review provided. In a second step, the actual relevance of these drivers is tested following a survey-based approach targeting senior representatives of terminal operating entities in charge of the 63 fully and semi-automated container terminals.

Third, the survey also includes a question targeting a re-examination of the initial decision-making factors. In particular, the survey established how accurate terminal operators predicted the benefits of automation once the terminal automation was in operation. This "within terminal" analysis is key to answering the question: *Did the benefits assumed by an individual terminal operator actually materialize once the automated terminal was in operation?* A gap analysis focusing on the differences between decision-making drivers and benefits realized adds a layer to this part of the analysis.

Fourth, this study pioneers in *assessing stakeholders' attitudes towards automation* as perceived by the respective terminal operators. To advance the understanding of this issue, the survey contains a question to test whether the various stakeholders either supported, opposed, or were neutral to terminal automation. Furthermore, we explore possible relationships between factors motivating automation and stakeholders' attitudes. This analysis focuses on the reactions of governments, port managing entities, dockworkers, and actors along the supply chain (carriers, logistics service providers). It is the first study attempting to place terminal automation in the broader context of stakeholders' relations management. This section also explores the terminal operators' perceptions of the reactions of the communities hosting the automated terminal.

Fifth, this study attempts to provide more insight into several *testing and implementation issues* (such as length of the testing period and the governance of system integration) and *financial/managerial matters* (such as the return on investment (ROI) period) connected to terminal automation.

Sixth, the obtained results for each of the above themes are analyzed in view of surfacing any *regional differences* in terminal automation processes and attitudes. Finally, special attention is given to the positioning of, and specific challenges to, the automated container terminals in the U.S.

Prior to the discussion of the different research topics presented above, the next sections introduce clear-cut definitions of fully and semi-automated terminals, and provide a more in-depth discussion of the research design and methodologies used.

DEFINITIONS OF CONTAINER TERMINAL AUTOMATION

A distinction is made between *fully-automated* container terminals and *semi-automated* container terminals. In line with earlier works:[1]

> *A **semi-automated terminal** has manned vehicles to move the containers from the berth to the yard with automated stacking equipment.*

This implies semi-automation only involves yard stacking automation (i.e., automation of the vertical transfer system on the yard). Automated Stacking cranes (ASCs) are widely used for such stacking operations. ASCs are automated rail-mounted gantry cranes (RMGs) that are generally aligned perpendicular to the berth. In some cases, such as at the Altenwerder Terminal in Hamburg, two ASCs with different dimensions (allowing one to pass under the other) work together on the same stack. The term ASC covers ARMG (Automated Rail Mounted Gantry), C-ARMG (Cantilever ARMG), and ARTG (Automated Rubber-Tired Gantry Crane). Automated straddle carriers (AutoStrad) are less common. AutoStrads are unmanned straddle carriers used for quay to stack operations and stack to truck loading operations. Examples include Brisbane AutoStrad Terminal and Sydney AutoStrad Terminal, both operated by Patrick Terminals in Australia.

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[1] See, amongst others: Martin-Soberon et al. (2014); Drewry (2018); McKinsey (2018); Moody's (2019); Camarero Orive et al. (2020); Rodrigue and Notteboom (2021).

A ***fully-automated terminal*** *is a terminal where both the horizontal movement of containers from the berth to the yard and the vertical movement of containers in the yard is automated (unmanned).*

In other words, full automation includes **berth to yard automation** (i.e., automation of the horizontal transfer system) and **yard stacking automation**. Berth to yard automation typically relies on the use of unmanned automated terminal tractors, automated guided vehicles (AGV), or runners (low straddle carriers without a driver onboard). Quite a few terminals use automated horizontal transfer systems. Diesel-hydraulic engines powered the first generation of AGVs, and movement was restricted to fixed tracks on the terminal floor. The latest generation of AGVs is guided by GPS technology and is battery-powered, resulting in zero CO2 emission and noise reduction. AGV speed can reach 6 meters per second. Some terminals, such as APMT in Rotterdam, use 'lift AGVs' to lift and stack containers.

A few fully-automated terminals can also have remotely operated ship-to-shore cranes for the **vessel to quay transfer.** These remotely operated ship-to-shore cranes use single or dual hoist technology. Examples of such automated quay cranes are found in Rotterdam (APMT at Maasvlakte 2), Shanghai (phase 4 of Yang Shan terminal complex), and Qingdao (Qingdao New Qianwan Container Terminal or QQCTN). While these remotely operated cranes are still manned versus unmanned automated operations, the skill set and pay scale for these remote operators may differ from traditional crane operators on the berth.

Automation can also be achieved in the fourth main functional area of a container terminal, which is the **in-out gate function***.* Automation in this area primarily concerns automated truck gates. However, this type of automation is not considered when distinguishing between full and semi-automated terminals.

Terminal automation requires advanced approaches to integrated scheduling of handling equipment[2] to optimize and synchronize the quay, intra-terminal transport, yard, and gate operations.[3] The optimization challenges are particularly significant when terminal automation involves a patchwork of traditional and state-of-the-art solutions from different suppliers.

METHODOLOGY

Research design and data collection

The research design in this study is set up to address the following research topics and questions:

- Where, when, under which conditions, and to what extent have container terminals been automated, and who is responsible for their operation;
- Identification and the relative importance of the multi-faceted array of factors that drive the decision to automate a container terminal;
- Re-examination of the above factors to establish how accurate terminal operators predicted the benefits of automation once the terminal automation was in operation;

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[2] Lau and Zhao (2008).

[3] For an overview, see: Stahlbock and Voß (2008); Sha et al. (2021).

- Assessment of stakeholders' attitudes towards automation as perceived by the respective terminal operators;
- Assessment of several testing and implementation issues and financial/managerial issues;
- Regional differences in terminal automation processes and attitudes, mainly focusing on the positioning of and specific challenges to the automated container terminals in the U.S.

A thorough review of extant literature and port and terminal company information was initiated to shed light on the precise number and geographical distribution of semi- and fully-automated container terminals and their characteristics in terms of technical layout and equipment use, year of automation, and governance-related characteristics such as type of terminal operator. This exercise resulted in 63 container terminals worldwide that are fully or partially (semi) automated - as of Q3 2021, 62 automated terminals were in operation, with one more planned to be operational in early 2024 (**Figure 1**). A list of all 63 terminals in the database is given in **Table 1**.

Figure 1. Geographical Dispersion of Automated Container Terminals

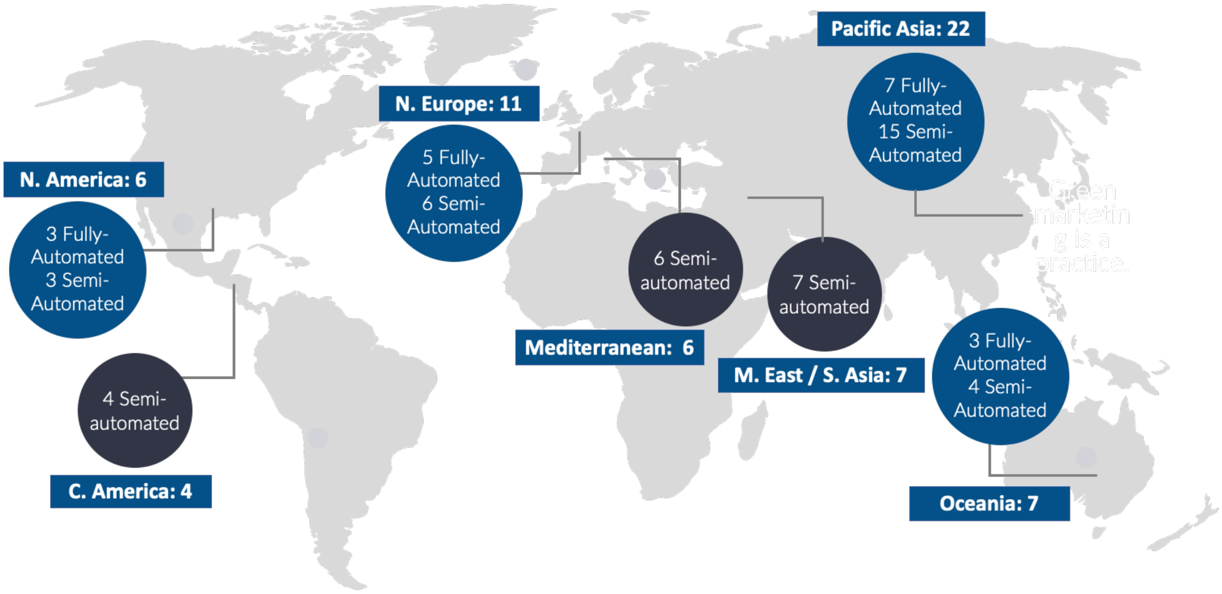

Table 1. List of 63 Automated Terminals as in January 2022

Country	Terminal name	Port	Type automation
Belgium	Antwerp Gateway	Antwerp	Semi
China	Xiamen Ocean Gate Terminal	Xiamen	Full
	Qingdao New Qianwan Container Terminal	Qingdao	Full
	Tianjin Port Second Container Terminal	Tianjin	Full
	Tianjin Port Container Terminal	Tianjin	Full
	Yang Shan, Phase 4	Shanghai	Full
	Hong Kong International Terminals	Hong Kong	Semi
England	London Gateway Port	Stanford-le-Hope	Semi
	Liverpool2 Container Terminal	Liverpool	Semi
Germany	CTA CTB Burdhardkai	Hamburg	Semi
	CTA CTB Altenwerder	Hamburg	Full

Ireland	Dublin Ferryport Terminal	Dublin	Semi
	Belfast Container Terminal	Belfast	Semi
Israel	Bayport Haifa	Haifa	Semi
	Hadarom Container Terminal	Ashdod	Semi
Italy	APM Vado Ligure*	Vado Ligure	Semi
Japan	Tobishima Container Berth Co., Ltd.	Nagoya	Full
	Oi Container Terminal (Berth 6)	Tokyo	Semi
Korea	Pusan Newport International Terminal (PNIT)	Busan	Semi
	Busan Newport Container Terminal (BNCT)	Busan	Semi
	Pusan New Port Company (PNC)	Busan	Semi
	Hanjin New Port Company (HJNC)	Busan	Semi
	HMM PSA Newport Terminal (HPNT)	Busan	Semi
	Hanjin Incheon Container Terminal	Incheon	Semi
Indonesia	Tanju Emas Semarang	Java Island	Semi
	Terminal Petikemas	East Java	Semi
Mexico	Tuxpan Port Terminal	Veracruz	Semi
	APM Lazaro Cardenas	Lazaro Cardenas	Semi
	New Port Veracruz	Veracruz	Semi
Netherlands	Rotterdam World Gateway	Rotterdam	Full
	ECT Delta Terminal	Rotterdam	Full
	ECT Euromax Terminal	Rotterdam	Full
Panama	Manzanillo International Terminal	Colon	Semi
Singapore	PSA Pasir Panjang Terminal, 1-2-3	Singapore	Semi
	PSA Pasir Panjang Terminal, 4-5-6	Singapore	Semi
	Tuas Container Terminal Phase I	Singapore	Full
Spain	Barcelona Europe South Terminal (BEST)	Barcelona	Semi
	Total Terminals International	Algeciras	Semi
United Arab Emirates	DP World Jebel Ali	Dubai	Semi
	Khalifa-TIL	Abu Dhabi	Semi
	Khalifa-TIL2	Abu Dhabi	Semi (2024)
	Khalifa Cosco	Abu Dhabi	Semi
United States	Long Beach Container Terminal	Long Beach, CA	Full
	TraPac	Los Angeles, CA	Full
	APM Terminal Pier 400	Los Angeles, CA	Full
	Norfolk International Terminal	Virginia	Semi
	Virginia International Gateway	Virginia	Semi
	Global Container Terminal	NY/NJ	Semi
Spain	Total Terminals International	Algeciras	Semi
	Barcelona Europe South Terminal	Barcelona	Semi
Morocco	APM Terminals MedPort Tangier	Ksar es Seghir	Semi
Australia	Brisbane AutoStrad Terminal	Brisbane	Full
	DP World Australia Brisbane Terminal	Brisbane	Semi
	Brisbane Container Terminal	Brisbane	Full
	Victoria International Container Terminal	Melbourne	Full
	Sydney AutoStrad Terminal	Sydney	Full
	Sydney International Container Terminal	Sydney	Semi
New Zealand	Fergusson Container Terminal	Auckland	Semi
Taiwan	Kaohsiung Intercontinental Terminal	Kaohsiung	Semi
	(Terminal 4) Kao Ming Container Terminal	Kaohsiung	Semi
	Taipei Port Container Terminal	Taipei	Semi
Saudi Arabia	Red Sea Gateway Terminal	Jeddah	Semi
India	Vizhinjam	Vizhinjam	Semi

* Notes: N=63; as of September 2021.

Once the terminals were identified, a two-pronged approach was undertaken to collect data, i.e., a database of terminal characteristics for all 63 terminals and a survey of the operators of these terminals. Fifty-nine different features of a terminal were identified for the database. Those 59 features can be broadly grouped into the following categories: operations, environmental and energy-saving, financial and cost savings, social, safety/security and resilience factors, and marketplace position. In addition, a catch-all category would note special circumstances like a local mandate for zero emissions, port authority funding to help defray costs typically born by terminal operators, equipment supplied by manufacturers for demonstration purposes, etc. Data was collected from port and terminal operator websites, industry journals and publications, and personal communications. Not all information was available for all 63 terminals, so a subset of key data was identified that would be readily available.

Those data included:

- Year terminal opened
- Year terminal automated
- Terminal ownership
- Terminal operator
- Length of berths
- Maximum ship size handled
- Maximum draft
- Terminal capacity
- Transshipment incidence, defined as the share of sea-sea transshipment (unloading of a container plus loading on another vessel) in the total TEU throughput
- Container throughput
- Semi-automated or fully automated

A descriptive statistics analysis was performed to provide a detailed explorative overview of automated terminals' technical characteristics, corporate and institutional aspects, and geo-economic characteristics, thereby distinguishing between fully and semi-automated terminals. The second part of the research is grounded on a survey of terminal operators. The survey inputs were complemented with additional operational information and statistics. For example, an in-depth analysis of truck turn times was undertaken at the automated and conventional terminals in the Port of Long Beach. Average weekly truck turn times were compared between a fully-automated terminal, a similarly-sized conventional terminal, and an average of all the conventional container terminals in the port.

Survey set-up

A survey instrument was developed to analyze the combination of factors likely to influence or challenge the decision-making process to automate a conventional terminal or, in some cases, construct a greenfield terminal, and to document whether anticipated benefits of automation were realized once the terminal was in operation. In addition, the survey was designed to shed light on stakeholders' attitudes towards automation and technical, financial, and implementation issues associated with automation.

Inherent in the design of the survey was to create a survey form that terminal operator would not immediately reject by asking for what might be considered proprietary information. The survey was also designed to be completed in a matter of minutes using an editable pdf format.

Although we did not collect data on the actual time (average and spread) needed to fill out the survey, we estimate that an average respondent would have taken between 15 and 20min.

The survey was sent out by email in the period February – July 2021 to senior representatives of the terminal operating companies that manage the respective automated container terminals. The initial distribution of surveys was followed by several rounds of reminders, including more personalized follow-up initiatives by phone or other communication means. In quite a few cases, we received assistance from the global headquarters of the terminal operating company or from branch associations and expert organizations to ensure that the right people received the survey. More specifically, several associations representing ports and terminal operators in different parts of the world (i.e., the International Association of Ports and Harbors (IAPH), the Asia Pacific Economic Cooperation (APEC) Port Services Network (APSN), the Federation of European Private Port Operators (FEPORT) and international organizations (the United Nations Committee for the Caribbean and Latin America - CEPAL), provided valuable assistance in facilitated outreach to key persons in automated terminals. No port authorities completed the surveys, only terminal operators. The introductory text accompanying the survey explicitly states that "*All the individual port information will be strictly confidential and we will only make public aggregated data - the reader will not be able to identify what any port terminal has responded*". This approach was deemed necessary to increase the willingness of terminal operators to complete the survey. However, this stipulation also implies that this report presents aggregated survey results, thereby avoiding presentations and comparisons of individual automated terminals.

The survey questionnaire included the following questions (see **Appendix A** for the complete survey). In the first question, terminal operators were asked to evaluate on a Likert scale from 0 (not important at all) to 7 (maximum importance) the importance of a list of factors in deciding whether to automate their container yard.

These factors or drivers were deducted from the literature review and discussion presented later in this report:

- Reduce labor cost;
- Reduce unit cost of container handling;
- Reduce air/greenhouse gas emissions;
- Improve efficiency to handle larger vessels;
- Cope with limited land for expansion;
- Improve truck turn time;
- Increase safety;
- 24/7 hours of operation;
- Reduce variability in performance (more consistency);
- Eliminate human factors (illness, risk of labor disruption, etc.);
- Meet Key Performance Indicators (KPIs) required by ocean carriers;
- Competitive forces from other terminal operators who opted for automation;
- Test-bed for new technologies/showcase technological expertise of local terminal and/or research community;
- The availability of financial incentives/subsidies by public entities or port authorities.

In the second question, terminal operators were asked to indicate their perception of the position of stakeholders towards the introduction of automation using a 7-point scale ranging from high opposition to neutral to high support. The stakeholder groups include government, the community, Port Authority (PA), dockworkers, carriers, shippers, and logistics service providers.

In a third question, terminal operators were then asked to rate the same factors/drivers based on the benefits realized from automation on the same scale of importance as in the first question.

The three remaining survey questions seek to gather information on (a) the length of the testing period for automated equipment/systems, (b) the length of time to realize a return on the investment for the automated system and, (c) whether the automation was implemented as a turnkey project or via single or multiple suppliers, and (d) what party undertook the terminal's system integration.

Response rate

More than half of the world's automated terminals participated in the study (50.7%) by returning valid and usable filled-out surveys. Responses came from all automated terminal operators in the United States, China, Germany, and Ireland, along with terminals in Europe, Korea, Japan, and the Middle East. The list of the 63 terminals in the database that completed the survey is detailed in **Table 2**.

Table 2. List of Automated Terminals that completed surveys

Country	Terminal name	Port
Belgium	Antwerp Gateway	Antwerp
China	Xiamen Ocean Gate Terminal Qingdao New Qianwan Container Terminal Tianjin Port Second Container Terminal Tianjin Port Container Terminal Yang Shan, Phase 4 Hong Kong International Terminals	Xiamen Qingdao Tianjin Tianjin Shanghai Hong Kong
England	London Gateway	Stanford-le-Hope
Germany	Container Terminal Burchardkai (CTB) Container Terminal Altenwerder (CTA)	Hamburg Hamburg
Ireland	Dublin Ferryport Terminal Belfast Container Terminal	Dublin Belfast
Israel	Bayport Haifa	Haifa
Italy	Vado Gateway	Vado Ligure
Japan	Tobishima Container Berth Co., Ltd. Oi Container Terminal (Berth 6)	Nagoya Tokyo
Korea	Pusan Newport International Terminal (PNIT) Busan New Container Terminal (BNCT)	Busan Busan
Mexico	Tuxpan Port Terminal APM Lazaro Cardenas	Veracruz Lazaro Cardenas
Netherlands	Rotterdam World Gateway	Rotterdam
Panama	Manzanillo International Terminal	Colon
Singapore	PSA Pasir Panjang Terminal, 1-2-3 PSA Pasir Panjang Terminal, 4-5-6	Singapore Singapore
Spain	Barcelona Europe South Terminal (BEST)	Barcelona
United Arab Emirates	DP World Jebel Ali	Dubai
United States	Long Beach Container Terminal TraPac APM Terminal Pier 400	Long Beach, California Los Angeles, California Los Angeles, California

	Norfolk International Terminal	Norfolk, Virginia
	Virginia International Gateway	Portsmouth, Virginia
	Global Container Terminals	New York/New Jersey

Table 3 indicates the regional distribution as well as the number of semi- and fully-automated terminals that contributed to the study by region. Despite the assistance from Ports Australia, no survey was completed by any of the six automated terminals in Australia.

In most cases, the CEO, COO, or managing director of the terminal filled out the survey. In a few cases, an automation project manager or a CIO (Chief Innovation Officer) responded to the survey questions. The survey had a temporal element, in that the person filling out the survey had to have knowledge of the initial drivers to decide to automate the terminal, as well as see the results after automation was implemented. This often involved tracking down people who had moved from one terminal to another or had retired

Table 3. Number of received replies by region and by type of terminal automation

Region	Total Replies		Fully-Automated		Semi-Automated	
	No	% of Total	No	% of Total	No	% of Total
North America	6	100%	3	100%	3	100%
Central America	3	75.0%	-	-	3	75.0%
North Europe / Atlantic	7	63.6%	2	20.0%	5	83.3%
Mediterranean	3	50.0%	-	-	3	50,0%
Pacific Asia	12	54.5%	6	85.7%	6	42.9%
South Asia / Middle East	1	14.3%			1	14.3%
Total	**32**	**50.7%**	**11**	**61.1%**	**21**	**22.7%**

The response time between sending out the survey and receiving the filled-out form ranged from immediate to up to a few months. In some cases, lengthy internal review and approval processes at the level of the terminal operating company prevented a fast response.

Methods applied to analyze survey results

Descriptive statistics facilitated an analysis of the hierarchy of the assessed factors and the data collected as part of the exercise. They also allowed an assessment of the variances of perspectives and experiences that might exist, either between operators that have opted for fully-automated and those that have endorsed semi-automated strategies or between types of operators (i.e., carriers vs. stevedores, etc.).

Moreover, a regional comparison of the findings in three regions was undertaken, aiming to understand better the sensitivity that might be produced due to local perspectives. The three regions that have provided enough data for such analysis are:

I. North America (replies by all six terminals);
II. Pacific Asia (12 terminals representing over 54.5% of all); and,

III. Europe (ten replies from North Europe and the Mediterranean combined or 50% of all automated terminals in these regions).

The number of replies (i.e., 32) is at the lower limit when considering the application of advanced statistical methods. While being aware of the potential limitations brought by the sample size, the dataset has been subjected to several statistical tests. In this context, the Analysis of Variance (ANOVA) and non-parametric Kruskal-Wallis tests have been applied, aiming to confirm variations between groups of replies.

The use of a **One-way Analysis of Variance (ANOVA)** enables statistically testing for significant differences per each criterion (i.e., driver of automation or benefit of automation, level of support/opposition) between the perspectives expressed by a group of respondents (i.e., regional perspectives, fully automated versus semi-automated terminals, etc.).
The independent variable (factor) is the group of respondents, and as a dependent variable each one of the criteria under examination. Testing the null hypothesis:

H_0: $\mu_1 = \mu_2 = \ldots = \mu_k$

Where:

μ = the mean of each group responses; and
k = the number of groups tested.

ANOVA allows comparing the means between data per group, determining whether any means are statistically significantly different from each other. When ANOVA testing shows a statistically significant result (F-value) we accept the alternative hypothesis H1: meaning that there are at least two group means that are statistically significantly different from each other ($\mu i \neq \mu j$ at least for one pair (i,j) of respondent groups.

To statistically test and strengthen the ANOVA results, we run a non-parametric analysis of independent samples such as (a) regional groups of respondents and (b) semi-automated versus fully-automated terminals, through **a Kruskal-Wallis one-way ANOVA** allowing all pairwise comparisons. The use of Kruskal-Wallis is suggested as (a) the dependent variable is measured at the ordinal or continuous level (i.e., the case of the Likert scale we used), and (b) the independent variable consists of two or more independent groups, whereas, in our case, there are groups offering a number of independent observations.

A correlation analysis of the received replies has also been performed. In particular, using the SPSS software, we searched for the Pearson coefficient calculation to determine whether and how statistical variables are linearly related. Pearson coefficients range from +1 to -1, with +1 representing a positive correlation, -1 representing a negative correlation, and 0 meaning no relationship. A correlation of -1 indicates a perfect negative correlation, and a correlation of 1 indicates a perfect positive correlation. If the correlation coefficient is greater than zero, it is a positive relationship. Conversely, if the value is less than zero, it is a negative relationship. A value of zero indicates that there is no relationship between the two variables. This is a measure of the strength and direction of the linear association between two variables with no assumption of causality. The Pearson coefficient shows correlation rather than causation. In other words, Pearson correlation cannot determine a cause-and-effect relationship but can only establish the strength of linear association between two variables. Conversely, the data provide information of any such linear association – as well as a background for further analysis of both these correlations and indicated causal relations.

Finally, a **stepwise regression analysis** identifies possible predictors of the drivers and the realized benefits. This technique uses an algorithm to select the best grouping of predictor variables that account for the most variance in an outcome (R-squared). The default elimination criterion is a p-value > 0.1. At each step, the variable X that has the lowest correlation with the outcome Y_i was removed from the model, if and only if it satisfied the elimination criterion. The procedure stopped when there are no variables left in the model that satisfy the elimination. The MATLAB software has been used for the stepwise regression analysis and SPPS for other statistical testing.

Replies were received by terminals located in different parts of the world. This makes the analysis unique, especially as replies account for more than half of the automated terminals in operation. It has, thus, to be acknowledged that some cultural response bias might be present. This type of bias is created by social factors that influence the way people perceive and respond to survey questions. Some respondents may have given more extreme answers, whereas other replies are more moderate; this was probably due to variations in personality, culture, or attitudes of the respondents rather than a reflection of factual differences in the parameters. This might be particularly relevant for the terminal operators' perspectives regarding the stance of stakeholders. Statistical techniques are available to adjust respondents' answers for potential bias. A commonly applied method consists of the computation of z-scores per respondent by centering on the average and scaling by the standard deviation of the whole respondent sample. However, the size of the sample in the report is rather small given the limited number of automated terminals across the world. The survey responses were not corrected for potential bias, as the responses on all questions provide a most useful databank that enables valuable analysis and conclusions.

GLOBAL OVERVIEW OF CONTAINER TERMINAL AUTOMATION

The global diffusion of automated container terminals

At the end of September 2021, 62 fully or partially (semi) automated container terminals were in operation worldwide. One more terminal, the semi-automated Hadarom Container Terminal at the port of Ashdod, Israel, was planned to be operational in early 2022.

Still, the number of fully or semi-automated terminals remains relatively small compared to the scale of the global container terminal business. Drewry (2018) identified about 1,300 full container terminal facilities worldwide, with just over 3% classed as automated. Moody's (2019) specified 46 semi- or fully-automated container terminals worldwide. Rodrigue and Notteboom (2021) identified 58 automated terminals globally, of which nine were in a planning phase.[4] Alho (2019) counted 60 automated terminals globally, mainly in Europe and Asia, with forecasts to reach 200 in the next five years. Camarero Orive et al. (2020) lists 44 container terminals in the world using automated handling technology. Kon et al. (2020) report that 54 automated terminals were opened between 1993 and 2020. ITF (2021) reports 53 automated container terminals, representing around 4% of the total global container terminal capacity. The (small) gaps between the 63 terminals in this study and the number of automated terminals reported in other studies might be explained by differences in the period considered and in the applied

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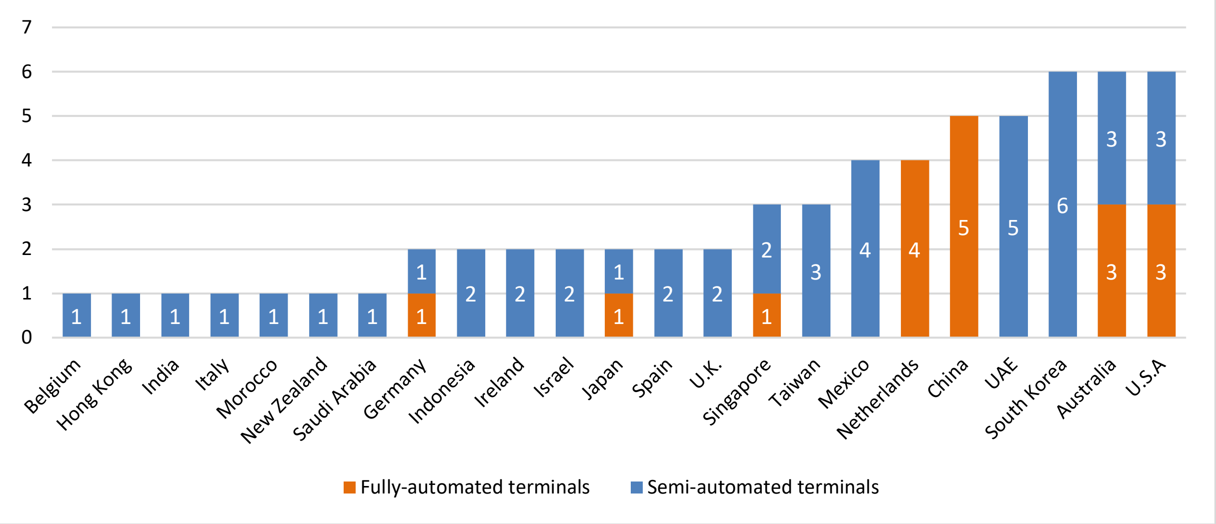
[4] See also: Notteboom et al. (2022).

terminal automation definitions (for example, some studies do not consider terminals which have only automated part of the terminal site).[5]

Geographical dispersion

Semi or fully-automated terminals exist in all continents except Africa and Antarctica, see (**Figure 1**). They are located in 23 countries (**Figure 2**), evenly distributed between semi- and full automation**.** Australia, China, and the United States each have six terminals. In 20 other countries, the number of automated terminals is smaller. Pacific Asia (22 automated terminals – 34%) and Europe Atlantic (11 automated terminals - 18%) are the hotspots for terminal automation in terms of terminal numbers. However, fully-automated terminals exist in only four regions; North America (U.S.), Oceania, Pacific Asia, and Europe Atlantic.

Figure 2. Dispersion of Automated Container Terminals per country



*Notes: N=63; See **Appendix I** for a complete list of the identified automated terminals.*

Automation type

Eighteen (18) of the 63 automated terminals, or 29% of the total, involve full automation (**Figure 3**). Among the semi-automated terminals, the application of ASCs is widespread. AutoStrad solutions are found in quite a few ports, mainly in Australia and the U.S.

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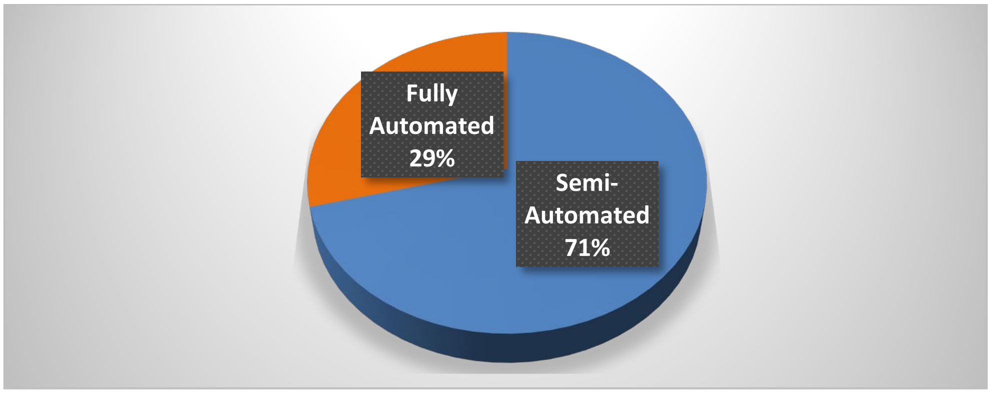
[5] A recent report by ITF (2021) identified 53 automated container terminals, with most of them located in Europe (28%), Asia (32%), Oceania (13%) and the United States (11%). All of them are included in the list of automated terminals in the present study.

Figure 3. Automated Container Terminals per type



** Notes: N=63; As of January 2022.*

Temporal aspects

By the end of the 20th century, the total number of automated container terminals amounted to just two. Full terminal automation was first implemented in 1993: the ECT Delta SeaLand terminal at Maasvlakte 1 in Rotterdam became the first terminal in the world to use AGVs and ASCs. Six years later, in 1999, PSA opened the semi-automated Pasir Panjang Container Terminal 1-2-3 in Singapore. Six more automated container terminals were in operation when the global financial crises of 2008/9 hit the port industry. While the crisis changed the port sector in many respects,[6] the trend towards automation continued. In the period 2008-2012, 12 more terminals were automated.

The real acceleration, however, has occurred in the last decade. The development of automated container terminals has been gaining popularity, particularly since 2012.[7] Our data shows that forty terminals have been automated since 2013 (**Figure 4**). At the time of writing (November 2021), three of these automated terminals are likely to start operations in late December 2021 (i.e., the first phase of Tuas terminal complex in Singapore, Khalifa-TIL2 in Abu Dhabi, and a retrofit to the automated Norfolk International Terminal in the U.S.). The most recent addition in the list, Hadarom Container Terminal at Ashdod Israel, plans to start operating as a semi-automated terminal in 2022. All other terminals in the dataset are in operation. The geographical distribution of these terminals is detailed in **Table 4.**

In October 2021, APM Terminals announced that it was forming a strategic alliance with China's Shanghai Zhenhua Heavy Industries Company (ZPMC) to develop a wide range of automated solutions for its global network of 76 terminals including automated container handling equipment. This strategic relationship could likely facilitate a more rapid conversion of conventional APM Terminals to automation.

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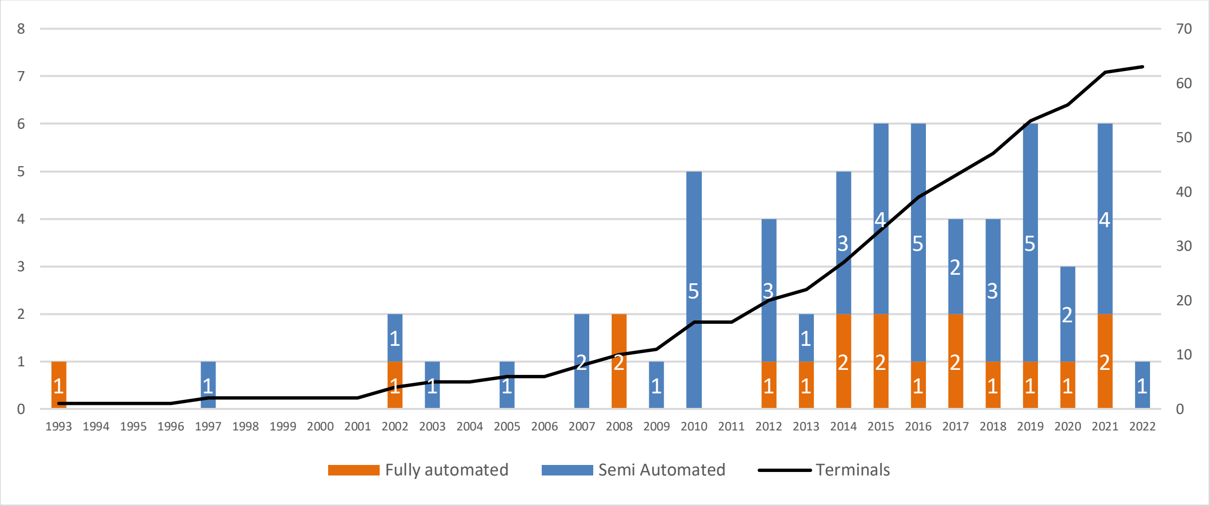
[6] Langen and Pallis, 2010; Notteboom and Rodrigue, 2012; Notteboom et al., 2021.

[7] PEMA (2016). Also, ITF (2021) reports that most automated terminals have been developed since the 2010s, after a very gradual uptake in the 1990s and 2000s.

Figure 4. Cumulative Number of Automated Terminals



** Note: N=63; As of January 2022.*

However, the decision to automate does not always translate to successful implementation. In two cases, London Thamesport in the UK and the Outer Northern Harbor terminal in Copenhagen, the process of automating the terminals has been canceled for commercial and other reasons. In other parts of the world, intentions and decisions to develop new port infrastructure are associated with automation, but port development advancement is on hold for several reasons. One such case is Mubarak Al Kabeer Port in Kuwait.

Table 4. Evolution of Container Terminals Automation per region

	Total	1993-1999	2000-2007	2008-2012	2013-2022	n.a.
North America	6		1		5	
Central America	4				4	
Europe Atlantic	11	1	2	2	6	
Mediterranean	6			2	4	
Pacific Asia	22	1	1	7	12	1
South Asia / Middle East	7			1	5	1
Oceania	7		2		5	
Total	**63**	**2**	**6**	**12**	**41**	**2**

Operators that opted to automate terminals

In the port operating industry, internationalization shifted from a dominantly regional structure, sometimes focusing on a single port, with several port terminal operators establishing a multinational portfolio. The terminal operating industry is increasingly complex, with competition, objectives and entry strategies diverging between heterogeneous terminal operators[8] and differences in local market entry conditions.[9] Several categorizations of terminal operating companies have been proposed.[10] Here, terminal operating companies are classified based on the origins and strategic rationale to invest in the global terminal infrastructure network:[11]

- *Carrier-linked terminal operators*: In recent decades, container shipping lines have developed dedicated terminal capacity to support their core shipping business. The derived benefits involve cost control, operational performance, profitability, and the ability to prioritize their ships during port calls. Terminal operating companies are separate business units or sister companies with terminal facilities operated on a single-user dedicated base or open to third-party shipping lines. For example, AP Moller-Maersk operates a network of container terminals through its subsidiary APM Terminals, a sister company of Maersk Line. CMA CGM (through a majority shareholding in Terminal Link), MSC (via a majority shareholding in Terminal Investment Limited), and Cosco (through fully-owned Cosco Shipping Ports) are also among the most involved shipping lines in terminal operations.
- *Financial holdings*. Port terminals have attracted several investment banks, retirement funds, and sovereign wealth funds as an asset class with a potential for revenue generation over long time periods. Most acquire an asset stake and leave operations to the existing operating company. Others directly manage terminal assets through a separate terminal operating company.
- *Stevedores*. This group includes independent port terminal operators offering container handling services to a broad customer base. They can be privately owned, or be part of the activities' portfolio of the managing body of a tool port or public service port.

The involvement of the above types of terminal operating companies can range from a minority shareholding to full ownership. In quite a few cases, *multiple types of actors* team up in a joint-venture or consortium. For example, stevedores such as Hutchison Ports or PSA mitigate risks through terminal joint ventures with shipping lines, making terminal ownership structures and partnership arrangements increasingly complex.

Eighteen *stevedoring companies* operate 39 automated terminals or 61.9% of all terminals (**Figure 5**). Eleven of them are fully automated.[12] Hutchison Ports operates six terminals, more than any other terminal operator. The portfolio of Hutchison Ports spreads in five different regions and includes the 1993-automated ECT Delta Terminal in Rotterdam. PSA is the operator of five automated terminals. All of these five terminals are in two ports in South East Asia, Singapore (three terminals) and Busan (two terminals). One of them, PSA Hyundai Pusan Newport Terminal, is operated by a partnership between PSA and Hyundai. Sixteen other stevedoring companies operate one or two terminals. Stevedoring companies (i.e., DP World) and carriers (i.e., COSCO Shipping Ports, APM Terminals) are also involved as partners in one or more of the four automated terminals operated by consortia (6.3% of all automated terminals) – these are the fully-automated Rotterdam World Gateway, Tianjin Port Second Container

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[8] Olivier (2005); Oliver et al. (2007); Notteboom and Rodrigue (2012); Parola et al. (2013); (2015).

[9] Pallis et al. (2008).

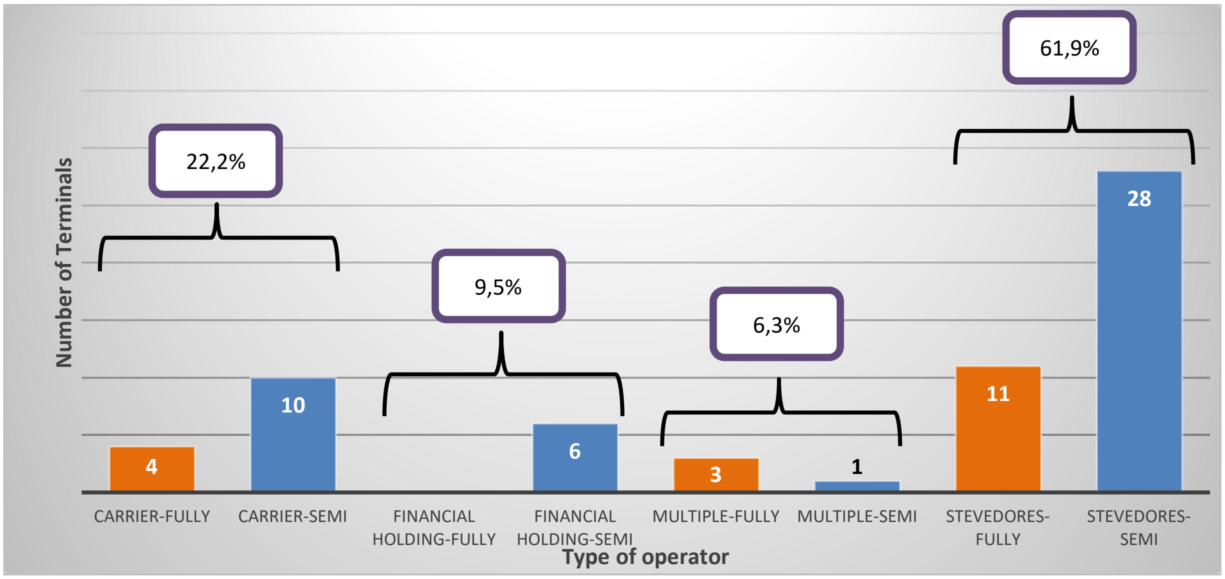
[10] See: Bichou and Bell (2007); Olivier et al. (2007); Parola and Musso (2007); Notteboom and Rodrigue (2012).

[11] See also Notteboom et al. (2022).

[12] Reference here is to the operator of the port; in some cases, this might be accompanied with the formation of companies where minority equities might be held by partners.

Terminal and the Qingdao New Qianwan Container Terminal, and the semi-automated Antwerp Gateway Terminal.

Figure 5. Automated Container Terminals per Type of Operator



N=63; As of January 2022.

Carriers who have assumed responsibility to operate container terminals (such as APM Terminals – part of Maersk, Evergreen, MSC (via TiL), COSCO Shipping Ports, MOL, and NYK) operate ten semi-automated terminals. They also operate four fully-automated ones, two of them in Los Angeles, U.S. (MOL's TraPac Terminal and the APM Terminals in Los Angeles), one in Rotterdam, Europe (the APM Terminals Maasvlakte 2), and one in Nagoya, Japan (Tobishima Container Berth).

Financial holding companies are also engaged in the operation of container terminals. They operate six automated terminals (9.7%) in the UK, Australia, Korea, and UAE.

Despite the growth in terminal automation, fully and semi-automated terminals still represent a small portion of the operators' global terminal portfolios. On the other hand, all top six global/international terminal operators (based on million TEU % share of world container port throughput for 2018-2019)[13] are involved in the operation of at least one automated terminal. For example, Hutchison Ports operates 52 container terminals globally, of which only six (11.5%) are fully or semi-automated (three and three respectively). APM Terminals has involvement in 59 container terminals, five which are automated terminals (8.5%), four fully-automated, and one semi-automated. Of the 50 terminals controlled by PSA, only five (10%) are automated. DP World operates seven other automated terminals (six semi-automated and one fully-automated). Terminal Investment Limited (TiL) is involved in two and China Cosco Shipping in one. Most of these automated terminals have a rather large capacity footprint.

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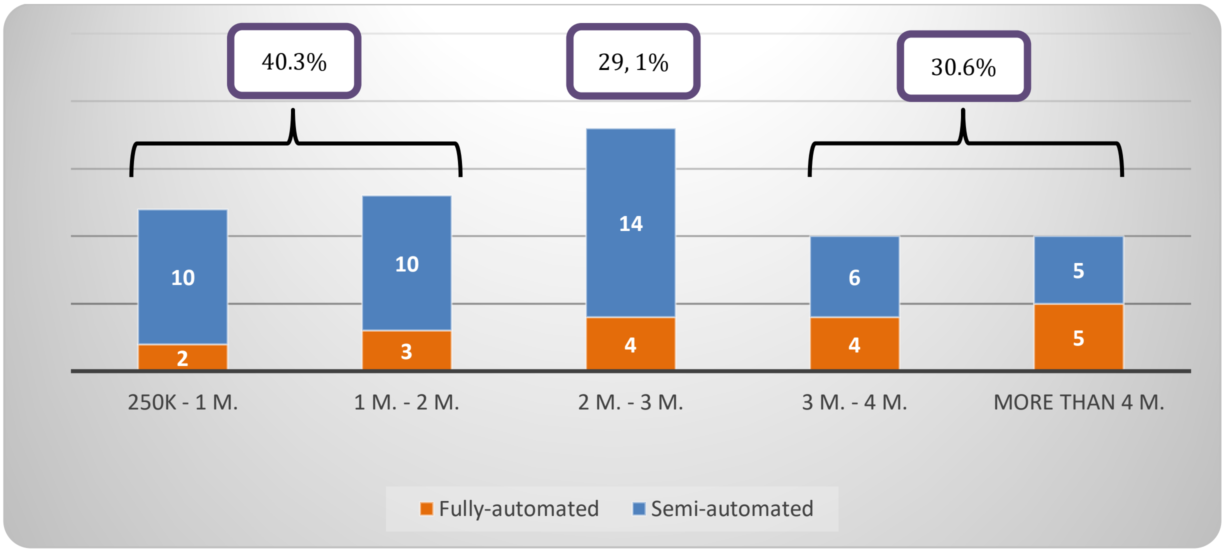
[13] Drewry (2020).

Terminal capacity

It is often reported in trade publications that a terminal has to have a capacity of at least one million TEU for automation to be worth the investment. However (**Figure 6**), 11% of the fully-automated terminals and 22% of the semi-automated terminals handle between 250,000 to 1 million TEU.

Most fully-automated terminals handle between 2 and 4 million TEU per year. Thirty-two percent of the semi-automated terminals handle between 2 and 3 million TEU per year.

Figure 6. Scale of fully and semi-automated terminals capacity (TEU)



** N=63; As of January 2022*

Technical characteristics

As regards **the technical characteristics** (**Table 5**), the average terminal acreage of the fully-automated terminals (98.6 ha) is 17.2% larger than the respective size of the semi-automated ones (84.1 ha). The range of **terminal size,** however, varies significantly for both fully-automated terminals (standard deviation = 69.4 meters) and semi-automated ones (standard deviation = 61.3 meters). The semi-automated Pasir Panjang Container Terminal 1-2-3 in Singapore has the largest acreage. The size of 24 terminals – six fully-automated terminals and 18 semi-automated ones – does not exceed 50 ha.

Based on data available for 60 of the 63 terminals, **the average length of berths** is 1,480 meters, without a significant difference observed between fully and semi-automated terminals (1,506 and 1,504 meters, respectively). Once more, the standard deviation from this average is substantial for both fully-automated (standard deviation 769 meters) and semi-automated (standard deviation 1,350 meters) container terminals. The length of berths in two terminals exceeds 5,000 meters. There are 10 more automated terminals with berth lengths of 2,000 meters or longer, and 27 terminals with berth lengths ranging between 1,000 and 2,000 meters. The length of berths in the other 21 terminals for which data are available is less than 1,000 meters.

The **max draft** at automated terminals is 16 meters. In the case of fully-automated terminals, the minimum draft is 13.7 meters and is observed in only one case; all other terminals have a draft that exceeds 14 meters. However, the situation differs in semi-automated terminals: the maximum draft is as low as nine meters at one terminal in Europe.

The semi-automated operations at a few of the terminals in the dataset only cover a part of the entire terminal surface, as the remaining terminal acreage relies on conventional container terminal equipment. A good example is the Antwerp Gateway terminal operated by DP World. Since 2006, Antwerp Gateway operates 20 ASCs on about a third of the terminal acreage. The remaining two-thirds of the container yard still rely on manned straddle carriers. These will gradually be phased out, between 2022-2026, and replaced by 34 new ASCs. Other examples of automation covering only a portion of a terminal surface are the two fully-automated terminals in Los Angeles, TraPac and APMT.

Table 5. Technical characteristics of automated container terminals

	Terminal acreage (ha)			**Length of Berths (meter)**			**Max draft (meter)**		
	Ave-rage	Range (Max- Min)	Std Dev	Av	Range (Max- Min)	Std Dev	Av	Range (Max- Min)	Std Dev
Fully-automated	**98.6**	**294.0-26,0**	**81.6**	**1,506**	**3,600 -550**	**769**	**16.8**	**21.0–13.7**	**2.1**
Europe Atlantic	124.6	265.0-80,0	79.2	1,840	3,600-1,000	1,016	18.4	19.7– 16.6	1.6
North America	82.5	139.0- 40,0	60.1	1,164	1,646-550	560	15.7	16.8– 13.7	1.7
Oceania	41.5	63.0-26,0	19.2	907	1,400- 660	427	14.7	15.2– 14.0	0.6
Pacific Asia	113.3	294.0-36,1	102.1	1,700	2,350-750	651	17.0	21.0– 14.8	2.1
Semi-Automated	**88.1**	**318.0-13,3**	**69.4**	**1,504**	**7,772-330**	**1,350**	**15.7**	**18.5- 9.0**	**1.9**
Central America	43.8	52.0- 33,0	8.5	1,012	2,040 – 556	691	15.9	16.5– 15.0	0.7
Europe Atlantic	83.2	176.0-14,0	72.2	1,253	2,850 – 330	915	14.5	17.0– 9.0	3.5
Mediterranean	53.8	79.0-19,0	27.8	1,192	1,600 – 700	356	16.9	18.5- 16,0	1.0
North America	112.7	152.0-68,0	42.3	1,348	2,020 – 823	612	15.2	15.2– 15.2	0.0
Oceania	38.5	46.0-32,0	6.0	1,010	1,300-- 610	309	14.5	16,0– 13.2	1.4
Pacific Asia	110.6	318.0-13,3	98.1	2,086	7,772-- 380	2,079	15.8	18.0– 11.0	1.8
S. Asia / M. East	82.4	149.0-50,0	34.2	1,322	1,862-- 800	383	16.1	18,0– 14.5	1.5
Total	88.30	318.0-13.3	73.4	1,505	7,772-- 330	1,208	16.0	21.0- 9,0	2.0

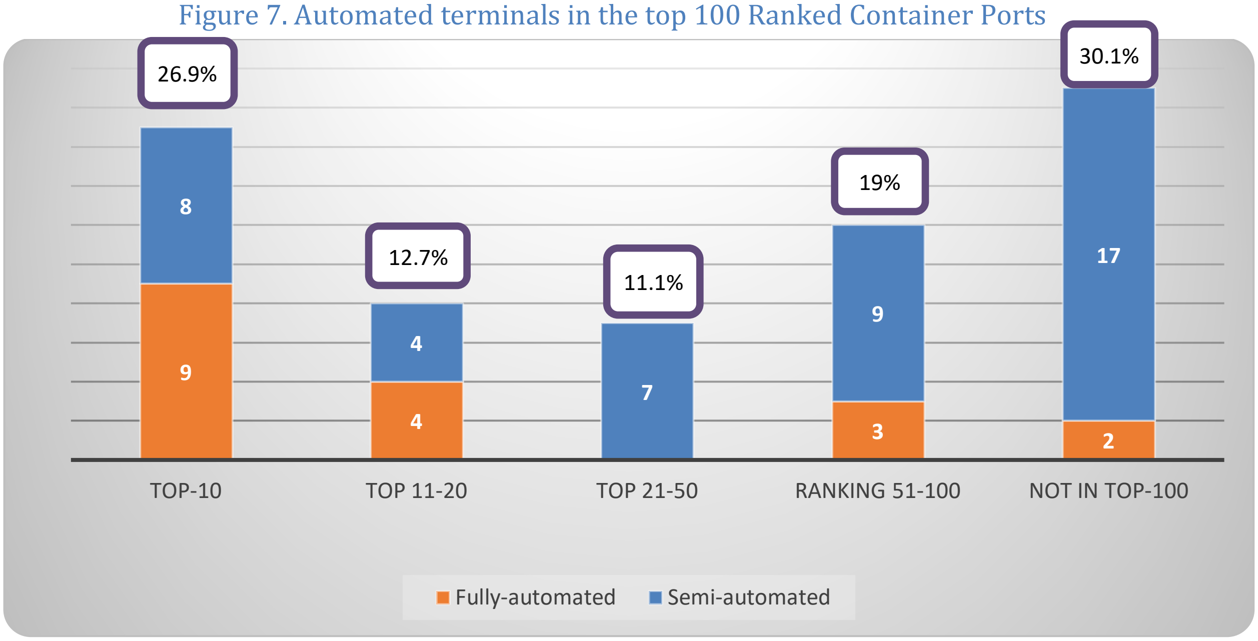
Container port scale

The 63 automated terminals are located in 43 different container ports. Sixteen of them operate in seven of the top-10 container ports in terms of annual throughput. Nine of those are fully-automated (one terminal in Shanghai, Singapore, Qingdao, two in Tianjin, and four in Rotterdam). Seven of them (two terminals in Singapore, four in Busan, and one in Hong Kong) are semi-automated.

A total of 44 of the 63 automated terminals operate in 27 of the top-100 container ports in terms of annual throughput (**Figure 7**). Sixteen of these terminals are fully automated and 28 semi-automated. Fully-automated terminals exist in the biggest container ports, with the exceptions being the initiatives by the Chinese government in the case of Xiamen Ocean Gate Container Terminal (fully-automated since 2012) and by Hutchison Ports, in the case of Brisbane (fully-automated since 2013).

Seventeen semi-automated and two fully-automated terminals (i.e., 30% of all automated terminals) have been developed in 16 other ports that host lower throughput per annum than the top-100 container ports. These are found in different regions of the world, i.e., four in Oceania (three terminals in Australia and one in New Zealand), three in Pacific Asia (in China, Indonesia, and Taiwan respectively), three in South East and West Asia (one in India, two in the United Arab Emirates), three in the Mediterranean Sea (two in Israel, and one in Italy), one in the UK, and three in Mexico.

Figure 7. Automated terminals in the top 100 Ranked Container Ports



Source: Compiled by the authors; N=63; Based on 2019 throughput; data as detailed in: Lloyd's List top 100 Container ports 2020. London: Lloyd's List.

Largest calling container vessel

Automation primarily takes place in terminals on the main East-West trade routes, i.e., Asia-Europe, trans-Pacific and trans-Atlantic. More than half of the automated terminals operate in ports receiving calls of containerships larger than 20,000 TEU (55.5%) (**Figure 8**).

Twenty-eight automated terminals (44.4%) exist in ports where the world's largest containerships are deployed. These vessels are primarily deployed on the Asia-North Europe and Asia-Med trade routes. The transpacific trade route has seen a considerable increase in the 20,000 TEU+ vessel class in the past few years, combined with significant increases in call sizes.[14] A further 25.4% of automated terminals are at ports that host calls of containerships exceeding 10.000 TEU capacity.

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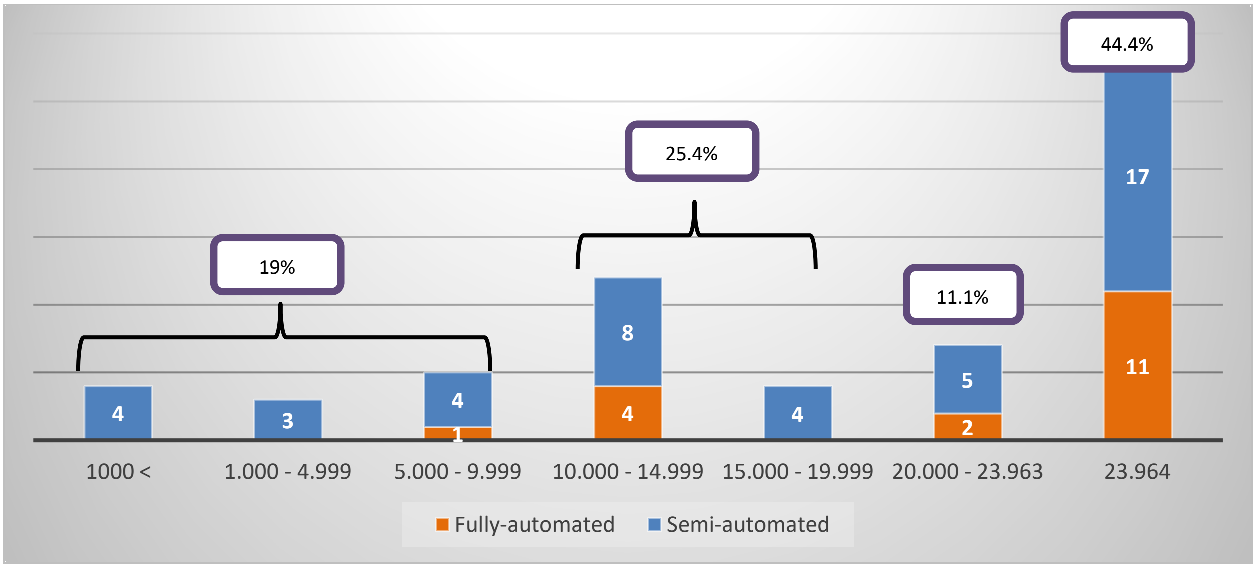
[14] For example, the MSC Isabella, with a nominal capacity of some 23,000 TEU broke earlier records when the Pier 400 terminal unloaded/loaded 34,263 TEU in the port of Los Angeles in June 2020.

Figure 8. Size of the biggest vessel calling at world ports hosting automated terminals[15]



Source: Compiled by the authors; data of maximum vessels size calling at each port as detailed in: UNCTAD Liner Shipping Connectivity Index (LSCI). UNCTAD: Geneva.

Transshipment incidences at ports

Each container terminal has a specific cargo mix. Most container terminals act as gateways for import and export cargo in relation to their captive or shared hinterlands. Other terminals combine import/export containers with sea-sea transshipment (T/S) flows whereby the containers arrive by vessel and leave on another vessel after a short dwell time at the terminal. The global port system also counts many almost pure transshipment hubs located at key locations in the liner shipping network close to strategic passageways such as the Straits of Gibraltar, the Suez Canal, the Panama Canal, and the Malacca Straits. Examples include Singapore, Freeport (Bahamas), Salalah (Oman), Tanjung Pelepas (Malaysia), Gioia Tauro, Algeciras, Tanger Med, Damietta, and Malta in the Mediterranean. These hubs have a transshipment incidence, i.e., the share of sea-sea transshipped containers in the terminal's total container traffic, of 65 to 100% (Notteboom et al., 2019). Some regional markets seem to offer the right conditions for the emergence of several transshipment hubs (e.g., the Med or the Caribbean), while other port systems only feature very minimal sea-sea transshipment activity due to unfavorable topological or regulatory conditions. For example, the 'Jones Act'[16] is widely considered as one of the reasons behind the absence of a sea-sea transshipment market in the U.S. port system.[17]

It is difficult to assess whether a terminal's (expected or actual) transshipment incidence will influence the decision to automate. On the one hand, container volumes are more volatile in

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[15] At the time of writing, 23,964 TEU was the capacity of the largest container vessel afloat. It concerns HMM Algeciras and sister ships measuring 228,283 gross tonnage (GT), 399m length overall (LOA), 24 containers wide and 16.52m draft. We created a separate bar for this vessel size to indicate how many automated terminals received this largest ship size.

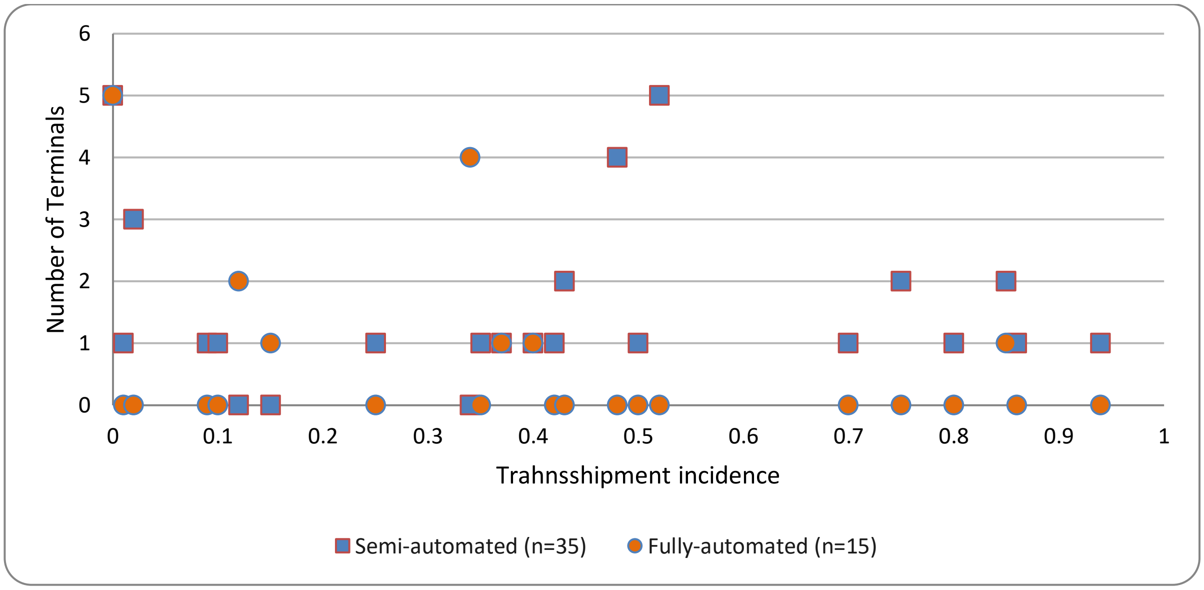
[16] Section 27 of the Merchant Marine Act of 1920, requires goods shipped between U.S. ports to be transported on ships built, owned, and operated by United States citizens or permanent residents.

[17] Brooks (2009).

transshipment terminals.[18] The expectation might be that these terminals require more flexibility and thus are better served with low levels of automation. Gateway terminals generally have more captive container volumes – implying less throughput volatility.[19] On the other hand, transshipment cargo typically has a shorter dwell time than gateway cargo (import/export) which makes yard management easier and results in higher land productivity for a given terminal layout. These factors might pave the way for automation.

Figure 9 confirms that **the relation between transshipment incidence and automation** is somewhat spurious. Only one fully-automated terminal is located in an almost pure transshipment hub. The other fully-automated terminals are found in ports with a mixed profile (i.e., gateway cargo plus transshipment cargo) or gateway ports with a low transshipment incidence. Semi-automated terminals are found in pure transshipment ports (transshipment incidence > 65%), mixed ports (between 25% and 65%), and gateway ports (<25%), with none of these groups having a dominant presence.

Figure 9. Transshipment incidences at ports hosting automated terminals



Source: own compilation based on transshipment data collected from port authorities' statistics and Drewry.

DRIVERS AND PERCEIVED BENEFITS OF AUTOMATION: A LITERATURE REVIEW

The decision to automate usually results from a complex interplay between multiple possible drivers and perceived benefits. Existing studies provide some indications of which factors might drive automation. In this section, possible drivers and benefits of automation are identified and subjected to a discussion using extant literature as input. This literature review provides the foundation for including factors in the survey questions on drivers and benefits (questions 2 and 4, see full survey in Appendix I).

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[18] Notteboom et al. (2019).

[19] Wang et al. (2019).

What can be extracted from previous research on terminal automation? A literature review study by Kon et al. (2020) focused on why a conventional container terminal would adopt automation, using a conceptual setup based on a set of criteria.[20] This literature review suggests that the adoption of automated container terminal technology could increase the terminal efficiency in productivity, leading to cost reduction, and improving environmental sustainability.

Camarero Orive et al. (2020) applied the BOT (Business Observation Tool) model to analyze the elements and factors that must be considered to formulate and implement automated container terminals from a business perspective. They consider four main aspects: (1) motivations and capacities/resources needed; (2) establishment of the working team taking into account both the knowledge and skills of each stakeholder involved; (3) understanding the external development environment which may hinder or facilitate the establishment of the implementation mechanism and strategies; and (4) macro-environment analysis including the technological, socio-cultural, economic, political and environmental factors that may condition or intervene in the achievement of the automation project. Their results show that motivations and available resources are fundamental in automation projects and that greater participation of economic stakeholders must be achieved through transparency so that the benefits derived from automation can be obtained. Collaboration in the planning phase is vital, particularly between the terminal operator and the port authority. The authors also point to the role of socio-cultural factors in successful implementation. Cybersecurity is considered a primary issue in the short term, while decarbonization is becoming increasingly important.

ITF (2021) argues that productivity gains and lower handling costs are among the main motivations for terminal operators to automate. However, the ITF study claims that terminal automation attractiveness depends on the local labor costs (i.e., low labor costs mean fewer financial incentives to automate) and the terminal profile (i.e., terminals that face a relatively stable market with guaranteed throughput volume would be more suitable for high levels of automation).

Based on further insights gathered from extant literature, we have identified a set of key drivers and dimensions that could play a key role when opting for the automation of a container terminal. Each of these drivers is discussed in detail using relevant source material and insights in the following sections.

Increase operational efficiency

There is an increased interest in terminal automation to improve quayside and land productivity given the scale increases in container vessel size and volumes. Increased automation could be a valuable strategy to improve workforce safety, ensure business continuity in port and terminal operation processes and vessel visits, and reduce processing times.[21] Automated terminals are supposed to be more productive and lead to increased quay use and yard densities, resulting in better use of available space and an increased facility capacity.[22] The operational efficiency gains would mainly result from eliminating uncertainty and more organized and methodological operations.[23]

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[20] Identified by Notteboom and Neyens (2017).

[21] ITF (2021).

[22] Monfort-Mulinas (2012).

[23] Martin-Soberon et al. (2014).

However, terminal productivity figures are generally not publicly available. When available, berth productivity figures usually are hard to compare on an equal footing among terminals due to differences in operational circumstances such as the cargo mix (e.g., sea-sea transshipment vs. gateway cargo) or ship sizes handled. For example, a report by JOC Group (2013) ranking berth productivity of world ports led to a wave of adverse reactions by individual ports and terminal operators. In recent years, several consultancies and advisory groups such as IHS Markit and Drewry have refined port productivity data collection and reporting. However, these raw datasets remain expensive, making it infeasible to present a comparative productivity analysis between automated and conventional terminals around the world.

According to a survey by Navis, a leading company in terminal operating systems (TOS), most terminal operators expect productivity increases between 25 and 50% when opting for automation.[24] However, anecdotal evidence presented by terminal operators, equipment manufacturers, and relevant trade press suggests that automation might present better terminal productivity figures than manual terminals in some cases, while in others, traditional terminals still outperform automated terminals such as in net crane productivity. For example, initial performance data for the TraPac automated terminal in Los Angeles had planned targets of 27 moves per hour for ship to shore cranes but only achieved 20 moves per hour. Additional equipment was anticipated to improve this performance.[25]

McKinsey (2017) concluded that, for a specific sample of automated ports, the productivity is 7 to 15% lower than conventional terminals. Ghiara and Tei (2021) found that automation has a reduced impact on the overall terminal productivity, and argued 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. Harsh outdoor conditions, poor information availability and accuracy, and a high degree of dynamics in vessel arrival times make productivity improvements through automation more difficult to achieve than in factory or warehouse environments (Miller, 2014). Limited information exchanges between supply chain actors (terminal operators, shippers, logistics service providers, and carriers) or bad/faulty information reduce operational productivity and increase overall handling costs, leading to a high level of avoidable re-handles in the yard.

The trade press also provides some clues on the performance profile of automated vs. conventional terminals. For example, in a press article, the spokesperson of APM Terminals in Rotterdam declared that their fully-automated container terminal at Maasvlakte 2 does not reach the productivity level of the older conventional facility at Maasvlakte 1 (which was sold to Hutchison Ports in mid-2021). APM Terminals argues the Maasvlakte 2 facility is too small to fully reap the benefits automation can bring: "*The high degree of automation only comes into its own when large volumes can be rotated, and these are insufficient at this time. Sometimes, processes are still carried out manually, which should actually be automated. If the terminal is expanded, with the same staffing, more volume is processed, and productivity goes to the intended level.*"[26] It is noteworthy that the APM Terminals facility at Maasvlakte 2 will be expanded from 86 hectares in 2021 to 180 hectares by 2024. A terminal manager, who preferred to remain anonymous, revealed that fully-automated quay cranes with operators who sit in a remote-control room have cycle times that are 20 to 30% longer than manned ship-to-shore cranes.

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[24] Port Technology International (2018).

[25] Moody's (2019).

[26] Mackor (2021).

Davidson (2016) argues that the actual operational efficiency gains of automation do not lie in the field of faster handling. It is more about achieving stability, predictability, and consistency of operational performance, which reduces downtime due to external factors (e.g., weather conditions) and allows continuous operations. Such operational conditions are easier to achieve when the cargo demand at the given terminal is consistent throughout the year, and only standardized boxes are used (thus, no open-top containers or oversized cargo units). When no ship is berthed at the terminal, the equipment can be used for other activities such as the reshuffling/restacking of containers or loading/discharging inland transport modes. Along the same lines, literature also points to the loss of flexibility linked to the standardization of automation processes.[27] In other words, automated terminals have difficulties dealing with unique scenarios and exceptions, such as open top containers or non-standard container weights. When these exceptions occur, manual intervention is usually required, thus interrupting normal operations at the automated facility.

Extant literature is not clear on the productivity gains brought by automation on the landside. Supply chain disruptions at Los Angeles/Long Beach ports during 2021 indicate how landside constraints, such as insufficient warehousing, which drastically increased container dwell time and chassis street time, can undermine the efficient operations at the port terminals. For an automated terminal to achieve its fullest potential, the entire supply chain must also have a certain level of reliability and efficiency to make the investment in automation worthwhile.

Lower the unit cost of container handling

Automation is often claimed to reduce generalized costs of terminal operations per unit handled. McKinsey's (2017) study concluded that automation could cut operating expenses (OPEX) by 25 to 55%. However, not all automation projects might realize savings in overall costs. Oliveira and Varela (2017) concluded that the realized reductions in handling costs are likely to be lower than expected. If a high degree of repetition and predictability and low volatility in cargo volumes cannot be achieved, the cargo handling cost per unit increases above conventional container terminals. As more knowledge and expertise are available, automation costs are being driven down, reducing risks and increasing benefits. Still, realizing cost savings through automation remains a challenge:

- Automation requires *high up-front capital investments* (CAPEX) in rather new technologies and involves large bespoke and customized terminal capacities that lack flexibility. Once fixed, the layout is challenging to change. Therefore, automated terminals carry greater risk and are harder to implement than traditional container terminals, which have been tested and improved over many decades. This uncertainty could imply that the expected cost savings per unit handled are not fully realized.
- Another factor that could weigh on the possibility of realizing cost savings per unit handled is the *complex interaction between different technologies*. Automation requires full synchronization and integration of hardware and software in all aspects of terminal operations. Purchasing automation components and equipment from different suppliers can result in expensive and lengthy integration processes and cost overruns.
- The extended test and start-up periods can also temper the cost-saving potential. The implementation period for an automated terminal is typically longer than for conventional

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[27] Martin-Soberon et al. (2014).

terminals. Thus, terminal operators have to invest large sums of money for more extended time periods before any ROI can be achieved. The long implementation time is caused by prolonged terminal construction and extended test periods.

- Finally, when an existing conventional terminal is retrofitted to an automated terminal, the *operational complications during the transition phase* could negatively affect the potential to realize cost savings. Upgrading a fully-operational terminal to an automated facility can be quite painstaking. The operator will temporarily have to give up some of its terminal capacity (and thus revenue generation) and will face running two systems (automated and conventional) concomitantly in the transition period. In the case of two U.S. terminals, the portions of the terminals that were automated were land areas separated from the primary conventional operation, which helped minimize disruption to the existing operations.

Shift from labor to capital costs

Even in the capital-intensive container handling industry, the share of dock labor costs in total operating costs of a conventional terminal can be as high as 50%.[28] Automation typically results in lower variable costs per container (OPEX) by reducing labor costs.[29] However, there is a robust regional dimension at play. Automated operations provide one way to counter the high price of labor in the U.S., Europe, and Australia, with unions having various degrees of impact on decisions to automate. In many developing countries, where most new terminals are being constructed, dock worker wages are relatively low. Chinese terminals face a high worker turnover, which implies that automation can be a way to avoid having to invest in skill development of dockworkers who, on average, do not stay long with the terminal operating company.

The fact that some inter-regional differences in labor conditions and costs exist does not imply that all ports in the same region follow the same logic when it comes to automation. For example, Van Den Driessche et al. (2019) did not find strong arguments to explain the automation differences between Rotterdam (characterized by many automated terminals) and Antwerp (only one semi-automated terminal) based on the differences in labor intensity and costs in both ports. Instead, they argue that the differences in automation might be more associated with the technological absorptive capacity and the first mover advantage of Rotterdam versus Antwerp's imbedded dock labor capability and performance.

Automation shifts the cost structure towards capital costs, reducing labor costs in absolute and relative terms and the uncertainty that manual labor can bring. Risks such as the availability of dockworkers and labor actions are some of the factors that can bring uncertainty and can have detrimental long-term effects on a terminal's reputation. An unmanned operation also avoids idle time caused by breaks and shift changes.

The willingness of terminal operating companies to invest in automation is partly related to the expected cost savings at the level of dock labor.[30] If automation allows reducing gang labor (or, in the case of full automation, even eliminating it), then the terminal operator will only benefit from the labor cost savings if the gangs are indeed reduced in number and/or size. If such a reduction

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[28] Notteboom (2018).
[29] PEMA (2012).
[30] Notteboom (2018); Notteboom and Vitellaro (2019).

in labor is not possible within the contours of the existing dock labor employment system, then the stevedoring company may be far less eager to introduce technological innovation.

The above trade-offs, when introducing new automated cargo handling technology, surfaced in a dispute between labor unions and terminal operator APMT in the port of Rotterdam. Their newest terminal (opened in late 2014) features remotely controlled ship-to-shore cranes. The company believed automation could reduce the potential for human error, impacting the reliability of terminal productivity linked to the handling of ever-larger container vessels. However, the new terminal development faced strong opposition from labor unions. They feared a possible loss of jobs and lower wages, given the shift from traditional crane drivers to remote operators of automated cranes. Consequently, APMT faced several weeks of labor union action at its terminals in Rotterdam in 2013 before a compromise was found for the opening of the APMT terminal at Maasvlakte 2.

The situation differs from one location to another. In some ports or port regions, labor unions are absent or only exert a very small impact on the decision-making process about automation. In other ports, labor unions have manifested themselves as key stakeholders and a force to reckon with in any automation trajectory. Their positions can range from very confrontational to highly constructive. Negotiations and disputes between terminal operators and unions emerge about who gets the rewards from the investment the operators make increasingly automated equipment. Dockworkers try to obtain a fair share of the benefits that can result when new technology is adopted. For example, carriers calling at U.S. ports manned by ILA members (east coast and gulf ports) pay royalties to ILA workers based on the tons of container cargo that move through the port, and, more than once, the pay-out amount formed a cornerstone in a social dialogue between dockworkers and port operators.[31]

High direct labor costs (i.e., wages, bonuses, benefits) can be a driver for automation. Automation can reduce the potential for variabilities in workforce availability and productivity. For example, the recent global COVID pandemic impacted the availability of the workforce at many terminals around the world. In some cases, however, local governance practices in terms of regulation and labor unions complicate the automation path to such an extent that a risk-averse terminal operator instead opts for the status quo.

Camarero Orive et al. (2020) argue that complete automation would only be feasible through dialogue and communication with labor unions, involving them in the project, and providing them with the information and retraining, so that workers acquire the necessary skills according to their capabilities. Indeed, even when opting for full automation, labor is still needed. However, automation typically requires a specialized and multi-skilled workforce which often implies an adaptation process for the existing port labor workforce. Terminal operators who opt for automation find themselves in the middle of the war for talent with firms from other industries when attracting people with a solid technical, IT, or engineering profile.[32]

Improve land productivity

Commonly used yard automation configurations are assumed to result in denser yard stacking. Terminals with limited land for expansion are generally located close to metropolitan areas. The proximity to urban areas can result in a scarcity of waterfront sites available for port

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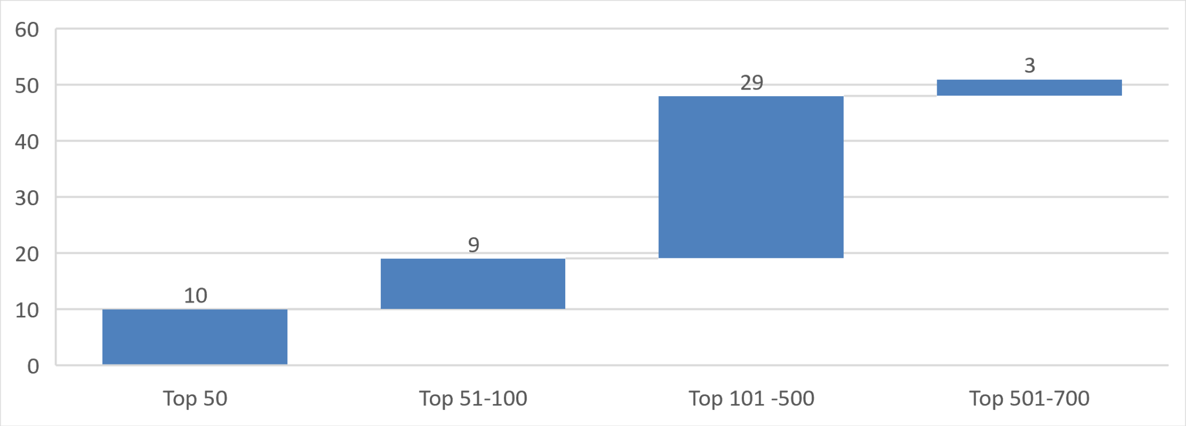
[31] See e.g., Scheyder (2013).

[32] Notteboom and Vitellaro (2019).

development. High land values and the need for expensive land reclamation works are a clear invitation to achieve high land productivity in terms of TEU handled per hectare per year. Developers typically focus on an optimal terminal design (including terminal equipment) and efficient terminal operations to achieve this goal. Low dwell times also help to maximize land productivity figures. However, dwell times are dependent on the market environment in which the terminal operates (such as the cargo mix import/export vs. seas-sea transshipment) and cannot be fully controlled by the terminal operator, even if high dwell time charges are imposed.

Only 19 of the 63 automated terminals are located in the top 100 port cities in terms of population (**Figure 10**). It may be an oversimplification to assume that the top urban areas based on population in the world might not have available land for port expansion projects. That may be the case for greenfield projects, but many automated terminals are conversions from conventional terminals. In addition, opportunities for a specific terminal expansion within a port may be dictated more by the terminal's specific locality within a port complex, its access to navigation channels, and the specifics of its lease agreement with the port authority. Thus, there is no strong relationship between the location of the automated terminals and the size of the surrounding population.

Figure 10. Automated terminals located near top cities in the world (in terms of population)



** Notes: N=63 terminals.*

The assumed land productivity gains of automation need to be put in perspective. First, ASCs typically have a stacking height and width, comparable to manual RMGs or RTGs. Stacking heights of such yard equipment typically ranges between 4 and 7 containers, with stack width reaching 5 to 10 rows. Similarly, AutoStrads do not reach higher stacking heights than manned straddle carriers (typically three high). Secondly, the use of AGVs between ship-to-shore cranes and container stacks might require wider aprons than those used for manned terminal tractors. Therefore, the primary land productivity gains associated with automation are not necessarily related to the equipment itself, but rather the result of the implementation of associated IT systems leading to more efficient use of the stacks (i.e., higher utilization degree of available slots) and a more efficient container flow throughout the terminal system.

Still, automation can bring significant land productivity gains in terminal retrofitting or reconversion. A good example is the gradual retrofitting of the Antwerp Gateway terminal operated by DP World. By replacing straddle carrier operations with ASCs, DP World expects to increase the terminal's container stacking capacity by some 50%. Since 2006, DP World Antwerp Gateway operated 20 ASCs on part of its terminal. The company has ordered another 34 ASCs (1-

over-6 in height and spanning nine container rows) to be delivered between Q2 2022 and 2026. Also, in Antwerp, PSA is shifting from straddle-carrier-only operations to ASC plus straddle carrier operations at its Europa Terminal. By 2025, the terminal's annual capacity will reach 2.4 million TEU or 700,000 TEU higher than the current situation.

The vertical storage yards or High Bay Storage (HBS) systems are among the latest innovations to increase land productivity. A good example is BOXBAY, a joint-venture of DP World and the SMS group. Each container is placed in an individual rack, making each one directly accessible. Containers can be stacked up to 11 tiers high. The system delivers more than three times the capacity of a conventional yard, thereby reducing the terminal footprint by up to 70%. In March 2021, DP World successfully completed the first 10,000 container moves in the BOXBAY high bay store system at Terminal 4 of the Port of Jebel Ali. Construction of that test facility with 792 container slots was completed in July 2020. While DP World claims BOXBAY can revolutionize how ports and terminals operate, the technology has not been tested and applied in a much larger scale setting.

Improve safety, security and environmental sustainability

Automation can help improve safety, security, and environmental sustainability, particularly if automation results in an increased density and productivity in the yard and quayside.

A fundamental safety challenge in the container terminal industry is that accidents, when they happen, can be extremely serious due to the heavy equipment and large workloads involved. Typical incidents involve hand injuries as well as people slipping on oily surfaces or when entering or exiting container handling machines. More serious incidents have resulted in the loss of life. Obviously, unmanned terminal equipment requires fewer dockworkers and thus a lower overall exposure to safety risks and human error. However, risks are not eliminated, as one of the main sources of accidents, i.e., lashing and securing activities onboard ship, still require human intervention. Still, automated terminals enable near-zero accidents simply by separating people from container handling equipment.[33] Sisson (2012) attempted to quantify potential reductions of injury rates by automating terminals on the U.S. west coast, but the evidence provided is not conclusive. Grau (2014) found that a reduction of the injury rate by 40% could be achieved when converting a conventional container terminal to full automation. Lower accident rates at terminals also have financial implications for lower insurance premiums and compensation costs.

Investments in automation often go hand in hand with full integration with security systems. A terminal's better safety and security profile has positive financial repercussions, such as lower insurance premiums. However, automation brings specific cybersecurity risks. Cybersecurity aims to protect hardware, software, and associated infrastructure, networks and the data on them, and the services they provide from unauthorized access, harm, misuse or destruction.[34] The management of cyber risks typically focuses on the system or network availability, integrity, and confidentiality, also known as the AIC-triad or CIA-triad.[35] The notion of availability implies that Users can access the data, the system, or the network when needed or desired. Confidentiality refers to ensuring that information or systems are only accessible to authorized Users. Integrity is about preserving information or system accuracy, thereby avoiding

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[33] Kaunonen (2017).

[34] Cybok (2019).

[35] Fenrich (2008); Samonas and Coss (2014).

unauthorized modification or deletion. Acknowledging the critical nature and possible far-reaching impact of cyber threats, terminal operating companies and port-related organizations and associations pay special attention to cyber risk management plans and guidelines.

Automation offers possibilities to reduce the environmental footprint of the terminal by reducing energy consumption. Various methodologies have been developed to assess the energy efficiency and CO2-emissions per terminal accurately.[36] Energy savings are typically achieved by optimizing container moves and horizontal transfers, reducing crane time per unit handled and distances covered, or using electric or hybrid power sources. Container handling equipment with high operating efficiency will accomplish their work assignments rapidly and lessen the berthing time of ships in the port, while saving energy and reducing CO_2 emissions. Recently, Yang (2017) found that electric ASCs can be considered green cargo handling equipment due to their significant contributions to working efficiency, energy savings, and CO_2 reduction. Still, it needs to be stressed that environmental savings are not only associated with automation. As the latest generation of terminal equipment (automated or not) has a smaller carbon footprint than earlier generations, the main environmental gains are made when updating old equipment or purchasing new equipment, improving working efficiency and conserving energy. Finally, an optimal layout can also reduce energy consumption and CO2 emissions in container terminals.[37]

Showcase technological innovation

Quite a few terminal automation projects have been realized in countries or regions which wanted to demonstrate their technological know-how. For example, the pioneering Delta SeaLand Terminal in Rotterdam was developed with the nearby Delft University of Technology, a leading technology and engineering university. Phase 4 of the Yang Shan terminal complex in Shanghai can be considered a demonstration project of Shanghai port and Shanghai-based leading equipment manufacturer ZPMC. Such technological showcases are real-life test-beds and learning opportunities for developing next-generation automation solutions.

Port authorities and governments might embrace terminal automation projects to promote the ‘smart port’ status or spotlight the innovation capabilities of the maritime cluster. However, some politicians and policymakers, particularly in western countries, are quite reluctant to communicate intensely on these technological achievements to the general public, as they fear this might trigger a social debate on potential job losses.

Compilation of a list of potentially relevant drivers/benefits of automation

The literature review and discussion presented above can be used to deduce a set of potential drivers/perceived benefits of automation:

1. Improve efficiency to handle larger vessels;
2. Reduce variability in performance (more consistency);
3. 24/7 hours of operation;
4. Meet KPI’s required by ocean carrier;
5. Improve truck turn time;
6. Reduce unit cost of container handling;
7. Reduce labor cost;

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[36] See e.g., Geerlings and Van Duin (2011); Spengler and Wilmsmeier (2016).
[37] See the study by Budiyanto et al. (2021).

8. Eliminate human factors (illness, risk of labor disruption, etc.);
9. Cope with limited land for expansion;
10. Reduce air/greenhouse gas emissions;
11. Increase safety;
12. Test-bed for new technologies/showcase technological expertise of local terminal and/or research community.

Next to the above factors, automation projects also need to consider the demand characteristics for container handling, including the competition with and strategies of competing terminal operators. The governance and user profile of the terminal and the availability of funding or subsidies might also be at play. Therefore, two more potential drivers are added to the above list:

13. Competitive forces from other terminal operators who opted for automation;
14. The availability of financial incentives/subsidies by public entities or port authorities.

The interplay of these 14 factors might promote automation in one location, but the absence of one or more drivers might undermine any automation project in another. Despite the above-mentioned economic, technical, environmental, and energy-related drivers that push towards automation, several terminal operators show reluctance or hesitation towards automation, adopting a 'wait-and-see' approach. In some cases, terminal automation plans were canceled or delayed. The main reasons for such behavior are the high irreversible investment costs of automation, the availability of skills and resources, governance issues, labor resistance, and the implementation time.

The 14 drivers listed in this section formed the backbone of Questions 2 and 4 of the survey (see Appendix I for the complete survey). In Question 2, terminal operators were asked to evaluate on a Likert scale from 0 (no importance) to 7 (maximum importance) the importance of a list of factors used in deciding whether to automate their container yard. Question 4 follows a similar approach, this time focusing on the perceived benefits of automation. A detailed discussion of the results follows in the following sections.

DRIVERS OF AUTOMATION VS. BENEFITS REALIZED: SURVEY RESULTS

Most important drivers and benefits realized

The survey results reveal a wide range of factors possibly contributing to the decision to automate a terminal. Next to purely economic and technical factors, more institutional factors and dynamics in stakeholder relations impact terminal automation. The most important factor driving the decision to automate among survey respondents was *increased safety* (**Table 6**). Three other primary factors driving the decision making were: *reducing the unit cost of container handling*, *reducing variability in performance,* and *reducing labor cost*.

Four terminals identified *improved truck turn-time* of maximum importance in driving their decision to automate. Only one of these four, a semi-automated terminal, did not realize the benefit of improved truck turn time. The three that realized their anticipated benefits of reduced truck turn-times were all fully-automated terminals. Two additional semi-automated terminals realized benefits to truck turn-times that were not anticipated.

Nearly the same factors were recognized as benefits by the terminal operators once automation was implemented (**Table 7**). *Improved safety* was the most important benefit realized with *reduced unit cost of container handling*, *reduced variability in performance*, and *reduced labor cost*. In addition, the *elimination of human factors that could cause disruption to operations* was also a realized benefit that was ranked somewhat lower as a driver to decision-making.

Secondary factors ranked slightly lower in importance, which drove the decision to automate include: *24/7 hours of operation*, *eliminate human factors*, *improve efficiency to handle larger vessels*, *reduce air pollution and greenhouse gases,* and *improve truck turn-time*. Terminals in China did not rank *24/7 hours of operation* as a key factor driving automation because their terminals already operate 24/7. This factor ranked high in other parts of the world where terminals have not traditionally operated 24/7. Although every terminal noted *improved truck turn time* as a driver in deciding to automate, it was generally not among the most highly rated factors in the decision-making.

Terminal operators had an opportunity to indicate other drivers not on the survey form. Several terminals input replies here, although many were already covered in the provided list. In one case, a terminal operator indicated that automating their terminal was part of an overall strategy of digitization.

The data for the drivers, which many terminals rated of greatest importance, was negatively skewed, meaning that for the majority of the terminal operators, their view of the importance of these drivers was very high, greater than the average score for those same factors across all terminals. In contrast, only a smaller number of terminals ranked these same factors of much lesser importance. For example, eighteen terminals ranked *increased safe*ty of maximum importance in their decision-making to automate their terminals, meaning these terminal operators scored this factor with a 7. The high value of negative skewness implies that most terminals scored this value over the average value of 6.28, while only a few had much lower scores.

On a scale from 0 to 7, all terminal operators, except for one, rated the importance of *increasing safety* as a driver towards automation with a 'score' of at least 5 (97.1%). A single operator that assigned no importance at all to safety when deciding to advance automation. Conversely, for the 18 terminal operators (56.3%), this has been a factor of major importance in deciding to automate the terminal.

The number of operators that realized the maximum benefits of *increased safety* is even higher, as 19 terminal operators ranked these benefits as 'maximum.' Only one automated terminal did not realize any increase in safety due to automation, while all the rest rated the benefits with a 4 or higher.

The second most important factor in driving automation was *reduced unit cost in container handling*. *Reduced unit cost* was also the second-highest ranked benefit realized by the terminal operators after automation. *Reducing costs of unit handling* is closely aligned with *reducing labor cost.* Despite the observation that reduced labor costs often drive the decision to automate, reduction in labor costs is only one of the primary factors driving the decision and not the most significant factor for many terminals. This observation is in line with the findings of the literature review, which already pointed to the mixed importance of labor cost as a driver for automation. Thirteen of the 32 terminals identified *reduced labor cost* as a driver of maximum importance. Of those 13 terminals, only 11 received the benefit of labor cost reduction they anticipated.

Table 6. Importance of drivers in deciding whether to automate container terminals

Driver	Mean	Std. Dev	Skewness	Kurtosis	Max Imp	No Imp
Increase safety	6.28	1.326	-3.659	16.593	18	1
Reduce unit cost of container handling	5.94	1.294	-1.403	1.786	14	1
Reduce variability in performance	5.62	1.641	-1.637	3.170	12	1
Reduce labor cost	5.37	1.930	-1.434	1.942	13	2
24/7 hours of operation	5.16	2.034	-1.159	.639	10	2
Eliminate human factors (illness, risk of labor disruption, etc.)	5.06	2.047	-1.534	1.252	5	2
Improve efficiency to handle larger vessels	4.97	1.823	-.940	.596	7	1
Reduce air/ GHG emissions	4.94	1.664	-.925	1.181	6	1
Improve truck turn time	4.66	1.450	-.231	.138	4	0
Meet KPIs required by ocean carrier	3.84	2.096	-.430	-.911	1	3
Limited land for expansion	3.63	2.406	-.105	-1.291	4	5
Test-bed for new technologies/ Showcase technological expertise of local terminal and/or research community	3.19	2.334	.148	-1.259	3	5
Competitive forces from other terminal operators who opted for automation	2.50	2.423	.501	-1.372	1	9
Financial incentives/subsidies by public entities or port authority	1.72	2.331	1.146	.045	2	17

** Notes: N=32 terminal operators; Scale: 1=limited importance; 7=Maximum importance; 0= Not a factor at all; Max Imp. = Number of terminals that ranked the specific factors as one of 'maximum importance'; No Imp. = Number of terminals that ranked the specific factors as 'not a factor at all'.*

Table 7. Benefits realized from the introduction of automation

Benefit	Mean	Std. Deviation	Skewness	Kurtosis	Max Ben	No Ben
Increased safety	6.28	1.373	-3.415	14.233	19	1
Reduce unit cost of container handling	5.63	1.314	-0.700	-0.592	10	0
Elimination of human factors (illness, risk of labor disruption, etc.)	5.59	1.829	-1.948	3.424	11	1
Reduce variability in performance	5.47	1.704	-1.342	2.108	12	1
Reduce labor cost	5.44	1.740	-1.279	1.698	12	1
Reduce air/GHG emissions	5.38	1.621	-1.771	4.015	8	1
Improve truck turn time	5.03	1.402	0.016	-1.365	6	5
24/7 hours of operation	4.88	2.612	-0.874	-0.577	14	5
Improve efficiency to handle larger vessels	4.72	1.971	-0.605	-0.301	8	1
Increase land productivity	4.59	2.298	-0.724	-0.620	8	3
Boost for technological and operational innovation by terminal operator	4.34	2.223	-0.652	-0.585	6	3
Meet KPIs required by ocean carrier	3.75	2.300	-0.403	-0.933	4	5

** Notes: N=32 terminal operators; Scale: 1=limited benefits; 7=Maximum benefits; 0= No benefit at all; Max Ben = Number of terminals that realized maximum; No Ben= Number of terminals that ranked the specific factors as 'not a factor at all'.*

Two terminals, one in the United States and one in Europe, did not realize the labor cost savings anticipated. One was a fully-automated and the other a semi-automated terminal. Twelve terminals identified reduced labor costs as a benefit of automation once implemented, 11 had anticipated those benefits and while an additional terminal in China realized benefits not anticipated.

All terminals realized some benefit in *reduced unit costs*, assigning a score of at least 3 out of 7 or higher with ten terminals realizing maximum benefits in *reduced unit costs*. All but one terminal realized savings in reduced labor costs. Twelve terminals realized maximum benefits in *reduced labor costs* while 7 terminals realized benefits of minor importance and one realized no benefits. Six of the seven terminals that realized only minor importance in *reduced labor costs* (scores 1 to 4) were semi-automated terminals in the United States and Europe. The terminal that realized no benefits from reduced labor costs was in the Pacific Asia region.

Seven terminals ranked *improved efficiency to handle larger ships* of maximum importance in driving their decision to automate. These seven terminals were scattered around the globe. Eight terminals realized benefits in *handling larger ships*, seven of those that anticipated improved efficiencies, and two additional terminals that had ranked this as a slightly lower driver.

Five of the 32 terminals ranked *elimination of human factors*, such as illness or risk of a labor disruption, as a driver of maximum importance. Three of these same terminals also ranked *reduced labor costs* as a primary driver. Eleven terminal operators indicated benefits related to the *elimination of human factors*, including the five who identified this factor as a primary driver. Five additional semi-automated terminals and one fully-automated terminal indicated that *elimination of human factors* was a benefit after automation. Note that the surveys were completed during the COVID period, after terminals around the world had to deal with lower dockworker availability due to the illness. Operators of automated terminals may have recognized that automation provided some protection against the virus spreading among their dockworkers. However, this factor had not been a driver when these terminal operators decided to automate.

Six terminals ranked *the reduction in air emissions and greenhouse gases* of maximum importance in driving their decision to automate, i.e., four fully-automated terminals and two semi-automated terminals. Eight terminals ranked the benefits in a *reduction in air emissions and greenhouse gases* of maximum importance once the terminal was automated; four of them are terminals that had anticipated those benefits. One fully-automated terminal did not realize the benefits in emission reduction they anticipated, however, the reason for this response was not explained. Two additional semi-automated and fully-automated terminals ranked *reduction in air emissions and greenhouse gases* of maximum importance as an outcome but not a driver.

Subsidies can affect investment by boosting internal and external (credit market) financial sources and increasing firms' financial capacity. Interestingly, a total of 17 respondents indicates that *financial incentives/subsidies by public entities or port authority* are not a factor at all when deciding to automate (score 0). This factor achieved the lowest average score of all the drivers considered. This observation can be interpreted in two ways: no financial incentives and subsidies were given or the provided financial incentives or subsidies did not alter the business case for automation. Four respondents, i.e., two from China and two from Japan, gave a score of 6 or 7 (maximum) on this factor, implying that they consider the awarded subsidies a key contributing factor in the decision to automate.

The data for benefits rated of greatest importance for most terminals was negatively skewed meaning that the majority of the terminal operators realized more benefits than the mean value of benefits averaged across all terminals while a few terminals achieved significantly lower benefits for these same factors.

Correlation of factors' importance in deciding whether to automate

Table 8 identifies the correlations of the importance of factors in deciding whether to automate container yard operations, based on the Pearson coefficient calculation (for further details, see Appendix II). This coefficient determines how statistical variables are linearly related. This measures the strength and direction of the linear association between two variables with no assumption of causality. Pearson coefficients range from +1 to -1. A correlation of -1 indicates a perfect negative correlation, and a correlation of 1 indicates a perfect positive correlation. If the correlation coefficient is greater than zero, it is a positive relationship. Conversely, if the value is less than zero, it is a negative relationship. A value of zero indicates no relationship between the two variables.

The correlation analysis found a strong positive relationship between reduced unit cost and reduced labor costs, as might be expected because labor costs are a key factor in the unit cost of handling a container. Other strong relationships were found between increased safety and elimination of human factors, indicating that terminal operators view the human factor as a fundamental factor in overall terminal safety. These findings underline one of the outcomes of the literature review: terminal operators embrace automation to reduce the impact of potential accidents by creating a physical gap between people and the area where operations are physically being carried out.

Meeting the key performance indicators (KPIs) established by ocean carriers for terminal operators showed a high correlation with *efficiency to handle larger vessels* and *competitive forces from other terminals*. Key performance indicators were not correlated with cost factors, but they were correlated with *reduced variability in performance* and *elimination of human factors*. This correlation indicates terminal performance and reliability are of greater importance to the ocean carriers than cost. Only two factors were negatively correlated with each other: *reduced unit cost* and *limited land for expansion*. These appear to be unrelated in the view of the terminal operators, although operational costs for terminals currently constrained with insufficient land would likely be reflected in unit costs. If there is limited land for expansion, then the opportunity to reduce unit costs by adding additional land to the terminal would not be available.

Table 8. Correlations of the importance of drivers to automate container yard operations

	High Correlation **	**Correlation***
Reduce labor cost	• 24/7 hours of operation (.511) • Reduce unit cost of container handling (.462) • Increase safety (.575)	• Competitive forces from other terminal operators who opted for automation (.400) • Eliminate human factors (illness, risk of labor disruption, etc.) (.394)
Reduce unit cost of container handling	• Reduce labor cost (.462)	• Limited land for expansion (-.391)
Reduce air/ GHG emissions	• Financial incentives/subsidies by public entities or port authority (.511)	• Improve truck turn time (.365)

Improve efficiency to handle larger vessels	• Increase safety (.498) • Meet KPIs required by ocean carrier (.607)	• Reduce variability in performance (.438) • 24/7 hours of operation (.438) • Eliminate human factors (illness, risk of labor disruption, etc.) (.424)
Limited land for expansion		• Competitive forces from other terminal operators who opted for automation (.393) • Reduce unit cost of container handling (-.391)
Improve truck turn time		• Reduce air/ GHG emissions (.365)
Increase safety	• Reduce variability in performance (.643) • Reduce labor cost (.575) • 24/7 hours of operation (.593) • Eliminate human factors (illness, risk of labor disruption, etc.) (.600) • Improve efficiency to handle larger vessels (.498)	• Meet KPIs required by ocean carrier (.446)
24/7 hours of operation	• Eliminate human factors (illness, risk of labor disruption, etc.) (804) • Reduce labor cost (.511) • Increase safety (.593)	• Improve efficiency to handle larger vessels. (428) • Competitive forces from other terminal operators who opted for automation (.367)
Reduce variability in performance	• Increase safety (.643) • Eliminate human factors (illness, risk of labor disruption, etc.) (.459) • Meet KPIs required by ocean carrier (.620)	• Competitive forces from other terminal operators who opted for automation (.397) • 24/7 hours of operation (.424) • Improve efficiency to handle larger vessels (.438) • Reduce labor cost (.382)
Eliminate human factors (illness, risk of labor disruption, etc.)	• 24/7 hours of operation (.804) • Increase safety (.600) • Meet KPIs required by ocean carrier (.544) • Reduce variability in performance (.459)	• Reduce labor cost (.394) • Improve efficiency to handle larger vessels .424) • Competitive forces from other terminal operators who opted for automation (.351)
Meet KPIs required by ocean carrier	• Improve efficiency to handle larger vessels (.607) • Eliminate human factors (illness, risk of labor disruption, etc.) (.544) • Competitive forces from other terminal operators who opted for automation (.549)	• Increase safety (.446)
Competitive forces from other terminal operators who opted for automation	• Meet KPIs required by ocean carrier (.549)	• Reduce labor cost (.400) • Reduce variability in performance (.397) • 24/7 hours of operation (.357) • Eliminate human factors (illness, risk of labor disruption, etc.) (.351) • Financial incentives/subsidies by public entities or port authority (.403)
Test-bed for new technologies / Showcase technological expertise of local	• Financial incentives/subsidies by public entities or port authority (.455)	•

terminal and/or research community		
Financial incentives/subsidies by public entities or port authority	• Reduce air/ GHG emissions (.511) • Test-bed for new technologies / Showcase technological expertise of local terminal and/or research community (.455)	• Competitive forces from other terminal operators who opted for automation (.403)

** Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); for details of all Pearson Correlations see Appendix II*

Correlation of benefits realized from automation

The strongest correlation among benefits realized from automation was the relationship between *improved efficiency to handle larger vessels* and *reduced variability in performance with meeting KPIs required by ocean carriers* (**Table 9**). *Reduced variability in performance* was also highly correlated with *increased safety*, while *increased safety* was also highly correlated with the *elimination of human factors*. Again, the tendency of the terminal operators to focus on the reliability of performance and all aspects of the terminal operation that could impact reliability was clearly visible over purely cost factors. This finding confirms one of the points presented in the literature review: the operational efficiency gains of automation are mainly found in achieving stability, predictability, and consistency of operational performance, which allows continuous operations.

Table 9. Correlations of benefits realized from automation

	High Correlation **	Correlation*
Reduced labor cost	• Increased safety (.514**) • 24/7 hours of operation (.545**) • Better meeting KPIs required by ocean carrier (.494**) • Reduced variability in performance (more consistency) (.473**)	• Reduced unit cost of container handling (.370*) • Elimination of human factors (illness, risk of labor disruption, etc.) (.362*)
Reduced unit cost of container handling		• 24/7 hours of operation (.400*) • Reduced labor cost (.370*)
Reduced air/GHG emissions		• Improved efficiency to handle larger vessels (.418*)
Improved efficiency to handle larger vessels	• Better meeting KPIs required by ocean carrier (.731**) • Increased safety (.566**) • Reduced variability in performance (more consistency) (.559**)	• Reduced air/GHG emissions (.418*) • 24/7 hours of operation (.369*)
Increased land productivity	• Better meeting KPIs required by ocean carrier (.444*)	
Improved truck turn time		• Improved efficiency to handle larger vessels (.566**) • Better meeting KPIs required by ocean carrier (.517**)
Increased safety	• 4-10-Elimination of human factors (illness, risk of labor disruption, etc.) (.676**)	

	• Better meeting KPIs required by ocean carrier (.544**) • Reduced labor cost (.514**) • 24/7 hours of operation (.505**)	
24/7 hours of operation	• Reduced variability in performance (more consistency) (.586**) • Elimination of human factors (illness, risk of labor disruption, etc.) (.576**) • Reduced labor cost (.545**) • Increased safety (.505**)	• Better meeting KPIs required by ocean carrier (.456**) • Reduced unit cost of container handling (.400*) • Improved efficiency to handle larger vessels (.369*)
Reduced variability in performance (more consistency)	• Increased safety (.797**) • Better meeting KPIs required by ocean carrier (.755**) • Improved efficiency to handle larger vessels (.559**) • 24/7 hours of operation (.586**) • Elimination of human factors (illness, risk of labor disruption, etc.) (.519**) • Reduced labor cost (.473**)	
Elimination of human factors (illness, risk of labor disruption, etc.)	• Increased safety (.676**) • 24/7 hours of operation (.576**) • Reduced variability in performance (more consistency) (.519**)	• Reduced labor cost (.362*) • Better meeting KPIs required by ocean carrier (.351*)
Better meeting KPIs required by ocean carrier	• Reduced variability in performance (more consistency) (.755**) • Improved efficiency to handle larger vessels (.731**) • Increased safety (.544**) • 24/7 hours of operation (.456**)	• Increased land productivity (.444*) • Elimination of human factors (illness, risk of labor disruption, etc.) (.351*)
4-12-Boost for technological and operational innovation by terminal operator	• Increased safety (.517**) • Reduced labor cost (.494**)	

** Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); for details of all Pearson Correlations values see: Appendix II.*

Differences between decision-making drivers and benefits realized

Table 10 presents the differences between the drivers for decision-making and the benefits realized from automation averaged for all 32 surveyed terminals. **Table 11** presents a regional comparison of the results. A positive difference means that the achieved benefits were greater than the anticipated benefits; a negative number indicates that the achieved benefits were less than expected. *Reduced labor costs, reduced air emission, improved truck turn-time, elimination of human factors* along with terminals having *limited land for expansion* and the opportunity to *serve as a test-bed for new technologies* were all factors where benefits exceeded expectations. However, in the case of the *reduced labor cost* the difference between expectations and realized benefits is marginal (slightly negative for the U.S. and Europe and slightly positive for Pacific Asia). The high observed difference for the factor *test-bed for new technologies* reveals that the learning curve and innovation trajectory linked to an automated terminal project led to a much stronger positive outcome than initially anticipated by the developer. Table 10 shows this is particularly the case for European and Pacific Asian terminals. The high positive difference between driver and benefits realized for the factor *increased land productivity* only relates to terminals in the U.S. and Pacific Asia. On average, automated terminals in Europe did not reveal any difference between benefits and expectations for this factor.

Table 10. Differences between benefits realized from automation and decision-making drivers

	Benefits realized	Decision-making drivers	Δ (Benefits-Expectations)
Test-bed for new technologies / Showcase technological expertise of local terminal and/or research community	4.34	3.19	1.25
Limited land for expansion	4.59	3.63	0.96
Eliminate human factors (illness, risk of labor disruption, etc.)	5.59	5.06	0.59
Reduced air/GHG emissions	5.38	4.94	0.44
Improve truck turn time	5.03	4.66	0.37
Reduced labor cost	5.44	5.38	0.06
Increase safety	6.28	6.28	-
Meet KPIs required by ocean carrier	3.75	3.84	-0.09
Reduce variability in performance	5.47	5.63	-0.16
Improved efficiency to handle larger vessels	4.72	4.97	-0.25
24/7 hours of operation	4.88	5.16	-0.28
Reduced unit cost of container handling	5.63	5.94	-0.31

** Note: N=32 terminals; 1=limited significance; 7=Maximum significance*

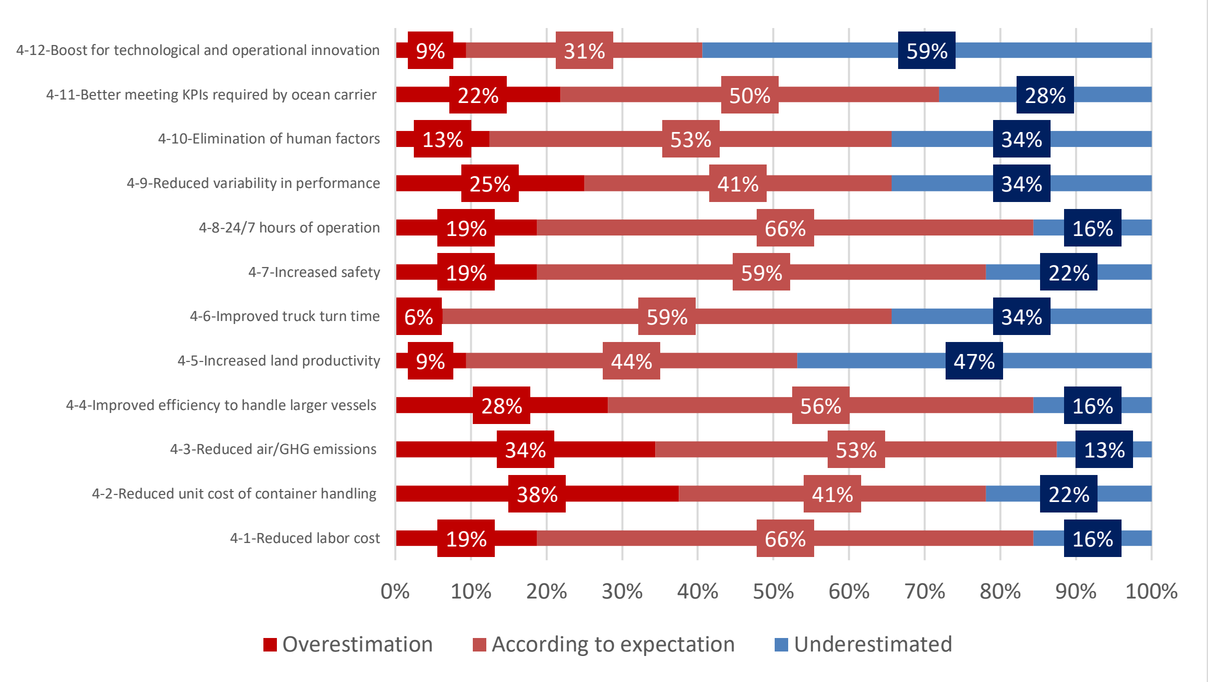
Table 11. Differences between benefits realized from automation and decision-making drivers, per terminal, per region

	U.S. (n=6)	**Pacific Asia (n=12)**	**Europe Atlantic & Med (n-=13)**	**Total (n=32)**
Reduced labor cost	-3	4	-3	2
Reduced unit cost of container handling	-2	-1	-7	-10
Reduced air/GHG emissions	2	0	8	14
Improved efficiency to handle larger vessels	0	-1	-4	-8
Increased land productivity6	11	10	0	31
Improved truck turn time	4	4	6	12
Increased safety	-2	3	-1	0
24/7 hours of operation	-2	4	-15	-10
Reduced variability in performance (more consistency)	-3	-2	-2	-5
Elimination of human factors (illness, risk of labor disruption, etc.)	4	11	-2	17
Better meeting KPIs required by ocean carrier	1	2	-8	-3
Boost for technological and operational innovation by terminal operator	5	12	16	37
TOTAL	**15**	**46**	**-12**	**77**

** Note: Sum of Δ ((Benefits-Expectations) for terminals in the region.*

Reduced cost of unit handling, the *ability to handle larger ships,* the *ability to operate 24/7*, and the *need to meet KPI required by ocean carriers* were all factors where expectations were not met. When examining the entire data set (**Figure 11**), it is clear that a relatively significant percentage of terminal operators (38%) have slightly overestimated the benefits of automation from *reducing the unit cost of container handling*. A third of those terminals were fully automated, while 2/3rds were semi-automated. Thus, yard automation may not solve all of a terminal's inefficiency problems, especially if the systems are not integrated. The literature review already hinted at this issue which is now confirmed by the survey results. For example, the TraPac terminal in Los Angeles initially experienced a reduction in ship to shore crane productivity (moves per hour) because there were too few shuttle carriers to move containers to the yard. For an automated terminal to achieve its greatest potential in terms of productivity, all facets of the terminal operation have to be in sync. This often requires a period of trial and error to smooth out any inconsistencies in cargo flows within the terminal. The high percentage of terminals (59%) that saw no benefit from as a *test bed for new technologies* is related to the fact that their terminals may not have served as a manufacturers' testing site for new equipment, or their automation journey may not have been part of a research study.

Figure 11. Percentage of operators that over/under estimated the benefits of automation



Variances between anticipated benefits per type of operator

Terminal operators were identified as stevedoring companies or ocean carriers or financial holding companies. An ANOVA analysis returned no statistically significant variance in either the drivers, or benefits realized from terminal automation, based on the type of terminal operator.

DRIVERS VS BENEFITS: FULLY VS SEMI-AUTOMATED TERMINAL

This section compares drivers that originally motivated terminal operators to automate against the benefits received separately for fully and semi-automated terminals.

For fully-automated terminals, drivers of importance were *increased safety*, *reducing unit costs of container handling*, *reducing labor cost*, *reducing variability in performance*, and *reducing air emissions and greenhouse gas production* (**Table 12**). For semi-automated terminals, *reducing labor costs*, and *reducing air emissions* were ranked of less importance compared to fully-automated terminals, while *24/7 hours of op*eration and *eliminating human factors* were ranked of higher importance.

Given the sample size (n=32), variations in the replies might be spontaneous or biased. An ANOVA test was performed to identify any statistically significant differences of the anticipated benefits by the operators who opted for fully automating the container terminal compared to those who opted to develop a semi-automated terminal. The results are not significantly different, with one exemption – the significance assigned to *elimination of the human factors*. The analysis identified (P-value <0.05) a statistically significant difference as regards the *elimination of human factors* (Mean Square 18.923, F 5.116; Sig .031). A Kruskal–Wallis non-parametric analysis confirmed these ANOVA findings: the importance of *eliminating human factors (illness, risk of labor disruption, etc.)* is not the same across fully or semi-automated terminals (F.0.037).

Table 12. Importance of drivers in deciding whether to automate container terminals: Fully vs Semi-automated containers

Drivers	**Fully-automated**		**Semi-automated**		**Δ (Full-Semi)**
	Average (1)	St. Dev	Average (2)	St. Dev	(1)–(2)
Increase safety	**6.18**	0.87	**6.33**	1.53	-0.15
Reduce unit cost of container handling	**5.91**	1.38	**5.95**	1.28	-0.04
Reduce labor cost	**5.82**	1.17	**5.14**	2.22	0.68
Reduce variability in performance	**5.73**	1.56	**5.57**	1.72	0.16
Reduce air/ GHG emissions	**5.45**	1.75	4.67	1.59	0.79
Improve efficiency to handle larger vessels	4.91	1.81	**5.00**	1.87	-0.09
Improve truck turn time	4.82	1.89	4.57	1.21	0.25
24/7 hours of operation	4.36	2.25	**5.57**	1.83	-1.21
Eliminate human factors (illness, risk of labor disruption, etc.)	4.00	2.49	**5.62**	1.56	-1.62
Test-bed for new technologies / Showcase technological expertise of local terminal and/or research community	4.00	2.79	2.76	2.00	1.24
Limited land for expansion	3.91	2.02	3.48	2.62	0.43
Meet KPIs required by ocean carrier	3.55	1.86	4.00	2.24	-0.45
Competitive forces from other terminal operators who opted for automation	2.73	2.49	2.38	2.44	0.35
Financial incentives/subsidies by public entities or port authority	2.45	2.94	1.33	1.91	1.12

Notes: N=32 terminal operators; Scale: 1=limited benefits; 7=Maximum benefits; 0= No benefit at all.

In short, the *elimination of human factors* was identified as a greater benefit for semi-automated terminals than fully-automated terminals. This is not expected as semi-automated terminals would have more dockworkers on a terminal than fully-automated terminals (**Table 13**). One explanation may be that terminal operators completed the surveys during the global pandemic. Only six of the 32 terminals that completed the survey indicated that the *elimination of human factors* was a driver of maximum importance. However, 11 terminals indicated *elimination of human factors* as a benefit of maximum importance; nine of these 11 terminals were semi-automated. It may be that semi-automated terminal operators, who recognized the risks to their dockworkers during the pandemic, also recognized that their risks were minimized to a large extent by the presence of automation. Whereas, fully-automated terminals operators might not have seen impacts on their workforce and may not have been influenced to rank *elimination of human factors* of maximum importance as a benefit when completing the survey. Only one automated terminal ranked *elimination of human factors* as a maximum driver when deciding to automate. Only one fully-automated terminal (different from the prior terminal) ranked *elimination of human factors* as a primary benefit. In the case of all other benefits, the findings were similar, irrespective of the level of automation that is endorsed.

Table 13. Benefits realized from the introduction of automation: Semi vs Fully-automated terminals

Benefits	Fully-automated		Semi-automated		Δ (Fully-Semi)
	Average (1)	St. Dev	Average (2)	St. Dev	(1)–(2)
Increased safety	**6.27**	1.104	**6.29**	1.521	-0,01
Reduced labor cost	**6.09**	.944	**5.10**	1.740	1.00
Reduced unit cost of container handling	**5.64**	1.029	**5.62**	1.465	0.02
Reduced variability in performance (more consistency)	**5.64**	1.804	**5.38**	1.687	0.26
Reduced air/GHG emissions	**5.64**	1.804	**5.24**	1.546	0.40
Improved truck turn time	**5.27**	1.555	4.90	1.338	0.37
Increased land productivity	**5.09**	1.921	4.33	2.477	0.76
Elimination of human factors (illness, risk of labor disruption, etc.)	4.91	2.119	**5.95**	1.596	-1.04
Improved efficiency to handle larger vessels	4.91	2.071	4.62	1.962	0.29
Boost for technological and operational innovation by terminal operator	4.91	2.809	4.05	1.857	0.86
24/7 hours of operation	4.55	2.841	5.00	2.490	-0.50
Better meeting KPIs required by ocean carrier	3.82	2.272	3.71	2.369	0.10

Notes: N=32 terminal operators; Scale: 1=limited benefits; 7=Maximum benefits; 0= No benefit at all.

The gap between decision-making drivers and benefits realized indicate that operators of fully-automated terminals were more successful in meeting expectations overall than operators of semi-automated terminals, particularly in the areas of *reducing the unit cost of container handling, improved efficiency to handle larger ships, 24/7 hours of operation* and *meeting KPIs required by ocean carriers (***Table 14***).* The most significant difference between fully vs. semi-automated terminals is for the factor *eliminating human factors*. Semi-automated terminals realized more benefits of *eliminating human factors* than fully automated terminals; however, semi-automated terminals generally saw more benefits in this same factor than they initially expected. See earlier sections for further discussion of how survey results for the factor elimination of human factors might have been influenced by the pandemic.

Table 14. Differences between benefits realized from automation and decision-making drivers and benefits realized from automation: Fully vs Semi-automated terminals

	Fully-automated Δ (Benefits-Expectations)*	Semi-automated Δ (Benefits-Expectations)*
Reduce labor cost	0.27	-0.04
Reduce unit cost of container handling	-0.27	-0.33
Reduce air/ GHG emissions	0.19	0.57
Improve efficiency to handle larger vessels	0.00	-0.38
Limited land for expansion	1.18	0.85
Improve truck turn time	0.45	0.33
Increase safety	0.09	-0.04
24/7 hours of operation	0.19	-0.52
Reduce variability in performance	-0.09	-0.19
Eliminate human factors (illness, risk of labor disruption, etc.)	0.91	0.33
Meet KPIs required by ocean carrier	0.27	-0.29
Test-bed for new technologies / Showcase technological expertise of local terminal and/or research community	0.91	1.29

** A positive difference indicates that the achieved benefits were greater than the benefits expected; a negative number indicates that the achieved benefits were less than the benefits expected; scale of importance of drivers from 1 to 7, 0= No benefit at all; scale of benefits realized from 1 to 7, 0= No benefit at all.*

STAKEHOLDERS AND AUTOMATION

Next to internal stakeholders within the terminal operating company (shareholders, staff, etc.), the automation decision-making process and the success of a terminal automation project are influenced by the interaction with and attitude of a wide range of external stakeholders:

- **Supply chain actors.** They have direct commercial interactions with the automated terminal. This category includes carriers, transport operators, shippers, and shippers' representatives such as freight forwards and logistics service providers. In this report, we distinguish between three groups, i.e., carriers, shippers, and logistics;
- **Dockworkers**. They can be civil servants in state-owned service ports, workers directly employed by a private terminal operating company or workers employed through dock labor schemes. Quite a few dock labor employment systems require that only registered dockworkers perform dock work in the port. This obligation can be imposed by national or regional legislation or might also be the outcome of collective bargaining agreements between port employers and trade unions;[38]
- **Port authority**. A port authority can be defined as the entity which, whether or not in conjunction with other activities, has as its objective under national/local law or regulation, the administration and management of the port infrastructures and the co-ordination and control of the activities of the different operators present at the port.[39] The

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[38] Notteboom, (2018).

[39] Verhoeven, (2010).

possible port management models include the landlord port, tool port, private port, and public port with many variations observed in practice for each of these solutions;[40] [41]

- **The governmen**t. This category includes government ministries and agencies at the supranational (e.g., European Union), national, regional, provincial and local levels. The relative power of each government level can differ widely among countries and is partly dependent on the port governance system in place (e.g., centralized vs. decentralized port management);
- **The communit**y. This category includes local inhabitants, taxpayers, and a wide range of community and environmentalist groups. Local inhabitants and tax payers usually are by-standers with limited knowledge of how terminals operate, but very sensitive to terminal's positive and negative environmental and social impacts. Community groups are generally well organized and informed and can, and often do, resort to legal means to fight decisions related to port development.

Extant literature does not explicitly consider the attitude of external stakeholders concerning terminal automation. Terminal operators were asked to identify the position of various stakeholder groups (Government, community, port authority, dockworkers, carriers, shippers, and logistic providers) towards the introduction of automation at their terminal. These results thus present the terminal operators' perspective of stakeholder positions (**Figure 12**). A survey of stakeholders was not done as part of this research. Results show the terminal operators view the port authority and the government as their primary allies in pursuing automation on a global basis. The carriers are also strongly supportive. Shippers and logistic providers are one step removed in the logistics chain, and that may explain why terminal operators believe that a large percentage of shippers and logistic providers are neutral toward terminal automation.

Support of stakeholders

Port authority support was characterized as predominately high (15 terminals) or moderate (6 terminals), with eight terminals reporting that their ports were neutral (**Figure 12**). Three terminals, two in Europe and one in Asia, reported their ports as moderately opposed to automation. These same three terminals also reported that the government was not supportive of automation. The same two European terminals also report high opposition from the carriers to automation, which reflects more on the arrangements for investment in these specific terminals (such as the opportunity for carriers to enter the local terminal operating market) rather than carrier opposition to automation.

Terminal operators view dockworkers as having the most significant opposition to introducing automation. This 47% value primarily represents the surveys from Europe and the Americas.

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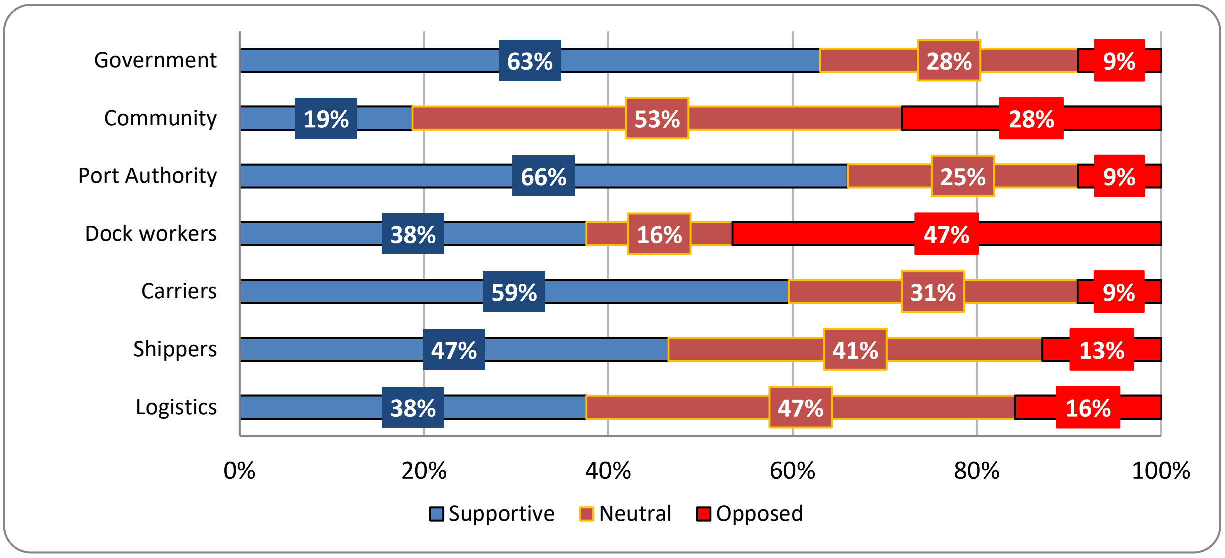
[40] Brooks and Pallis, 2012)

[41] There are five main models based upon the public and private sector's responsibility in port management (Notteboom et al., 2022 based on World Bank Port Reform Toolkit). In a public service port, the port authority provides a range of port-related services and owns all the infrastructure. The tool port differs only in the private handling of its cargo operations, albeit the port authority still owns all or part of the terminal equipment. In a landlord port, terminals are leased to private operating companies, with the port authority retaining control of the land where the port develops either by owning it or retaining the rights for exclusive exploitation (as granted by the competent public authority). Corporatized ports have almost entirely been privatized, except that ownership remains public and is a public entity is often a majority shareholder. Private service ports result from complete privatization of the port facility with a mandate that the facilities retain their maritime role.

The dock labor costs in the U.S. and Europe are high compared with Asia. Trade unions are generally well organized and have a clear 'voice' in the automation debate. The 38% support and 16% neutral positions from dockworkers were primarily from terminals in Pacific Asia, where dockworkers are not organized into larger regional unions. Three of the terminals from China reported high support for automation from dockworkers; two reported dockworkers' position as neutral, and one terminal reported minor opposition. Chinese dockworkers, however, have used their collective power to represent their interests, as was shown by the 2013 strike in Yantian (Cao and Meng, 2017), but as yet, have not opposed automation efforts.

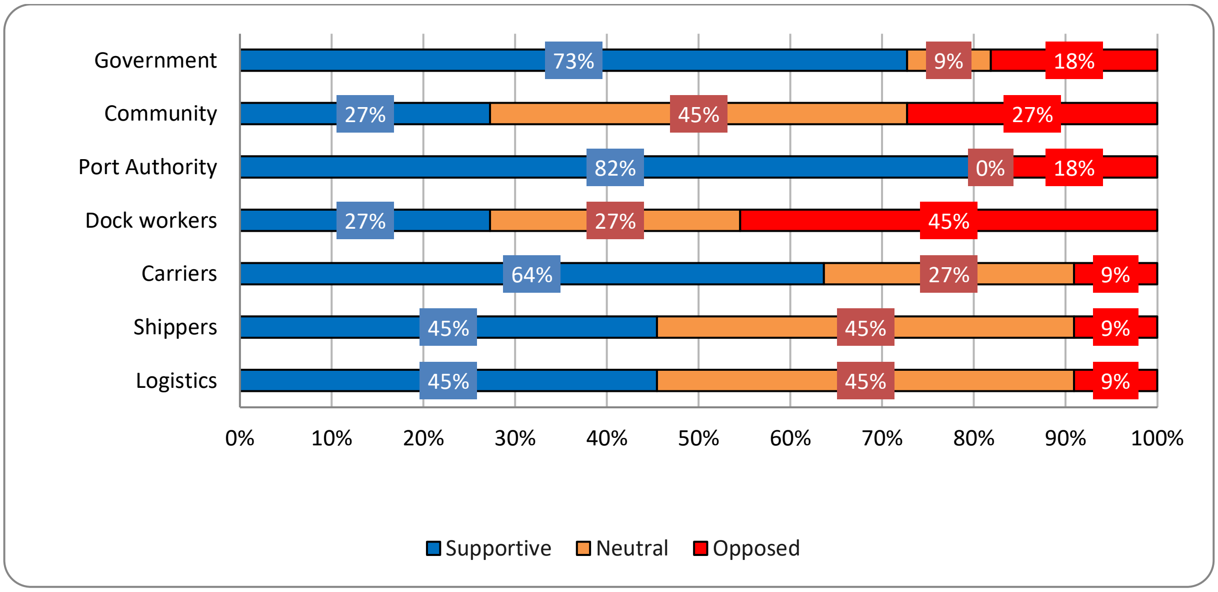
Figure 12. Levels of Stakeholder Support / Opposition towards the introduction of automation



The port authority, government, and carriers were the primary supporters of terminal automation regardless of whether the terminals were fully or semi-automated (**Figure 13** and **Figure14**). Dockworkers and community members had the greatest opposition.

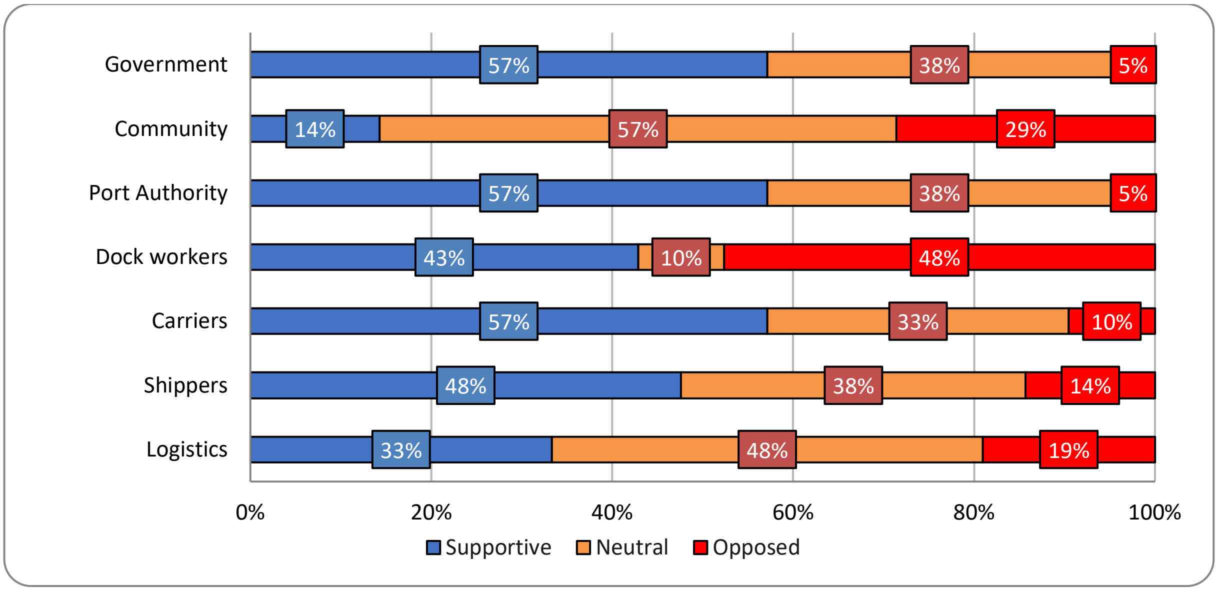
On a percentage basis, 45% of the dockworkers strongly opposed the introduction of fully-automated terminals. A similar percentage of opposition (48%) was noted by terminal operators of 19 semi-automated terminals surveyed. Community opposition at 27% for full automation was not vastly different from the 29% opposition for semi-automated terminals. Community members were largely neutral to automation, indicating they are unaware of the fundamental differences between fully and semi-automated terminals and/or not engaged in the debate. Shippers and logistic service providers are predominately supportive or neutral, reflecting being one step removed in the supply chain from the port itself, or even the lack of visibility into which terminal within a port their container might travel through.

Figure 13 Stakeholders support towards the introduction of full automation of terminals



Notes: N=11.

Figure 14. Stakeholders support towards the introduction of semi-automation of terminals



Notes: N=21.

Table 15 enables a more in-depth look at survey results concerning the terminal operator's perspective of dockworker support for fully and semi-automated terminals. Four semi-automated terminals reported only minor opposition, the same number as reporting strong opposition, and at two other semi-automated terminals, opposition from labor was moderate. The four terminals where labor had strongly opposed the introduction of semi-automation are in the U.S., Europe, Korea, and Japan. The four terminals where labor has moderate or strong support for full automation are located in Asia, of which three are in China.

Table 15. Dockworkers Support/Opposition for Full and Semi-Automated Terminals

Dockworkers	Fully-automated (n=11)	Semi-Automated (n=21)
Strong opposition	5	4
Moderate opposition		2
Minor opposition		4
Neutral	3	2
Minor support		8
Moderate support	1	
Strong Support	2	1

Industry-related stakeholders support: Do factors motivating automation matter?

Except for community members, the majority of the stakeholder groups are more directly related to the industry (although community members could also be employed in the maritime industry). Governments set policies that affect ports, including policies that can affect the automation of terminals. Landlord port authorities, common in Europe (except for private service ports in the UK) and the U.S., provide the facilities that support terminal operations and engage in concession or lease arrangements with the (private) terminal operators. Chinese ports are examples of public service ports whereby state-owned port groups (such as SIPG in Shanghai) manage the port and get involved in terminal operations with or without other partners. Dockworkers operate within those terminals. The carriers, shippers, and logistic service providers are all part of the supply chain reliant on terminal operations.

The replies received by the 32 container terminals enable exploration of the potential correlations between motivations for automation of container terminals and the levels of support for the automation initiative by decision-makers and industry-related groups, such as the government, the port authorities, dockworkers, and stakeholders along the supply chains.

Table 16 provides the results of such exploration by detailing the (Pearson's) correlation between the replies received by terminals on the anticipated benefits and the stance of the industry-related stakeholders. Two notes of caution are, however, essential. The first is factual: stakeholders might not always have a comprehensive, or even any idea of the motivations of the terminal operator but react based on their overall stance as regards automation and its implications. Second, the Pearson correlation cannot determine a cause-and-effect relationship but can only establish the strength of linear association between two variables. Conversely, the data provide information of any such linear association and background for further analysis of these correlations and indicated causal relations. The results show the highest correlations between the importance of safety as a driver for automation and support from carriers, shippers, and logistics service providers**.**

Table 16. Correlations of factors motivating automation with levels of industry-related stakeholders support towards the introduction of automation

	High Correlation **	Correlation*
Reduce labor cost		Carriers (.353*) Shippers (.374*)

		Logistics Providers (.431*)
Reduce unit cost of container handling		Shippers (.380*)
Reduce air/ GHG emissions		Shippers (.374*) Logistics Providers .426*)
Improve efficiency to handle larger vessels		Carriers (.386*)
Increase safety	Carriers (553**) Shippers (.518**) Logistics Providers (.457**)	
Financial incentives/ subsidies by public entities or port authority		Logistics Providers (.431*)

PREDICTORS OF DRIVERS TO AUTOMATE & REALISED BENEFITS

A stepwise linear regression identified possible predictors of the drivers towards automation out of the following qualitative variables:

X_1 = Fully- or semi-automated terminal
X_2 = Year of terminal opening
X_3 = Year of the first automation
X_4 = Operator type (i.e., stevedoring companies, shipping companies, financial institutions)
X_5 = Terminal acreage (hectares)
X_6 = Length of Berths (meters)
X_7 = Max draft (meters)
X_8 = Maximum Ship Size called (the port) (2020)
X_9 = Liner Shipping Connectivity Index (LSCI) of the port (2020)
X_{10}= Listed in the top-100 Container ports (2019)
X_{11}= Rank in top-700 Cities of the world in terms of population (2019)

The findings suggest that three out of the 14 drivers examined are associated at statistically significant levels with some of the qualitative variables examined (**Table 17**).

- The first one is the *limited land for expansion* (Y_5). This driver is negatively linked with *the year of opening of the terminal* (X_2). In the most recent terminals scarcity or other land-related limitations tend to be less significant drivers for the more recent automation projects. The limitation of land became a more significant driver towards automation the higher *the traffic of the port* (X_{10}= Listed in the top-100 Container ports), and the higher the *maximum ship size calling at the port* (X_8).
- The *competitive forces from other terminal operators who opted for automation* (Y_{13}) was found to be a less significant driver *the larger the terminal acreage* (X_5), and a more significant driver the larger the *ship size calling the port* (X_8). When a terminal has enough space to develop its activities, the less important the pressure from competitors. When a terminal handles larger vessels, competition seems to generate motivation to automate the terminal.
- The presence of *financial incentives/subsidies by public entities or port authorities* (Y_{14}) is negatively related to *the larger-sized terminals* (X_5), and *the size of the port-city in terms of population* (X_{11} = rank of the city in the top-700 cities in terms of population), and positively related to the maximum draft (X_7) of the berth.

The stepwise linear regression was also used to identify possible predictors of the realized benefits from automation. In this case, we estimated the relationship out of 20 variables to the 11 variables examined in the case of the regression analysis of the determinants of the drivers towards automation. Seven additional variables were included, following the reply of the survey by terminal operators:

X_{12}=How many years has it taken to realize a return on investment for the automated system?
X_{13}=Number of suppliers that implemented automation
X_{14} = Level of support of automation of the terminal by the government (strong-moderate-minimum opposition / neutral /minimum-moderate-strong support)
X_{15} = Level of support of automation of the terminal by the Community
X_{16} = Level of support of automation of the terminal by the Port Authority
X_{17} = Level of support of automation of the terminal by dockworkers
X_{18} = Level of support of automation of the terminal by carriers
X_{19} = Level of support of automation of the terminal by shippers
X_{20} = Level of support of automation of the terminal by logistics service providers

For five of the 12 benefits, the scale of the benefits realized following automation is not related at a significant statistical level with any of the 20 examined variables (**Table 18**). For the other seven benefits, the stepwise regression analysis identifies specific determinants:

- The *increase of land productivity* (Y_5) is more significant than the length of the berths (X_6).
- The *reduction of labor costs* (Y_1), the consistency of performance variability (Y_9), and *increased safety* (Y_{17}) are positively related to the *time taken to realize a return on investments for automation* (X_{12}).
- The benefits *of 24/7 operations* are linked with the year of the first automation (X_3), the max draft (X_7), and the levels of support of automation by governments (X_{14}) and the community (X_{15}).
- Meeting KPIs required by ocean carrier (Y_{11}) benefits are higher the deeper the maximum draft of the terminal (X_7) and the higher the level of support of automation of the terminal by the community (X_{15}).
- A more significant boost for technological and operational innovation by terminal operator (Y_{12}) is positively linked with the levels of liner shipping connectivity of the port (X_9) and the level of support of automation of the terminal by the community (X_{15}).

Table 17. Predictors of the importance of the drivers towards automation

		Constant	X_2	X_5	X_6	X_7	X_8	X_{10}	X_{11}
Y_5 - Limited land for expansion	Estimate tStat	33.65 (3.067)	-0.0157 (-2.879)		0.0003 (2.968)			0.008 (2.804)	
Y_{13}-Competitive forces from other terminal operators who opted for automation	Estimate tStat	-0.288 (-0.651)		-0.008 (-3.358)			9.944 (4.528)		
Y_{14}-Financial incentives/subsidies by public entities or port authority	Estimate tStat	-0.223 (-0.136)		-0.016 (-4.317)		0.292 (2.467)			-0.002 (-3.072)

Table 18. Predictors of the realized benefits of automation

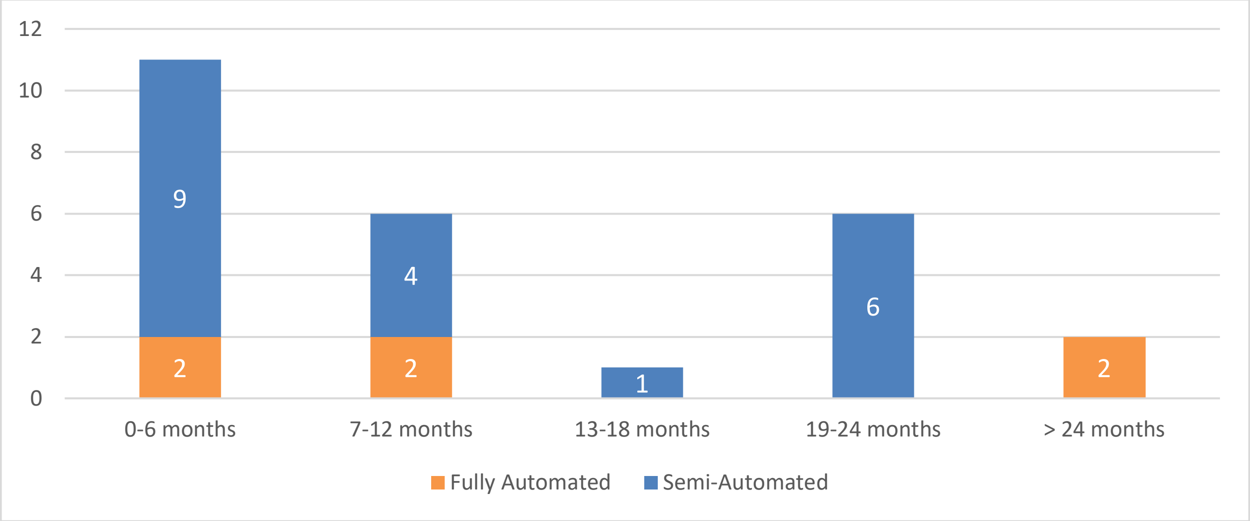
		Constant	X3	X6	X7	X9	X12	X14	X15	X19
Y_1-Reduced labor cost	Estimate tStat	0.544 (0.1.067)					0.253 (2.322)			
Y_5-Increased land productivity	Estimate tStat	1.784 (12.76)		0.0001 (2.221)						
Y_7-Increased safety	Estimate tStat	0.914 (2.028)					0.204 (2.108)			
Y_8-24/7 hours of operation	Estimate tStat	80.603 (2.699)	-0.041 (-2.761)		0.237 (3.997)			-0.159 (-2.088)	0.339 (3.988)	
Y_9-Reduced variability in performance (more consistency)	Estimate tStat	0.621 (1.245)					0.239 (2.234)			
Y_{11}-Better meeting KPIs required by ocean carrier	Estimate tStat	1.146 (-1.193)			0.153 (2.623)					1.146 (-1.193)
Y_{12}-Boost for technological and operational innovation by terminal operator	Estimate tStat	1.202 (6.559)				0.004 (1.970)				1.202 (6.559)

TESTING AND IMPLEMENTATION ISSUES

Length of Testing Period

The cost reduction potential of automation can be tempered in the long testing and start-up period. Terminal operators were asked how many months automated equipment was tested before entire operations began. Twenty-six of the 32 terminals surveyed answered this question (**Figure 16)**. There was a wide variation in the length of the testing period with no apparent pattern between semi and fully-automated terminals. Forty-two percent of the terminals had a testing period of 6 months or less. Testing periods ranged from two months (a case where the terminal had experience from automating a previous. terminal) to 37 months for a fully-automated terminal, with multiple suppliers and terminal integration done by the primary equipment supplier. One other terminal reported a testing period of 36 months; in this case, the terminal operator integrated the equipment supplied by multiple vendors.

Figure 15. Length of testing period for automation equipment



It is not surprising to find that 75% of the terminal operators integrated the automated equipment themselves, giving them greater control over the process and the length of the testing period (**Table 19**). Terminal operators would be anxious to begin realizing the benefits of automation and minimizing the testing phase.

The second most common option was using one supplier of automated equipment with the terminal operator doing the integration. This was the case for both semi- and fully-automated terminals. Less typical was integration by the leading supplier of the equipment. Again, there was no discernable pattern. When the lead equipment supplier did the integration, the testing ranged from six months to 37 months. Three terminals (two Irish and one in China) used one supplier for a turn-key operation. In all three turn-key operations, the length of the testing period was 24 months.

Another factor that could weigh on the benefits of automation is the complex interaction between different technologies. Automation requires full synchronization and integration of hardware and software in all aspects of terminal operations. Purchasing automation components and equipment from different suppliers can result in expensive and lengthy integration processes and cost overruns. Globally, the most common method of automating a terminal used multiple equipment suppliers with the integration done by the terminal operator.

Recognizing the complexity of developing an automated terminal, APM Terminals recently announced an arrangement with ZPMC focused on shifting the relationship between terminal operator and equipment supplier from a transactional one to a partnership that should facilitate the integration process.

There were no distinct regional patterns in how terminals were integrated. Integration of the automated equipment by the terminal operator was found around the globe. In the four cases where the lead equipment supplier undertook the integration, the terminals were in Belgium, China, and Hong Kong. There were six terminals that responded that their terminal automations were driven by the opportunity to be used *as a test-bed for technology* (score of 6 or 7). Five of these terminals are found in the Pacific Asia Region and one in the Middle East. In only two of these cases was the lead equipment supplier the integrator.

Table 19. Integration Options for Automated Equipment

Terminals that Used	Total * (n=31)	Semi-automated terminals (n=21)	Fully-automated terminals (n=11)
Multiple equipment suppliers with integration by Terminal Operator	19	14	5
Multiple equipment suppliers with the main supplier as integrator	4	2	2
One supplier as a turn-key operation	3	2	1
One supplier with integration by Terminal Operator	5	2	3

**One terminal indicated another arrangement, unspecified.*

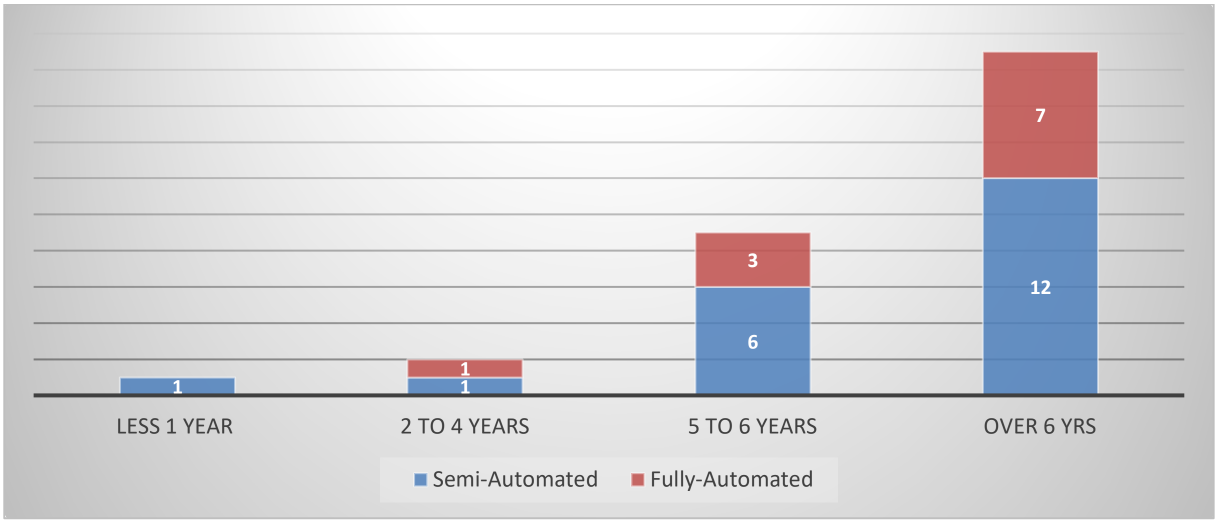
RETURN ON INVESTMENT

Automated terminals require a significant upfront investment for equipment procurement and the necessary terminal modifications. One survey question asked terminal operators how long before they realized a return on their investment. A total of 31 of the 32 terminals that responded to the survey completed this question (**Figure 16).** Sixty-one per cent of the terminals indicated that it would take over six years to realize a return on the investment. Twenty-nine percent of the terminals realized a return on investment between five and six years.

There was no discernable difference between the length of time a fully automated terminal took to realize a return on investment compared with a semi-automated terminal. One Pacific Asia terminal reported an unlikely low return on investment period of less than one year. That is an outlier for which we were unable to find an explanation.

There is also no correlation between the time needed for a return on investment and the length of the testing period of the automation equipment/system (Pearson Correlation: 0.239; Sig. (2-tailed): 0.250). Moreover, we did not identify any correlation between the time needed for the return of investment and whether the automation was implemented by one or more suppliers (Pearson Correlation: -0.031; Sig. (2-tailed): 0.870) or whether the automation was implemented by a terminal operator or a supplier (Pearson Correlation: -0.0323; Sig. (2-tailed): 0.108).

Figure 16. Years to Reach Return on Investment in Automated Equipment- Raw Data



REGIONAL PERSPECTIVES: DRIVERS, BENEFITS, STAKEHOLDER SUPPORT

Sufficient surveys were collected from three regions that allowed for the study of regional differences in drivers, benefits and attitudes toward automation. Those regions were the United States, the Pacific Asia Region, and Europe **(Table 20**).

Drivers of Automation by Region

In the U.S. and Europe, *increased safety* was ranked the driver of greatest importance in deciding to automate. In contrast, in the Pacific Asia Region, the ability to *reduce the unit cost of container handling* was the driver of most importance. European-based terminals also ranked *24/7 hours of operation, reduced variability in performance*, and *elimination of human factors*, of high importance. *Competitive forces* were of minor importance in deciding to automate in Europe, whereas in the United States, *competitive forces* were of little importance. *Financial incentives or public/governmental subsidies* played a more important role in driving automation in the Pacific Asia region than in the other two regions. Similarly, terminals in the Pacific Asia region were most likely to serve as a *test-bed for new technologies and research or showcase new equipment. Improving truck turn times* was of greater importance to U.S.-based terminals than the other two regions.

Table 20. Importance of drivers in deciding whether to automate container terminals: Regional Analysis

	Total (n=32)	United States (n=6)	Pacific Asia (n=12)	Europe (n=10)
Increase safety	**6.28**	**6,33**	**5,83**	**6,70**
Reduce unit cost of container handling	**5.94**	**6,00**	**6,25**	**5,57**
Reduce variability in performance	**5,63**	**5,00**	**5,67**	**6,20**

Reduce labor cost	**5,38**	4,67	**5,75**	**5,60**
24/7 hours of operation	**5.16**	3,17	4,83	**6,30**
Eliminate human factors (illness, risk of labor disruption, etc.)	**5.06**	4,33	4,33	**6,20**
Improve efficiency to handle larger vessels	4,97	4,33	4,33	**5,60**
Reduce air/ GHG emissions	4,94	**5,17**	4,83	**5,30**
Improve truck turn time	4,66	4,83	4,25	4,60
Meet KPIs required by ocean carrier	3,84	3,33	3,25	4,80
Limited land for expansion	3,63	2,83	3,42	4,90
Test-bed for new technologies / Showcase technological expertise of local terminal and/or research community	3,19	1,17	4,67	2,60
Competitive forces from other terminal operators who opted for automation	2,50	1,33	2,58	3,10
Financial incentives/subsidies by public entities or port authority	1,72	0,33	3,00	1,00
Others (please identify)	0,28	0,00	0,00	0,20

** Note: 0= of no importance; 1=minimum importance; 7=Maximum importance.*

Realized Benefits of Automation by Region

The greatest benefits realized from automation in all three regions was *safety* (**Table 21**). The Pacific Asia region realized the greatest benefits in *reduced labor cost*s from automation, followed by Europe and the United States. The difference in realizing benefits from *reduced labor costs* may be labor contract protections that guarantee wages for workers displaced by automation. None of the U.S. terminals realized greater benefits of *reduced labor costs* than expected, while two overestimated the reduction in labor costs they had anticipated. The largest variation in benefits received was for the *24/7 hours of operation*. Comparing the United States with Pacific Asia and Europe indicated that automation's ability to allow for *24/7 hours of operation* was less important in the United States than Pacific Asia and Europe. This is reasonable as not all aspects of a terminal operation in the United States may or can operate 24 hours a day.

Table 21. Benefits realized from the introduction of automation: Regional Analysis

	U.S. (n=6)	**Pacific Asia** (n=12)	Europe (n=10)	Δ (NA-PA)	Δ (NA-E)	Δ (PA-E)
Reduced labor cost	4,17	6,08	5,30	-1,92	-1,13	0,78
Reduced unit cost of container handling	5,67	6,17	4,80	-0,50	0,87	1,37
Reduced air/GHG emissions	5,50	4,83	6,10	0,67	-0,60	-1,27
Improved efficiency to handle larger vessels	4,33	4,25	5,20	0,08	-0,87	-0,95
Increased land productivity	4,67	4,25	4,90	0,42	-0,23	-0,65
Improved truck turn time	5,50	4,58	5,20	0,92	0,30	-0,62
Increased safety	6,00	6,08	6,60	-0,08	-0,60	-0,52
24/7 hours of operation	2,83	5,25	4,80	-2,42	-1,97	0,45

Reduced variability in performance (more consistency)	4,50	5,50	6,00	-1,00	-1,50	-0,50
Elimination of human factors (illness, risk of labor disruption, etc.)	5,00	5,25	6,00	-0,25	-1,00	-0,75
Better meeting KPIs required by ocean carrier	3,50	3,42	4,00	0,08	-0,50	-0,58
Boost for technological and operational innovation by terminal operator	2,00	5,67	4,20	-3,67	-2,20	1,47
Others	0,00	0,25	1,00	-0,25	-1,00	-0,75

** Note: 0= of no importance; 1=minimum importance; 7=Maximum importance.*

Regional Perspectives: Differences between decision-making drivers and benefits realized

Table 22 summarizes the differences between expectations and benefits realized by region. *Reduced labor costs* were either met or overestimated in Europe and the United States. Only in Pacific Asia did labor cost savings exceed anticipated benefits. In the United States*, increased safety*, *24/7 hours of operation*, and *reducing variability in performance* were also factors that were overestimated by terminal operators while deciding to automate. In the U.S., benefits exceeded expectations for the factors *limited land for expansion*, *test-bed for new technologies* and *elimination of human factors*, and improved truck time. In the Pacific Asia region, *limited land for expansion* and *test-bed for new technologies* exceeded expectations. Also, in Pacific Asia, *eliminating human factors* was a benefit that exceeded expectations. Overall, the results for European and U.S. terminals are similar when compared with Asia.

Table 22. Differences between benefits realized from automation and drivers to introduce automation: Regional Analysis

	U.S. Δ (Benefits-Expectations)*	Pacific Asia Δ (Benefits-Expectations)*	Europe Δ (Benefits-Expectations)*
Reduce labor cost	-0,50	0,33	-0,30
Reduce unit cost of container handling	-0,33	-0,08	-0,77
Reduce air/ GHG emissions	0,33	0,00	0,80
Improve efficiency to handle larger vessels	0,00	-0,08	-0,40
Limited land for expansion	1,84	0,83	0,00
Improve truck turn time	0,67	0,33	0,60
Increase safety	-0,33	0,25	-0,10
24/7 hours of operation	-0,34	0,42	-1,50
Reduce variability in performance	-0,50	-0,17	-0,20
Eliminate human factors (illness, risk of labor disruption, etc.)	0,67	0,92	-0,20
Meet KPIs required by ocean carrier	0,17	0,17	-0,80
test for new technologies / Showcase technological expertise of local terminal and/or research community	0,83	1,00	1,60

** Note: 0= of no importance; 1=minimum importance; 7=Maximum importance.*

** A positive difference indicates that the achieved benefits were greater than the benefits expected; a negative number indicates that the achieved benefits were less than expected.*

Comparison of U.S. and China Survey Results

Since there are survey responses for all automated terminals in China and the United States, a comparison of results was made. The rise of the Chinese container port system started to take off strongly in the late 1990s, first in the Pearl River Delta (Shenzhen, Guangzhou), but ten years later, also in the Yangtze River Delta (Shanghai, Ningbo, Taicang) and the Bohai Rim in Northeast China (Qingdao, Dalian, Tianjin, and many other ports). Given the steep rise of containerization in China, most container terminals were developed in the new millennium on greenfield sites. Despite the importance of the Pearl River Delta as one of the most important container handling regions in the world, all automated terminals in China are located in other port regions, i.e., in Xiamen, Qingdao, Tianjin, and Shanghai.

The U.S. port system was the first in the world to adopt containerization in the late 1950s and early 1960s. Initially, maritime container trade with the U.S. was mainly focused on the trans-Atlantic route, with the first large container ports emerging on the U.S. east coast. Container port development along the west coast saw strong growth in the early 1980s with the rise of Asian trade (Japan, and later also Taiwan, China, and South Korea). In the past decade, ports along the southeast coast (such as Savannah, Charleston, and Norfolk) also developed strongly, partly due to the opening of the new and larger Panama Canal locks in 2016. While the U.S. container port system is more mature than the Chinese port system, the U.S. handles far fewer containers, i.e., about 50 million TEU for the U.S. in 2020 against 265 million TEU in China (based on figures from AAPA and China Ministry of Transport). The comparison between both nations is interesting as there are also some significant differences in port management models and policies in both countries. For example, state-owned port groups manage Chinese ports and terminals, which in most cases control the ports in the entire province (e.g., Zhejiang Port Group, Liaoning Port Group, and Shandong Port Group). With a few exceptions, U.S. ports are landlord ports with a strong link to the local level (County, city).

Despite the differences in history, scale, and governance, the survey results on automation drivers are, with a few exceptions, remarkably similar on many fronts (**Table 23**). In China, terminal automation as a *test-bed or showcase for new technology* was significantly more important in driving automation of terminals compared to the United States. China is home to some leading equipment manufacturers (ZPMC - Shanghai Zhenhua Heavy Industries Co., Ltd. - the leading container terminal equipment manufacturer in the world; and SANY Port Machinery Co., Ltd.), which undoubtedly seek to introduce their latest equipment within their own country. This focus on new technology is further enhanced by the strong focus of the Chinese central and regional governments on terminal automation projects to promote the innovation capabilities of their maritime sector.

While the terminals in both countries sought to *reduce labor costs*, *reduce the unit cost of container handling, reducing air and GHG emissions*, and *increase safety*, *competitive forces from other terminal operators*, *24/7 hours of operation* and *maximizing the use of land* were all more important drivers in China than in the United States. *Financial incentives or funding by public entities or the port authority* played little role in driving automation of terminals in the United States but a moderate role in China.

Table 23. Comparison of the importance of drivers to automate between terminals in U.S. and China

	U.S. (n=6)	China (n=6)	Δ (U.S.-China)
Reduced labor cost	4.66	5.66	-1.00
Reduced unit cost of container handling	6.00	5.83	0.17
Reduced air/GHG emissions	5.16	5.00	0.16
Improved efficiency to handle larger vessels	4.33	5.50	-1.17
Increased land productivity	2.83	4.33	-1.50
Improved truck turn time	4.83	4.50	0.33
Increased safety	6.33	6.16	0.17
24/7 hours of operation	3.16	4.50	-1.34
Reduced variability in performance (more consistency)	5.00	6.50	-1.50
Elimination of human factors (illness, risk of labor disruption, etc.)	3.33	4.33	-1.00
Better meeting KPIs required by ocean carrier	3.33	4.50	-1.17
Competitive forces from other terminal operators	1.33	3.16	-1.83
Boost for technological and operational innovation by terminal operator	1.16	6.00	-4.84
Financial Incentives	0.33	3.50	-3.17

** Note: 0= of no importance; 1=minimum importance; 7=Maximum importance.*

China's terminal operators realized more benefits in *reducing labor costs* than U.S. terminals (**Table 24)**. This is likely attributable to the strength of U.S. dockworker unions compared to China where labor unions are either absent or don't have the power of a coastwise agreement as in found in the U.S. Generally, labor will negotiate for worker protection in exchange for the withdrawal of their opposition to the automation of a conventional terminal. The authors are unaware of any case in China where dockworkers have gained concessions or job protections from terminal operators due to automation.

Table 24. Comparison of the realized benefits of automation between terminals in the U.S. and China

	U.S. (n=6)	**China (n=6)**	**Δ (U.S.-China)**
Reduce labor cost	4.16	6.33	-2.17
Reduce unit cost of container handling	5.66	6.33	-0.67
Reduce air/ GHG emissions	5.50	6.00	-0.50
Improve efficiency to handle larger vessels	4.33	5.83	-1.50
Limited land for expansion	4.66	5.00	-0.34
Improve truck turn time	5.50	4.66	0.84
Increase safety	6.00	6.66	-0.66
24/7 hours of operation	2.66	4.83	-2.17
Reduce variability in performance	4.50	6.33	-1.83
Eliminate human factors (illness, risk of labor disruption, etc.)	5.00	5.00	0
Meet KPIs required by ocean carrier	3.50	4.83	-1.33
Test-bed for new technologies / Showcase technological expertise of local terminal and/or research community	1.66	6.50	-4.84

** Note: Scale: 0= of no importance; 1=minimum importance; 7=Maximum importance.*

China's terminals averaged greater benefits *in handling larger ships, reducing variability in performance*, and *meeting KPIs required by ocean carriers*. Again, of all factors surveyed, terminal automation as a *test-bed for new technologies* was not only a strong driver in China but also a strong benefit.

There are differences in how terminal operators viewed support from stakeholder groups between China and the U.S. In the United States, west coast terminal operators and one east coast terminal operator reported that opposition was high from dockworkers. The two other east coast terminals reported that opposition from dockworkers was minor or neutral. However, in China, no terminal operator reported having moderate or high opposition from dockworkers, and only one terminal reported minor opposition. Except for one Chinese terminal that reported minor opposition from dockworkers, the terminal operators reported that all stakeholder groups supported automation at some level or were neutral. Two Chinese terminals reported high support from all stakeholder groups. The results reflect cultural differences between the two countries and the absence of strong labor unions in China.

FOCUS ON AUTOMATED TERMINALS IN THE U.S.

Overview of automated terminals in the U.S.

There are six automated terminals in the United States, three semi-automated terminals on the east coast, and three fully-automated terminals on the west coast. One additional terminal In the Port of Long Beach has announced its intention to automate while other terminals in Los Angeles/Long Beach have studied the possibility of automating. The first terminal in the U.S. to use yard automation was a private terminal developed by APM Terminals (APMT). AMPT acquired property in Portsmouth, Virginia, and decided to develop a semi-automated terminal in 2004. The $540 million terminal was developed without public investment and opened in 2007. A combination of the economic recession and competition from the publicly owned terminals of the Virginia Port Authority (VPA) resulted in the terminal operating well below capacity. In 2010, AMPT leased the property to the VPA for operation, and it is now known as the Virginia International Gateway. VPA has a wholly-owned subsidiary that operates the terminal. In 2015 VPA decided to invest in automated stacking cranes at the Norfolk International Terminal. Those cranes began to arrive in 2016 with the last batch arriving in 2020.

The third semi-automated terminal on the U.S. East Coast is the Global Container Terminals in the Port of New York/New Jersey. The terminal redevelopment project, which included a 50% increase in terminal size and automation, opened in 2014.

The first automated terminal on the west coast was the TraPac Terminal at the Port of Los Angeles. A terminal expansion project was under development in 2010 when the decision was made to switch to automated yard equipment. The automated yard was developed on land adjacent to the terminal that was incorporated into the terminal leasehold. While the existing terminal retains its traditional operation, the expansion area was fully automated using a combination of AutoStrads to carry containers between the apron and yard and Automated Stacking Cranes for yard management. The automated portion of the terminal opened in 2016.

Long Beach Container Terminal (LBCT), also known as Middle Harbor, in the Port of Long Beach is a fully-automated terminal created by combining two existing conventional terminals and the reclamation of additional land for additional size and optimization of the configuration. The cost was

$1.3 billion. The terminal uses automated guided vehicles and automated stacking cranes. The terminal opened in 2016, with the project's final phase completed in late 2021, bringing the capacity to 3.5 million TEU.

AutoStrads appear to be an emerging automation strategy for terminals on the West Coast. In addition to TraPac, APM Terminal at Pier 400 in Los Angeles automated a portion of their terminal using AutoStrads. AMP Terminal began the process to automate a 100-acre portion of its 484-acre terminal in 2019. This 100-acre site, formerly leased to Hyundai and operated as a "terminal within a terminal," became available after Hyundai relocated. The rest of the terminal currently retains its conventional operation.

Differences in Drivers- U.S. East vs U.S. West Coast

Different factors drove the automation of terminals on the U.S. west and east coast. Language in the current International Longshoreman's Association (ILA) agreement covers the U.S. east and gulf coast ports and International Longshore and Warehouse Union (ILWU) agreement covers the U.S. west coast ports. The ILA and ILWU agreements provide the provisions necessary for the further automation of conventional terminals in the United States. As currently written, the east and gulf coast ILA agreement will only allow the introduction of semi-automated terminals meeting specific criteria, while the West Coast ILWU agreement will allow for the implementation of full automation. Subsequent labor agreements may have different provisions.

On the U.S. East and Gulf Coast, the Master Contract between the U.S. Maritime Alliance and the International Longshoremen's Association, effective October 1, 2018 through September 30, 2024, has the following two provisions[42]:

> *(b) There shall be no fully-automated terminals developed and no fully-automated equipment used during the term of this Master Contract. The term fully-automated is defined as machinery/equipment devoid of human interaction.*
>
> *(c) There shall be no implementation of semi-automated equipment or technology/automation until both parties agree to workforce protections and staffing levels.*

Technology has been part of the U.S. West Coast ILWU agreement since 2002. The 2008 agreement provides for the use of automated cargo-handling equipment along with additional job training for workers displaced by automation and expanded the ILWU jurisdiction to include maintenance and repair of the automated equipment. The current ILWU agreement, originally approved in 2014, and extended in 2019 until July 1, 2022, includes the following language:[43]

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[42] Section L., New Technology Implementation and Workforce Protection, U.S.MX-ILA Master Contract memorandum of Settlement Between Unites States Maritime Alliance, Ltd. (for and on behalf of Management) and International Longshoremen's Association, AFL-CIO (for and on behalf of itself and each of its affiliated districts and locals representing Longshoremen, Clerks, Checkers and Maintenace Employees Working on Ships and Terminals in Ports on the East and GUlf Coasts of the United States. Available online at https://ilaunion.org/wp-content/uploads/Master-Contract-2018.pdf : accessed August 25, 2021.

[43] Section 1.72, Scope of This Contract Document and Assignment of Work to Longshoremen, Pacific Coast Longshore Contract Document, July 1, 2019 0 July 1, 2020 between International Longshore and Warehouse Union and Pacific Maritime Association. Available online at https://apps.pmanet.org/pubs/LaborAgreements/2019-2022_PCLCD.pdf.

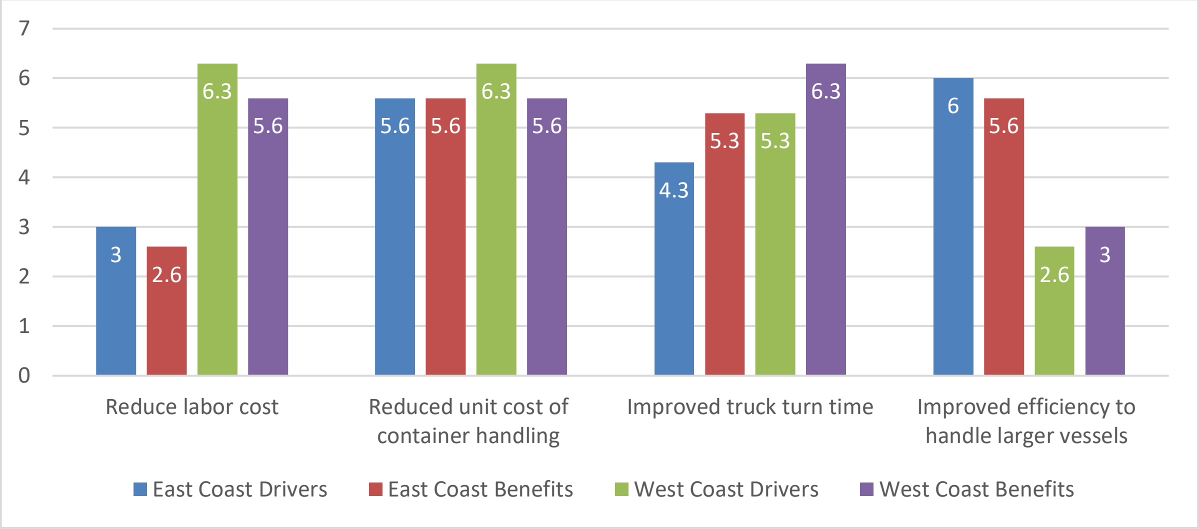
> *The parties recognize robotics and other technologies will replace a certain number of equipment operators and other traditional longshore classifications.*
>
> *It is agreed that the jurisdiction of the ILWU shall apply to the maintenance and repair of all present and forthcoming stevedore cargo handling equipment...*

Despite the contract language, a significant controversy erupted over automating a portion of the AMP Terminal in Los Angeles in 2019. The two existing automated terminals, TraPac in Los Angeles and Middle Harbor in Long Beach did not engender the same opposition and political interest that occurred at APM Terminals. The TraPac terminal automation project was proposed when the U.S. West Coast ports were looking at strategies to prepare for the opening of the expanded Panama Canal. Having the first automated terminal on the U.S. West Coast at TraPac became part of the Port of Los Angeles' "Beat the Canal" strategy. Also, the terminal was retaining conventional container handling on its existing terminal footprint and automating a new land area previously not used for container operations, unlike the APM Terminal project, which converted property used for conventional operations to automated operations. The Middle Harbor automated terminal in the Port of Long Beach included the creation of new terminal lands used for automated operations and the conversion of existing terminal areas to automated container terminal operations. Like TraPac, the entitlement process for Middle Harbor benefitted from occurring at the time of the perceived threat of the expanded Panama Canal. Although the impact on labor was greater at Middle Harbor than at TraPac, the Middle Harbor terminal operator, Long Beach Container Terminal, worked closely with longshore labor during the development process.

Survey results from the six U.S. terminals indicate that the *ability to handle larger containerships* was the primary driver for automation of east coast terminals. The opening of the new Panama Canal locks in 2016 gradually resulted in the upscaling of the largest vessels visiting east coast ports from 8,000 TEU to 14,000 TEU. These latter vessels were used as the work horses of the Europe-Far East trade between 2005 and 2015, before they were eventually replaced by larger units of 18,000 to 24,000 TEU. However, with respect to the *ability to handle larger containerships*, the implementation of automation produced slightly less than the desired results (**Figure 17**). Also, driving the decision-making at U.S east coast ports was *reducing the unit cost of container handling*, and the benefits achieved at the terminals were as expected. *Handling larger containerships* was a significantly less important factor on the west coast which had been handling the largest containerships for some time. Instead, *reducing labor costs* was the primary driver. Again, the anticipated savings in labor costs realized were slightly less than anticipated. *Improving truck turn time* was a driver on both U.S. coasts and benefits realized were greater than anticipated.

The fact that west coast terminals tend to be operated by the terminal operating branches of ocean carriers implies that the containers handled come from shipping lines part of the same alliance. This could imply simpler yard sorting operations as large blocks of containers can belong to the same cargo owner. Therefore, full automation may be less complex to implement. East coast terminals tend to be called by numerous ocean carriers, implying more complex yard sorting operations. The use of AGV or AutoStrads is less suitable, implying that semi-automated terminals are the preferred design. Environmental regulations, which are more stringent on the west coast, are also a key driver for the automation of horizontal movements. Converting to AGV allows for potentially reaping the benefits of automation while lowering emissions.

Figure 17. Drivers for Automation and Benefits Realized in U.S. ports: East Coast vs. West Coast



** Note: Scale: 0= of no importance; 1=minimum importance; 7=Maximum importance. One U.S. survey was completed by a former terminal president who oversaw implementation of terminal automation.*

Figure 18 is from a report titled "The Anatomy of the Container Terminal Logistics Supply Chain Congestion Issues at the San Pedro Bay Ports during the Covid-19 Pandemic- an Update" prepared by Martin Associates and attached to a letter to U.S. Secretary of Transportation from the Pacific Maritime Association, dated October 15, 2021.[44] This figure is labeled "TEUS per ILWU hour" and illustrates a distinct difference between automated and conventional terminals during the period January 2019 through August 2021. Martin Associates noted that the productivity of the automated terminals was nearly two times the productivity of the traditional terminals and that as terminal congestion increased, the productivity of traditional terminals declined slightly. Note, however, that the data in this figure is a comparison between the average monthly ILWU payroll at the two automated terminals, TraPac and Middle Harbor Terminal (LBCT), compared with the monthly ILWU payroll averaged across all conventional terminals in Los Angeles and Long Beach ports. Total ILWU payrolls costs for the entire terminal could include workers not necessarily involved in container handling but other jobs under the jurisdiction of the ILWU, like chassis maintenance. As such, this graphic represents a comparison of average terminal operating costs rather than a real measure of automated versus traditional terminal productivity. It represents one side of the tradeoff that terminal operators make when they decide to make the capital investment to automate terminals, trading off high capital investment costs for lower operating costs. Comparable terminal productivity for automated and conventional terminals, expressed in container moves per ship per hour, has not been readily available to the public.

This study was conducted during the global pandemic. Terminals completed surveys during periods of intense terminal congestion and supply chain bottlenecks. As part of an effort to provide more data to supply chain partners, both the Ports of Los Angeles and Long Beach made data available on a daily or weekly basis that traditionally was not readily available to the general public or was behind paywalls. Some of this data was useful in comparing conventional and automated terminals operations, specifically truck turn times.

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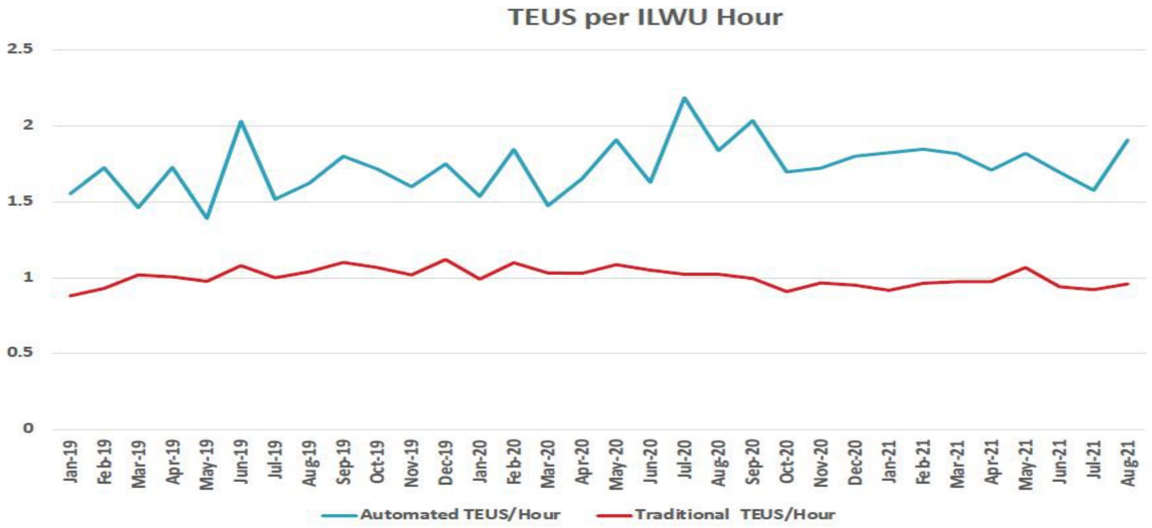
[44] Pacific Maritime Association letter to Honorable Pete Buttigieg, Secretary of U. S. Department of Transportation, U.S. Department of Transportation Request for Information: America's Supply Chains and the Transportation Industrial Base, Docket Number DOT-OST-2021-0106, posted at Regulations.gov.

Figure 18. Cargoes handled per ILWU Hour



Source: Pacific Maritime Association as prepared by Martin Associations, Oct. 13, 2021.

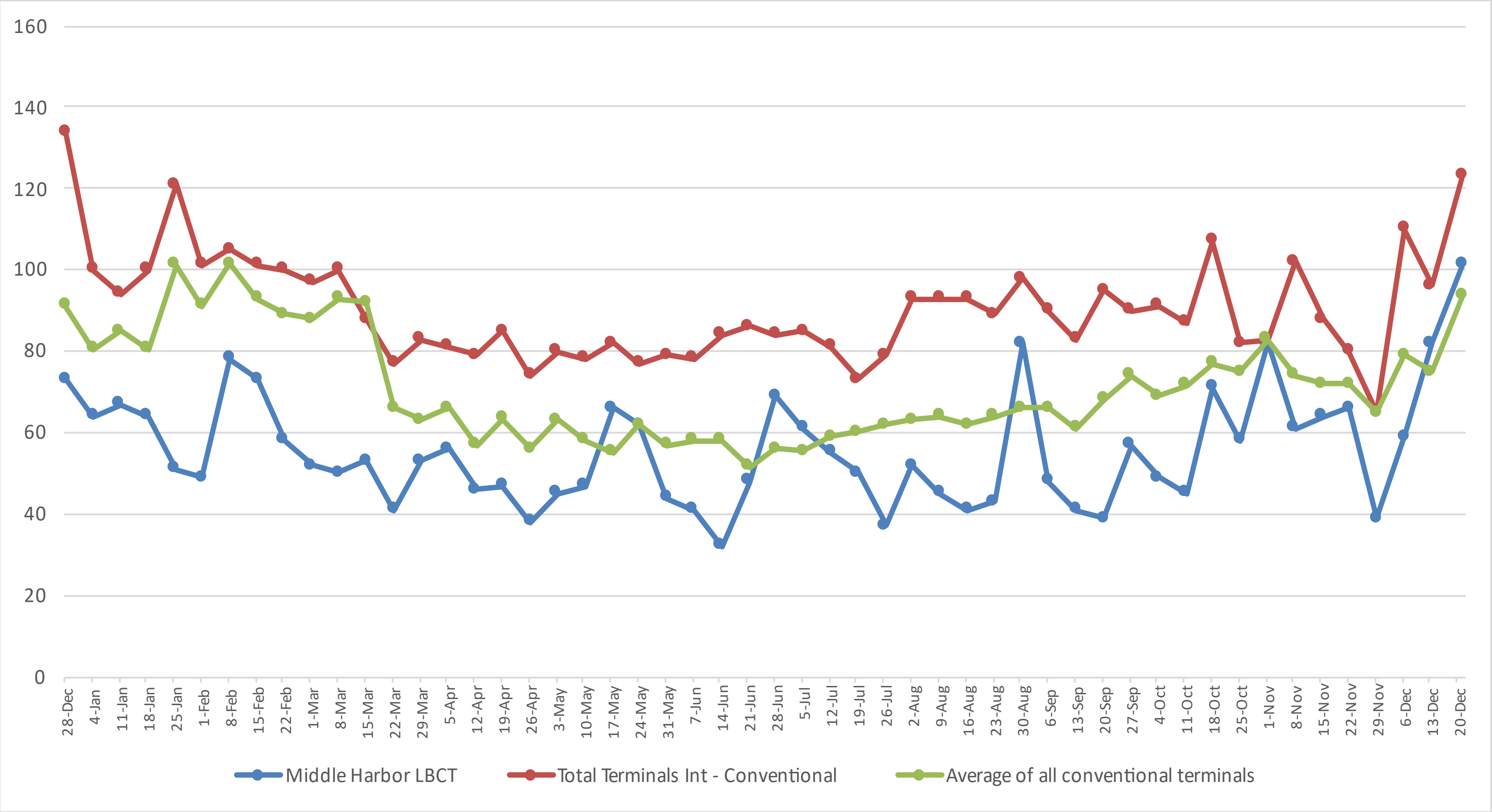
The weekly average truck-turn times for all Port of Long Beach terminals was tracked for an entire year. A comparison between the day shift average gate turn-times in minutes was made between the fully-automated Long Beach Container Terminal (345 acres) against the largest similarly-sized conventional terminal (Total Terminals International at 385 acres) and with the average turn-time at all the other international terminals. **Figure 19** shows that truck-turn time is always lower at the automated terminal and consistently below the average turn time of all four conventional international terminals in the Port of Long Beach.

The Future of Terminal Automation in the U.S.

Container terminal automation in the U.S. port system has mainly occurred in large-scale import terminals. Although the ownership of some of these terminals has evolved, generally, the decision to automate occurred during carrier ownership of terminal operators. The decisions to automate have been supported, at least initially in the case of TraPac in Los Angeles and Middle Harbor (LBCT) in Long Beach, by the financial support of public entities. The Port of Los Angeles invested over $ 0.5 billion in TraPac, while Long Beach's investment in Middle Harbor was over $1 billion. The TraPac project also received $60 million in government grants in addition to port funding for the terminal project. Both projects were completed at higher costs than originally envisioned by the ports. The most recent automation project in Los Angeles, the APM Terminal at Pier 400 in Los Angeles, was not subsidized by an investment in public dollars.

Like the terminal operators, the ports also have return on investment policies that would typically guide any future investments in terminal automation infrastructure. However, as public entities with decision-making Boards appointed by local authorities or elected by the public, ports will continue to walk a fine line between supporting the desires of their terminal operators and responding to the ongoing political debate over automation.

Figure 19. Comparison of automated and conventional average weekly terminal gate turn times at the Port of Long Beach, U.S. (December 21, 2020 – December 13, 2021)



Notes: Middle Harbor LBCT is a fully automated terminal (345 acres), Total Terminal is the largest conventional terminal (385 acres). Average of all conventional terminals refers to the average of all the four international conventional terminals; Source: Compiled from Port of Long Beach Weekly Wave Report from beginning 21 December 2020 to 13 December 2021.

The controversy over the automation at Pier 400 in Los Angeles resulted in governmental efforts to shape the debate through the legislative process in California and the U.S. In 2019, California Senator Mike Gibson proposed Assembly Bill 1321, which would have transferred control of automation projects from local port authority boards to the California State Lands Commission (SLC). The SLC is a board of three California officials: the Lieutenant Governor, the State Controller and the Governor's Director of Finance. The bill was amended to a study bill, which would require the SLC to hold a series of meetings to consider the impacts of automation and submit reports to the legislature. This bill was not passed. Congresswoman Nanette Diaz Barragán whose congressional district overlaps the port area, along with 25 Congressional co-sponsors, introduced the Climate Smart Ports Act in the House of Representatives which would create a billion dollar a year "zero emission" ports infrastructure program that would assist ports in eliminating the use of diesel fuel. Language was included to protect dockworkers from automation. The bill was first introduced in 2019 and re-introduced in January 2021. A companion bill was introduced in the U.S. Senate. In September 2020, Governor Newson signed into law Assembly Bill 639 addressing climate change and port automation. Specifically, the bill creates a stakeholder process to develop findings and recommendations on how to mitigate the impacts of port automation at the San Pedro Bay ports. An eight-member industry panel consisting of representatives of labor, marine terminal operators, the Los Angeles and Long Beach port directors and one member with experience in workforce development appointed by the Speaker of the Assembly and the Senate Committee on Rules, will oversee the process.

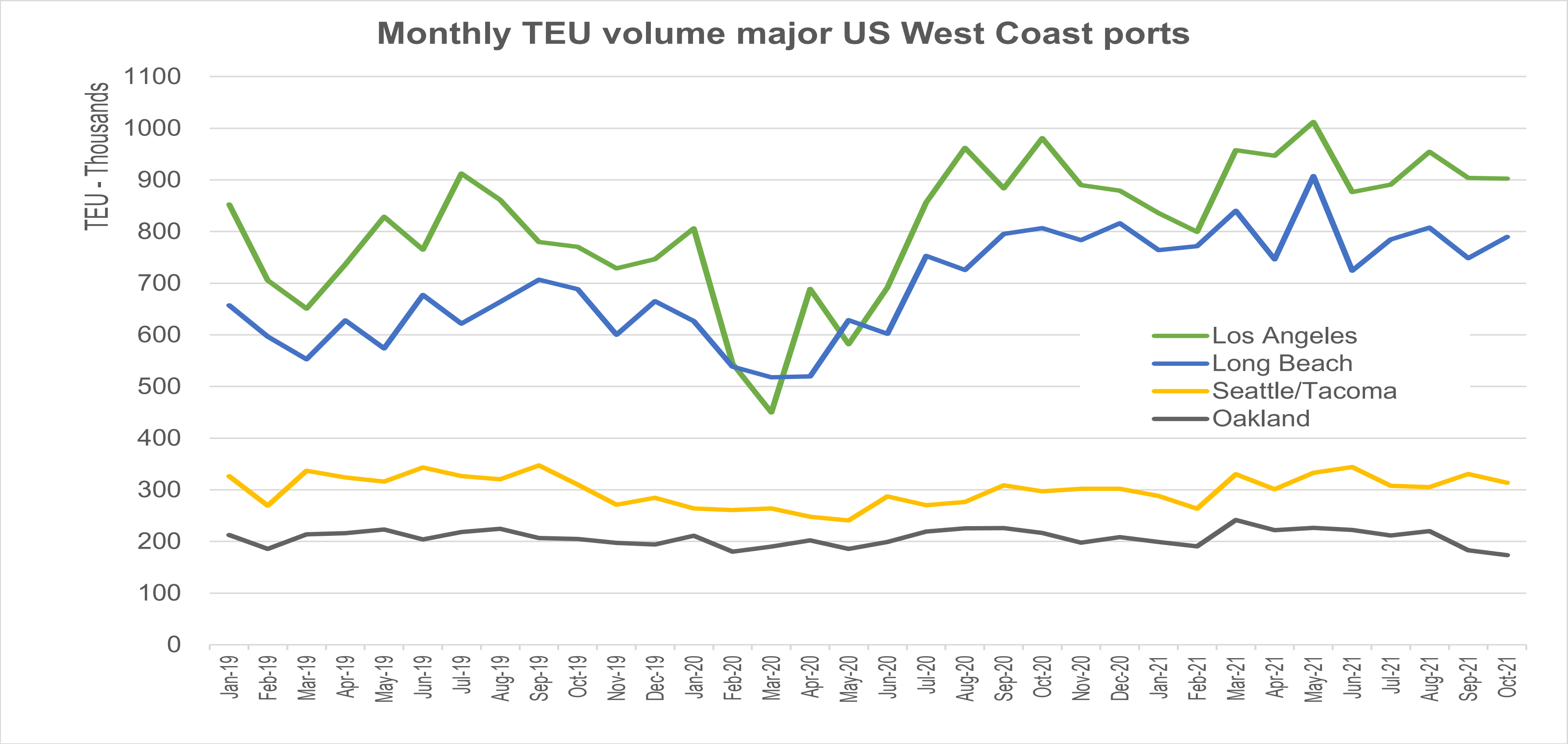
In addition to an increase in legislative activity related to automation in response to the Pier 400 project, other organizations announced their intention to study port automation. In 2021, the California Air Resource Board contracted with the Center for International Trade and Transportation to undertake a study of automation titled "Workforce and Economic Impact Evaluation of Future Zero-Emission Requirements for Cargo Handling Equipment." One of the goals of this study is similar to this work, examining the reason driving the decision to automate port terminals and the corresponding impacts of those decisions.

While it appeared that substantial subsidies by the port authorities in automated terminals may not be likely going forward, the recent supply chain crisis has brought increasing attention to the infrastructure needs at U.S. ports, especially Los Angeles and Long Beach. Both ports have recorded a massive increase in handled container volumes since the summer of 2020, after a steep dip in container traffic in the first half of 2020 (**Figure 20**).

The peak in demand, combined with COVID-related temporary terminal closures in China (e.g., in Tianjin, Ningbo, and Yantian), has resulted in disruptions in the global supply chain, particularly in the transpacific trade. This supply chain disruption has manifested itself in multiple ways, including ships waiting at anchorage for extended periods, a dramatic rise in the average container dwell time at the terminals, and increased street time for chassis.

Given the supply chain pressures on U.S. ports, it is likely that infrastructure funds, in the form of grants or low interest loans, might be available to U.S. ports, including the ports of Los Angeles and Long Beach, or directly to its terminal operators. However, recent federal appropriations bills have included language that Port Infrastructure Development Program grants from the federal government could not be used for automated technologies that would result in net job loss.

Figure 20… Monthly TEU volumes handled at the main ports along the U.S. West Coast, (January 2019 -October 2021)



Source: based on data from respective port authorities

In December 2021, the U.S. House of Representatives approved the National Defense Reauthorization Act, which would reauthorize the Port Infrastructure Development Program with the same exclusion for automation. Whether this language would apply to port grants through the Infrastructure and Jobs Act, signed by President Joe Biden in November 2021, is still not clear. However, if grants are provided to U.S. ports only for more traditional infrastructure that could free up other port funds to make investments in terminal automation as has been done in the past. Generally, port investments are in the infrastructure necessary to support automation, not the automated equipment itself.

With Los Angeles and Long Beach port terminals facing a 2030 deadline for terminals to be zero-emission in the latest version of the San Pedro Bay Ports Clean Air Action Plan, some additional terminals are already considering automation options. At a minimum, the conversion of two existing large conventional terminals to automation in Los Angeles/Long Beach is under consideration. The Total Terminals International Terminal in the Port of Long Beach has already announced its intention to automate. This terminal struggled with excessive truck-turn times during 2021 compared to all other terminals in the Port of Long Beach (see **Figure 19**). Other terminals are clearly not pursuing automation.

In this context, automation is an evolutionary process. It is a way for large terminals to catch up with the increase in vessel sizes and call sizes at U.S. ports. It satisfies spatial and environmental constraints faced by ports, which are compressing terminal operations and placing pressures on the terminal footprint. The pandemic will likely influence future decision-making. Terminals that did not rate the importance of "elimination of human factors" as a primary driver in deciding to automate clearly recognized the benefits that automation brought to their terminals during the pandemic, and that was apparent in the survey results. How many additional terminals automate in the U.S. is likely to be a complex trade-off between the availability of capital, supply chain pressures, the chosen strategy to become zero-emission, the political climate, the attitude of the stakeholders' groups and whether future management-labor contracts are modified to address continued concerns regarding automation.

Compared to other regions in the world, terminal developments in the U.S. rely more on retrofitting of existing facilities instead of new large-scale greenfield projects. In combination with the absence of a transshipment market and the realities of the U.S. dock labor systems, this observation makes the large-scale adoption of automated terminals less likely in the U.S. compared with other regions of the world, particularly developing countries.

There are currently no automated terminals on the U.S. Gulf Coast. The Port of New Orleans, as of this writing, is currently soliciting a partner to develop and operate a proposed "greenfield" container terminal development, known as the Louisiana International Terminal[45]. The port is considering this $1.5 billion, two million TEU terminal will be semi-automated.

The further massification of import/export cargo flows is likely to extend the automation evolution to landside operations through the automation of intermodal transport systems and a further synchronization and integration with transport chains. For this to happen, automation will benefit from further standardization, an ongoing process since containerization began. Automation will further incite distribution systems to "wrap around" the technology.

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[45] See: https://portnola.com/info/louisiana-international-terminal/p3-opportunity

FINDINGS AND CONCLUSIONS

Terminal automation is a full or partial substitution of manned terminal operations through automated equipment and processes. This study focuses on the automation of terminal equipment used to handle containers. A distinction is made between *semi-automated terminals,* which have manned vehicles to move the containers from the berth to the yard with automated stacking equipment in the yard, and *fully-automated terminals,* where both the horizontal movement of containers from the berth to the yard and the vertical movement of containers in the yard, is automated (unmanned). Container terminal automation has gained popularity in the past two decades. Yet, only certain terminals will fit the profile where unmanned automated equipment brings added value.

Temporal, institutional and spatial factors play a role in the decision to automate, as well as more operational and economic drivers. This study provides an in-depth analysis of the drivers of automation, the realized benefits, stakeholders' attitudes towards automation, and specific implementation and investment considerations.

The first layer of analysis focuses on **where, when, under which conditions, and to what extent container terminals have been automated and who is responsible for implementing these terminal automations**. A dataset was compiled covering all 63 automated container terminals in operation, their organizational features, technical dimensions, and the maritime and urban markets they serve. These 63 operating automated terminals are found in 23 countries, in all continents except Africa (and Antarctica). The greatest number of terminals are located in Pacific Asia and Europe. Eighteen of the 63 terminals are fully automated, the rest semi-automated. Although the first automated terminal opened in 1993, the real acceleration has happened in the last decade with 41 terminals automated since 2013. Twelve of those 40 are in the Pacific Asia region.

Stevedoring companies operate 39 automated terminals, carriers operate 14 terminals while financial holding companies operate 6 terminals, and multiple types of partners operate 4 as a joint venture or a consortium. Most automated terminals handle between 2 and 3 million TEU. While many trade publications suggest that automation needs a minimum of 1 million TEU to operate effectively, the survey results found twelve automated terminals handling less than 1 million TEU, of which two are fully-automated. The average size of fully automated terminals is 98.6 hectares, while the average size of semi-automated terminals is 84.1 hectares. The range of terminal sizes varies significantly for both fully and semi-automated terminals, with 24 being less than 50 hectares. The average berth length based on 59 of the 62 terminals is 1,504 meters without a significant difference between full and semi-automated terminals. Again, variability is high, with two terminals having over 5,000 meters of berth. All but one terminal have drafts over 14 meters, with the maximum draft of automated terminals at 16 meters. There is no strong relationship between transshipment incidence and automation, but expectations based on cargo mix would dictate higher levels of automation in gateway ports and less in transshipment hubs. Only one fully-automated terminal is in a transshipment hub, while semi-automated terminals can be found in pure transshipment ports, ports with a mixed cargo mix, and gateway ports.

The second part of the analysis relies on a unique survey-based approach targeting senior representatives of terminal operating entities in charge of the fully and semi-automated container terminals. Thirty-two terminals participated in the survey, representing 51.6% of all automated container terminals worldwide. The survey served five purposes.

First, it identifies the **multi-faceted array of factors that drive the decision to automate a container terminal** and analyses the variation of the relative importance of these factors by several parameters, such as terminal operator and locality. The potentially relevant drivers were shortlisted based on the extensive literature review: *Improve efficiency to handle larger vessels; Reduce variability in performance; 24/7 hours of operation; meet KPI's required by ocean carrier; improve truck turn time; reduce unit cost of container handling; reduce labor cost; eliminate human factors; limited land for expansion; reduce air/greenhouse gas emissions; increase safety; test-bed for new technologies/showcase technological expertise of local terminal and/or research*. These drivers serve to motivate terminal operators to make the necessary capital investment. The research team identified two additional drivers: *a terminal's competitive position in the marketplace and financial subsidies by public entities of port authorities*. These factors became the backbone of the terminal operator survey.

The results show that the most important driver motivating terminal operators to automate was *increased safety*. Three other primary factors driving the automation decision were *reducing the unit cost of container handling, reducing variability in performance,* and *reducing labor cost*. Second, the survey tool was used to re-examine the initial decision-making factors by asking the respondents to score **potential realized benefits**. In other words, the survey established how accurate terminal operators predicted the benefits of automation once the terminal automation was in operation. The findings show that most of the benefits assumed by an individual terminal operator materialized once the automated terminal was in operation. Nearly the same factors were recognized as benefits by the terminal operators once automation was implemented. Globally, the terminal operators identified the most important benefit of automation as *increased safety* along with *reduced unit cost of container handling*, r*educed variability in performance* and *reduced labor cost. Elimination of human factors* was a benefit realized by terminals operators who did not consider this an important driver. This could be because the survey was filled out during the pandemic and terminal operators may have realized that the automated operation provided some protection against the virus spreading among their workers. Correlation was high among factors that related to cost and performance. For example, among drivers, *reduced labor cost* is correlated with *reduced unit cost of container handling*. Similarly, the strongest correlation among benefits was *improved efficiency to handle larger vessels* and *reduced variability in performance*. *Reduced variability in performance* was also highly correlated with *increased safety*, while *increased safety* was also highly correlated with *elimination of human factors*.

For fully automated terminals, drivers of importance were *increased safety*, *reduced unit cost of container handling*, *reduced labor costs, reduced variability in performance* and *reduced air emissions*. For semi-automated terminals, *reducing labor costs* and *air emissions* were ranked of less importance compared to fully-automated terminals while *24/7 hours of operation* and *elimination of human factors* were ranked more important for semi-automated terminals. This latter point would not be expected since semi-automated terminals would have more dockworkers but could be a result of terminal operators completing the survey during the pandemic.

An analysis of the **gaps between decision-making drivers and benefits realized** revealed that *reduced labor cos*ts, *reduced air emissions*, *improved truck-turn times*, *elimination of human factors* along with terminals having *limited land for expansio*n and the opportunity to *serve as a test-bed for new t*echnologies were all factors where benefits exceeded expectations. In the case of *reduced labor costs*, the differences between expectations and benefits realized is marginal, slightly negative for U.S. and Europe and slightly positive for Pacific Asia.

Reduced cost of unit handling, *ability to handle larger ships*, the ability to *operate 24/7*, and the need to *meet KPIs required by ocean carriers* were all factors where the expectations were not met. Thirty-eight percent of the terminals slightly overestimated the benefits of automation for reducing the unit cost of container handling (1/3rd fully automated, 2/3rds semi-automated). Thus, yard automation may not solve all a terminal's efficiency problems nor provide the cost savings expected, especially if the systems are not fully integrated.

Third, the survey contained a question assessing the **terminal operators' view on stakeholders' attitudes towards automation**. Several stakeholder groups are considered, including governments, port managing entities, dockworkers, carriers, logistics service providers, and communities. The analysis of the terminal operators' perceptions of the reactions of stakeholders to automation shows that terminal operators view port authorities, carriers, and the government as their primary supporters for automated operations, although this was not always the case. Terminal operators viewed dockworkers as having the greatest opposition to the introduction of automation. This was primarily the case in Europe and the U.S. where dockworker unions are well organized and have a clear "voice" in the debate over automation. Community members are predominately neutral to automation. Shippers and logistic service providers are predominately supportive or neutral.

Fourth, the survey sheds light on specific **testing and implementation issues** (such as length of the testing period and the governance of system integration) **and financial/managerial issues** (such as the return on investment (ROI) period) connected to terminal automation. Forty-two percent of terminals had a testing period of 6 months or less. The most common method of automating a terminal was using multiple equipment suppliers, with 75% of the terminal operators integrating the automated equipment themselves. All but one terminal responded to the question on the length of time to reach a return on investment (ROI). Nine terminals indicated that they realized a ROI between 5 to 6 years while most (19) indicated that ROI will take over 6 years. There was no discernable difference between length of time that a fully automated terminal took to realize a return on investment compared with a semi-automated terminal.

Throughout this report, statistical analyses were used to test for significant differences per criterion (i.e., drivers of automation, benefits of automation, level of support/opposition per stakeholder) between the perspectives expressed by groups of respondents (i.e., regional perspectives, the perspectives of fully-automated versus semi-automated terminals, terminal operator type, etc.). Correlation analysis of the received replies was also performed to determine whether and how statistical variables are linearly related.

The study also provides a regional comparison of the findings covering three regions (i.e., U.S., Europe, and Pacific Asia), aiming to understand better the sensitivity that might be produced due to local perspectives and culture. Further detailing of the regional components compared the U.S. results with those of China and comparing the U.S west coast and east coast terminals.

For all regions, the greatest benefits realized from automation was *increase*d *safety*. The Pacific Asia region realized the greatest benefit in *reduced labor costs*, followed by Europe and the U.S. The difference may be due to the wage guarantees for workers displaced by automation. None of the U.S. terminals realized the level of benefits for *reduced labor costs* that they anticipated, and two overestimated the reduction in labor costs.

Despite differences in history, scale and governance, the survey results on automation drivers from China and the U.S. are remarkably similar at many fronts, with a few exceptions. In China, terminal automation as a *test-bed or showcase for new technologies* was a significantly more important driver than in the U.S., likely due to the presence of leading equipment manufacturers in China. In China, no terminal reported any moderate or high opposition from dockworkers to automation, and only one Chinese terminal reported minor opposition from dockworkers. Chinese terminal operators reported that all stakeholder groups supported automation at some level or were neutral. This is vastly different from the terminal operator viewpoint of stakeholders' positions in the U.S.

Survey results for the three fully-automated terminals on the U.S. west coast and the three semi-automated terminals on the U.S. east coast reveal different drivers to automate by coastline. Under current U.S. contractual agreements between management and labor, only semi-automated terminals can be implemented on the east coast, while fully-automated terminals can be implemented on the west coast. The *ability to handle larger ships* was the primary driver for automating terminals on the east coast. On the west coast, *reduced labor cost* and *reduced unit cost of container handling* were the primary drivers. Although all U.S. terminals realized some benefits of reduced labor costs after automating, none of the U.S. terminals realized the reduction in labor costs they had anticipated. East coast terminals realized a reduction in *unit cost of container handling* they were expecting, while the west coast realized less benefits than anticipated. Both east and west coast terminals realized a *greater reduction in truck turn time* than anticipated when they decided to automate.

The findings of this report have relevance to practitioners and policy-makers when engaging in decision-making processes regarding automation. There is much similarity in the drivers for automation on a global basis, with *increased safety* generally considered the most important driver. But whether or not terminal operators receive the level of benefits they anticipated varies. Despite some level of similarity across terminals at the level of the decision-making drivers and realized benefits at a global and regional level, the survey exercise demonstrates that every automation project is unique and embedded in its local spatial, economic, and social context. One example is the driver on *reducing labor costs*, which many terminals in Asia realized as expected but in the U.S. that did not happen, reflecting tradeoffs terminal operators have made to secure stakeholder support for automation. Therefore, the successful implementation of a terminal automation project is not so much dependent on the technological solutions adopted, which are now widely available across the world. It is more a matter of demonstrating a high level of adaptive capacity of the terminal operator to respond adequately to the imperatives brought by the local market environment and customer base, the social dialogue, and the stance of public entities. All these factors are highly embedded in the local context and differ from one port to another. While terminal operators can learn from each other's' experiences and best practices, there is no 'one size fits all' approach possible to automation.

This study is the first of its kind using terminal operators' survey inputs to deepen our understanding of the drivers and benefits of terminal automation, going beyond the mere description of terminal facts and figures and anecdotal evidence. It is also the first attempt ever to bring stakeholders into the equation, at least from the perspective of the terminal operator. The study breaks new ground in understanding the attitudes and perspectives of terminal operators regarding automation.

There is ample room for further deepening the analysis where meaningful, for example, by applying more advanced methods to obtain cross analyses between survey questions, comparison of results per sub-group, etc. Exploring the relationships between the results with some economic or logistics indicators of the country, region, port or city in which the terminal is located could provide some greater insight. The World Bank, UNCTAD and other international and regional organizations publish a wide range of indicators that might be useful to consider.

While the sample size at over 50% is high, the dataset still contains some 'blind spots' preventing a more inclusive picture of the entire world. For instance, despite the assistance from Ports Australia, no survey was completed by any of the six automated terminals in Australia. The regional comparison can be further extended in future research to examine potential aspects that would reflect some level of regional embeddedness of terminal automation processes.

This study has demonstrated that most automated terminal projects are still fairly new, with limited years of operations. Therefore, some of the answers provided might not provide a complete picture of the long-term outcomes of automation, particularly at the level of the realized benefits and financial implications.

The literature review section of this report provided some fragmented information on the actual performance of automated terminals compared to conventional terminals. Future studies can attempt to develop a more systematic approach to terminal performance comparison based on hard data. Such data is available, but typically confidential in nature at the terminal operator level, or hidden behind 'high' paywalls in case one wants to rely on relevant information collected by advisory or data firms.

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DISCLAIMER

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APPENDIX I - THE SURVEY

Automating Container Terminals

Dear Sir/Madam,

We would like to invite you to fill in a short questionnaire of six (6) questions, assisting an academic research project on the conversion of conventional container terminals to semi-or fully- automated terminals.

The Project is developed by METRANS Transportation Center, which was established in 1998 and is a joint partnership of the University of Southern California (U.S.C) and California State University, Long Beach (CSULB). The aim is to generate knowledge on the drivers, benefits, and related factors in the progress towards automated container terminal terminals.

The research team will produce a report on the drivers/impediments of automation, focusing on the combination of factors that seem to be the precursors of the decision to automate and assess the policy implications from different perspectives (labor, port Users, the environment, energy consumption, etc.).

The Questionnaire:

- The questionnaire is divided into six (6) questions and takes no more than 10 minutes to complete.
- All the individual port information will be STRICTLY CONFIDENTIAL and we WILL ONLY MAKE PUBLIC AGGREGATE DATA - the reader will not be able to identify what any port terminal has responded.

If you have any queries or questions, please do not hesitate to contact the research team.

Sincerely,
The Research Team
Prof. Geraldine Knatz
Prof. Theo Notteboom,
Prof. Thanos Pallis

1. **Name of Terminal / Port: ______________________________**

2. **Grade the importance of the following factors in deciding whether to automate your container yard operation.**

Driver	**Not a factor at all**	**Limited importance**						**Maximum importance**
	0	1	2	3	4	5	6	7
Reduce labor cost								
Reduce unit cost of container handling								
Reduce air/ GHG emissions								
Improve efficiency to handle larger vessels								
Limited land for expansion								
Improve truck turn time								
Increase safety								
24/7 hours of operation								
Reduce variability in performance (More consistency)								
Eliminate human factors (illness, risk of labor disruption, etc.)								
Meet KPIs required by ocean carrier								
Test-bed for new technologies / Showcase technological expertise of local terminal and/or research community								
Financial incentives/subsidies by public entities or port authority								
Others (please identify)								

3. **What was the position of stakeholders towards the introduction of automation?**

	Opposition				**Support**		
Stakeholder	**High**	**Moderate**	**Minor**	**Neutral**	**Minor**	**Moderate**	**High**
Government							
Community							
Port Authority							
Dockworkers							
Carriers							
Shippers							
Logistics Service Providers							

4. **Now that the terminal yard is automated, please ran the benefits realized from automation in order of importance**

Benefit	**Not Realized**	**Limited benefits**						**Major benefits**
	0	1	2	3	4	5	6	7
Reduced labor cost								
Reduced unit cost of container handling								
Reduced air/GHG emissions								
Improved efficiency to handle larger vessels								
Increased land productivity								
Improved truck turn time								
Increased safety								
24/7 hours of operation								
Reduced variability in performance (more consistency)								
Elimination of human factors (illness, risk of labor disruption, etc.)								
Better meeting KPIs required by ocean carrier								
Boost for technological and operational innovation by terminal operator								
Others (please identify)								

5. **How long was the testing period of the automation equipment/system? __________ (months)**

6. **How many years will it take to realize (or has it taken to realize) a return on investment for your automated system?**

JUSt months after	**1-2 years**	**2-4 years**	**5-6 years**	**More than 6 years**

7. **Was the automation implemented by:**
   a. One supplier as a turnkey project____________
   b. One supplier with system integration by Terminal Operator__________
   c. Multiple suppliers with system integration by main supplier__________
   d. Multiple suppliers with system integration by Terminal Operator__________
   e. Other arrangements (please specify ____________________)

APPENDIX II – CORRELATIONS OF FINDINGS

Table 25. Correlations of the importance of factors behind the introduction of automation

		2-1-	2-2-	2-3-	2-4-	2-5-	2-6-	2-7-	2-8-	2-9-	2-10-	2-11-	2-12-	2-13	2-14
2-1-Reduce labor cost	Pearson Correlation	1	.462**	0,218	0,077	-0,128	0,255	.575**	.511**	0,249	.394*	-0,017	.400*	-0,009	0,146
	Sig. (2-tailed)		0,008	0,230	0,676	0,483	0,159	0,001	0,003	0,169	0,026	0,927	0,023	0,961	0,425
2-2-Reduce unit cost of container handling	Pearson Correlation	.462**	1	0,253	-0,097	-.391*	0,143	0,199	0,286	-0,133	0,221	-0,170	0,000	-0,060	0,283
	Sig. (2-tailed)	0,008		0,163	0,599	0,027	0,435	0,276	0,113	0,468	0,225	0,352	1,000	0,744	0,117
2-3-Reduce air/ GHG emissions	Pearson Correlation	0,218	0,253	1	0,138	0,115	.365*	0,111	0,041	0,003	0,011	-0,021	0,104	0,036	.511**
	Sig. (2-tailed)	0,230	0,163		0,453	0,532	0,040	0,547	0,823	0,987	0,954	0,908	0,571	0,844	0,003
2-4-Improve efficiency to handle larger vessels	Pearson Correlation	32	32	32	32	32	32	32	32	32	32	32	32	32	32
	Sig. (2-tailed)	0,077	-0,097	0,138	1	0,130	0,142	.498**	.428*	.438*	.424*	.607**	0,267	0,221	0,074
2-5-Limited land for expansion	Pearson Correlation	0,676	0,599	0,453		0,479	0,437	0,004	0,015	0,012	0,016	0,000	0,140	0,223	0,688
	Sig. (2-tailed)	-0,128	-.391*	0,115	0,130	1	0,073	-0,188	-0,093	0,167	-0,080	0,218	.393*	0,220	0,343
2-6-Improve truck turn time	Pearson Correlation	0,483	0,027	0,532	0,479		0,692	0,302	0,612	0,360	0,662	0,230	0,026	0,227	0,055
	Sig. (2-tailed)	0,255	0,143	.365*	0,142	0,073	1	0,253	-0,047	-0,042	-0,047	-0,018	0,197	-0,123	0,266
2-7-Increase safety	Pearson Correlation	0,159	0,435	0,040	0,437	0,692		0,162	0,799	0,818	0,799	0,921	0,279	0,501	0,141
	Sig. (2-tailed)	.575**	0,199	0,111	.498**	-0,188	0,253	1	.593**	.643**	.600**	.446*	0,336	-0,299	-0,109
2-8-24/7 hours of operation	Pearson Correlation	0,001	0,276	0,547	0,004	0,302	0,162		0,000	0,000	0,000	0,011	0,060	0,096	0,552
	Sig. (2-tailed)	.511**	0,286	0,041	.428*	-0,093	-0,047	.593**	1	.424*	.804**	0,278	.357*	-0,054	-0,065
2-9-Reduce variability in performance	Pearson Correlation	0,003	0,113	0,823	0,015	0,612	0,799	0,000		0,016	0,000	0,123	0,045	0,769	0,723
	Sig. (2-tailed)	0,249	-0,133	0,003	.438*	0,167	-0,042	.643**	.424*	1	.459**	.620**	.397*	0,103	0,106
2-10-Eliminate human factors (illness, risk of labor disruption, etc.)	Pearson Correlation	0,169	0,468	0,987	0,012	0,360	0,818	0,000	0,016		0,008	0,000	0,024	0,574	0,562
	Sig. (2-tailed)	.394*	0,221	0,011	.424*	-0,080	-0,047	.600**	.804**	.459**	1	.544**	.351*	-0,158	-0,179
2-11-Meet KPIs required by ocean carrier	Pearson Correlation	0,026	0,225	0,954	0,016	0,662	0,799	0,000	0,000	0,008		0,001	0,049	0,388	0,328
	Sig. (2-tailed)	-0,017	-0,170	-0,021	.607**	0,218	-0,018	.446*	0,278	.620**	.544**	1	.549**	0,079	0,110
2-12-Competitive forces from other terminal operators who opted for automation	Pearson Correlation	0,927	0,352	0,908	0,000	0,230	0,921	0,011	0,123	0,000	0,001		0,001	0,669	0,551
	Sig. (2-tailed)	.400*	0,000	0,104	0,267	.393*	0,197	0,336	.357*	.397*	.351*	.549**	1	0,274	.403*
2-13-Test-bed for new technologies / Showcase	Pearson Correlation	0,023	1,000	0,571	0,140	0,026	0,279	0,060	0,045	0,024	0,049	0,001		0,129	0,022

technological expertise of local terminal and/or research community	Sig. (2-tailed)	-0,009	-0,060	0,036	0,221	0,220	-0,123	-0,299	-0,054	0,103	-0,158	0,079	0,274	1	.455**
2-14-Financial incentives/subsidies by public entities or port authority	Pearson Correlation	0,961	0,744	0,844	0,223	0,227	0,501	0,096	0,769	0,574	0,388	0,669	0,129		0,009
	Sig. (2-tailed)	0,146	0,283	.511**	0,074	0,343	0,266	-0,109	-0,065	0,106	-0,179	0,110	.403*	.455**	1

**. Correlation is significant at the 0.05 level (2-tailed).   **. Correlation is significant at the 0.01 level (2-tailed).*

Table 26. Correlations of factors motivating automation with levels of (perceived) stakeholders' support towards the introduction of automation

N=32		Government	Port Authority	Dockworkers	Carriers	Shippers	Logistics Providers
2-1-Reduce labor cost	Pearson Correlation	0,008	0,028	0,092	.353*	.374*	.431*
	Sig. (2-tailed)	0,967	0,878	0,617	0,048	0,035	0,014
2-2-Reduce unit cost of container handling	Pearson Correlation	0,103	0,061	0,125	0,342	.380*	0,315
	Sig. (2-tailed)	0,575	0,739	0,497	0,055	0,032	0,079
2-3-Reduce air/ GHG emissions	Pearson Correlation	0,220	0,276	0,010	0,322	.374*	.426*
	Sig. (2-tailed)	0,227	0,127	0,958	0,073	0,035	0,015
2-4-Improve efficiency to handle larger vessels	Pearson Correlation	0,111	0,152	0,208	.386*	0,293	0,200
	Sig. (2-tailed)	0,545	0,407	0,253	0,029	0,103	0,274
2-5-Limited land for expansion	Pearson Correlation	-0,328	-0,306	-0,174	-0,299	-0,339	-0,294
	Sig. (2-tailed)	0,067	0,088	0,340	0,097	0,058	0,102
2-6-Improve truck turn time	Pearson Correlation	0,158	0,112	0,239	0,196	0,264	0,268
	Sig. (2-tailed)	0,388	0,543	0,188	0,283	0,144	0,139
2-7-Increase safety	Pearson Correlation	-0,087	-0,062	0,249	.553**	.518**	.457**
	Sig. (2-tailed)	0,637	0,735	0,169	0,001	0,002	0,009
2-8-24/7 hours of operation	Pearson Correlation	-0,145	-0,149	0,178	0,176	0,170	0,060
	Sig. (2-tailed)	0,429	0,416	0,329	0,335	0,352	0,746
2-9-Reduce variability in performance	Pearson Correlation	-0,127	-0,241	0,295	0,206	0,230	0,328
	Sig. (2-tailed)	0,489	0,184	0,101	0,258	0,205	0,067
2-10-Eliminate human factors (illness, risk of labor disruption, etc.)	Pearson Correlation	-0,254	-0,317	0,126	0,182	0,106	0,045
	Sig. (2-tailed)	0,160	0,077	0,492	0,318	0,564	0,809
2-11-Meet KPIs required by ocean carrier	Pearson Correlation	-0,229	-0,245	0,135	0,254	0,137	0,163
	Sig. (2-tailed)	0,207	0,177	0,462	0,161	0,454	0,373
2-12-Competitive forces from other terminal operators who opted for automation	Pearson Correlation	-0,248	-0,184	-0,007	0,015	0,015	0,059
	Sig. (2-tailed)	0,171	0,314	0,971	0,934	0,933	0,749
2-13 -Test-bed for new technologies / Showcase technological expertise of local terminal ……	Pearson Correlation	0,277	0,239	0,235	-0,148	-0,065	0,033
	Sig. (2-tailed)	0,125	0,187	0,196	0,419	0,724	0,856
2-14-Financial incentives/ subsidies by public entities or port authority	Pearson Correlation	0,307	0,296	0,163	0,306	0,321	.404*
	Sig. (2-tailed)	0,087	0,100	0,374	0,089	0,073	0,022

Table 27. Correlations of levels of stakeholders support towards the introduction of automation with benefits realized

		4-1-Reduced labor cost	4-2-Reduced unit cost of container handling	4-3-Reduced air/GHG emissions	4-4-Improved efficiency to handle larger vessels	4-5-Increased land productivity	4-6-Improved truck turn time	4-7-Increased safety	4-8-24/7 hours of operation	4-9-Reduced variability in performance (more consistency)	4-10-Elimination of human factors (illness, risk of labor disruption, etc.)	4-11-Better meeting KPIs required by ocean carrier	4-12-Boost for technological and operational innovation by terminal operator
3-1-Government	Pearson Correlation	0,119	0,257	-0,098	0,007	-0,108	0,052	-0,013	0,188	0,173	-0,151	-0,006	0,210
	Sig. (2-tailed)	0,532	0,170	0,606	0,972	0,569	0,785	0,944	0,319	0,362	0,425	0,975	0,265
3-2-Community	Pearson Correlation	.561**	0,316	0,114	0,287	-0,186	0,262	.411*	.453*	.438*	0,281	0,274	0,316
	Sig. (2-tailed)	0,001	0,089	0,547	0,124	0,326	0,163	0,024	0,012	0,015	0,132	0,143	0,089
3-3-Port Authority	Pearson Correlation	0,127	0,161	-0,083	0,061	-0,077	0,114	-0,032	0,213	0,146	-0,200	-0,002	0,166
	Sig. (2-tailed)	0,549	0,383	0,654	0,823	0,697	0,585	0,810	0,309	0,455	0,224	0,923	0,414
3-4-Dockworkers	Pearson Correlation	0,229	0,112	-0,117	0,155	-0,164	0,191	0,327	0,144	0,265	0,197	0,086	.453*
	Sig. (2-tailed)	0,224	0,556	0,537	0,415	0,385	0,311	0,078	0,447	0,157	0,297	0,652	0,012
3-5-Carriers	Pearson Correlation	0,307	0,032	-0,143	0,253	0,000	.444*	.472**	0,276	.375*	0,344	0,259	0,148
	Sig. (2-tailed)	0,099	0,868	0,451	0,177	1,000	0,014	0,008	0,139	0,041	0,063	0,167	0,435
3-6-Shippers	Pearson Correlation	0,331	0,064	-0,047	0,167	-0,103	.466**	.425*	0,226	0,211	0,281	0,155	0,070
	Sig. (2-tailed)	0,074	0,737	0,806	0,377	0,589	0,009	0,019	0,230	0,264	0,133	0,414	0,712
3-7-Logistics Service Providers	Pearson Correlation	.404*	0,148	0,015	0,148	-0,109	.463*	0,338	0,090	0,129	0,164	0,115	0,121
	Sig. (2-tailed)	0,027	0,434	0,939	0,436	0,565	0,010	0,068	0,636	0,498	0,385	0,544	0,525

Table 28. Correlations of benefits realized

		4-1	4-2-	4-3	4-4	4-5	4-6	4-7	4-8	4-9	4-10	4-11	4-1
4-1-Reduced labor cost	Pearson Correlation	1	.370*	-0,003	0,178	-0,293	0,153	.514**	.545**	.473**	.362*	0,173	.494**
	Sig. (2-tailed)		0,037	0,988	0,330	0,104	0,404	0,003	0,001	0,006	0,042	0,343	0,004
4-2-Reduced unit cost of container handling	Pearson Correlation	.370*	1	0,235	0,257	-0,073	-0,063	0,042	.400*	0,110	0,002	0,331	0,046
	Sig. (2-tailed)	0,037		0,196	0,156	0,689	0,730	0,818	0,023	0,549	0,993	0,064	0,804
4-3-Reduced air/GHG emissions	Pearson Correlation	-0,003	0,235	1	.418*	0,137	0,094	-0,107	-0,171	-0,159	-0,175	0,112	-0,135
	Sig. (2-tailed)	0,988	0,196		0,017	0,453	0,609	0,561	0,348	0,384	0,337	0,540	0,460
4-4-Improved efficiency to handle larger vessels	Pearson Correlation	0,178	0,257	.418*	1	0,337	0,248	.566**	.369*	.559**	0,325	.731**	0,214
	Sig. (2-tailed)	0,330	0,156	0,017		0,059	0,171	0,001	0,038	0,001	0,069	0,000	0,239
4-5-Increased land productivity	Pearson Correlation	-0,293	-0,073	0,137	0,337	1	0,264	0,078	0,067	0,273	0,013	.444*	0,186
	Sig. (2-tailed)	0,104	0,689	0,453	0,059		0,144	0,670	0,718	0,131	0,943	0,011	0,308
4-6-Improved truck turn time	Pearson Correlation	0,153	-0,063	0,094	0,248	0,264	1	0,297	0,036	0,223	0,194	0,173	-0,055
	Sig. (2-tailed)	0,404	0,730	0,609	0,171	0,144		0,099	0,844	0,219	0,288	0,345	0,764
4-7-Increased safety	Pearson Correlation	.514**	0,042	-0,107	.566**	0,078	0,297	1	.505**	.797**	.676**	.544**	.517**
	Sig. (2-tailed)	0,003	0,818	0,561	0,001	0,670	0,099		0,003	0,000	0,000	0,001	0,002
4-8-24/7 hours of operation	Pearson Correlation	.545**	.400*	-0,171	.369*	0,067	0,036	.505**	1	.586**	.576**	.456**	0,346
	Sig. (2-tailed)	0,001	0,023	0,348	0,038	0,718	0,844	0,003		0,000	0,001	0,009	0,052
4-9-Reduced variability in performance (more consistency)	Pearson Correlation	.473**	0,110	-0,159	.559**	0,273	0,223	.797**	.586**	1	.519**	.755**	.561**
	Sig. (2-tailed)	0,006	0,549	0,384	0,001	0,131	0,219	0,000	0,000		0,002	0,000	0,001
4-10-Elimination of human factors (illness, risk of labor disruption, etc.)	Pearson Correlation	.362*	0,002	-0,175	0,325	0,013	0,194	.676**	.576**	.519**	1	.351*	0,289
	Sig. (2-tailed)	0,042	0,993	0,337	0,069	0,943	0,288	0,000	0,001	0,002		0,049	0,108
4-11-Better meeting KPIs required by ocean carrier	Pearson Correlation	0,173	0,331	0,112	.731**	.444*	0,173	.544**	.456**	.755**	.351*	1	0,219
	Sig. (2-tailed)	0,343	0,064	0,540	0,000	0,011	0,345	0,001	0,009	0,000	0,049		0,228
4-12-Boost for technological and operational innovation by terminal operator	Pearson Correlation	.494**	0,046	-0,135	0,214	0,186	-0,055	.517**	0,346	.561**	0,289	0,219	1
	Sig. (2-tailed)	0,004	0,804	0,460	0,239	0,308	0,764	0,002	0,052	0,001	0,108	0,228	