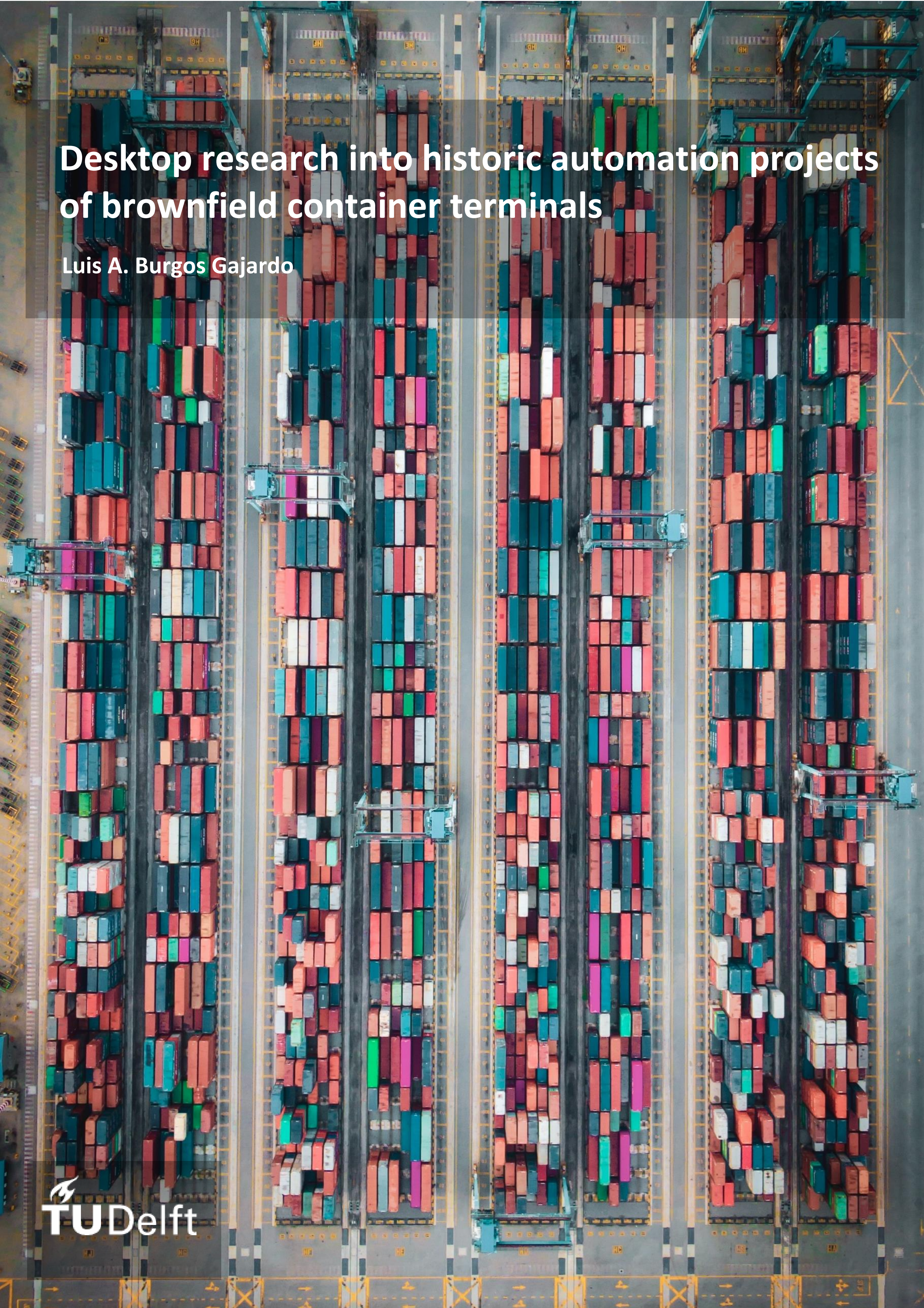
Desktop research into historic automation projects of brownfield container terminals

Luis A. Burgos Gajardo



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Desktop research into historic automation projects on brownfield container terminals

By

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PREFACE

Automated container terminals have been around for almost 30 years. However, a minority of existing container terminals use automated technologies. This trend has been changing in the last years since more and more terminals are being converted to some level of automation. But little literature is available on the implementation process of automated solutions on existing terminals. Also, no collection of challenges and solutions employed in practice so far have been found in literature. This thesis aims to shed some light on the particularities of brownfield automation projects. This is done by identifying drivers, challenges, and solutions adopted by converted terminals in the past. This way, an overview of brownfield automation projects until the present has been built. This overview is not exhaustive but broad, covering many terminals worldwide, with different challenges and varied solutions.

Many people contributed to the development of this document in a variety of ways. I would like to thank first to Dr. Ir. Poonam Taneja, my daily supervisor during this work. Her guidance and expertise greatly helped me shape this document. Moreover, her enthusiasm represented an important motivator to me. I also want to thank the members of the committee: Prof. Dr. Ir. Mark van Koningsveld, Dr. Ir. Yusong Pang, Ir. Thijs de Boer, and Ir. Jan Kees Krom. Thank you all for the time invested in this thesis, for your sharp comments, and for your support along the process.

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Many thanks to my relatives in Chile, who supported us from the moment we decided to come to Delft. Thanks to mom, dad, Cami, Andrés, and many others, for helping us enormously during the process. I would also like to thank my in-laws for their support and care.

Finally, but most importantly, I want to thank my son Tomás and my wife Paulina. Tomás did not really understand what was going on, but his joy and love gave me the strength and energy to carry on and to do my best. Pauli, thank you so much for motivating me to come to study in the Netherlands, for leaving everything behind to come with me, and for your constant love and encouragement during this process. You have been the perfect partner in this adventure. I am sure we will treasure these years for the rest of our lives.

Luis A. Burgos Gajardo
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ABSTRACT

Container traffic worldwide has shown a growing trend during the last years. Also, the number of containers handled per call has increased for many terminals. This poses challenges to existing terminals for more efficient operations and higher productivity. Automation is a way some terminals have tried to achieve this. Most existing automated container terminals were greenfield projects, but brownfield automation is gaining momentum.

Literature on brownfield automation of container terminals is limited. The PIANC MarCom WG Report n° 208 – 2021, Planning for Automation of Container Terminals is the most recent and complete guideline for automation projects, but it is mainly focused on greenfield projects. Challenges for automating brownfield terminals are different than for greenfield ones. All of this translates into little guidance being available for future brownfield automation projects. Therefore, the experiences and lessons learnt from historical brownfield automation of container terminals are a valuable source of information to guide future projects. The aim of this thesis is then to present a characterisation of historic container terminals converted, or in the process of being converted, to some degree of automated operations.

An empirical research methodology was defined to gather data on drivers for automation, challenges, observed benefits, drawbacks, and solutions adopted by brownfield automated terminals. A questionnaire was used for this purpose. Also, satellite images of the conversion process were analysed to observe implementation strategies. Additionally, terminal throughput, equipment, yard size and quay length were determined through a desk study. Data was analysed through categorization. Trends regarding the type of automation, i.e., semi-automation (automated yard equipment) or full automation (automated yard + automated transport between the stacks and the quay), and regarding the type of yard equipment adopted were determined.

For the historic conversions analysed, it was concluded that the main drivers for automation are operational cost reductions, labour shortage, productivity increase, reliability/safety, and capacity. But these drivers are case specific. No benefits can be assumed a priori from automation. Objectives for automating should be defined by each terminal and solutions to achieve them proposed. The main challenges were continuity of operations during the conversion, adaptation to new operations, labour relations, and communication systems. Most terminals adopted semi-automated solutions, due to fewer labour issues expected and improved vessel productivity compared to full automation, among other reasons. It was observed that terminals with yards smaller than 10 [ha] chose aRTGs as their stacking equipment, while terminals with larger yards chose either an aRMG or the automated version of their yard equipment before automating.

Three implementation strategies were observed: greenfield-like, phased, and big bang approaches. The first one refers to developing the automated yard in a new location, with little disruption of the operations of the old yard. A phased approach means that the implementation is divided in phases, and operations of the old yard must be disrupted from phase 1. The big bang approach was observed only for conversions from straddle carriers (SC) to auto SC. In these cases, a small site is used to test the technology. When the testing is finished, the terminal is closed for 2-3 days, and the technology is rolled out onto the entire yard or a large portion of it.

GLOSSARY

AI	:	artificial intelligence
aRTG	:	automated rubber tyred gantry crane
ASC	:	automated stacking crane
aShC	:	automated shuttle carrier
aTT	:	automated terminal tractor
auto SC	:	automated straddle carrier
CAPEX	:	capital expenses
CARMG	:	cantilever automated rail mounted gantry crane
CRMG	:	cantilever rail mounted gantry crane
DWT	:	deadweight tonnage
FL	:	forklift truck
ITV	:	internal transport vehicles
OCR	:	optical character recognition
OOG	:	out-of-gauge
OPEX	:	operational expenses
OTR	:	over-the-road (trucks)
RMG	:	rail mounted gantry crane
RS	:	reach stacker
RTG	:	rubber tyred gantry crane
SC	:	straddle carrier
ShC	:	shuttle carrier
TEU	:	twenty-foot equivalent unit
TT	:	terminal tractor

1. Introduction

1.1. General

Maritime transport is essential to the world's economy, as more than 80% of global trade by volume is carried by sea (UNCTAD, 2021). Measured by deadweight tonnage (DWT) of the global fleet, approximately 18% correspond to containerised cargo (UNCTAD, 2021). However, container ships carry goods of higher unitary value and usually travel at higher speeds, which results in more than 50% of the monetary value of the total seaborne trade being carried by containers (UNCTAD, 2018).

Container world throughput has experienced a long-term tendency to grow, except for a few exceptions. This increase is explained partly by the absolute growth of cargo volume, but also by the shift of conventional general cargo to containerised cargo (Ligteringen, 2017). In Figure 1-1, left, container traffic worldwide in million TEUs between the years 2000 and 2019 is presented. An increase of container traffic worldwide of 3.5 times in 20 years is evidenced. This growth has been accompanied by an increase in the size of the largest container vessels, as presented in Figure 1-1 right, where the largest vessel's capacity in TEU along the period 2000-2020 is presented. This vessel size increase has been driven by the advantages of the economies of scale, reducing the cost per unit transported over long distances (PIANC, 2021).

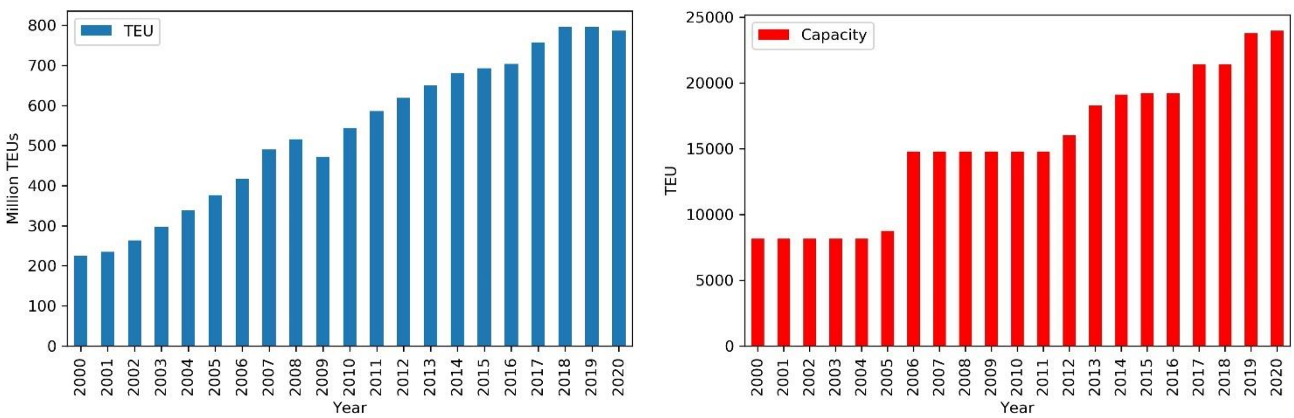

Figure 1-1: left: container traffic worldwide (UNCTAD, 2021, World Bank, 2020); right: largest container vessel capacity (Notteboom et al., 2021, Lane and Moret, 2015).

A maritime container terminal is a place where there is a transfer in the transportation mode of a certain container, where one of the modes is maritime transport, while the other mode is by road, rail, barges, or another sea vessel (transhipment). The growth in container throughput worldwide and in the size of container vessels result in a continuously increased demand on container terminals, overall and per call. This demand has been satisfied either by building new terminal areas or by improving the performance of existing ones, through a more efficient operation or higher productivity. A solution that terminals have used to try to achieve the latter, has been to switch to automated operations.

Automation has been applied in a limited number of terminals so far; most of them have been greenfield developments. But the number of brownfield automation projects has started to grow (PIANC, 2021). Current publications on container terminal automation are mainly focused on greenfield developments, even though brownfield conversions face different challenges. This thesis aims to shed some light on the particularities of brownfield automation projects, by presenting a high-level characterisation of the motivations, challenges and solutions historically adopted.

1.2. Introduction to automation

At a machine level, automation can be understood as "the technology by which a process or procedure is performed without human assistance" (PIANC, 2021). In the case of ports, container terminals have a larger potential of automation compared to other types of cargo, given the standardised shape of containers and the standardised procedures a container goes through in a terminal. These procedures are discussed in chapter 2.

Drivers for adopting automated solutions in container terminals are varied and case specific. The most repeated ones are higher productivity and the reduction of operational costs per container handled (Martín-Soberón et al., 2014, Notteboom et al., 2021, PEMA, 2016a, Saanen, 2004). This is achieved through reducing labour costs (Saanen, 2004) and a more efficient operation (PEMA, 2016a). Some other drivers are safer, more sustainable, and more predictable operations.

Regarding sustainability, automation can help reduce the levels of noise and air pollutants (Martín-Soberón et al., 2014, Sotiriadou, 2019, Hirvonen et al., 2017), reducing the negative impact of the operation of container terminals to nearby cities. Therefore, it is expected that an automated terminal could perform a more environmentally friendly operation at a reduced OPEX, compared to a traditionally operated facility. This reduction could be relevant in a broad sense, given the current context of climate change, especially when considering the commitment several countries made to reduce CO_2 emissions in the Paris Agreement.

Usually, a distinction is made between the so-called semi-automated and fully automated terminals. The former refers to terminals that have robotised the operation of their container yard only, while fully automated terminals consider in addition the automation of the transportation from the quay to the container stacks and vice versa (PIANC, 2021), also referred to as horizontal transport. This definition is arguable since some quay processes and gate processes are also potentially automatable. However, they have not been considered within the concepts of semi- or full automation in container port business (PIANC, 2021). Therefore, the definitions presented above will be considered further in this thesis.

Automation technologies were first implemented in ECT's Delta/Sea-Land terminal, in the port of Rotterdam, starting operations in 1993. The second automated terminal came into operations in 1997 (The PPT terminal, port of Singapore) and the third one in 2000 (London Thamesport, UK) (PEMA, 2016a). Yet, less than 5% of the share of container terminals worldwide are automated (UNCTAD, 2018). This number is expected to rise. In a survey conducted by McKinsey & Company in 2017, 80% of the respondents expected that in the next five years, at least half of all greenfield port projects will be semi- or fully automated (Chu et al., 2018). According to another survey, nearly 75 per cent of terminal operators consider automation critical to remain competitive in the next three to five years (UNCTAD, 2018).

Given the long-term perspective of ports and the potential benefits of automated technologies, the possibility to apply these solutions or to employ options that will make the adaptation to automation easier in the future, must be explored by port operators.

1.3. Automation of brownfield container terminals

The first brownfield automated terminal started operations in 2005 (Patrick Terminal in Brisbane, Australia). Up to the year 2020, approximately 70 container terminals worldwide were automated (PIANC, 2021). Approximately 25% of these terminals were brownfield conversions. The number of automated and brownfield automated terminals over the years is presented in Figure 1-2.

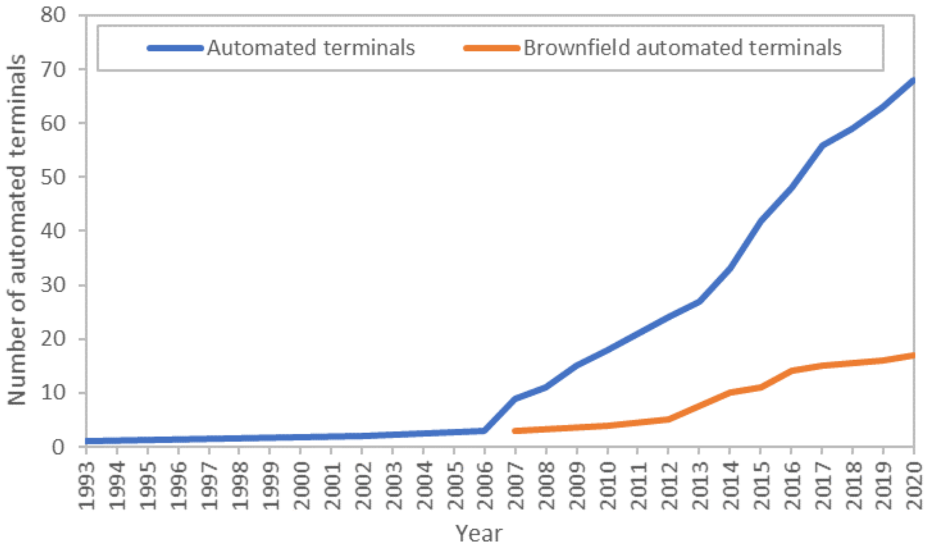

Figure 1-2: number of automated terminals worldwide. Source: PIANC (2021).

For greenfield developments automation is already the norm, rather than the exception (Alho et al., 2018). According to Bernat Goni-Ros from TBA, brownfield developments are already relatively frequent, and are expected to become more frequent than greenfield developments in the next few years (personal communication, November 18th, 2021). According to Yvo Saanen from TBA, the future of automation is brownfield since “there are not many places to develop greenfield sites anymore” (White, 2018).

Brownfield automation involves added difficulties compared to greenfield automation. According to Notteboom et al. (2021), a major challenge for brownfield automation is how to phase the process with existing operations. Also, the implementation may take longer than greenfield developments, and will result in a temporary loss of capacity and operational efficiency (Notteboom et al., 2021). Even if automated operation can reduce the operational expenditures (OPEX), these reductions have not always been considered enough to compensate for the capitalised cost of lost revenue (PIANC, 2021). Also, operational complexities are expected, such as the difficulty of managing two operational systems during the conversion process, or beyond (Martín-Soberón et al., 2014).

Given that cost reduction is one of the main drivers for automation as discussed in §1.2, the financial complexities of brownfield conversions may discourage the implementation of automation in existing terminals. Even so, the number of brownfield automated terminals is increasing as depicted in Figure 1-2.

1.4. Problem statement

A larger number of brownfield automation projects is expected in the next years. Since most existing container terminals in the world are manned, given the potential benefits of automation, and considering the reduced possibilities for greenfield developments, there are many potential future brownfield automation projects.

Literature on brownfield automation of container terminals is limited, as presented in §1.5. Moreover, there is a lack of standards for digitalization and automation projects (White, 2018). The PIANC MarCom WG Report n° 208 – 2021 “Planning for Automation of Container Terminals” is the most recent and complete guideline for container terminal automation, but it is focused on greenfield projects. Brownfield automation projects present different challenges than greenfield ones, such as giving continuity to operations. All of this translates into little guidance being available for future brownfield automation projects.

The development of guidelines specifically for brownfield container terminal automation projects would need to consider the experience of historic brownfield automated terminals, especially given the limited literature available. A characterisation of historically converted terminals, where these experiences could be found, has not been published so far.

1.5. Literature gap

A review of literature on container terminal automation was performed with a focus on brownfield automation. The topics discussed in the cited documents are briefly discussed. Then, a discussion on missing elements is made to identify a research gap.

The automation of container terminals is a topic that has been studied since the ECT’s Delta/Sea-Land terminal started operating in the early nineties. Kon et al. (2020) recently performed a systematic review on automated container terminals literature. They determined approximately 200 documents discussing results of applying automated technologies in container terminals have been published. The research focusses of these documents are presented in their publication. Most of them focus on specific issues of automated container terminal operations, such as yard operations, AGV operations, ASC operations, effect on transhipment or quay crane operations. None of the research focusses is on brownfield automation.

Documents introducing the concept of container terminal automation have mentioned some of the issues of brownfield conversions. Martín-Soberón et al. (2014) included a brief discussion on greenfield vs brownfield. They indicated a temporary reduction of performance and efficiency is the main problem of brownfield automation, and that a phased implementation is the way to allow for continued operations. They also mentioned the operational complexities of working 2 yards, manned and automated, during the implementation period. Notteboom et al. (2021) briefly mention that phasing the automation process with existing manned operations is the main challenge for brownfield automation. No solutions are presented, or other challenges of brownfield automation are discussed.

Other sources of information are white papers, mainly from vendors or companies that provide services related to automation projects. These documents usually have commercial purposes and focus on the specific services or products the issuing company may provide. Konecranes port automation white paper (Konecranes, 2021) dedicates a chapter to brownfield conversions. They present the advantages of remote operation and the different automation levels of their solutions. TBA also presented the document “Taking The Best Path To Automation” (Kats, 2020), where a list of challenges of brownfield automation is presented with a discussion on the available automated technologies and the process followed by the company to choose the best one. No solutions for the challenges are discussed. Kalmar presented a white paper focused on aRTG conversions (Alho et al., 2018). They describe the benefits of operations with aRTG, some challenges to convert and the solutions they offer. No discussion on other automated technologies is presented.

PEMA, the Port Equipment Manufacturers Association, has published 2 information papers about brownfield container terminal automation on their website (PEMA, 2019, PEMA, 2021). A succinct description of potential benefits and challenges is presented, but no ways to overcome those challenges are discussed. The documents focus on equipment only. Interesting details are given on infrastructure, control systems and safety systems for the types of automated equipment available in the market. But issues unrelated with equipment directly, such as labour issues, are not discussed.

Study cases of specific projects have also been published. Meglio and Sisson (2013) described the planning of the automated solution in the Trapac terminal in the port of LA. They indicated ASCs are the current standard for automated solutions, without discussing other equipment, and presented some alterative layouts using ASCs before defining the definitive one. No discussion on challenges, or motivations was given. Henriksson et al. (2020) described the retrofitting process of existing CARMG with automated technology in the former Tianjin Five Continents International Container Terminal Co. Ltd. A concise description of the motivation and the solution adopted was presented. Finally, Ozolin and Cornell (2016) discussed issues regarding the deployment of CARMG in an existing yard in the Manzanillo International Terminal in Panama. These documents are valuable, since they discuss motivations, challenges and solutions adopted. But they individually focus on the specific project they are analysing only.

The PIANC MarCom WG Report n° 208 (PIANC, 2021) presents a complete path from early planning stages until operational go-live and beyond. The focus of the document is on greenfield terminals, so this path does not necessarily apply to brownfield automation projects. Particularities on brownfield conversions are tangentially touched upon in the text, which allows the use of these guidelines in brownfield projects as well. However, no clear views on the motivations, challenges, and results of historic brownfield automation projects are presented.

The literature reviewed focusses on one type of technology, or on a specific project. No documents discussing drivers, challenges, and solutions covering all available automated technologies in use have been presented. The challenge of brownfield automation most mentioned in existing literature is continuity of operations, but no discussions of strategies followed to solve this problem has been presented so far. This document intends to help partially fill that gap by characterising historic brownfield automation projects.

1.6. Aim and research questions

The aim of this thesis is to present a characterisation of historic container terminals converted, or in the process of being converted, from manned to some degree of automated operations. This overview was built on a desktop study using publicly available data, and from answers to a questionnaire sent to brownfield converted terminal operators. To achieve this objective, the following research questions have been developed.

1.6.1. Main question

What information can be extracted from historic automation projects on brownfield container terminals to inform the initial planning stage of future container terminal conversions to automation?

1.6.2. Sub-questions (SQ)

1. What are the main automatable processes in a container terminal?
2. How can the information on past conversions be systematically gathered and analysed?
3. What are the main drivers for automating existing terminals?
4. What are the main challenges, and how have these been addressed during the conversion process?
5. What are the benefits and drawbacks observed from past brownfield automation projects?
6. What are the main trends observed regarding the type of automated technologies chosen?

1.7. Research methods

Before characterising historic brownfield conversions, a literature review is conducted to identify the state-of-the-art of automated equipment. Literature on container terminal processes and container handling equipment is used for that purpose, complemented with publications on automated equipment, properly cited in chapter 2. This way, sub-question 1 (SQ1), i.e., “what are the main automatable processes in a container terminal and the expected effects of automation?” is answered.

A list of brownfield automated terminals to be studied is built through a desk study. The main source of data is the PIANC MarCom WG Report n° 208 – 2021, but other sources specified in §3.4.2 are considered to build a more complete list. Considering the number of brownfield conversions is relatively low (see §1.3), a multiple case study approach is used for this work, since it allows managing data of several research units (Flynn et al., 1990) but a relatively small number (Verschuren et al., 2010).

Brownfield automated terminals are characterised by identifying the terminal sizes and container handling equipment, before and after conversion, and establishing the drivers for automation, main challenges, and observed benefits and drawbacks. Terminal container handling equipment and terminal size, the latter represented by yard areas, quay length, and terminal capacity in [TEU/year], is determined through desk research, by retrieving information from terminal websites, or other publicly available sources presented in §3.4.2. Terminal yard areas and quay lengths are determined using Google Earth™ imagery. Drivers for automation, main challenges, and observed benefits and drawbacks are not generally available on publications. Therefore, a questionnaire is built to ask these directly to terminal operators. An empirical research methodology, based on the generic empirical research systematic approach on operations management presented by Flynn, et al. (1990), is established to give a clear framework to this process. This systematic approach is presented in detail in chapter 3.

Data gathered is analysed using the thematic analysis approach, possibly the most widely used method of qualitative data analysis (Ngulube, 2015). It allows to reduce qualitative data from the questionnaire by the identification of themes and codes, the display of reduced data, and the use of the reduced data to explore relationships (Alhojailan, 2012). This approach is used on questionnaire answers to produce tables on drivers, challenges, observed benefits and drawbacks. This way SQ3, SQ4, and SQ5, i.e., “what are the main drivers for automating existing terminals?”, “what are the main challenges, and how have these been dealt with during the conversion process?”, and “what are the benefits and drawbacks observed from past brownfield automation projects?” are answered.

Terminals are categorised as semi- or fully automated depending on the automation degree of the horizontal transport, according to the definition presented in §1.2. Terminals are also categorised by the type of automated yard equipment chosen, and according to the implementation strategies identified. These categories are then compared with terminal sizes and with yard equipment to determine general trends observed from historically adopted solutions.

A general overview of the research methodology is presented in Figure 1-3. The parts of the process where sub-questions are addressed are highlighted in the diagram. A complete description on the empirical research methodology is presented in chapter 3.

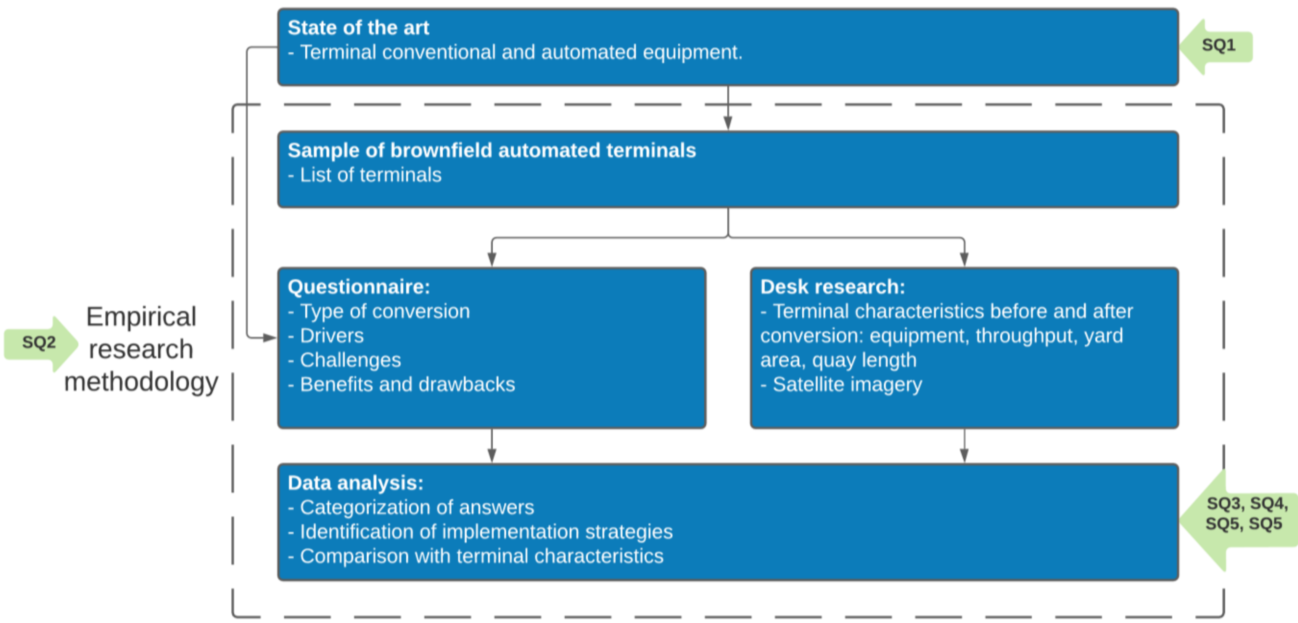

Figure 1-3: research methodology.

1.8. Report outline

The report structure and the related sub-questions are presented as follows:

Chapter 2: Container terminal processes, manned and automated alternatives: overview of the current state-of-the-art. Potential effects from implementing automated solutions in container terminals are discussed (SQ1).

Chapter 3: Empirical research methodology: a description of the methodology, information sources and data analysis tools are presented for the questionnaire and desk study (SQ2).

Chapter 4: Questionnaire and desk study results: categorised results for the questionnaire are presented. Also, data gathered with the desk study is introduced.

Chapter 5: Data analysis and findings: questionnaire results about drivers and benefits, drawbacks, challenges are discussed and compared with findings from available literature (SQ3, SQ4, SQ5). Implementation strategies identified from questionnaire answers are clearly defined and analysed in all terminals using satellite imagery. Trends regarding the type of automated solution chosen and the type of yard equipment are discussed (SQ6).

Chapter 6: Reflections, conclusions, and further research: reflections on the issues faced during the research, and limitations of the method are presented. Conclusions on the research sub-questions and the main research question are presented. Further research is proposed.

2. Container terminal processes, manned and automated alternatives

2.1. General

The goal of this chapter is to present the equipment existing in the market for the different processes a container must go through in a maritime terminal. Also, the effects expected from automated solutions, compared with the traditional ones, are discussed. This way, SQ1 "what are the main automatable processes in a container terminal?" is answered.

This chapter includes descriptions on the main terminal processes, existing manned and automated cargo handling equipment, and their impact in the layout. Readers informed on these matters do not necessarily need to go through it and could go straight to chapter 3. Other elements relevant for automating, such as sensors, control systems, control buildings, etc., are not mentioned in this document. Details about these elements can be found on the PIANC MarCom WG Report n° 208 – 2021.

The processes a container must go through in a terminal are discussed in this chapter in chronological order, following the typical path of an export container, i.e., a container arriving from the hinterland to the terminal by truck and leaving the terminal through the quay. The processes for import or transhipment containers are either the same or a subset of the export container processes, with a different order. Containers arriving by other means as barge or rail are not described in detail, but they can be linked to some of the processes described in this chapter. Variations to these processes can occur between terminals.

The arrival of a container to the terminal occurs through the gate. After a truck is cleared, it is driven with the container to the stacks. The container is then picked up by a container handling equipment and disposed in the yard for temporary storage. Once it is time for the container to be loaded in a vessel, it is driven from the stack to the quay, where it is picked up by a crane and loaded onto a vessel. The process is summarised in Figure 2-1.

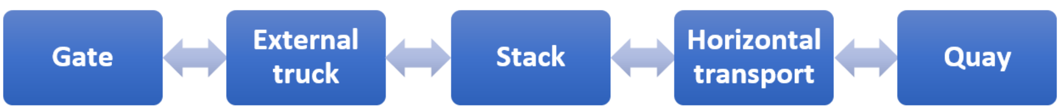

Figure 2-1: general procedure for containers in a maritime terminal.

The horizontal transport from the truck gate to the stacks is done by trucks, which are external to the terminal. The processes analysed in this chapter consider only terminal equipment. Therefore, gate, yard (container stacks), horizontal transport, and quay activities are described in this chapter.

2.2. Gate processes

2.2.1. Description

The gate is the interface of the terminal with the outside world. Lines to enter and to exit the terminal are usually defined, where the number of lines depends on the predicted inbound and outbound traffic (PIANC, 2014).

The most common processes at the gates are listed as follows:

- Registration of truck plate
- Registration of the driver
- Registration of container number
- Registration of temperature for reefers
- Seal number and condition check
- Document exchange

Other processes that can also take place at the gate area are:

- Container check for damages
- Container scan
- Radiation detection
- Customs inspection
- Health inspection
- Cargo weighting

Depending on the terminal, sometimes the gate processes can be divided into a pre-gate and a gate. At the pre-gate, container number, truck and driver are quickly checked in. The truck is then driven to the gate, where the remaining gate procedures such as the exchange of documents and registration take place (PIANC, 2014). Usually, these operations are performed at a control booth by a gate clerk.

2.2.2. Automation possibilities

Automated gates lack manned control booths. Tasks are typically divided in two stages of automated gate equipment (PIANC, 2021):

- Drive-through portals with cameras and sensors for capturing data about trucks and containers.
- Barriers with driver pedestals for driver credential checks and communication.

To use automated gates, typically the terminal would require truck drivers to prepare an online booking in advance. In this booking the container to be handled or delivered is identified.

Drivers with a booking, either to deliver an export container or to pick up an import container, arrive at the terminal. At the drive through portals, cameras register the truck plate and container number using Optical Character Recognition (OCR) (Chao, 2017). At the barrier with drive pedestals, the driver is identified, either by tapping a terminal ID card previously acquired or by fingerprint identification. Also, the driver's license is used at some terminals (Chao, 2017). For this process truck drivers are usually pre-enrolled. If they are not, then they need to do so before entering the terminal.

Container weight may also be measured at the gates. Usually, weighbridges are embedded into the lanes for these purpose (Chao, 2017).

Another relevant task carried out at the gates is checking the seal number and condition. Seals ensure containers have not been open without authorisation, preventing theft and contraband. This task is hard to automate, because seal numbers are small, which could prevent a clear reading of the seal number, and customs may require to check their condition (Chao, 2017). Therefore, a clerk must perform this process manually. Electronic seals are being used by some terminal operators. These would allow complete automation of the gate. They are, however, more expensive and, according to some terminal operators, probably not going to be widely applied unless it is required by the International Maritime Organization (IMO).

For gates serving terminals with automated yards, automated or not, it is also essential to identify the container door direction for proper storage in the yard (PIANC, 2021).

2.2.3. Automation effects

Automated gates can potentially increase the gate capacity within the same footprint, allowing for faster gate in and out processes. According to Chao (2017), one of the industry's benchmark is set by the automated gate of PSA terminal in Singapore, where a truck can complete the gate in process in 25 seconds.

Also, operational costs are lowered, given the removal of most clerks from the gates, since no document exchange and registration into the terminal system are required. Although some operators are still required to remotely watch for recognition problems of the OCR systems and the inspection of container condition. Also, a clerk is usually still required to check seal numbers and condition at the gate.

Another effect from automation is safer operations, given the reduced number of people working at the gates. This reduces the possibility of accidents, but also improves the working conditions of operators, who are no longer exposed to constant noise and fumes from the traffic.

Finally, a reduced waiting time for trucks during their gate-in and -out processes can result in lower emissions from their engines and less noise.

2.2.4. Automated gate processes

Automated gates are a solution usually offered as a package from vendors in the industry. The gate capacity should be designed to attend peak hourly truck traffic within a reasonable level of total time (PIANC, 2014). Ideally, gate, yard and quay should be planned to handle a similar capacity in similar conditions (PIANC, 2021).

However, the gate capacity is usually not considered a constraint since it is relatively inexpensive to expand it (PIANC, 2021). Considering this, and to limit the scope, gate automation will not be considered as a variable to be further analysed.

2.3. Yard and horizontal transport processes

2.3.1. Description

Once a container enters a terminal, it is usually stored in container stacks on the container yard, before being moved to another mode of transportation. The container stacks operate as a buffer, to temporarily hold cargo between the dropping time and the loading time onto its new transportation mode.

Several types of equipment are used to handle containers in the yard, namely forklifts (FL), reach stackers (RS), straddle carriers (SC), rubber tyred gantry cranes (RTG) and rail mounted gantry cranes (RMG). The layout of the yard, the density of containers, usually expressed in the standard unit TEU (twenty-foot equivalent unit) per unit of area, the capacity of the yard, and the handling costs are heavily dependent on the type of equipment chosen for the container yard.

Horizontal transport equipment is used to exchange containers between the quay and the yard. Three types of equipment are mainly used for this purpose: terminal tractors (TT), straddle carriers (SC) and automated guided vehicles (AGV), the latter only used in fully automated terminals. SC are used for both, horizontal transport, and container yard handling. A variant on the SC, the shuttle carrier (ShC), is used only for the horizontal transport between the quay and the yard.

2.3.1.1. Reach stackers and forklifts

RS and FL are yard equipment to handle containers, usually in the stacks only, receiving the containers from the quay brought by a TT. Sometimes the horizontal movement is also done with an RS or FL. Containers are lifted and stacked by a FL or RS as presented in Figure 2-2. Some variations of FL can be observed, like empty container handlers, top loaders, or side loaders, but the principle remains similar.

The RS system is used for stacking up to 4 containers deep and 6 high, but normally the stacking is 2 deep and 3-4 high to avoid too much reshuffling (Thoresen, 2018). It has a relatively low storage density, with a requirement of 25-30 [m^2/TEU] in the yard (this area includes storage and travelling lanes), considering a nominal stacking height of 3 containers (Ligteringen, 2017).

RS and FL are labour intensive and require a relatively large area per TEU, but the CAPEX is low (Thoresen, 2018). It is the recommended option for small terminals, with a throughput between 60,000 and 80,000 [TEU/year] (Thoresen, 2018). They are usually diesel driven, although in the latest years electric and hybrid alternatives have been developed.

Figure 2-2: reach stacker[1] (left) and forklift[2] (right).

2.3.1.2. Straddle carriers

Straddle carriers can cover both tasks, horizontal transport and stacking containers. Sometimes they are used exclusively for one of those tasks, sometimes for both. They can pick up containers directly from the pavement, decoupling quay, and yard operations. An SC carrying a container is presented in Figure 2-3 left, an aerial view of an SC terminal layout is presented in Figure 2-3 right.

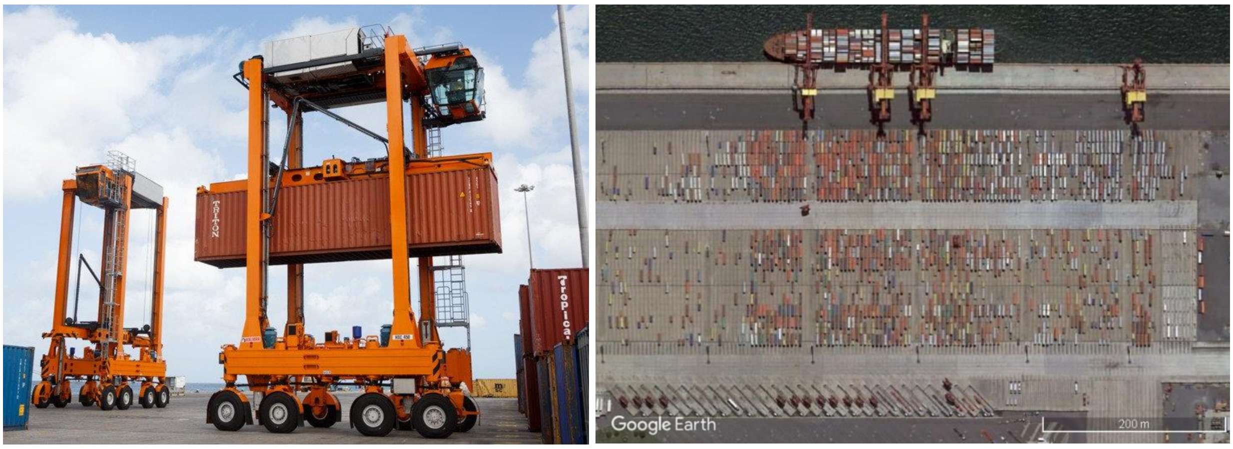

Figure 2-3: straddle carrier[3] in operation (left) and SC terminal layout, Patrick Terminals in Brisbane, Australia (right).

As previously indicated, when straddle carriers are used only for horizontal transport purposes, they are usually called shuttle carriers (ShC). They are basically the same, but shorter in height since stacking is not required.

When used for stacking operations, SCs can stack containers up to 4 high. Compared to RSs, SCs yield a lower storage area occupancy per container (including travelling lanes), 10-13 [m^2/TEU], considering a nominal stacking height of 3 containers (Ligteringen, 2017). SCs can also access all stacking rows, reducing the need of

[1] Joost J. Bakker from Ijmuiden, the Netherlands, CC BY 2.0 <https://creativecommons.org/licenses/by/2.0>, via Wikimedia Commons
[2] Alf van Beem, CC0, via Wikimedia Commons
[3] Figure from Kalmar website: https://www.kalmarglobal.com/news--insights/articles/2021/eco-efficiency-at-barbados-port/

reshuffling. Another difference compared to reach stackers is the lower wheel load, resulting in a lower bearing capacity requirement for the pavement (Thoresen, 2018).

SC present lower labour costs than RS, but a relatively high CAPEX and OPEX. They used to be diesel driven, but nowadays there are electric and hybrid versions available.

2.3.1.3. Rubber Tyred Gantry cranes

Rubber Tyred Gantry cranes (RTG) are a portal-frame gantry running on rubber tyres, equipped with a trolley that traverses its span, which in turn mounts hoist machinery that lifts the load using wire ropes (PIANC, 2021). They are used to receive, handle, and deliver container at the stacks. It must be combined with equipment for horizontal transport from the quay, usually TT. It is the most popular yard equipment worldwide (Alho et al., 2018).

They usually operate with blocks 5-10 containers wide and 4-6 containers high, plus one free lane along the block for trucks and TTs to deliver and receive containers from the stacks, as presented in Figure 2-4 left.

RTGs allow for a high stacking density, with a requirement of 6-8 [m^2/TEU] in the yard, considering a nominal stacking height of 5 containers (Ligteringen, 2017). This allows for a very efficient use of the land. The cranes can be moved between stacks, since they are driven over wheels, giving the terminal operator flexibility to focus operations according to demand. A typical RTG layout is presented in Figure 2-4 right.

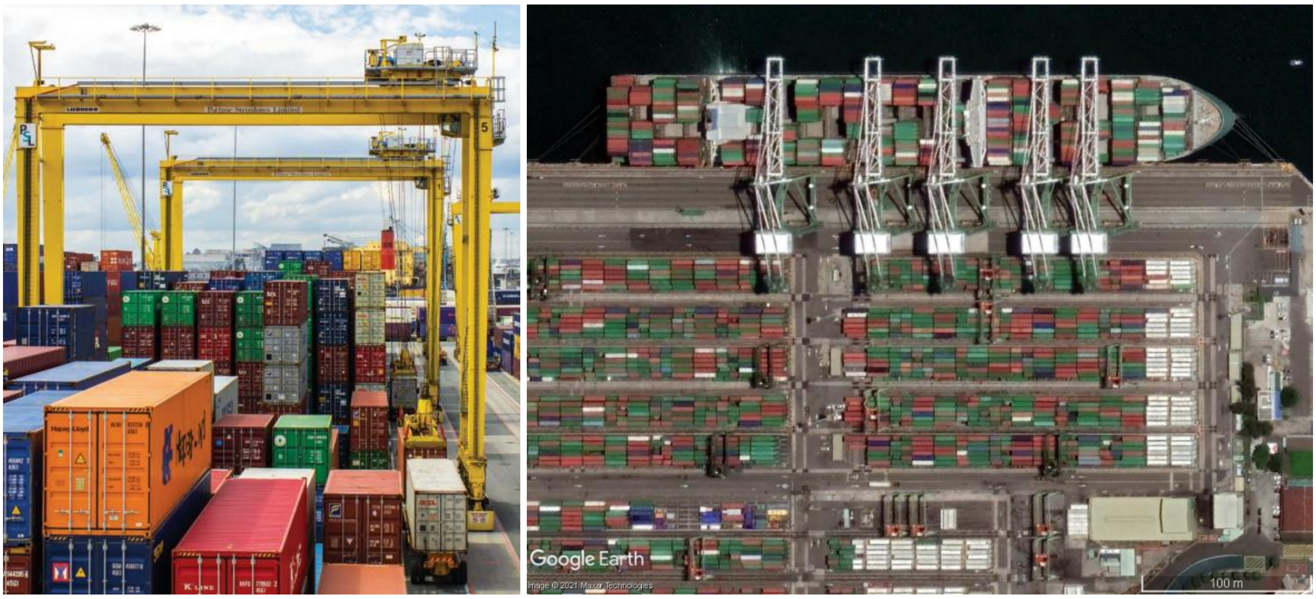

Figure 2-4: RTG operating[4] (left) and RTG terminal layout at Kaohsiung port in Taiwan (right).

[4] From https://www.liebherr.com/shared/media/maritime-cranes/downloads-and-brochures/brochures/lcc/liebherr-rtg-cranes-technical-description.pdf

RTGs used to be mainly diesel driven, given their autonomy to move around the terminal. Nowadays, electric and hybrid equipment are available and operating in several terminals.

2.3.1.4. Rail Mounted Gantry cranes

Rail Mounted Gantry cranes (RMG) are also yard equipment, like RTGs, but mounted on rails. This allows for faster movements and potentially a higher productivity, compared to RTGs (Huang and Chu, 2004, Koster, 2019). On the other hand, they cannot be moved between stacks, resulting in lower flexibility. They are usually larger and heavier, resulting in larger loads on the supporting structure than RTGs.

They usually operate with blocks of approximately 10 containers wide and 4-6 containers high. Two typical configurations can be observed, depending on where the cargo exchange occurs. When it occurs along the block side, then the cranes have a cantilever beam to cover the truck lanes, these are usually referred to as Cantilever RMGs or CRMG. Another configuration is that of the Automatic Stacking Crane (ASC), where cargo exchange occurs at the block ends. More details about ASCs can be found in §2.3.2.4.

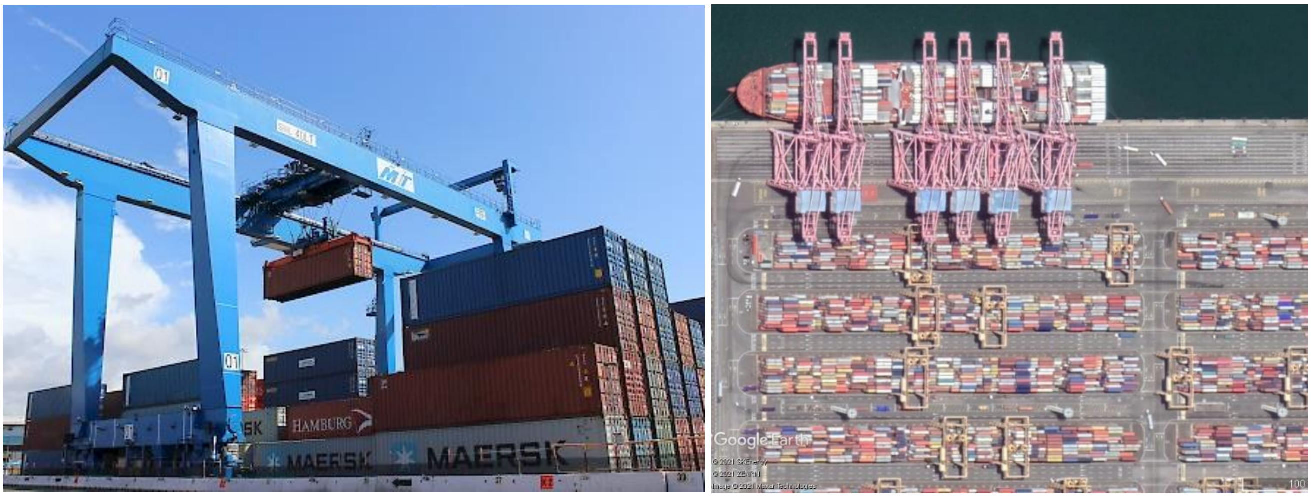

Figure 2-5: CARMG at MIT, Panama[5] (left) and CARMG terminal layout at Busan Port, South Korea (right).

RMGs allow for a similar stacking density as RTGs (Ligteringen, 2017) and typically are electrically driven.

2.3.1.5. Terminal Tractors

Terminal Tractors (TT) are the most common equipment for horizontal transport from the quay to the stacks and vice versa. They are similar to a truck cabin, but lighter and more manoeuvrable (PIANC, 2021). Containers are directly placed or taken from the chassis they carry, either by quay cranes, RTGs, RMGs or reach stackers. A TT is presented in Figure 2-6. TTs are typically diesel-powered.

[5] From https://www.mitpan.com/operaciones/equipos/

Figure 2-6: TT attached to a chassis during the transfer of a container[6].

2.3.2. Automation possibilities

According to the PIANC report WG 208 on automation (PIANC, 2021), automated versions of the RTGs, RMGs and SCs can be found in the market. Additionally, Automated Guided Vehicles (AGV) are used for horizontal transport, and lately automated TTs are being offered by different manufacturers, although no applications have been observed yet for the latter.

2.3.2.1. Reach stackers and forklifts

There are no automated versions of RS and FL. Hence, these will not be treated any further in this document.

2.3.2.2. Straddle Carriers

Automated SCs (auto SCs) were originally developed for the conversion of Patrick Terminals in the Port of Brisbane, starting operations in 2005. They were the first automated SC terminal in the world and the first brownfield automated terminal. According to Patrick Terminals, the driver for this project was to introduce process line concepts into container stevedoring and reduce costs, principally labour costs.

Manned shuttle carriers (ShC) or automatic Shuttle Carriers (aShC) are also used for horizontal transport purposes, usually in combination with ASCs.

2.3.2.3. RTG

An early attempt for RTGs with some level of automation was made in Japan, with the Tobishima Container Berth terminal in the port of Nagoya, Japan, where remotely operated RTGs with AGVs for horizontal transport were introduced in a greenfield fully automated terminal in 2005. But it was not until 2016 when automated

[6] https://www.kalmarglobal.com/equipment-services/terminal-tractors/TL2-Essential-Terminal-Tractor/

RTGs (aRTGs) were used in brownfield automation, in the TPKS terminal in the port of Semarang, Indonesia, and in the Sjursøya terminal in the port of Oslo, Norway. Thereafter, at least a dozen terminals have adopted aRTGs.

RTGs are the most common equipment in container yards. It is estimated that approximately 60% of the world's container terminals use RTGs (Alho et al., 2018). One of the driving goals of aRTG is the retrofitting of existing terminals, with minor changes in the overall geometry of the terminal (PIANC, 2021). This would result in a less invasive solution, compared to ASC for example. The CAPEX is also relatively low in terms of equipment and infrastructure, compared with ASCs (Kats, 2020).

Several levels of automation have been developed for RTGs, which could be applied in an incremental process (Alho et al., 2018). For example, Kalmar automated RTGs present 5 automation levels, from remote control, where all movements are controlled by a remote operator, to a fully automated RTG, where all movements are automated, and operators are only required for supervision and exception handling. Intermediate levels involve different supervised movements.

Old RTGs can also be retrofitted. Generally, old RTGs must be converted to electric ones to become automated, but the crane manufacturer Konecranes® also offers the possibility to retrofit diesel driven cranes into automated ones. The decision of retrofitting needs to consider the remaining lifetime of the structure.

2.3.2.4. RMG

Automated versions of the CRMGs are offered in the market, for instance, by the Chinese manufacturer ZPMC. Also, manned CRMGs have been retrofitted into automated ones, such as at the former Tianjin Five Continents International terminal, now part of Tianjin Port Container Terminal Co, in China.

ASCs are a popular choice for automated terminals. They are RMG cranes, usually disposed perpendicularly to the quay, where the cargo transfer occurs at both ends of the block, also called end loaded. The transfer between trucks and the stacks occurs on the land side, while the transfer between the stack and the horizontal transport system takes place on the quay side, usually with ShC (manned or automated) or AGVs. This segregates the manually operated truck traffic from outside the terminal and the potentially automated AGVs or ShC traffic. It also reduces the distances travelled by either trucks or horizontal transport equipment. An ASC layout is presented in Figure 2-7.

The blocks usually have 2 cranes. This way, land and quay operations can be performed at the same time. These cranes are commonly the same, but in some cases, like the HHLA terminals in Hamburg (CTA and CTB), one crane is slightly larger, allowing it to cross over the smaller ones, so 2 cranes can perform quay or yard operations at the same time (Saanen and Valkengoed, 2005). In the case of CTB Hamburg, 3 cranes per block are used, 2 small ones and 1 larger.

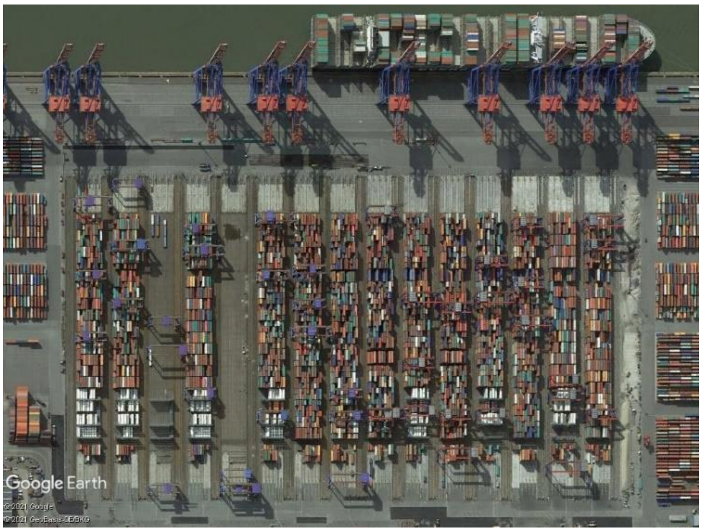

Figure 2-7: ASC terminal layout, CTB Hamburg.

2.3.2.5. Automated Guided Vehicles

AGVs were developed originally for the ECT's Delta/Sea-Land terminal, in the port of Rotterdam (Ligteringen, 2017). They are driverless rolling platforms, able to receive a container at the yard and transport it to the quay, and vice versa. Two kinds of AGV can be found in the market lift-on/lift-off (LOLO) AGV and lift AGV (PIANC, 2021). The former requires the yard crane to place or remove the container from the AGV, while the latter can drop or retrieve a container from a rack placed at the container transference interface. This ability allows for the decoupling of the operations in the stacks and the horizontal transport, which can result in a more efficient use of the equipment. Both kinds of AGV are presented in Figure 2-8.

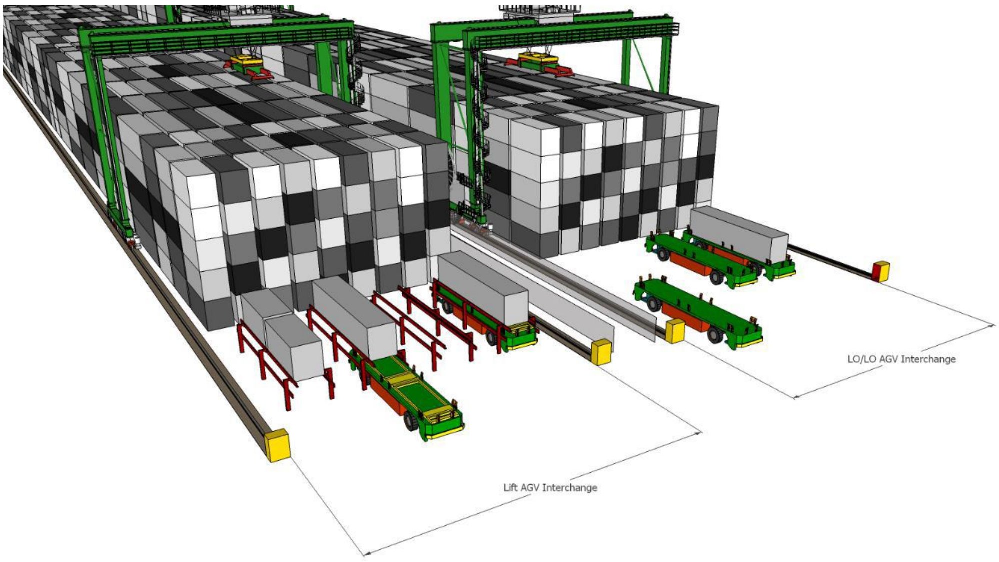

Figure 2-8: Lift and LOLO AGVs. Reproduced from(PIANC, 2021).

2.3.2.6. Automated Terminal Tractors

Recently, automated versions of TTs (aTT) are being offered. One of the advantages of aTTs when compared to AGV would be a less invasive and faster implementation in brownfield terminals already using TTs, especially considering that manned TTs are one of the most used equipment for horizontal transfer. An image of an aTT is presented in Figure 2-9.

Figure 2-9: automated TT[7].

2.3.3. Automation effects

The expected benefits from automating the yard are transversal to all equipment, however, the impact might be different depending on the type of equipment. The benefits are discussed in the following paragraphs.

2.3.3.1. Productivity and efficiency

Automated terminals are not necessarily more productive than manned ones. It has been reported that reaching expected theoretical productivities will take some time, productivity expectations might be set too high, and productivity gains from automation may even be negative (White, 2018). According to the McKinsey & Company survey from 2017, fully automated terminals expected productivities between 13% and 35% higher than manned ones but realized productivities between 7% and 15% lower. Some of that lower productivity could be attributed to exception handling. According to the same survey, “many ports find that exception handlings are the greatest single challenge for raising productivity” (Chu et al., 2018). Exceptions are non-standard cargo, such as out-of-gauge (OOG) or hazardous containers.

It is also possible that productivity, efficiency, and, as a result, profitability may increase. As presented in chapter 4, productivity is one of the drivers to automate. For example, according to Mr. Ivor Chow, CEO of HPH Trust and Managing Director of Hongkong International Terminals (HIT), “remote-controlled cranes are 20% more efficient and productive than purely manually operated ones”[8]. Although achievable improvements, if any, will depend on local circumstances, this statement underlines the expectations in the industry with regards to productivity enhancements.

In terms of cost-efficiency, savings can be achieved by reducing labour (discussed separately in the next section), reducing unproductive time, training costs, less wear and tear, and energy consumption (PIANC, 2021).

[7] https://www.konecranes.com/equipment/container-handling-equipment/automated-terminal-tractor
[8] https://www.worldcargonews.com/news/news/cosco-hit-opens-remote-operations-centre-for-rtgs-66875

Automated operation may allow these changes, with reduced labour requirements, easier shift changes, more precise movements from equipment, and optimised stacking (PEMA, 2016b).

2.3.3.2. Labour cost reduction

According to Alho et al. (2018), generally automated terminals will require a smaller but more highly trained staff. PIANC (2021) indicates a migration from a more manual, labour-intensive environment to a more data and systems driven environment is expected from automation. Therefore, a reduction in the number of operators with lower salaries is expected, but also an increase of IT personnel with higher salaries.

Automation is expected to reduce labour costs of operators. According to an example presented in PIANC (2021), a potential reduction between 40% and 60% could be achieved in operational labour costs (in that fictitious terminal). The actual reduction, however, depends on several factors, such as the type of automation chosen and local labour salaries. Terminals from high-income countries, where operator salaries are higher than in low-income countries, could face a more significant financial benefit (PIANC, 2021).

Regarding the new data and systems skilled personnel required, it may be more difficult to recruit experienced people in low-income countries. It could also be difficult in some high-income countries facing a high demand of these workers.

Depending on the automation level chosen, fully automated terminals are expected to require fewer operators than semi-automated ones. Therefore, there is a larger potential reduction in labour cost. Also, the kind of equipment is a factor. If only yard operations are automated, which is the most common automation for brownfield terminals as presented in §5.6.1, then savings from SC can be larger than for RMG and RTG, for the same automation level. According to Thoresen (2018), a manned SC approximately performs 10 moves/hr, while a manned RMG/RTG can vary from 15-25 moves/hr. So, for a certain number of moves, more people are required using SC than RMG/RTG. When converting to automation, more people are replaced by auto SC than aRMG/aRTG, which results in a more significant impact on labour costs.

For RTGs, RMG/RTGs automation could also result in savings in labour for periods with low working loads. According to Alho et al.(2018), "… a terminal might need to keep 10 RTGs manned at night even with only a few road trucks arriving because the required containers are located in different stacks around the yard". The same author indicates that with remotely operated cranes, 1 or 2 operators could keep the same 10 cranes running under a low working load. Under a high working load, 1 operator could operate 2 or 3 cranes. The number of remote operators required would also depend on the automation level of the cranes.

2.3.3.3. Safety and health

Safer operations can be achieved with automated operations (Martín-Soberón et al., 2014), with a proper safety design. This design usually translates into fences, controlled gates, sensor loops, laser scanners, among others (PIANC, 2021). When adequate safety layers are in place, automation reduces the possibility for human errors in the operation, reducing potential accidents that would endanger operators. There is also a strict separation between automated equipment and operators. The removal of operators from the quay and the yard eliminates the possibility of accidents involving people.

Working conditions are also greatly improved for workers. They do not need to remain hours within a moving cabin, subject to the effects of vibrations, noise, and fumes, but they can comfortably sit in an office. This reduces the risk for back problems, which has been reported for crane operators (Bovenzi et al., 2002).

2.3.3.4. Sustainability

Most automated equipment is electric. This means zero local emissions, and the potential use of electricity produced with renewable sources. Also, due to more efficient operation, energy consumption could be reduced. Finally, lower noise levels and fewer illumination requirements for overnight operations (PEMA, 2016b) may also result in a more sustainable operation.

Even if local emissions are reduced, emissions could occur elsewhere, depending on the source of the electricity. Also, if the equipment is battery powered, the environmental impact of battery handling and recycling must be addressed and mitigated (PIANC, 2021).

2.3.3.5. Predictability

Predictability is achieved due to more reliable and stable performance of automated operations compared to manned operations. This helps reduce the risk of delays when planning port operations.

2.3.3.6. Maintenance

Automation allows for smoother operations. This could result in less wear and tear of the equipment, allowing for lower maintenance costs (PEMA, 2016a). Also, data from the equipment can be easily gathered and analysed to better program maintenance operations.

2.3.4. Consideration of automated yard and horizontal transport processes

Yard operations and horizontal transport are the tasks that have been automated in container terminals. These are the tasks traditionally referred to when the concept of container terminal automation is used. Therefore, these tasks are the focus of this thesis and will be treated further on.

2.4. Quay processes

2.4.1. Description

Quay processes occur between the storage yard and the vessel. They involve picking up a container from the horizontal transport equipment, or the pavement, and loading it onto a vessel (or the opposite unloading process). The equipment used is either a ship's crane, a harbour crane, or an STS crane.

Only vessels up to feeder size have their own cranes, i.e., up to 1,800 [TEU] capacity and up to 240 [m] of LOA (Ligteringen, 2017). These relatively small vessels are used to carry cargo from large hub terminals to small terminals, where they sometimes need to use their own cranes. Since automated terminals are usually relatively large (the lowest capacity from terminals presented in Appendix C is 250,000 [TEU/year]), they always have quay cranes. Therefore, the use of the vessel's own crane is outside the scope of this work.

Harbour cranes are used in relatively small terminals, given their lower capacity (moves/hr) compared to an STS crane (Thoresen, 2018). Considering these terminals are usually not automated (see list from Appendix C) and given there are no automated alternatives for these cranes, they are outside the scope of this work.

Ship-to-shore cranes or STS are widely used for container transfer, due to its high capacity (30-40 lifts/hr with one trolley). These cranes have a beam that is displayed horizontally above a vessel when they are operating. When idle, they rest with the beam in vertical position.

For containers being loaded on a vessel, twist locks must be placed in the container's lower corners before loading. These are used to interlock containers with the container below them in the vessel (or with the deck). For unloaded containers, twist locks must be removed. This task may take place at the quay, or in a specific location where the container is taken in between the stack and the quay.

2.4.2. Automation possibilities

STSs with some automated movements of the trolley have been introduced in recent years. A remote operator is still required for some operations, such as lifting hatch covers and gantry movements (PIANC, 2021). Therefore, there are currently no fully automated cranes.

Other quay task that has been automated is the registration of containers handled by the STS, i.e., containers entering or leaving the terminal by sea (PIANC, 2021). This task is automated using several cameras mounted on the STS structure and OCR systems, which register container numbers.

Regarding the handling of twist locks, there have been efforts to develop equipment for partial or full automation of this task, like Bromma ALP/ALS system or RAM's Pin Smart, but in most terminals this task remains manual (PIANC, 2021). When applied, this equipment is mounted on the pavement, or, if available, on the lashing platform of the STS cranes.

2.4.3. Automation effects

The potential benefits are the same as described in chapter 2.3.3. Constant productivity and predictability, less wear, tear and maintenance, less energy consumption, safer operations and better working conditions for operators, are among the main benefits. Since manned STSs are electric, no change in local emissions or noise is expected from automation.

2.4.4. Automated quay processes

Automated twist lock handling has not been extensively used in ports, so little experience can be gathered from past conversions. The use of remotely operated STSs has started to grow recently. However, given their limited use so far and to limit the scope of this work, the primary focus of this thesis is on yard and horizontal transport processes.

2.5. Other processes

Other processes that have been automated in terminal are automated decision-making and automated mooring systems. Regarding decision making, automated processes can be used to plan berthing of incoming vessels in the different berths, cargo stowage, and yard management. These tasks are usually integrated in the Terminal Operating System (TOS) (Notteboom et al., 2021). As indicated in §2.1, the focus of this chapter is mainly on equipment and layout, so automated decision-making is not directly addressed any further.

Automated mooring systems have also been developed to reduce or eliminate the need to use mooring lines, reducing berthing and unberthing time for vessels and resulting in a safer operation (Kuzu and Arslan, 2017). Considering that most terminals still perform traditional berthing with ropes (Kuzu and Arslan, 2017), these systems will not be considered any further.

2.6. Summary of automation processes

A summary of the maritime container terminal processes is presented in Table 2-1. The first column presents the process category as presented in this chapter, the second column the subprocess, the third column presents the automated alternative, and the last column indicates if the process is within the thesis scope. A discussion on why certain processes are considered or excluded is presented in the respective sub-chapter. As presented in the chapter and in Table 2-1, only yard and horizontal transport processes and equipment will be considered for further analysis in this thesis, which are the processes traditionally referred to when the concept of container terminal automation is discussed (PIANC, 2021).

Table 2-1: maritime container terminal processes, automation possibilities and consideration in this thesis.

Category	Process	Automated alternative?	Whitin the scope of this thesis
Gate processes	Cargo and driver registration	Yes (online booking, OCR, self-check in)	No
	Weighing	Yes (embedded weighbridges)	
	Seal check	No (for regular seals)	
	Container condition and cargo inspection	Yes (remote inspection, scanner)	
Yard and horizontal transport processes	Container pick-up/drop-off on OTR (over-the-road) trucks.	Solutions available, but not often used	Yes
	Container pick-up/drop-off on ITVs (Internal Transport Vehicles).	Solutions available, but not always used.	
	Yard-quay transport.	Yes	
	Hoist, trolley, and gantry for cranes	Yes	
	Housekeeping	Yes	
	Rail terminal/yard exchange	Possible. Depends on terminal configuration.	
	Container handling in rail terminal	Remotely operated aRMG.	No
Quay processes	STS operation	Remote operation	No
	Twist lock management	Yes, but no applications observed	
Other processes	Decision making	Yes	No
	Berthing	Yes, but not often used	

3. Empirical research methodology

3.1. General

This chapter presents the methodology and procedures used to collect and process data from historic automation projects on brownfield container terminals. A framework based on the empirical research method on operations management presented by Flynn, et al. (1990) was established to answer SQ2 “how can the information on past conversions be systematically gathered and analysed?”.

3.2. Research approach

An empirical research methodology is proposed in this chapter to define a systematic approach to conduct the gathering and the processing of the data. The term “empirical” means “knowledge based on real world observations or experiment” according to Flynn, et al. (1990). For the purposes of this study though, these observations are not directly made from the field but requested from people deployed on the field through a questionnaire, gathered from the publicly available sources described later in this chapter, or observed from satellite imagery.

Flynn, et al. (1990) proposed a 6-step approach, the first 5 steps were considered in this thesis[9]. The methodology is presented in Figure 3-1. Definitions for each step are discussed in the next paragraphs.

Figure 3-1: empirical research systematic approach according to Flynn, et al.(1990).

Step 1: Establish the theoretical foundation:

Empirical studies can be used to either build or verify theory (Flynn et al., 1990). Theory verification requires clear hypotheses to be tested. Theory-building does not originate from a hypothesis, but from assumptions, frameworks or a perceived problem (Flynn et al., 1990). In this case, the development of a theory is not the final goal of this work, but a conscious attempt is made to compile empirical knowledge on brownfield automation, to help solve the perceived problem presented in §1.4. Therefore, a theory building approach is followed.

[9] The original paper presents an additional 6th step, “Publication”, which does not apply for this study.

With this approach, knowledge is grounded on data. According to Flynn et al. (1990), a conscious attempt at theory building would prevent the degeneration of the research into what is called “data dredging”, i.e., “the ad hoc collection and analysis of data for whatever conclusions can be found” (Flynn et al., 1990).

Step 2: Select research design

The research took place by analysing multiple case studies, since it allows managing data of several research units (Flynn et al., 1990) but a relatively small number (Verschuren et al., 2010). This fits well with the relatively small number of historic brownfield conversions, a s presented in §1.3.

Step 3: Selecting a data collection method

Two data collection methods were used in this thesis, a questionnaire, and desk research on publications.

A questionnaire was chosen as a first approach to gather experiences from past conversions, particularly about drivers (SQ3) and challenges of automation (SQ4). Details about the questionnaire are presented in §3.3.

This information was completed with desk research. Characteristics of the terminals before and after converting, namely terminal equipment and size, were gathered from publicly available sources presented in §3.4.2.

Step 4: Implementation

In this step, population selection, sample selection, questionnaire construction, and mailing are the main issues to address. For this work, the population targeted is existing terminals that have converted, or are in the process of converting, to some level of automated operations. Some terminals were retrieved from the PIANC report MarCom WG Report n° 208 – 2021, Planning for Automation of Container Terminals (PIANC, 2021), and complemented with terminals identified from the list of sources mentioned in §3.4.2.

The number of terminals identified is relatively small (30 terminals). Considering that the total number of automated terminals is already small (~80) and given that most of them are greenfield developments, the number of brownfield automated terminals is expected to be small. Therefore, the sample of 30 terminals is expected to be close to the population of converted terminals. So, biases between the sample and the population are considered negligible. A respondent analysis is to be performed to analyse the potential biases between respondents and the sample. This analysis is presented in §3.3.3.

The questionnaire construction process is presented in §3.3. Within each terminal, management positions were targeted, given their wide strategic vision on the projects. Mainly terminal managers and operations managers were targeted. People were identified from the terminal websites and from LinkedIn™. Sources and data gathered from the desk study are presented in §3.4.

Step 5: Data analysis

Data gathered for this research is mainly qualitative. There is a perception that qualitative research is not rigorous (Ngulube, 2015). Thus, clear rules for qualitative data analysis are relevant to produce reliable results.

A thematic analysis approach was followed, which is possibly the most widely used method of qualitative data analysis (Ngulube, 2015). The process starts with data that is reduced into codes and themes; then conclusions are drawn from the transformed data (Ngulube, 2015). The process of data reduction is divided in 3 stages (Alhojailan, 2012):

- Preparing and organizing the data: this process involves the preparation and initial reading of the data. In this case, answers were collected in a spreadsheet for each question.
- Highlighting relevant sentences: to identify these sentences the text should be screened keeping in mind the research questions, to be able to relate both (Alhojailan, 2012).
- Breaking down sentences into themes: the entire set is coded with initial labels. Then, these codes are collated into themes. Relationships are analysed from these themes (Ngulube, 2015).

The process was done per question since they refer to different aspects. The first two steps involved ordering and reading the data and they are not explicitly presented in this report. The third step regarding codes and themes is presented in Appendix D.

Regarding the data obtained from publications in what has been called desk research, terminals were also categorised, but in terms of semi- or fully automated solution, and regarding the type of yard equipment. These categories were then compared with terminal characteristics to identify trends, i.e., tendencies towards certain automated solutions for terminals with specific characteristics.

Given the small number of case studies, statistical testing was discarded. Moreover, since the purpose of the research in this case is theory building, "confirmatory statistical analysis is not expected or desired" (Flynn et al., 1990).

A summary with the definitions presented herein is presented in Figure 3-2.

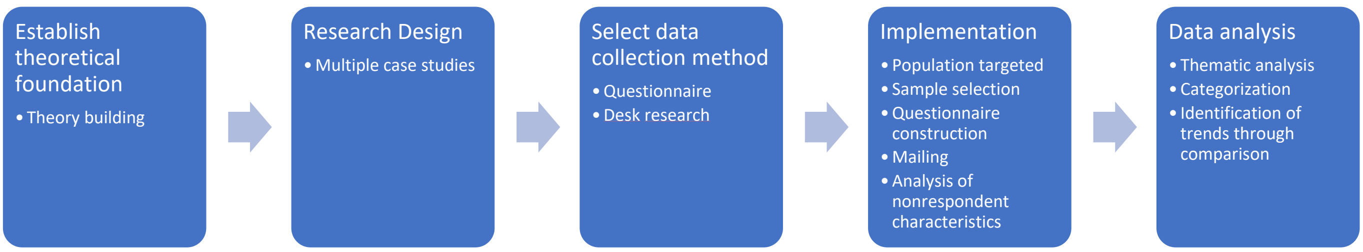

Figure 3-2: defined research methodology.

3.3. Questionnaire

3.3.1. Questionnaire construction

To answer SQ3, i.e., "what are the main drivers for automating existing terminals?", the question "**What were the main drivers to automate the operation of your terminal?**" was included in the questionnaire. With these answers an overview of motivations was built.

Equipment used before automation was determined from terminal websites or from the other sources presented in §3.4.2. This was not directly asked to keep the questionnaire short, increasing the likelihood of receiving answers (Flynn et al., 1990). To determine the equipment after conversion, the question "**What is the automation level selected and why? Is further automation being considered in the future?**" was included. The automation level could also have been determined from public sources, but the justification could not. The second question was included to get a general evaluation of automated technologies.

To answer SQ4, i.e., "what are the main challenges, and how have these been addressed during the conversion process?", the open question "**From your experience, what are the main challenges of developing and implementing new automated operations?**" was included in the questionnaire. Also, questions directly addressing how the main challenges were dealt with were included. To determine these main challenges, a preliminary list of challenges was developed, based on literature and interviews to experts in the field[10]. These preliminary challenges and a discussion to determine the main ones are presented in Appendix A. The questions included in the questionnaire are the following:

- **How were the automation works planned to give continuity to the terminal operations and services?**
- **How were labour relations managed to face the possible loss of jobs?**
- **How was the handling of exceptions considered? Were there any exceptions that were not considered initially?**
- **How long was the commissioning period and how long was the ramp-up period?**

Additionally, the question "**What benefits and drawbacks are observed from the automated operation?**" was included to directly evaluate the results from automating the terminals.

Regarding continuity of operations, it is expected to be less challenging to convert a very large RTG/RMG terminal block by block, than converting a small RTG terminal with only 2 blocks. Therefore, knowing the terminal size is also desired. For the nominal capacity, the question "**What is the design throughput of your terminal in [TEU/year] before and after automating?**" was included in the questionnaire.

Summarizing, a questionnaire with 9 questions was developed. The questionnaire is presented in Appendix B.

3.3.2. Sample: list of converted terminals

An updated list of converted terminals or terminals being converted was developed. A first draft was obtained from the PIANC MarCom WG Report n° 208 – 2021. Twelve terminals were added to the list, from the sources indicated on §3.4, totalising 30 terminals[11]. Only 29 terminal operators could be identified. Therefore, the sample of terminals studied was reduced to 29.

The complete list, including equipment used and terminal size, is presented in Appendix C. Some terminal operators who replied, asked not to be directly mentioned in the report. These terminals are referred to as

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[10] Interviews with Bob Post from Royal HaskoningDHV, Remmelt Thijs from TBA, and Christopher Saavedra from Kalmar.
[11] This list was closed on May 15th, 2021.

Terminal X plus the region where they are located. A map with the approximate location of the 29 terminals studied is presented in Figure 3-3.

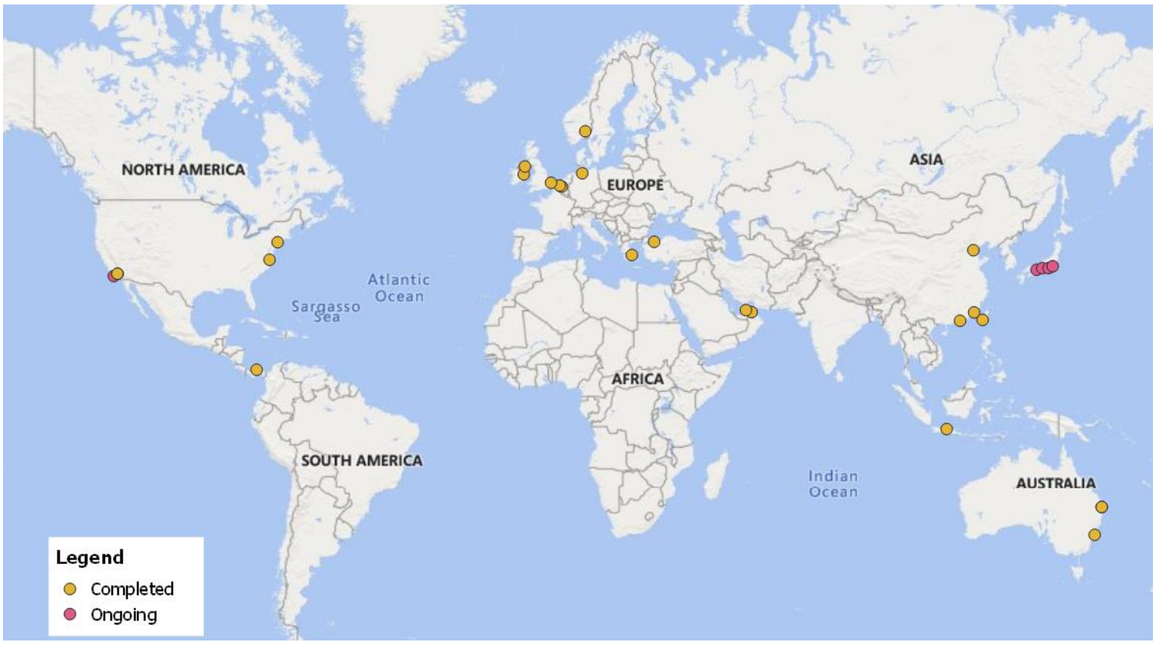

Figure 3-3: completed and ongoing container terminal conversions worldwide (source: own elaboration over Google Maps™).

Terminal managers, operation managers, or automation managers for all terminals were targeted, although it was not always possible to identify them. They were contacted either via email when available, or through LinkedIn™. If no names were identified, terminals were contacted through their general enquiry's emails available on the terminal websites.

Additionally, headquarters of international operators were addressed with the questionnaire, indicating what were the terminals of interest. Particularly this was the case for APM terminals, CSPL, DP World, Hutchison Ports, and Yilport.

3.3.3. Respondent analysis

Twelve answers out of 29 were received. These terminals are presented in Table 3-1. These responses represent a 41.4% response rate. According to Flynn et al.(1990), researchers in social sciences look sceptically at surveys with response rate below 40-60%, but studies in operations management literature have been published with response rates below 10-20%. They also recommend setting a higher standard, around the 50% response range and to include respondent analysis for more reliable results. The response rate of this study is considered sufficient.

Answers received in this study represent the opinions of the people who responded to the questionnaire; these do not necessarily represent the official position of their respective companies. Respondents' positions within each terminal are presented in Appendix C.

Table 3-1: terminal operators with responses to the questionnaire.

Number	Country/ Region	Port	Terminal	Operator	Year of automation
1	Australia	Brisbane	Fisherman Islands Terminal	Patrick Terminals	2005
2	Australia	Port Botany	Sydney AutoStrad Terminal	Patrick Terminals	2014
3	Germany	Hamburg	Burchardkai	HHLA	2010
4	Ireland	Dublin	CT N°50 berth	Dublin Ferryport T.	2017
5	Japan	Nagoya	Nabeta	Nagoya United	2023
6	Japan	X	X	X	2025
7	Netherlands	Vlissingen	Blijeveldhaven	Kloosterboer CT	2020
8	Middle East	X	X	X	2017
9	Panama	Colon	Manzanillo	MIT	2015
10	Turkey	Yarımca	Yarımca	DP World Yarımca	2018
11	UK	Belfast	Belfast Container Terminal	Belfast CT (ICG)	2020
12	USA	Virginia	Norfolk International Terminals	VIT	2018

A respondent's analysis was performed, according to the empirical research method, to identify potential biases. Four characteristics of respondents and of the entire sample were compared: the kind of operators that have answered the question (single terminal or multi-terminal operator), the kind of equipment operators used before automating, the kind of equipment after automating and the size of the terminal.

Operators from the sample and from respondents are compared, because it is expected that the global operators could be more open to automation than local ones, since they already may have the experience of automating other terminals. This hypothesis was not proved during this thesis. From the 29 terminals contacted, 24 are multiterminal operators, i.e., they operate more than one terminal in different ports. Some of them in the same country, such as Patrick Terminals, with 4 terminals in Australia. Some others with dozens of terminals worldwide, such as DP World. From respondents, 9 are multiterminal operators and 3 single terminal operators. Therefore, all kinds of operators are represented within the respondents.

The kind of equipment after conversion from the sample and from respondents are compared, to determine whether all potential solutions are covered within the responses. The number terminals per type of equipment after conversion are shown in Table 3-2 for yard equipment, and in Table 3-3 for horizontal transport equipment.

Table 3-2: type of yard equipment before and after automation. Total sample and respondents only.

Stacking equipment	Total population				Respondents			
	Before conversion		After conversion		Before conversion		After conversion	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
RMG	3	10%	-	-	1	8%	-	-
aRMG (ASC, CARMG)	-	-	13	45%	-	-	3	25%
RS	2	7%	-	-	1	8%	-	-
RTG	13	45%	-	-	6	50%	-	-
aRTG	-	-	12	41%	-	-	7	58%
RTG/chassis	3	10%	-	-	-	-	-	-
SC	8	28%	-	-	4	33%	-	-
auto SC	-	-	4	14%	-	-	2	17%

Table 3-3: type of horizontal transport equipment before and after automation. Total sample and respondents only.

Horizontal transport equipment	Total sample				Respondents			
	Before conversion		After conversion		Before conversion		After conversion	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
AGV	-	-	3	10%	-	-	-	-
SC	9	31%	4	14%	5	42%	2	17%
auto SC	-	-	3	10%	-	-	2	17%
ShC	-	-	2	7%	-	-	-	-
aShC	-	-	1	3%	-	-	-	-
TT	20	69%	16	55%	7	58%	8	67%

Respondents using all kinds of container yard equipment answered the questionnaire, except for terminals using chassis/RTG for stacking. Chassis terminals are usually located in the US, and present large yards due to the high area utilization per TEU of chassis. Results from the questionnaire may not be representative for these terminals.

Regarding horizontal transport, no responses from terminals using AGVs or ShC were received. Moreover, only 2 responses from fully automated terminals were received, both using auto SC. Questionnaire results may not be representative for other type of terminals converting to full automation.

Terminal capacities in [TEU/year] and yard areas in [ha], before converting, are compared between the sample and respondents, according to the definition presented in §3.4.2,. Histograms are presented in Figure 3-4.

In the upper graphs of Figure 3-4 it is observed that most of the terminals have capacities below 3 million [TEU/year]. These terminal capacities are well represented in the respondents group. Terminals above this capacity are almost non-existent in the sample (except for one outlier). Questionnaire results may not be representative of terminals with a capacity larger than 3 million [TEU/year].

From Figure 3-4, it is observed that most of the terminals have yard areas below 70 [ha]. These terminals are well represented in the respondents group. Two terminals present much larger areas. Questionnaire results may not be representative of terminals with yard areas larger than 70 [ha].

No biases were detected between respondents and the sample. Since the sample is considered representative of the population of terminals, biases between population and respondents are considered negligible. However, this does not mean results can be generalised. The small number of subjects in the population results in an even smaller number of respondents. Not robust enough rules can be inferred with too few subjects. Therefore, results should not be directly extrapolated to future conversions but used only as a reference.

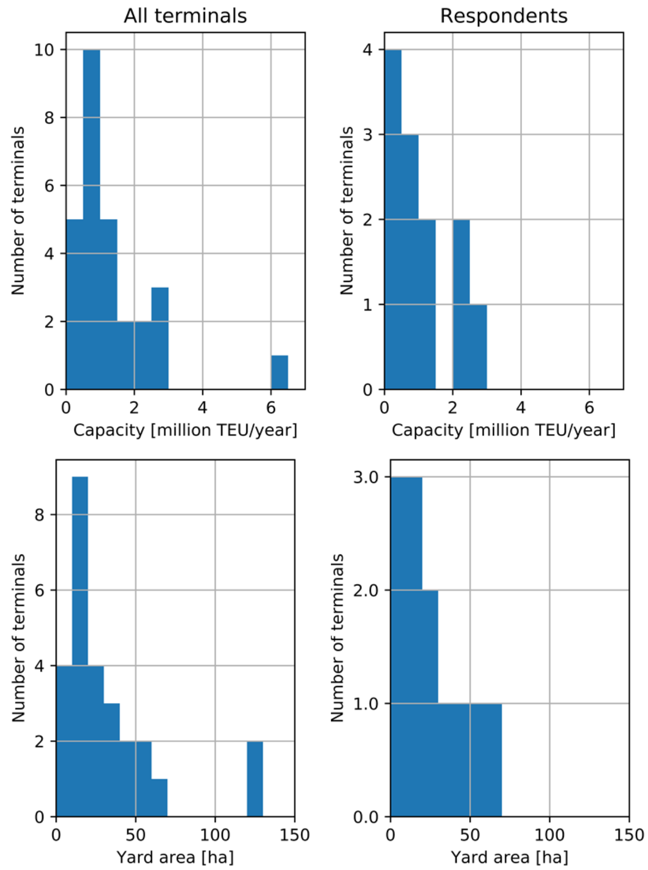

Figure 3-4: terminal capacities (above) and terminal yard areas (below). Sample (left) and respondents (right).

3.4. Desk study

3.4.1. General

To answer SQ6, i.e., “what are the main trends observed regarding the type of automated technologies chosen?”, the solutions implemented in all 29 terminals from the sample were studied. The following information was determined from the desk study for all terminals in the sample:

- Yard and horizontal transport equipment before and after conversion.
- Terminal size: yard area, quay length, and nominal capacity.
- Satellite imagery.

3.4.2. Information sources

The main sources of information are listed below. All sources are also included in the bibliography.

- PIANC report WG208 “Planning for automation of container terminals”
- The specialised journal Port Technology International.
- Whitepapers from equipment suppliers: Kalmar, Konecranes, ZPMC.
- Port Equipment Manufacturers Association (PEMA) publications
- Specialised media sites: World Cargo News, Port Strategy, Port Technology International.
- Google Earth™ imagery.

- Attendance to the Container Terminal Automation Conference 2021.

Terminal equipment before and after conversion were determined either from the terminal website, publications, or from Google Earth™ imagery. Images before and after the conversion year were gathered. Physical changes were tracked by comparing subsequent images.

Regarding the size of the terminals, data on 3 different measures were considered:

- Terminal capacity: in this document, terminal capacity refers to the nominal throughput in [TEU/year]. This capacity was directly asked to questionnaire respondents. For non-respondents, it was found in terminal descriptions, usually on the terminal website, or other publications from the list above. It represents the number of moves measured in TEU the terminal is capable to perform over the quay, where one move corresponds to either an import or export. A transhipment TEU will be counted twice.
- Terminal yard area: the yard area in hectares was measured. The entire yard was considered, including empties and internal roads, leaving out road lanes between the yard and the apron, between the yard and the gates, and the apron and gate areas. Buildings, parking lots, and workshops were also left out. These areas were measured from Google Earth™ satellite imagery. An example is presented in Figure 3-5.

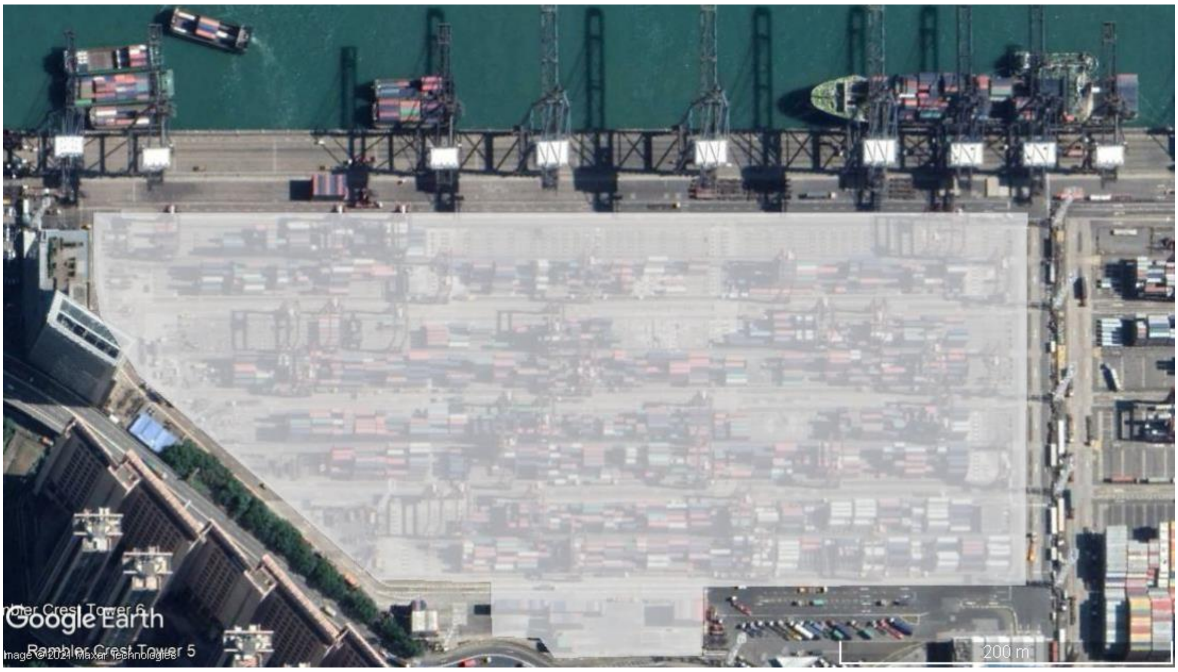

Figure 3-5: yard area for T9 North, Hong Kong Internaitonal Terminals.

- Terminal quay length: the quay length was also measured from Google Earth™ satellite imagery.

3.4.3. Data analysis

Classification of terminals in groups after conversion were made to identify trends regarding what type of automation is being adopted by brownfield converted terminals, and what kind of yard equipment is being chosen. Therefore, terminals were classified according to the following categories:

- Semi- or full automation.
- Type of automated yard equipment.

Only yard equipment was classified. Horizontal transport equipment is related to the type of yard equipment.

Also, satellite imagery was analysed to evaluate the conversion process. Images from before, during and after converting were observed. Changes were tracked and interpreted, to roughly determine a high-level description on the implementation strategy.

Comparisons of these categories with equipment used before and after conversion, and with terminal yard size, were performed to identify trends in these past conversions. Regarding yard size, the comparison parameter was always the yard size after converting, given that this is the size used to plan the automated terminal. Results are presented in chapter 5.

4. Questionnaire and desk study results

4.1. General

In this chapter, the data gathered from the questionnaire and results from the desk study are presented. The analysis of the data is presented in chapter 5.

4.2. Questionnaire results

The complete questionnaire is presented in Appendix B.

Answers to question 1 “what is the design throughput of your terminal in TEU/year before and after automating?” are presented in Appendix C.

Answers to question 3 “what is the automation level selected and why? Is further automation being considered in the future?” are presented without applying thematic analysis. For the first question, results are presented in Table 4-2. For the second question, only the number of respondents indicating “yes” or “no” were counted; results are presented in §4.2.7.

Answers to question 7 “how long was the commissioning period and how long was the ramp up period?” are also presented without thematic analysis. Periods and comments are presented in Table 4-6.

For the remaining questions, i.e., 2, 4, 5, 6, 8 and 9, a thematic analysis was followed to reduce the number of responses to categories. Results are presented in this chapter. The processing is presented in Appendix D.

4.2.1. Drivers for automation

Answers to the questions “**Why did you decide to automate? What were the main drivers?**” were categorised. Results are presented in Table 4-1. The first column identifies the terminal name. Driver’s categories are presented along the first row. Terminals indicating a certain category as a driver are marked with an ‘X’.

Yarımca terminal did not provide any drivers, since they indicated it was a proof of concept suggested by their headquarters to evaluate results.

The most frequently mentioned driver for automation was operating cost reduction with 7 out of 11 responses. The second most mentioned driver was labour shortage with 5 mentions, the third one productivity with 3 mentions, and the fourth one is capacity with 2 mentions.

Table 4-1: drivers indicated by respondents for converting to automated operations.

Terminal name	Operating cost reduction	Higher capacity	Higher productivity	Reliability/ Safety	Sustainability	Predictability	Labour shortage	Marketing	Government subsidy
Fisherman Island (Patrick)	X								
Sydney AutoStrad (Patrick)	X								
CTB Hamburg	X		X	X					
CT N°50, Dublin	X						X		
Nabeta			X				X		X
Japan, X							X		
Blijeveldhaven (Kloosterboer)			X		X		X		
ME, X				X		X			
Manzanillo	X	X						X	
Yarımca	*PoC proposed by HQ. No clear drivers. Opportunity to evaluate the benefits.*								
Belfast CT	X						X		
Norfolk International	X	X		X					

4.2.2. Automation level selected

Answers to the question "**What is the automation level selected and why?**" are shown in this subchapter. The question objective is twofold. On one hand it is asked to describe the automated solution, on the other hand a justification for that decision is requested. Answers are reproduced in Table 4-2. The first column presents the name of the terminal; the second column presents the type of automated solution adopted; and the third column presents the justification.

Table 4-2: automated solution chosen and justification.

Terminal name	Automated solution	Justification from terminal operators
Fisherman Island (Patrick)	FA auto SC	Patrick used SCs, so it was decided to automate them. Equipment did not exist but was developed by pioneering work with the University of Sydney Robotics Centre.
Sydney AutoStrad (Patrick)	FA auto SC	
CTB Hamburg	SA SC+ASC	High automation level in a 5-year plan.
CT N°50, Dublin	SA TT+aRTG	Stack automation, store, shuffle and retrieve order. Manual gantry, lift on / off trucks below 7m. Variation in trailer design and scope.
Nabeta	SA TT+aRTG	Terminal's high density prevents horizontal transport from automating.
Japan, X	SA TT+aRTG	The automated RTGs means automatic operation except handling containers from/to chassis (crewed trucks) which is fixed by labour standard law of Japan.
Blijeveldhaven (Kloosterboer)	SA TT+aRTG	Currently it is only the RTGs, but further automation is being considered.
ME, X	SA TT+aRMG	Automation level they are comfortable with, based on the maturity of the automation systems available in the market.
Manzanillo	SA TT+aRTG	Automated stack movements and to ITVs. Remote operation of OTR trucks.
Yarımca	SA TT+aRTG	The terminal already had eRTG, same equipment was used.
Belfast CT	SA TT+aRTG	Extended from the previous conversion in Dublin.
Norfolk International	SA SC+ASC	SA due to union labour restrictions, improved vessel productivity, better agility in dealing with disruptions, lack of maturity in the control systems for FA.

Note: FA: full automation; SA: semi-automation.

4.2.3. Challenges

Answers to the question “**From your experience, what are the main challenges of developing and implementing an automated container terminal?**” were categorised. Results are presented in Table 4-3. The first column identifies the name of the terminal. Challenges’ categories are presented along the first row. Terminals indicating a certain category as a challenge are marked with an ‘X’.

Table 4-3 challenges indicated by respondents to convert to automated operations.

Terminal name	**Continuity**	**Labour relations**	**Suppliers**	**System development**	**Integration of systems**	**Adaptation to new operations**	**Communication System**	**Infrastructure**	**Local market**	**Variation and gaps in scope**	**Optimization for higher productivity**
Fisherman Island (Patrick)		X									
Sydney AutoStrad (Patrick)	X	X									
CTB Hamburg	X										
CT N°50, Dublin							X			X	
Nabeta											X
Japan, X			X	X							
Blijeveldhaven (Kloosterboer)					X						
ME, X								X	X		
Manzanillo						X					
Yarımca						X	X				
Belfast CT											
Norfolk International	X					X					

Results are more varied and scattered than for drivers. The most mentioned challenges were continuity and adaptation to new operations with 3 mentions each.

4.2.4. Continuity

Answers to the question “**How were the automation works planned to give continuity to the terminal operations and services?”**, were categorised. Results are presented in Table 4-4. The first column identifies the name of the terminal. Continuity categories are presented along the first row. Terminals indicating a certain continuity category are marked with an ‘X’.

Half of the respondents indicated that a phased approach was the solution to give continuity to operations. One terminal indicated their conversion was closer to a greenfield project since they developed a new automated terminal in a different location, then gradually moved operations to the new terminal. In this report this approach was named “Greenfield-like”. Another respondent indicated an adjacent test site and then fast rolling out of the technology by shutting down the terminal for 3 days; this approach has earlier been described as a “big bang” approach (Saanen, 2004). Two other terminals indicated continuity not to be a problem due to idle yard capacity.

Table 4-4 strategies to overcome the challenge of continuity indicated by respondents.

Terminal name	Phased approach	Under-capacity operation	Adjacent berth for trials + fast rollout	Test bed within the footprint	Greenfield-like	Fall back solutions	Strategic partners	Communication
Fisherman Island (Patrick)					X			
Sydney AutoStrad (Patrick)			X					
CTB Hamburg	X					X		
CT N°50, Dublin				X				
Nabeta	X							
Japan, X	X							
Blijeveldhaven (Kloosterboer)		X						
ME, X	X							
Manzanillo	X							
Yarımca		X						
Belfast CT	X							
Norfolk International								X

4.2.5. Labour relations

Answers to the question "**How were labour relations managed facing the possible loss of jobs?**", were coded. Results are presented in Table 4-5. The first column identifies the name of the terminal. Labour strategies are presented along the first row. Terminals indicating a certain category are marked with an 'X'.

Table 4-5: labour strategies.

Terminal name	Negotiation with unions				Unions did not oppose	No union	Staff retained, growing terminal	Personnel not member of a syndicate
	Compensations	Relocations	Communication strategies	No details				
Fisherman Island (Patrick)					X			
Sydney AutoStrad (Patrick)	X							
CTB Hamburg	X	X	X					
CT N°50, Dublin			X				X	
Nabeta		X						
Japan, X				X				
Blijeveldhaven (Kloosterboer)							X	
ME, X		X						
Manzanillo								X
Yarımca						X		
Belfast CT			X				X	
Norfolk International							X	

Most terminals had to negotiate with unions. The most repeated strategy within these negotiations were "Relocations" and "Communication strategies". Regarding the latter, it was indicated that opportunities were explained. The necessity to secure future jobs was one of the main arguments.

4.2.6. Commissioning and ramp-up process

Commissioning is the process of ensuring that all systems and components of the new equipment are installed, tested, and operating properly. The ramp-up process is the process from the go-live, i.e., the start of operations with revenue cargo (PIANC, 2021), until the theoretical or expected productivity are reached. Answers to the question "**How long was the commissioning period and how long was the ramp up period?**" are presented in Table 4-6. Only 5 answers about the ramp-up and 2 about the commissioning periods were received.

Table 4-6: commissioning and ramp-up periods.

Terminal name	Commissioning [month]	Ramp-up [month]	Comments from respondents
Fisherman Island (Patrick)	NI	24	Long period influenced by new technology up to that date.
Sydney AutoStrad (Patrick)	NI	NI	Short period due to previous experience with Brisbane.
CTB Hamburg	NI	6-12	-
CT N°50, Dublin	12	10	Only for the first 2 aRTG. Commissioning for next 2 aRTGs 2-3 weeks.
Nabeta	NI	NI	Under commissioning up to the date of this report.
Japan, X	NI	NI	It was only informed that the project was evaluated for 10 years.
Blijeveldhaven (Kloosterboer)	NI	NI	Dedicated team plus consultant managed the processes.
ME, X	NI	NI	Depends on vendors.
Manzanillo	NI	NI	Integration and training tests started 1 year before the equipment arrival.
Yarımca	12	>4	It took 4 months to take operators off the yard.
Belfast CT	NI	NI	-
Norfolk Int.	NI	<4	Most participants had experience with automated operations.

NI: not informed

4.2.7. Benefits, drawbacks, and further automation

Results of two questions are presented. Firstly, answers to the question "**What benefits and drawbacks are you seeing from your automation?**", are analysed. Then, answers to the second question of "What is the automation level you selected and why? **Are you considering any further automation in the future?**" are also presented.

Answers to "**What benefits and drawbacks are you seeing from your automation?**" were categorised. Benefit categories are presented in Table 4-7. The first column identifies the name of the terminal. Benefit categories are presented along the first row. Terminals indicating a certain benefit are marked with an 'X'. Drawback categories are presented in Table 4-8. The first column identifies the name of the terminal. Drawback categories are presented along the first row. Terminals indicating a certain drawback are marked with an 'X'.

Norfolk International answered "promises related to the business case that drove the decision were fulfilled". No details about the business case were given, therefore no categories could be defined for this answer.

Table 4-7: benefits observed from automation as indicated by respondents.

Terminal name	OPEX reduction	Better working conditions	Increased productivity	Faster shift changes	Reliability / Safety	Decrease on footprint	Standardisation/ Integration with stakeholders	Moving to an AI terminal	Predictability
Fisherman Island (Patrick)	X	X			X				
Sydney AutoStrad (Patrick)	X	X			X				
CTB Hamburg	X								
CT N°50, Dublin	X	X							
Nabeta	X		X		X				
Japan, X							X	X	
Blijeveldhaven (Kloosterboer)		X				X			
ME, X					X				X
Manzanillo							X		
Yarımca		X		X					
Belfast CT	X	X							
Norfolk International	*Unable to process answer.*								

Table 4-8: drawbacks from automation as indicated by respondents.

Terminal name	Non-existent	Removal of expert performance	Lower average productivity	Unpredicted technical issues/ High impact of failures	Higher maintenance cost	Long time for exception and breakdown handling	New skills for staff
Fisherman Island (Patrick)	X						
Sydney AutoStrad (Patrick)	X						
CTB Hamburg	NI						
CT N°50, Dublin		X	X	X			
Nabeta					X		
Japan, X			X	X			
Blijeveldhaven (Kloosterboer)	NI						
ME, X						X	
Manzanillo	NI						
Yarımca							X
Belfast CT	NI						
Norfolk International							X

NI: not informed

Regarding answers to the question "**Are you considering any further automation in the future?**", 10 out of 12 respondents answered affirmatively. The other two terminals, Japan X and Norfolk International, answered "not for now".

4.2.8. Handling of exceptions

Answers to the question "**How did you consider the handling of exceptions in your planning? Were there any exceptions that were not considered originally?**" were categorised. The process yielded only one category, i.e., exceptions were always handled with a manned crew. “Forklift and terminal tractors” is the answer for both fully automated auto SC terminals. Other terminals would use the automated equipment with remote operation.

4.3. Desk study results

A desk study was performed to describe all terminals from the sample presented in §3.3.2, i.e., 29 terminals. Terminal throughput, yard area, quay length, and yard and horizontal transport equipment before and after converting to automation were determined, with the goal of establishing the trends regarding the type of automated solution adopted. The results are presented in Appendix C and discussed in chapter 5.

Also, satellite images from the conversion process were obtained for the terminals of the sample, to evaluate the implementation process. The images were obtained to analyse visually answers to the question “how were the automation works planned to give continuity to the terminal operations and services?”, and to evaluate if these strategies were also applied in other terminals from the sample. Some of these images are presented and analysed in chapter 5. All images are presented per terminal in the terminal conversion datasheets described in §5.7 and included in Appendix E.

5. Data analysis and findings

5.1. General

In this chapter results presented in chapter 4 are analysed to answer SQ4, SQ5, SQ6, and SQ7, i.e.:

- What are the main drivers for automating existing terminals?
- What are the main challenges, and how have these been addressed during the conversion process?
- What are the benefits and drawbacks observed from past brownfield automation projects?
- What are the main trends observed regarding the type of automated technologies chosen?

5.2. Drivers and benefits of brownfield automation

To answer SQ4 "what are the main drivers for automating existing terminals?", relevant results from the questionnaire and desk study are discussed. Since drivers could be understood as expected benefits, these are also analysed in this section. This way, the benefit part of SQ6 “what are the benefits and drawbacks observed from past brownfield automation projects?” is also answered. The sub section includes observations made by the author depending on the insights gathered during the research.

The main drivers for brownfield automation are found to be operating cost (OPEX) reductions, labour shortage, productivity increase, reliability/safety, and capacity. Other drivers identified are sustainability, predictability, and marketing. The main benefits are similar to drivers, i.e., OPEX reductions, better working conditions (it can be compared to labour shortage), and reliability/safety, which is interpreted like expectations were generally met. Higher productivity, and predictability were also mentioned. Whether these drivers and benefits will be achieved by a certain terminal cannot be assumed a priori from automation only. Terminals evaluating the incorporation of automation should set their objectives during the initial business case planning. Then, solutions targeted to achieve them will be chosen. Finally, other consequences from those solutions can be evaluated. A detailed discussion is presented as follows.

The most frequently mentioned drivers for automation in questionnaire answers were identified as the main ones. The main driver is OPEX reduction, mentioned by 7 out of 12 respondents. OPEX reductions are expected from labour costs, maintenance, and power consumption (PIANC, 2021). Labour may represent one of the largest savings (PIANC, 2021, Saanen, 2004), but this is heavily dependent on the local labour market. Terminals from high income countries may present a higher financial benefit, due to higher salaries (PIANC, 2021). Also, the availability and costs of newly required labour highly skilled in IT technologies may vary from region to region. The overall effect may not necessarily yield positive financial results, especially in developing countries.

It is observed from Table 4-1 and Table 4-7 that most respondents who mentioned OPEX reduction as a driver for automation also mentioned it as an observed benefit, which is interpreted like the expectations were met.

All terminals were located in high income countries (World Bank, 2021), namely Australia, Germany, Ireland, and Northern Ireland (UK). These results emphasise the expectation of a higher financial benefit in high income countries.

Former SC terminals are the only subgroup of respondents fully represented in the 7 respondents mentioning OPEX reductions. This could be related to SC terminals being labour intensive compared to RTG or RMG (see §2.3.3.2), although the sample is too small to tell. Also, 2 of these terminals converted to full automation, which results in more labour reductions compared to semi-automation.

“Labour shortage” was the second most mentioned driver for automation, with 5 operators. Both Japanese respondents mentioned it, probably related with their aging population and population reduction. The labour shortage problem seems to be an issue also in other industrialised countries. The Kloosterboer CT in the Netherlands, Dublin Ferryport Terminals (DFT) in Ireland, and Belfast Container Terminal (BCT) in Northern Ireland also reported labour shortage as a driver.

It was found that automation can help fight labour shortage in 2 ways. One way is by improving working conditions, which is expected to attract new labour according to DFT and BCT. They indicated automation would result in improved hygiene factors, extending working careers, opportunity to gender balance, greater appeal to younger work force, among other benefits. Most terminals indicating labour shortage as a driver for automation, also indicated better working conditions as one of automation observed benefits. The second way is by reducing the number of operators required per crane. For example, as discussed in §2.3.3.2, one operator could work 2-3 aRTG cranes under a high working load, and even more cranes under a low working load.

The third main driver for automation is higher productivity, according to 3 terminals: CTB Hamburg, Nabeta, and Kloosterboer. It is not clarified what kind of productivity they refer to, but average productivity is assumed, since automated terminals are expected to present a consistent and predictable performance (Chu et al., 2018) and it would not make sense to discuss automated peak performances.

As discussed in §2.3.3.1, automated terminals are not necessarily more productive than manned ones, especially for fully automated terminals, where the expected horizontal transport productivity is lower than in manned terminals (§5.6.1). All 3 terminals that included productivity in their drivers for automation were converting to semi-automation. Also, all 3 increased their capacities after conversion, all of them within the same terminal footprint. CTB Hamburg migrated from SC to ASC and Kloosterboer migrated from RS to aRTG. In both cases a higher productivity (move/h) and a higher capacity (TEU/m^2) is expected from the kind of equipment chosen only (see §2.3.1). It is not clear whether some of that increased capacity is also attributable to automation itself. The third terminal is the Nabeta, which expected higher productivities when changing from RTGs to aRTGs. It was indicated a 20% improvement in shipside productivity was expected from seamless transfer and just in time operation, but they stressed that the cycle time for an automated RTG is not faster than for a manned RTG.

On the other hand, lower average productivity was mentioned as a drawback by DFT and Japan X terminals. Despite this fact, DFT increased its capacity from 330,000 to 360,000 [TEU/year] after automation. The stacking area of the terminal was increased by extending 2 RTG blocks into an area formerly used for empties and adding more cranes. Some empties were taken outside the terminal. These changes can be observed in Figure 5-5 and in the terminal automation datasheet presented in Appendix E. Therefore, despite the lower productivity, the terminal could make changes to maintain, even increase their capacity. The case of Japan X terminal is still unknown since they have not implemented the automated solution yet.

Three terminals mentioned reliability/ safety as a driver for automation. More reliable operations are expected from reducing human error by automating formerly manned tasks. Safety is expected by reducing the risks of accidents involving humans, achieved by a proper safety design. This design translates into fences and controlled gates to segregate automated areas from manned ones, a series of sensors, among other measures (PIANC, 2021). An inadequate safety design may result in unsafe operation. For further information, a systematic process to plan for safety is presented in chapter 6 of the PIANC (2021) guidelines.

Two terminals mentioned a higher capacity as a driver, the Manzanillo International terminal (MIT), and the Norfolk International terminal (NIT). None of them increased the yard area. Therefore, a higher productivity must have been achieved. For MIT, they replaced RTG and empties blocks with CARMG blocks. These cranes allow for wider blocks and faster movements than RTGs, resulting in a larger yard capacity (see §2.3.1.4). This, together with the construction of new berths, increased the overall capacity of the terminal from 2.2 to 3.5 [million TEU/year]. For NIT, the capacity was also increased by migrating from SC to ASC. Even though no new quay length was built, the nominal terminal capacity was doubled from 0.7 to 1.4 [million TEU/year]. In contrast, many brownfield automated terminals did not increase their capacity after implementing automated technologies. Therefore, automation by itself will not necessarily increase the terminal capacity.

Other drivers mentioned are sustainability, predictability, and marketing. The first one refers to environmentally sustainable operations, achieved through less emissions on site and the use of electricity potentially produced from clean sources. The achieving of this goal depends on the use of electric equipment, not just on automation. Predictability relates to a more stable productivity, that allows for better planning of operations. Sustainability and predictability are also discussed in §2.3.3. MIT in Panama mentioned “Marketing” as a driver, indicating they wanted to become pioneers in the utilization of automated equipment in the Latin American market, being the first terminal to apply it. In this case, automation may serve for marketing purposes. But when other competitors have already automated, the marketing effect may be reduced.

One Japanese terminal mentioned government subsidy as a driver. Even if this is not a primary driver, in the sense that there must be other reasons to motivate the conversion, it is a facilitator. Considering OPEX reductions have not always been considered enough to compensate for the capitalised cost of lost revenue (PIANC, 2021), subsidies can be an important tool to help terminals build a financial model with positive results.

The previous discussion has shown that achieving the mentioned drivers cannot be assumed a priori as a direct consequence from automation. They depend on the terminal conditions and on the solutions adopted. These solutions should be targeted to achieve the terminal goals, usually manifested in the business case (PIANC, 2021). The effects of those solutions on other key performance indicators (KPIs) should then be evaluated during the planning stage. Methods to perform these evaluations are discussed in chapter 4 in PIANC (2021).

When asked about observed benefits, answers were usually similar to drivers, which is interpreted like the expectations were met. A newly mentioned benefit is “Decrease on footprint” by Kloosterboer, related to the change of equipment (RS) towards an equipment that requires less area per TEU handled (aRTG). This was also observed from satellite imagery for the DP World Brisbane terminal, where a conversion from mainly RS and one block of CRMG to ASC resulted in a reduced footprint of the area used to handle containers, but an increased nominal capacity from 0.6 to 1 million [TEU/year]. In this case the old yard is barely used anymore. The yards before and after conversion are presented in Figure 5-1.

Figure 5-1: reduced footprint for DP World Brisbane.

New benefits mentioned by terminal X from Japan are “standardisation/ Integration with stakeholders” and “moving to an AI terminal”. The first one is related to the standardization of procedures, files, software, and data. Standardisation allows for a more efficient flow of information between different stakeholders involved in the handling of cargo, e.g., customs, transport community, or other ports. “Moving to an AI terminal” means going beyond robotisation. In order to automate, processes must be digitalised, where “digitalisation” is understood as “the process of moving from systems that are manual or paper-based to computerised systems that organise information into units called data” (Gurumurthy, 2019). This results in large amounts of data being continuously generated. Given this data, many terminals are looking beyond automation into a “SMARTization” process, according to Younus Aftab, CTO of Navis (Maundrill, 2020). In this process, artificial intelligence tools make use of this data allowing equipment and systems to become smarter (Maundrill, 2020).

Ultimately, the conclusions of this section, based on the data gathered, are:

- The main drivers for brownfield automation are found to be operating cost (OPEX) reductions, labour shortage, productivity increase, reliability/safety, and capacity.
- Whether these drivers will be achieved cannot be assumed a priori from automation only. Terminals evaluating the incorporation of automation should set their main objectives during the initial business case planning. Then, solutions targeted to achieve them will be chosen. Finally, other consequences from those solutions can be evaluated.
- Benefits are similar to drivers, so often expectations were met. Observed benefits different from drivers are decrease on footprint, standardisation/ Integration with stakeholders, and moving to an AI terminal.

Since drivers for automation may also be understood as expected benefits, a summary of expected benefits, including answers from drivers and benefits, is presented in Table 5-1. The first column presents these benefits, the second column includes comments.

Table 5-1: potential benefits from automating.

Expected benefits	Comment
OPEX reduction	▪ Achieved by 6 terminals from high income countries. ▪ OPEX reductions depend on the local conditions, particularly on the labour market. ▪ Whether OPEX reductions will be achieved should be evaluated during the planning stage, once solutions that fulfil the terminal goals have been determined.
Better working conditions/ Reducing labour shortage	▪ Four terminals from high income countries indicated labour shortage as an issue. ▪ Higher comfort from shifting into an office environment, and improved health conditions by eliminating or reducing the exposure to vibrations, noise, and fumes, are expected consequences from automating. ▪ Automation helps solve the labour shortage issue in two ways, by reducing the number of operators required and by improving working conditions.
Productivity increase	▪ Higher average productivities were reported as drivers and benefits, but also lower as drawbacks. ▪ Automation has sometimes resulted in lower productivity, especially in fully automated terminals. ▪ The actual performance (and capacity) should be evaluated in the planning stage following PIANC (2021).
Higher reliability and safety	▪ Well planned automated operations are always more reliable and safer than manned ones. ▪ Reliability is achieved by reducing human error; safety by segregating people and automated equipment (PIANC, 2021). ▪ PIANC presents a systematic process to plan, test and validate the safety design (PIANC, 2021).
Higher capacity	▪ Terminals answering higher capacity as a driver for automation always migrated to more productive yard equipment (move/h) and with higher usage of the land (TEU/m^2). ▪ None of the 29 terminals reduced their overall yearly capacity, but some terminals maintained it. ▪ A higher capacity can be achieved by improving productivity or by increasing the terminal size.
More sustainable operations	▪ Sustainability is achieved by more efficient operation and by shifting to electric equipment, which reduces emissions locally, potentially also globally, using electricity produced from renewable sources. ▪ There are diesel automated alternatives (Pihkala and Malesci, 2020) and electric manned equipment. Therefore, some sustainable benefits are not a consequence from automation, but from the use of electric equipment. ▪ For more sustainable results, electric equipment should be chosen, keeping in mind the source of it.
More predictable performance	▪ Predictability is a consequence of more stable and reliable performance of automated operations. ▪ It allows for less risks of delays when planning operations. ▪ Predictability could be included in the business case as a lower risk for delay penalties.
Marketing	▪ Indicated by a terminal being the first to use automated equipment in their region. ▪ Prestige and political ambition is also among the criteria mentioned to automate (PIANC, 2021). ▪ The marketing effect is expected to be relative to the automation conditions of competing terminals.
Reduced physical footprint	▪ It is a consequence of the equipment change rather than automation. ▪ Respondent switched from RS to RTG, which results in higher stacking density (see §2.3.1). ▪ Most terminals did not reduce their physical footprint, because they were not changing equipment or they were, but they were also increasing their capacity. The final size of the yard should be determined by evaluating the expected capacity and the performance of alternative layouts during the planning stage.
Standardisation/ Integration with stakeholders”	▪ Allows for a more efficient flow of information between different stakeholders involved in the handling of cargo. ▪ Terminals willing to convert should involve other stakeholders from the early planning stages.
Moving to an AI terminal	▪ Automation can generate large amounts of data. AI tools can use this data to optimise processes. ▪ This is not necessarily a natural consequence of automating, there should be a conscious attempt to incorporate AI tools into the process.

5.3. Challenges

To answer SQ5 “what are the main challenges, and how have these been addressed during the conversion process?”, relevant results from the questionnaire and desk study are discussed. The sub section includes observations made by the author depending on the insights gathered during the research.

The main challenges from automation are continuity, adaptation to new operations, labour relations, and communication systems. Regarding continuity, phasing is the most common strategy to deal with it, but greenfield-like and big bang approaches were also reported. For adaptation to new operations, a training and evaluation strategy should be defined during the planning stage. Regarding labour relations, most semi-automated conversions did not require to reduce their staff, while fully automated conversions always did. Open communication from early planning stages with workers and other stakeholders, plus negotiation strategies such as redundancy packages, retraining, and relocations were reported. The communication system is paramount for operating an automated terminal. A robust design and testing during commissioning should prevent issues after the go live. Further details are discussed as follows.

When the questionnaire was built, it was assumed that continuity, labour relations, commissioning and exception handling were among the most important challenges, after the discussion presented in Appendix A. When terminals were asked about the main challenges of developing and implementing automated technologies, it was found that only continuity and labour relations were among the main challenges, i.e. the most mentioned ones, while commissioning and exception handling were not even mentioned, although exception handling was mentioned as one of the drawbacks from automation, as discussed in §5.4.

The most frequently mentioned challenges for automation in questionnaire answers were considered as the main challenges. Continuity was found to be the main challenge, as answered by 3 terminals, all of them converting from SC, although the sample is too small to tell whether continuity is more of a problem for SC terminals. When asked directly about continuity, half of the respondents (6) indicated that a phased approach was the solution to give continuity to operations. Regarding other respondents, Patrick Terminals Brisbane indicated their conversion was closer to a greenfield project since they developed a new automated terminal in a different location, then gradually moved operations to the new terminal; this approach is later described in this work as a greenfield-like. Patrick Terminals Sydney indicated an adjacent test site and fast rolling out of the technology by shutting down the terminal for 3 days; this has been called a big bang approach (Saanen, 2004). Two other terminals indicated continuity not to be a problem due to idle yard capacity. The remaining terminals, DFT and NIT, provided answers where it was not clear the continuity strategy adopted. From DFT it was indicated the use of a test bed within the terminal original yard before going live, as a strategy for continuity. But live testing to test and validate the new system must occur in all conversion processes (PIANC, 2021, White, 2018). NIT indicated “communication” as the strategy, without further details. Implementation strategies for these terminals, and all terminals from the sample, are analysed from satellite imagery and discussed further in §5.5.

Adaptation to new operations was also one of the main challenges. Respondents indicated it was difficult to adapt to the new way of operating, not just for terminal workers but also for other stakeholders such as truckers, or custom authorities. From NIT it was also indicated to be challenging for operators to deal with 2 operational strategies simultaneously, while a phased implementation was taking place. In their case this was temporary, but many terminals have kept manned and automated operations simultaneously for years, as discussed in §5.5. A training and evaluation strategy should be developed during the planning stage, not just for operators, but also for managers (PIANC, 2021) and other involved stakeholders, such as external truck drivers (PEMA, 2019). For terminals operating both manned and automated yards, dedicated personnel would help avoid issues.

Labour relations is also one of the main challenges. It was reported by 2 terminals, both converting to full automation with SC. A larger reduction of staff is expected for conversions to full automation since more operations become unmanned. But for semi-automation, a lower requirement of personnel compared to the before automation situation may also occur. Whether this led to less staff in the terminals was also informed by some respondents when asked directly about labour relations. A categorization is proposed to analyse the relation between the kind of conversion and labour issues. Terminals are listed in Table 5-2, indicating whether less staff was a consequence of automation or not. Rows of terminals with less staff were also marked in yellow, while rows with no reductions were marked in green. “NI” stands for not informed. The characteristics of the terminals before and after conversion are presented, to check whether they were growing.

Table 5-2: terminals with staff reduction due to automation conversion.

Terminal name	Lower staff	Type of automation	Yard equipment		Capacity [MM TEU/year]		Yard area [ha]	
			Before	After	Before	After	Before	After
Fisherman Island (Patrick)	Yes	Full automation	SC	auto SC	0.4	1.1	7	20
Sydney AutoStrad (Patrick)	Yes	Full automation	SC	auto SC	0.6	1.6	20	30
CTB Hamburg	Yes	Semi-automation	SC	ASC	2.8	5.2	74	78
CT N°50, Dublin	No	Semi-automation	RTG	aRTG	0.3	0.4	9	9
Nabeta	No	Semi-automation	RTG	aRTG	1.1	1.3	52	52
Japan, X	NI	Semi-automation	RTG	aRTG	unk.	unk.	16	16
Blijeveldhaven (Kloosterboer)	No	Semi-automation	RS	aRTG	0.1	0.3	-	-
ME, X	No	Semi-automation	RTG	aRTG and RTG	1.5	1.8	16	48
Manzanillo	NI	Semi-automation	RTG	CARMG and RTG	2.2	3.5	40	40
Yarımca	NI	Semi-automation	RTG	aRTG and RTG	1.3	1.3	26	26
Belfast CT	No	Semi-automation	RMG/SC	aRTG	0.3	0.4	7	7
Norfolk International	No	Semi-automation	SC	ASC	0.7	1.4	36	36

NI: not informed

Six terminals out of 9 did not report less staff. Five of them were converting to aRTG, and only one of these is increasing considerably the terminal physical footprint, i.e., terminal X from the ME. Since it is expected that one remote operator could operate 2-3 aRTGs (§2.3.3.2), less operators are expected to be required for the remaining 4 terminals. But these 4 terminals indicated labour shortage as one of the drivers and they are also increasing their capacity, which would justify keeping the operators under their payroll. Additionally, DFT and Kloosterboer are among these 4 terminals, both are keeping most of their manned operations going for now.

NIT is the remaining terminal with no staff reduction. The terminal moved from SC, an equipment with relatively intensive labour requirements as discussed in §2.3.3.2, to equipment with little labour requirements (ASC), which would suggest a reduced staff is necessary. However, horizontal transport remained manned (with SCs) and terminal capacity doubled. This allowed the terminal to keep all operators. According to Rich Ceci from Virginia International Terminals, “there was no loss of jobs by design”.

CTB Hamburg performed the same conversion as NIT, in terms of initial and final yard equipment (ASC), also with manned operations for horizontal transport. But the capacity increase of CTB is lower. Also, CTB is performing a longer phased process than NIT. CTB indicated this issue was responsibly managed with retirement programmes and qualification to new jobs, which is interpreted like less staff was required after implementing automation.

To manage labour relations and relations with other stakeholders, a stakeholder analysis may be considered. In this analysis, stakeholders are identified and characterised, and strategies to maximise their engagement and positive impact would be identified and incorporated in the project (Jepsen and Eskerod, 2009).

Communication systems is the fourth main challenge. Respondents indicated achieving the required reliability was challenging. The network infrastructure is the most critical element for successful container terminal automation (Konecranes, 2021), with more robust and resilient requirements than for manual operations (PIANC, 2021). A robust design and commissioning testing should prevent problems after the go live.

Commissioning was not among the main challenges, but terminals were asked about the duration of it. Two terminals reported 1 year for commissioning, both converting to semi-automation. The ramp up period was reported by 5 terminals and varied between 4 months and 2 years, except for NIT, where less than 4 months were informed. They justified this low period due to the previous experience of the team with automation. Also, Patrick Terminals in port Botany and BCT reported low ramp up and commissioning periods given their previous experience, but they did not give a number.

According to PIANC (2021), commissioning is part of the implementation process, which together with the engineering stage take between 24 and 36 months for semi-automated greenfield terminals, so it is not possible to compare it with brownfield conversions. PIANC (2021) also indicates the operation period, i.e., integration testing, training, go live and ramp-up, would take 12-24 months for semi-automated terminals, and 12 more months for fully automated terminals. The only fully automated terminal responding this question was Patrick Terminals Brisbane, indicating a 24-month period of ramping up, against 4-12 months indicated by semi-automated conversions. This difference is larger, but close to the differences in the timeline presented by PIANC (2021). This longer ramp-up period may be explained since Patrick Terminals Brisbane developed and implemented the first auto SC ever used, so a more difficult learning curve is expected.

Another challenge, mentioned by Terminal X ME, is infrastructure, but no further details were given. Challenges of reusing infrastructure may be related with remaining service life of existing infrastructure, the suitability of existing infrastructure to deploy automated equipment, particularly regarding pavement condition, drainage slopes, or bearing capacity, and the interference of existing service infrastructure, e.g., drainage or electric lines. Ozolin and Cornell (2016) described some of the infrastructure issues for the MIT in Panama, particularly related to adapting the requirements of the new equipment to existing drainage slopes and installing the supporting system for the new CARMG cranes. In general, solutions that would cause the lower impact to current operations were preferred in that case.

Finally, the conclusions of this section, based on the data gathered, are:

- The main challenge from automation is continuity. Phasing is the most common strategy to deal with it, but greenfield-like and big bang approaches were also reported.
- Adaptation to new operations is the second main challenge. It can be faced with a training and evaluation strategy, defined during the planning stage.
- Labour relations is the third most important challenge. Open communication from early planning stages, plus negotiation strategies such as redundancy packages, retraining, and relocations were reported. Most semi-automated conversions did not require to reduce staff though, probably since they were increasing capacity and facing labour shortage.
- Communication systems is the fourth most important challenge. A robust design and testing during commissioning should prevent issues after the go live.

A summary of challenges is presented in Table 5-3. The first column presents the challenges, the second column includes comments.

Table 5-3: potential challenges from automating.

Challenges	Comment
Provide continuity in operations	▪ Especially relevant for terminals without idle capacity and not increasing the terminal footprint. ▪ Terminals have dealt with it mostly following a phased approach. Greenfield-like, or big bang approaches also observed. ▪ A greenfield-like approach would result in less disruptions to operations. If this is not possible, as many stages as necessary should be planned to allow the terminal to comply with its commercial commitments. Big bang approaches are an option for SC terminals converting to auto SC only.
Adaptation to new operations	▪ It was reported difficult for operators and other stakeholders to adapt to automated operations and confusing for workers to operate both a manned and an automated yard simultaneously. ▪ Resistance to fully utilise automated capabilities is expected from operators in a terminal converting to automation (PIANC,2021). ▪ A training and evaluation strategy should be developed during the planning stage. For terminals operating both manned and automated yards, dedicated personnel would help avoid issues.
Labour issues	▪ Most terminals converting to semi-automation did not report staff reduction, terminals converting to full automation always reported staff reductions. ▪ Labour issues was reported as a reason why terminals may choose semi-automation over full automation. ▪ Open communication about the motivation for converting and the measures to be taken is advised. Measures to deal with labour changes include redundancy packages, retraining and relocations within or outside the terminal. Stakeholder analysis may help manage relations with labour and other stakeholders.
Communication systems	▪ For some respondents It was challenging to achieve the required reliability of the communication system. ▪ The enormous amount of information flow of automated terminals requires a robust fibre optic network (PIANC, 2021). New reliable wireless systems have also become available (Pihkala and Malesci, 2020). ▪ A robust design and testing during commissioning should prevent problems after the go live.
Infrastructure	▪ One respondent mentioned existing infrastructure as a challenge. ▪ Infrastructure requirements depend on equipment, so early engagement between designer, operations planner and suppliers is critical (PIANC, 2021). ▪ Pavement bearing capacity, pavement condition, maximum admissible slopes, and remaining lifetime of pavements and structures should be evaluated in the planning process.
Other challenges	▪ Other challenges mentioned were suppliers, system development, integration of systems, local market, variation and gaps in scope, optimization for higher productivity.

5.4. Drawbacks

To answer the drawbacks part of SQ6 “what are the benefits and drawbacks observed from past brownfield automation projects?”, relevant results from the questionnaire and desk study are discussed. The sub section includes observations made by the author depending on the insights gathered had during the research.

The main drawbacks were found to be unpredicted technical issues/ high impact of failures, lower average productivity, and the requirement of staff with new skills. Other mentioned drawbacks are long time for exception handling, high maintenance cost and removal of expert performance. For the technical issues and failures, resiliency and redundancy are the recommended actions. Regarding productivity, the outcome cannot be assumed a priori, the performance of the terminal should be determined in the planning stage. The availability or training cost and time for personnel with new skills should also be considered in the planning stage. Further details are discussed as follows.

The main drawback, i.e., the most frequently mentioned one, is unpredicted technical issues/ high impact of failures. Respondents recommended planning fallback solutions and building redundancy and resilience. Redundancy means spare equipment and installations, while resiliency is the ability to recover fast from failures. Both point to reducing the risk by reducing the impact of failures. For example, it is indicated in PIANC (2021) that some terminals have installed redundancy in data systems, including data centre and network. They also recommend considering 2 different external electric power sources, and internal redundancy in power distribution. Other redundancies such as battery charging stations, or some essential sensors are also mentioned (PIANC, 2021). An approach to evaluate when redundancies should be considered could be based on risk, evaluated through the product of probability of failure and impact. The latter could be easily determined by presenting scenarios, but the probability of failures may not be readily available.

Additionally, a preventive maintenance strategy over a reactive one is recommended for automated terminals, since breakdowns would have a larger impact on automated terminal operations compared to manned ones (PIANC, 2021). This strategy would be based on data gathered by equipment sensors (Keskinen et al., 2017, PIANC, 2021). Subtle deviations from expected performances would evidence trends that would be used to schedule maintenance for a certain equipment before a breakdown occurs (Keskinen et al., 2017). This will result in a reduction of the risk of failures by reducing the probability of occurrence.

A larger exposure of automated terminals to cyberattacks compared to manned ones is a drawback not directly mentioned by respondents, but understood as an unpredicted technical issue. PIANC (2021) acknowledges cyberattacks result in a high risk to a business and presents guidelines to plan for cybersecurity in chapter 6.

Lower productivity is the second most mentioned drawback with 2 mentions. It was also reported as a benefit. A discussion about productivity was presented in §5.2.

The third most mentioned drawback is new skills for staff, reported from Yarımca in Turkey and NIT in the USA. The first one points to the new electronics skills required for operators. The second one stresses the difficulty of retraining staff to operate a semi-automated terminal. They indicated that for things to work properly, operators must work “almost as consistently as a robot”, which is difficult to achieve. In some countries, it may be difficult to recruit workers with the level of training necessary to work in the higher skilled roles (PIANC, 2021), either due to a lack of workers or a high demand of them. In any case, training and hiring (locally or abroad) are the strategies to address this problem, and they should be evaluated in the planning stages to consider the associated time and costs. If staff operating a manual terminal would be retrained to operate the automated terminal, particular attention to training may be necessary, since there may be resistance to fully utilise the capabilities of the automated tools (PIANC, 2021).

Long time to handle exceptions was also reported as a drawback. Exceptions are hazardous, OOG or damaged containers (PIANC, 2021). Exceptions may also occur due to disruptions in the process, such as incapacity to automatically read a container ID, truck/chassis that appear to be different than expected, or breakdowns (PEMA, 2016a). A simplification of operations to reduce the number of exceptions as suggested by Chu et al. (2018) would help reduce the number of events from the first group. The second group falls into the category of unpredicted technical issues, which was discussed above. But it is likely that there will always be exceptions. The highest productivity in automated terminals is achieved if exception handling has been efficiently arranged (Keskinen et al., 2017). Planning and testing exception scenarios during the testing phase is a way to be prepared for them.

Higher expected maintenance cost was reported from the Nabeta terminal, where aRTG will be implemented. But from the auto SC Patrick Terminals in Brisbane and Port Botany “cost efficiencies in maintenance” were reported. Alho et al. (2015) and Alho et al. (2018) said maintenance cost of both auto SC and aRTG terminals are brought down in the long term with automation, due to no accidents by human errors and a reduced need for ad hoc repairs. Keskinen et al. (2017) indicated automated terminals require equipment in perfect condition to properly operate, in contrast with manned terminals where human operators can work around deficiencies. Given the relatively high impact of breakdowns in automated terminals, a preventive maintenance strategy is required. Also, short term regular checks are necessary on top of regular maintenance, to evaluate the condition of equipment and sensors (Keskinen et al., 2017). This suggests automated terminals may present higher maintenance costs in scheduled maintenance, but lower maintenance costs in unscheduled maintenance. Additionally, the management of infrastructure maintenance may be more expensive (PIANC, 2021). Thus, the overall result is not clear a priori and should be analysed on a case-by-case basis, considering equipment requirements and infrastructure condition.

The loss of expert performers was also mentioned as a drawback. Expert performers present above-the-average productivities, allowing for flexibility to use them to handle a high demand. This drawback is compensated by a more stable productivity, that allows for less risky planning of future operations.

Finally, the conclusions of this section, based on the data gathered, are:

- The main drawback from automation is unpredicted technical issues/ high impact of failures. This drawback has been addressed by considering redundant systems and fallback plans for
- The second most important drawback is lower productivity. On the other hand, productivity is more stable, which is an advantage for planning future operations.
- The third most important drawback is the requirement of staff with new skills. Retraining or hiring are the strategies to overcome this challenge.

- Other mentioned drawbacks are long time for exception handling, high maintenance cost and removal of expert performance.

A summary of drawbacks discussed is presented in Table 5-4. The first column presents the expected drawbacks, the second column includes comments.

Table 5-4: potential drawbacks from automating.

Drawbacks	Comment
Unpredicted technical issues/ High impact of failures	▪ Respondents planned redundancy and resilience measures to reduce the impact of failures. ▪ A preventive maintenance strategy would reduce the probability of failures (PIANC, 2021). ▪ Both measures above contribute to reducing the risk of failures.
Lower average productivity	See Table 5-1, "Productivity".
Staff with new skills is required	▪ Respondents indicated people with new IT and electronic skills were required. ▪ In some countries it may be difficult to recruit workers with the required preparation (PIANC, 2021). ▪ Training or hiring locally or abroad are the strategies to address this drawback.
Long time for exception handling	▪ Exceptions may occur from not standard containers or from disruptions in the process. ▪ Chu et al. (2018) propose to reduce the number of exceptions before converting. ▪ Terminals should plan and test exception scenarios to put in place procedures to handle them.
Higher maintenance cost	▪ Reported by an aRTG terminal. But lower maintenance costs were reported by 2 SC terminals. ▪ Larger scheduled maintenance requirements expected from predictive maintenance strategy in automated terminals, but also less accidents and less ad hoc repairs. Infrastructure maintenance may be more expensive (PIANC, 2021). ▪ The overall effect of automation on maintenance costs should not be assumed a priori but be evaluated during the planning stage.
Removal of expert performers	▪ Expert performers present above-the-average productivities, automation presents a stable performance. ▪ On the other hand, a more stable performance can also be a benefit from automating. ▪ Flexibility from operating with expert performers is lost, but a more stable performance allows for less risks in planning operations.

Despite these drawbacks, 10 out of 12 respondents indicated further automation is under consideration, which is interpreted as a good evaluation for automated technologies.

5.5. Implementation strategy

Main challenges were identified in §5.3. It was stated that continuity of operations was the main challenge, and 3 implementation strategies to give continuity to operations were identified: greenfield-like, phased, or big bang approaches. The objective if this section is to complement the analysis of §5.3, by further analysing these strategies using satellite imagery. This sub section also includes observations made by the author depending on the insights gathered during the research.

The main conclusion of this section is that the 3 strategies mentioned above were also followed by non-respondent terminals. It was also observed that to release land within the terminal footprint, relocation or removal of empties and warehouses, relocation of the rail terminal, or rearrangement of operations for terminals with spare capacity, were observed. Old yards were either fully converted, partially converted, not converted, or vacated. A detailed discussion is presented as follows.

Characteristics for the 3 implementation strategies found from questionnaire answers were identified. Satellite imagery was evaluated before, during and after the time of conversion for all 29 terminals studied, according to the dates presented in Appendix C. Definitions were proposed for the 3 strategies based on these observations. These definitions were assigned to each terminal. Some of the satellite images used are presented with the definitions proposed below, other images are presented in the terminal conversion datasheets in Appendix E.

- **Greenfield-like approach**: these terminals have increased their footprint or have been able to free land within the terminal but not from the existing yard, to develop at least the first conversion stage. By doing this, a new yard is (partially) built and tested while the old one keeps operating with little disruptions.

  A example for this approach is the conversion of the DP World terminal in the port of Brisbane, Australia, presented in Figure 5-2. Previously unused terminal area, plus land freed from relocating some empty stacks, were used to develop new ASC blocks. Another example from the TPKS terminal in the port of Semarang, Indonesia, is presented in Figure 5-3. Here the first phase of automation was developed in newly reclaimed land. When this new piece of yard was operational, the old yard was partially converted using a phased approach. More terminals using a greenfield-like approach are presented in Appendix E.

  Three conversions to full automation, and 6 to semi-automation adopted this approach. Capacities of terminals following a greenfield-like approach increased between 25% and 467%.

Figure 5-2: implementation process of new ASC stacks in the DP World Brisbane terminal, Australia.

Figure 5-3: implementation process of new aRTG stacks in the TPKS terminal, Semarang, Indonesia.

- **Phased approach**: these terminals have not been able to increase their footprint or to release an area large enough to develop the automation yard without disrupting the existing yard. So, part of the existing yard must be cleared to install the new automated technology. Disruptions to operations are expected. Conversion phases must be planned so that the yard capacity is enough to fulfil the demand during the process.

  Two examples are presented in the next images. The CTB terminal in the port of Hamburg, Germany, is presented in Figure 5-4. Before implementing ASCs, more room was made by removing a warehouse and empty stacks and relocating the rail terminal, as observed when comparing photos from 2004 and 2008. Then, ASC blocks have been implemented gradually in a process that is still going on. The second example is from the CT N°50 in the port of Dublin, Ireland (DFT). When comparing images from 2016 and 2017 it is observed how 2 blocks were extended into an area previously used for empties. In the process, infrastructure along the new aRTG paths was intervened. Then, in 2018, the first 2 aRTG are observed in the block closer to the quay. It is difficult to spot in the figure, but the new aRTG blocks are one container wider. In 2021, 2 more aRTG are observed in the block further from the quay. Press reports indicate the process is ongoing, with more aRTG being incorporated in DFT in the next years[12]. Images of more terminals using the phased approach are presented in Appendix E.

[12] https://www.ship-technology.com/news/kalmar-dublin-ferryport-terminals/

Sixteen terminals were identified to fit into the phased category. Most of them increased their capacity. Fourteen out of the 16 terminals converted to semi-automation. Only Trapac and Pier 400, both in the port of LA, converted to full automation with a phased approach.

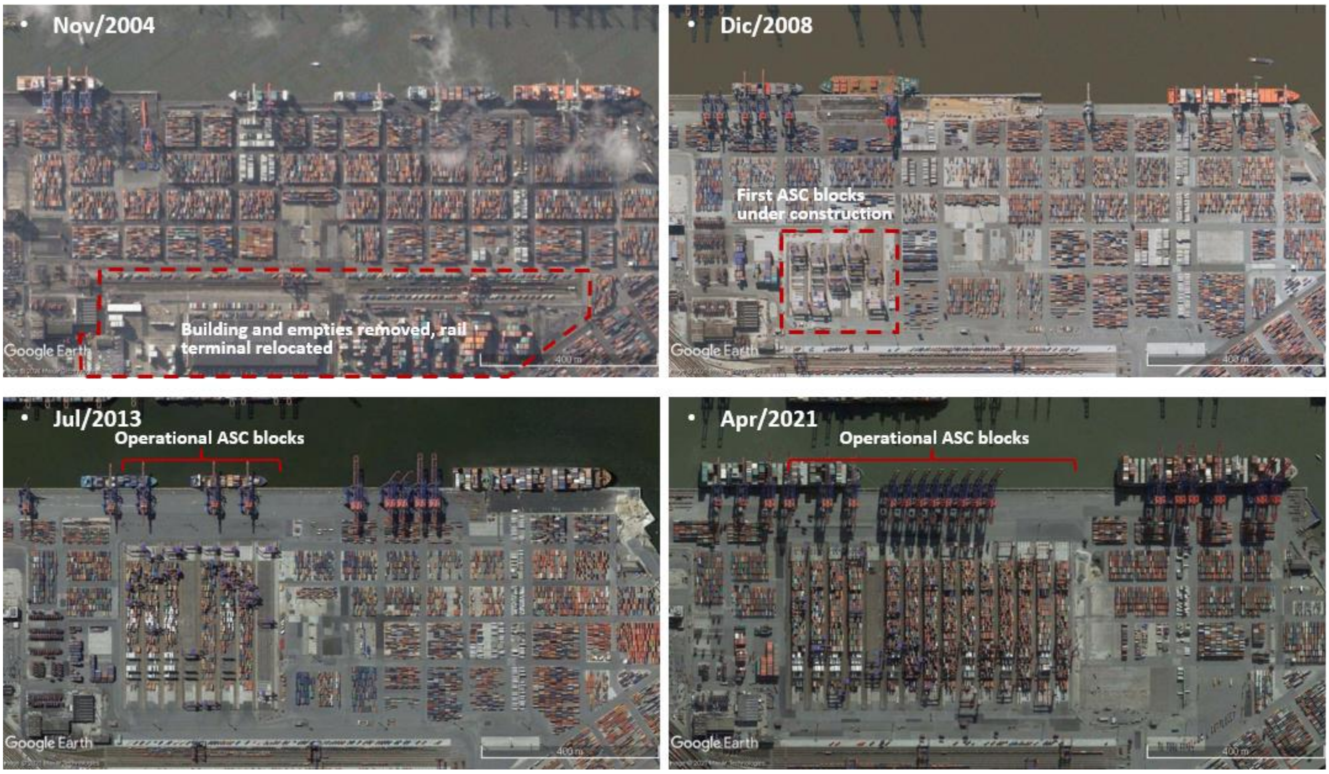

Figure 5-4: implementation process of new ASC stacks in the CTB terminal, Germany.

Figure 5-5: implementation process of new aRTG stacks in the CT N°50, Dublin, Ireland.

- **Big bang approach**: a small testing site is built within the terminal or right next to it. This site allows for trials while the old terminal keeps operating. Small adjustments necessary to extend the technology to the old yard are made during this period. Once bugs have been solved and people have been trained, the old terminal (or a big part of it) is closed for a short period (2-3 days) so that the new technology is rolled-out onto the old yard. This was observed only in 2 SC terminals. This approach seems unlikely for other equipment such as aRTG or aRMG since civil works are often required for their installation.

  The 2 observed terminals are presented. The conversion to a fully automated auto SC terminal of Patrick Terminals in port Botany, Australia is shown in Figure 5-6. When comparing 2009 and 2013 images, it is observed that a newly reclaimed area is developed next to the terminal. In the image of 2014, a small testing area for the new auto SC is observed in the newly reclaimed land, while the old terminal keeps operating. In 2015 the new auto SC have been deployed in the entire terminal. The process took place during the last days of March 2015. Figure 5-7 shows the ongoing conversion process of the Fergusson terminal, port of Auckland, New Zealand, where auto SC are considered for the yards and manned SC for the horizontal transport. Pictures from 2014, 2016 and 2017 show increase in the berth length and the addition of newly reclaimed land. In 2019 a small test bed on the newly reclaimed land is observed, where blue auto SC are tested in a fenced area. An area to transfer containers to trucks is included. The auto SC have not been deployed to the rest of the yard yet, but according to POAL website[13] that will occur first for the new berth and the stacking areas behind it, and then for the rest of the terminal.

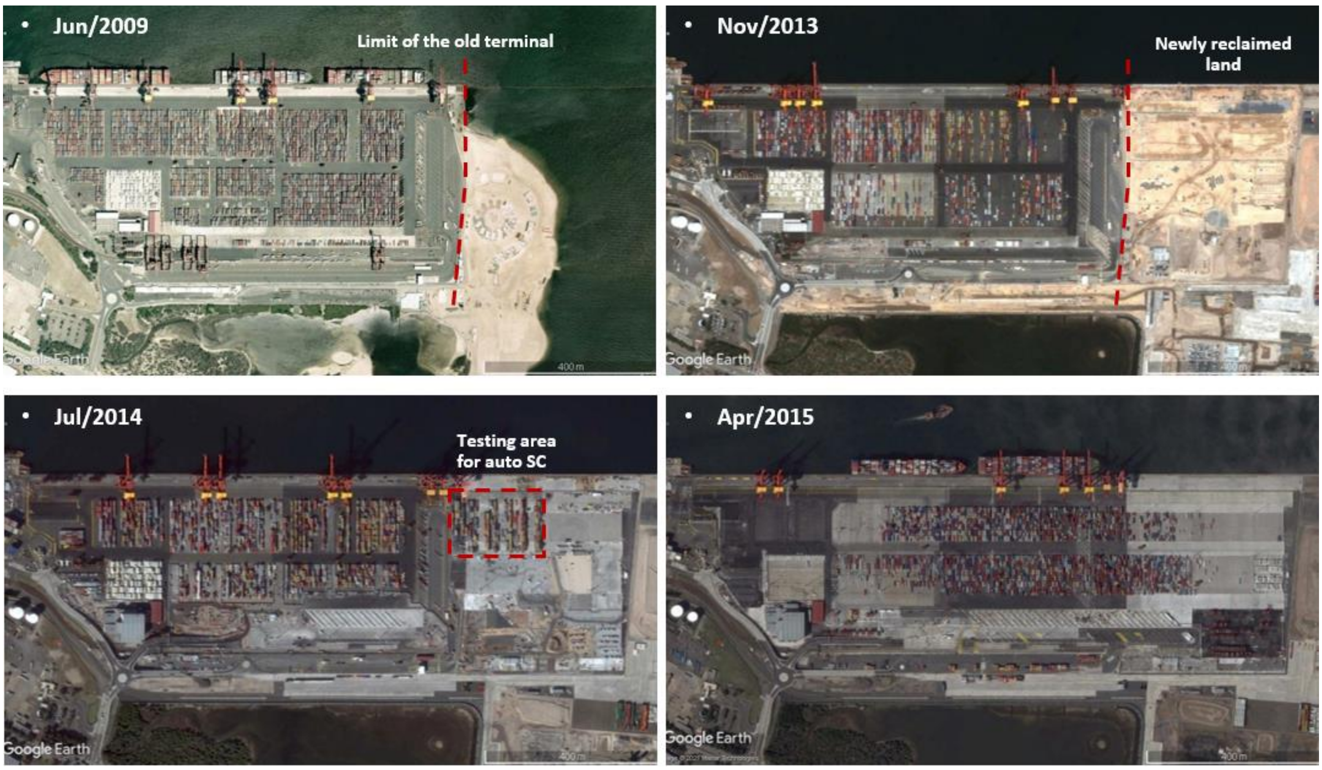

Figure 5-6: implementation process of the new auto SC of Patrick Terminals, port Botany, Australia.

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Figure 5-7: implementation process of new auto SC of Fergusson terminal, port of Auckland, New Zealand.

Most terminal implementation processes are presented in automation terminal datasheets in Appendix E.

From the observation of satellite imagery of the conversion processes, elements common to more than one implementation strategy were identified, namely way to free area within the terminal footprint and changes to the old yard during the process.

Usually in the phased approach, but also in some greenfield like approaches, part of the existing terminal area was cleared to develop the automated yard. Some of the techniques observed to do this with the least affection of the existing yard are:

- Removal or relocation of empties.
- Removal or relocation of warehouses.
- Relocation of rail container terminal.
- Rearrangement of operations of terminals with overcapacity.

Regarding changes to the old yard, it was observed that terminals following a greenfield-like approach followed one of the following categories:

- Vacated: the old yard was abandoned; operations were moved to the new automated yard.
- Kept manned: the automated solution was deployed on new land, while the old yard was kept intact.
- Mixed: the automated solution was partially deployed on the old yard. Some of the manned equipment keeps operating. Sometimes these terminals may still be in the process of gradually converting the yard.

- Completely converted: the yard is completely converted to full automation, except for equipment to handle exceptions.

For phased approaches mixed and fully converted yards were observed. For big bang approaches the yard is completely converted. In the table presented in Appendix C, implementation approach and old yard conditions observed are presented. A justification for each category assigned is included in the terminal datasheets presented in Appendix E.

Finally, some observations from terminals using a phased approach are presented. Terminals implementing aRTGs or CARMGs with a phased approach, commonly did it block by block or in groups of blocks. This decision is related to the phasing plan, which is expected to satisfy the minimum capacity requirements of the terminal. Terminals implementing ASCs with a phased approach required an area between 6-14 [ha] for the first implementation stage, depending on the block dimensions and the number of blocks considered for that stage. On the right side of Figure 5-8, the top figure presents the first stage for NIT in Virginia, involving 12 230 [m] long blocks with an area of 14 [ha] (1.2 [ha] per block). The bottom figure on the right corresponds to the first stage of the Trapac terminal. Four 250 [m] long blocks took approximately 6 [ha] (1.5 [ha] per block). On the left side is presented the first stage for CTB Hamburg, with 5 260 [m] long blocks, taking approximately 10 [ha] (2 [ha] per block). It was also observed that commissioning and testing started with shorter blocks in CTB, evidenced by the observation of containers in the first stack on the right.

Figure 5-8: first ASC stages with phased approach.

5.6. Observed trends in automation

To answer SQ7 "what are the main trends observed regarding the type of automated technologies chosen?", two characteristics of the solutions identified through the questionnaire and desk study are discussed:

automation level chosen and type of yard equipment. Main trend regarding the type of automation chosen, i.e., semi- or full automation, is discussed in §5.6.1. The main trend regarding selection of yard equipment is discussed in §5.6.2. Each sub section includes observations made by the author depending on the insights gathered during the research.

5.6.1. Automation level selected by brownfield converted container terminals

In this section, the trend regarding automation level selected by brownfield conversions, i.e., semi- or full automation, is discussed. Characteristics of terminals choosing full automation and the type of yard equipment chosen by fully automated terminals are presented. The main trends observed are that most terminals converted to semi-automated operations. Fully automated conversions only took place in terminals increasing their footprint or with spare capacity, and they always used either auto SC or ASC as yard equipment.

Questionnaire respondents mainly chose semi-automated solutions. Reasons given were fewer labour issues, improved vessel productivity, less required space, better agility in dealing with disruptions, and lack of maturity in the control systems for full automation, as presented in Table 4-2. This trend is repeated when analysing the entire sample of brownfield converted terminals. Twenty-three out of 29 terminals converted to semi-automation (79%). The 6 fully automated conversions are further discussed below.

- Patrick terminals in Brisbane and port Botany. Both terminals increased their quay length and yard area, one of them by reclaiming land next to it, the other by developing a new terminal in a different location and then moving operations.
- The Xiamen Ocean Gate Container Terminal in China. ASC blocks fed by AGVs were built in a previously unused piece of land of the terminal (greenfield-like approach), so manned operations were not disturbed while the terminal was under construction. After construction, the manned RTG yard was kept intact.
- The Long Beach Container Terminal in the USA. The Cal United terminal located at the Pier E of the Long Beach port moved their operations to the port of LA in 2011. OOCL operated Pier F at the time. They took over the vacated Pier E, built an automated terminal with AGVs and ASCs. Once ready, they relocated to the new terminal at Pier E and converted the old terminal in the vacated Pier F. This was a complete redevelopment, and it was classified as a greenfield-like implementation since the sites were fully vacated before starting construction.
- The TraPac Container Terminal in the USA. The terminal apparently had unused capacity. Without the conversion project, Trapac capacity was 1.7 million [TEU/year], but the project baseline presented in the EIA indicated a reference throughput of 900,000 [TEU/year] (USACE, 2007). The project was phased in 3 stages. The construction took 6 years. The yard behind berths 136-139 (20 [ha] approx.), has not been converted so far.
- The Pier 400 terminal in the port of LA. The terminal had spare capacity in the yard (The port of LA Executive Director, 2019). From the original 120 [ha] yard using RTG and chassis to stack containers, 30 [ha] approximately were closed and converted to operate with auto SC. Since this is a fully automated project, the area was fenced including a berth to exclusively operate with the new automated yard.

It is observed fully automated conversions took place in terminals with increasing area or with spare capacity. One of the difficulties for converting to full automation is that a larger portion of the terminal must be closed for testing compared with semi-automation, i.e., stacks and area between the stacks and the quay. Also, commissioning and testing typically take longer than for semi-automated terminals. Terminals operating near full capacity and not increasing their physical footprint may not be able to lose an important part of the terminal for a long period to allow a fully automated conversion.

Regarding yard equipment chosen for fully automated solutions, no aRTG conversions were observed. One of the reasons for this may be the difficulty of segregating automated ITVs with OTR trucks, since RTGs only have one transfer lane. According to PIANC (2021), up to 2 container rows may need to be removed from the stacks to achieve this segregation. Since "much of the interest in RTG automation is driven by the desire to retrofit existing manual RTG-based terminals into semi- or full automation without changing the terminal's underlying infrastructure" (PIANC, 2021), this remotion of rows would result in a diminished yard capacity.

Also, no conversions to fully automated CARMG were observed. Even if with these cranes is easier to segregate ITVs and OTR trucks in the stacks, crossings between them would still need to be resolved at the junctions.

ASCs have been observed for both, semi- and fully automated solutions.

Conversions to auto SCs had always been to full automation, since auto SC can perform both horizontal transport and stacking operations. However, a container terminal in the port of Auckland (POAL) is converting from 1-over-2 manned SCs to a new semi-automated solution with manned SCs for the horizontal transport and auto SC for the yard. According to Matt Ball, head of communications of POAL, the terminal needed to increase the yard capacity without increasing the terminal footprint[14]. The solution chosen was to use 1-over-3 auto SCs, which can stack containers higher and closer together than the previous equipment. Matt Ball explained a semi-automated solution was chosen due to the terminal throughput. He explained SC drivers are faster than automated SCs in the difficult quay tasks.

As discussed in §2.3.3.1, it has been reported that fully automated terminals are less productive than manned ones. Saanen (2016) presented an evaluation of horizontal transport equipment. He concluded that manual ShCs present the largest productivity with 14 box/hr, over 12 box/hr for aShCs and down to 6.5 box/hr for AGVs. But when considering the yearly OPEX, the lowest value was that of the lift AGV, which represents a fully automated solution. He used a labour cost of 50 €/hr, representative for high income countries. So, in POAL the solution with the lowest OPEX was not necessarily chosen, but the one that fulfilled the terminal goal of increasing their capacity. This aligns well with the discussion presented in §5.2.

Finally, the conclusions of this section based on the data gathered are:

- Most terminals converted to semi-automated operations. Fewer labour issues, less required space, and improved vessel productivity, among other reasons, explain this choice.

[14] The Hundred-Tonne Robots That Help Keep New Zealand Running. https://www.youtube.com/watch?v=kQ8WI3nc1l0

- Fully automated conversions only took place in terminals increasing their footprint or with spare capacity, and they always used either auto SC or ASC as yard equipment.

5.6.2. Yard automated equipment selected by brownfield converted container terminal

In this section trends regarding the type of yard equipment selected by brownfield conversions are discussed. Yard equipment chosen is compared to yard equipment existing before conversion and with the yard area of the automated terminals. The main trend identified regarding yard equipment is that terminals with yard areas under 10 [ha] implemented aRTG in the yard, while terminals with larger yard areas and using RTG, SC or RMG before conversion, either converted to aRMG (CARMG or ASC), or to the automated version of their yard equipment before automation.

Only yard equipment was analysed in this chapter, since only six terminals used automated horizontal transport. Also, the type of horizontal transport equipment usually depends on the type of yard equipment. The relation between automated solution and yard equipment before automation is analysed using the matrix presented in Table 5-5. Rows present the type of yard equipment before automation. In the last row the total number of automated equipment chosen is presented. Columns present the automated yard equipment chosen. In the last column, the total number of terminals from the corresponding manned equipment is presented.

Table 5-5: yard equipment before and after conversion.

Yard equipment before conversion	Yard equipment after conversion				Total
	auto SC	aRTG	aRMG		
			ASC	CARMG	
RS	0	1	1	0	2
RTG/chassis	1	0	2	0	3
RTG	0	9	2	2	13
RMG	0	1	0	2	3
SC	3	1	3	1	8
Total	4	12	8	5	

According to Kats (2020), when it comes to yard equipment, terminals would convert either to the automated version of their existing equipment or to a version of aRMG (either CARMG or ASC). Results from Table 5-5 show that this statement generally applies to the observed terminals, with 22 out of 24 terminals complying with it. Five other terminals are not considered in this subsample, since they used yard equipment with no automated equivalents, namely RS and chassis. But there are 2 exceptions to the rule: the Belfast Container Terminal (BCT) converting to aRTG from RMG, and the Sjursøya terminal converting to aRTG from SC.

Considering the BCT equipment before conversion was primarily RMG, the terminal should have converted to aRMG (either CARMG or ASC) to comply with Kats' statement. Alec Colvin, former general manager and currently director at BCT, was one of the respondents of the questionnaire. He explained that they also operate the Dublin Ferryport Terminal (DFT) in the Republic of Ireland. This terminal used RTGs before automating, and they decided to convert DFT to aRTG. This occurred before the conversion of BCT. He referred to Dublin as the “test site”. Then, the solution was extended to Belfast “totally de-risked” due to the Dublin experience.

The second exception is the Sjursøya terminal in the port of Oslo, Norway. To comply with Kats’ statement, the terminal would have chosen either auto SC or aRMG. The reason why Sjursøya terminal opted for aRTG is not known, since they did not respond the questionnaire (A possible explanation could be the desired capacity. The terminal was intended to increase their capacity to 450,000 [TEU/year][15]. Considering the average area use per TEU, presented in §2.3.1.2 for SC and §2.3.1.3 for RTG, is 10 [m^2/TEU] and 6 [m^2/TEU] respectively, considering an average dwell time adopted for all containers of 5 days[16] and operations over all 365 days, the maximum capacity that could be achieved with SC is of 365,000 [TEU/year], while with RTG is 608,333 [TEU/year]. Given this is a rough estimation using the most optimistic values for area use per TEU, and that no reductions were considered, such as factors accounting for irregular shape of the yard as observed in Figure 5-9 or reduced occupancy rates, RTG may have been the required solution to achieve the desired terminal capacity).

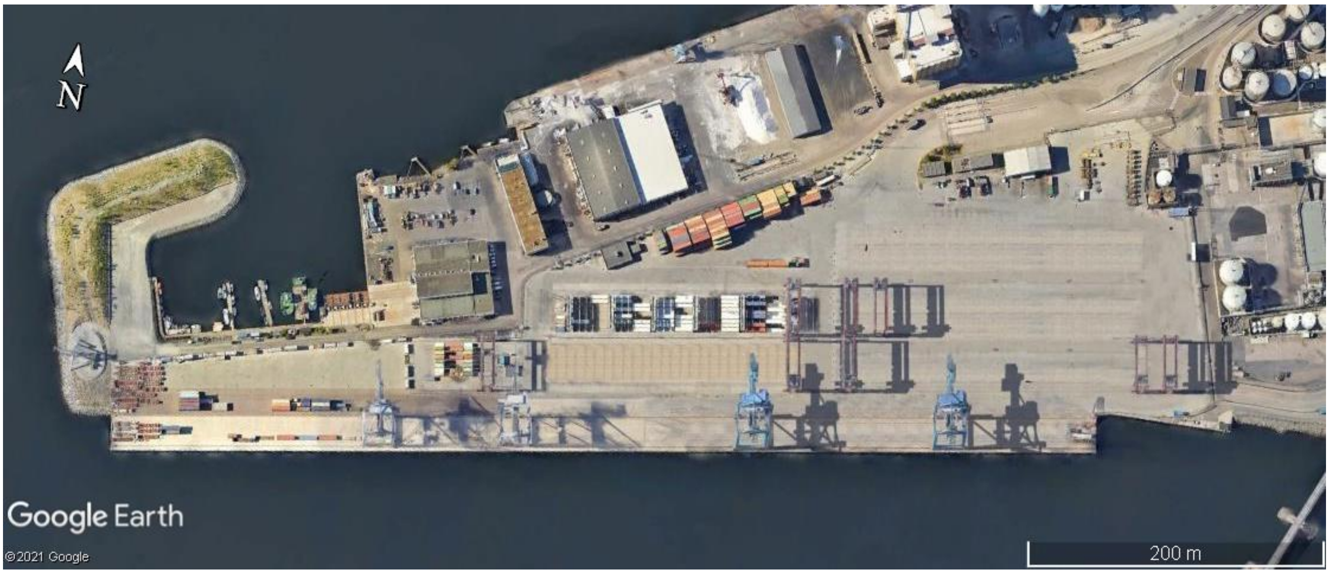

Figure 5-9: aerial view of Sjursøya container terminal at the port of Oslo. Source: Google Earth™.

The relation between the automated solution and yard area of the terminal was also studied. The yard area after automation was chosen as the comparison parameter because the solution chosen is designed over that area.

Again, only yard equipment was analysed. Histograms per type of yard equipment, with the size of the terminal on the horizontal side, and the number of terminals on the vertical size, were developed. The histograms are presented in Figure 5-10.

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[15] https://www.kalmarglobal.com/customer-cases/all-customer-cases/opa-port-of-oslo/

[16] Dwell times vary from terminal to terminal. An average dwell time of 5 days was chosen. A value representative for Western Europe terminals for laden containers is around 4 days (Koster, 2019). Since maximum dwell time for Western Europe is 10 days and empties usually have much longer dwell time than laden containers (Ligteringen, 2017), 5 days is considered a reasonable, even optimistic, estimation.

Regarding conversions to aRTG, it is observed that 9 of these terminals have a yard area smaller than 30 [ha]. Two outliers are observed, with yard areas around 50 [ha], namely 48 and 52. One is the Nabeta terminal in the Nagoya port, but 15 [ha] correspond to a yard for empties. The RTG yard area has approximately 25 [ha]. The second outlier is terminal X in the Middle East. Around 40 [ha] correspond to the RTG yard exclusively.

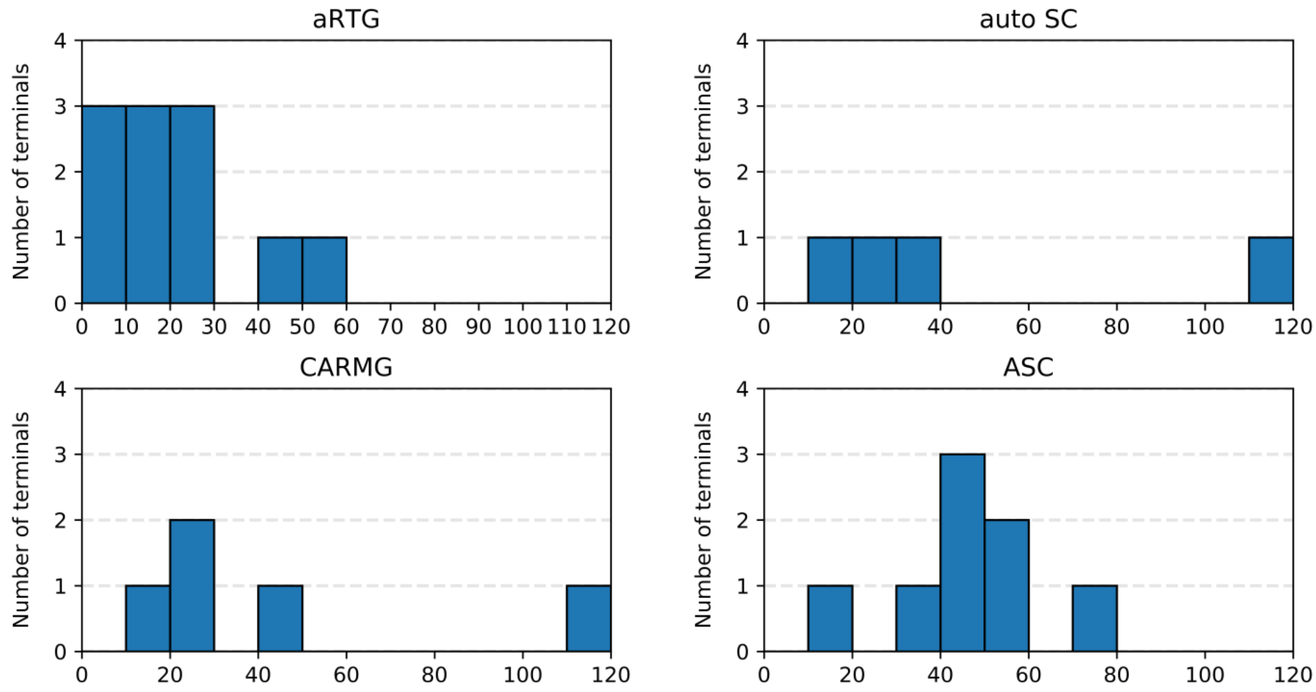

Figure 5-10: histograms of yard areas in hectares of converted terminals per type of automated yard equipment.

The 3 terminals with yard areas smaller than 10 [ha] converted to aRTG, regardless of their yard equipment before conversion. Three terminals fit in this category, DFT where RTGs were in use before conversion; Oslo, where SC were in use before conversion; and BCT, were an RMG was in use before conversion. For terminal areas larger than 10 [ha] all automated yard equipment alternatives have been observed.

Regarding CARMG and ASC terminals, the smallest yard for both presented an area of 19 [ha]. Regarding auto SC, 3 terminals presented yard sizes between 10 and 30 [ha], and one outlier presented 120 [ha]. The latter corresponds to APM Pacific terminal at Pier 400, port of LA. This is the size of the entire yard, where a mix of RTG, chassis and auto SC is observed, so it is not really a 120 [ha] SC yard.

It has also been observed that terminals from the sample using aRMG in their yards always had yard areas larger than 17 [ha]. This might also help explain the 2 exceptions from Kats' statement discussed earlier. The BCT yard area is 7 [ha] and 5 [ha] for Oslo, so yard areas might be too small to develop aRMG solutions. Therefore, RTG was the available option that would make the most intensive use of the yard area.

Finally, the conclusions of this section based on the data gathered are:

- Terminals with yard areas under 10 [ha] implemented aRTG in the yard.
- Terminals with larger yard areas and using RTG, SC or RMG before conversion, either converted to aRMG (CARMG or ASC), or to the automated version of their yard equipment before automation.

5.7. Automated solution per terminal

In this section, results per terminal are presented. First, a two-dimensional taxonomy per type of yard equipment before and after conversion is presented, to individualise the type of yard solution adopted per terminal. Then, results per terminal presented in Appendices C and E are introduced.

A taxonomy for terminals adopting fully automated solutions is presented in Table 5-6, and for terminals adopting semi-automated solutions is presented in Table 5-7. Rows present yard equipment before automation and columns present yard equipment after automation.

Table 5-6: fully automated conversions.

	Yard equipment after conversion			
Yard eq. before conversion	**auto SC**	**aRTG**	**aRMG**	
			ASC	**CARMG**
RS	-	-	-	-
RTG + chassis parking	▪ APM Pacific, LA.	-	▪ LBCT, Long Beach ▪ Trapac, LA	-
RTG	-	-	▪ Xiamen Ocean Gate CT, Xiamen	-
RMG	-	-	-	-
SC	▪ Patrick terminal, Brisbane ▪ Patrick terminal Port Botany	-	-	-

Table 5-7:semi-automated conversions.

	Yard equipment after conversion			
Yard eq. before conversion	**auto SC**	**aRTG**	**aRMG**	
			ASC	**CARMG**
RS	-	▪ Kloosterboer, Vlissingen	▪ DP World, Brisbane	-
RTG + chassis parking		-	-	-
RTG	.	▪ Pelindo III, Semarang ▪ DFT, Dublin ▪ Kamigumi, Kobe ▪ Nagoya United, Nagoya ▪ Terminal X, Japan ▪ Terminal X, ME ▪ HIT, Hong Kong ▪ DP World, Yarımca ▪ HPH, Felixstowe	▪ GCT Bayonne, NY/NJ.	▪ MIT, Colón ▪ EMC, Kaohsiung
RMG	-	▪ BCT, Belfast	-	▪ Tianjin Port G., Tianjin ▪ DP World, Jebel Ali T2
SC	▪ POAL, Auckland	▪ Yilport, Oslo	▪ DP World G., Antwerp ▪ HHLA CTB, Hamburg ▪ VIT, Virginia	▪ PCT, Piraeus

A summary of characteristics per terminal is presented in Appendix C. Yard area, terminal capacity, quay length, and container handling equipment before and after automation are presented. Also, the type of automation (semi- or full), implementation strategy observed, and a classification regarding the fate of the old yard is included.

Additionally, an automation datasheet per terminal is presented in Appendix E for 22 terminals. Seven terminals were not considered due to the following reasons:

- Not enough information was found on terminal 2 at the Jebel Ali port, nothing could be observed from satellite images.
- Nothing could be observed from satellite images for the Tianjin Port Container Terminal because it was a retrofit of CRMG, although it is known they used a phased approach (Henriksson et al., 2020).
- The Yarımca terminal was originally built with cranes and systems ready to automate, so no works were observed from satellite images. A phased approach was followed according to their answers to the questionnaire.
- Three terminals have not started the process yet, so there are no images to present.
- Finally, terminal X from the ME was not considered since they requested to remain anonymous.

Datasheets present the following information per terminal:

- Terminal name, port name, country, and operator. Image with location.
- Yard equipment and horizontal transport equipment before and after conversion.
- Type of conversion, i.e., semi-, or full automation.
- Yard area, terminal capacity, and quay length before and after conversion.
- Implementation approach and an explanation of the category assigned, including details regarding whether the old yard was converted or not.
- Images presenting the implementation process.

6. Conclusions, reflections, and further research

6.1. Introduction

Given the lack of characterization of historic brownfield automated terminals, such a characterisation was presented in this document. Drivers and benefits, challenges and solutions, and drawbacks from automation were collected from a questionnaire. Brownfield converted terminal characteristics in terms of size and container handling equipment were gathered from a desk study. Additionally, trends in brownfield automation were identified and discussed. This characterisation allows the reader to understand the current state of brownfield container automation projects worldwide, particularly in terms of automated solutions adopted, expected outcomes from automation, potential challenges, and ways these have been dealt with in the past.

In this section, first reflections on the research process and limitations of the methods are discussed. Then, conclusions and their relation to the sub-questions are presented. Finally, potential further research is proposed.

6.2. Reflections and limitations of the research process

In this section reflections of the research process and limitations on the methods are discussed. Thereby, the results presented in this document can be accurately interpreted.

During the scope definition stage of this thesis, the presentation of guidelines for brownfield automation based on empirical information was defined as the original goal. Halfway through the process, it was understood that the development of robust guidelines was unfeasible, due to two reasons. Firstly, every brownfield automation process is different and depends on the goals defined by each terminal. Therefore, solutions from one terminal may not be a solution for another, even if the terminal characteristics are similar. Secondly, the number of brownfields converted terminals is small, and the number of respondents was even smaller. When categorising them only a few terminals per category were left. Not robust enough rules can be inferred with too few subjects.

The eventual development of guidelines necessarily would need to consider the experience of historic automation conversions. Therefore, a characterisation of historic automation projects was considered as a first step to gather that experience. Such a characterisation, in addition to the PIANC guidelines for the planning of automated terminals, do not replace guidelines for brownfield conversions, can be considered a starting point for anyone interested in understanding the current state of brownfield automation of container terminals worldwide. This information could also be of use during the early stage of development of a new brownfield automation project, probably developed in-house and before bringing a consultant into the project.

Two ways to gather data were used: a questionnaire and a desk study. The questionnaire adds practical views of people with field experience on brownfield automation of container terminals. The desk study was used to gather terminal characteristics before and after conversion. Additionally, existing literature was considered during the analysis of the results. Also, satellite images were gathered to evaluate the implementation strategy through the observation of physical changes in the terminal layout during the conversion process.

Given the small number of brownfield converted terminals, a low number of responses was expected. Therefore, it was discarded to perform pilot testing of the questionnaire with one or a few subjects. When responses were received and analysed, it was observed that pilot testing may have helped obtain better answers. For example, where two questions were asked together, respondents answered only one of them. That is the case of question N°8 in the questionnaire (see Appendix B), where operators were asked about benefits and drawbacks. All respondents listed their observed benefits, but some terminals did not include drawbacks. This might be related to a logical unwillingness to expose weaknesses. Pilot testing may have helped detecting this issue and solving it by splitting the question in 2 parts. Also, for question N°2, i.e., “what is the automation level you selected and why?”, some respondents answered whether they chose semi- or fully automated solutions, while others went into details about the automated processes performed by their equipment. Therefore, the question was not clear enough. This problem may have also been spotted and solved with a pilot test. It is advised to include this step in the research methodology and consider it in further work.

The questionnaire had to be built at the beginning of the research, when it was not clear to the author what were the main aspects to focus on. This induces a bias towards what the author thinks are the main aspects to focus on, by giving more importance to the issues directly addressed in the questionnaire. For example, no direct questions were asked regarding the selection of the TOS or how interfaces with stakeholders outside the terminal were dealt with. Therefore, these subjects are not directly discussed in the document, which does not necessarily mean they are irrelevant. On the other hand, challenges directly asked for such as continuity or labour relations may have induced answers including these to the open question, “what are the main challenges of developing and implementing new automated operations?”. The extent of this bias is unknown, but expected to be low, considering 2 of the challenges asked about were not mentioned within the terminal answers to this open question.

Another limitation of the analysis of questionnaire results is the potential bias from respondents. Possibly, the field of expertise of each respondent played a role in their answers, for example, the operational managers may focus their answers on operational issues. The extent of this bias was not analysed in this work, but it is assumed to be low since most respondents were general managers or directors who usually have a broad vision of the project. Another potential bias is that terminals with successful automation projects may be more open to sharing their experiences by answering the questionnaire than terminals with unsuccessful automation projects, so the second group may be underrepresented in the respondents. It was not possible to test this hypothesis in the context of this work.

Therefore, the reader should be aware that the list of drivers, challenges, benefits, and drawbacks from automation presented in this document is not exhaustive. They represent an overview on what are the main aspects according to a limited sample of respondents (12) and given the limited number of questions asked. Despite this fact and the limitations discussed, a questionnaire is considered a good tool given the context of this work. They are an inexpensive and fast way to gather data from respondents, regardless of their location, and were the main source to build the overview of drivers, challenges, benefits and drawbacks presented in this document.

Satellite images from Google Earth™ are also one of the sources of data. Major changes from brownfield automation projects were tracked from satellite images. Clear changes could be mapped from analysing images from different dates for converted terminals developing civil works. For terminals with no civil works (e.g. terminals retrofitting equipment) or for terminals that have not started the process yet, no changes could be observed from these images. Google Earth™ proved to be a powerful tool since many images from different dates were available per location. On the other hand, the method presents the limitation that only observations on the dates that were available on Google Earth™ could be made, which does not mean the changes occurred exactly on those dates. Additionally, many aspects, such as the integration of systems and software or staffing changes, cannot be analysed from satellite imagery. Therefore, only a high-level description of the implementation strategies employed in brownfield automated terminals could be achieved.

Results presented in this thesis could be considered as a reference during the early development stage of the business case of a new project, but they do not replace more detailed analyses that should be performed in more advanced planning stages before an investment decision for a new brownfield automated container terminal is made. Details on these analyses can be found in chapter 4 of the PIANC (2021) guidelines.

Despite the limitations listed above, conclusions could be reached for all research questions. Even if the overview of historic brownfield container terminals presented here is incomplete, it is an overview that was not available before. Additionally, results presented may not be exhaustive, but are expected to capture some of the main aspects to consider in brownfield container terminal automation. Conclusions per research question are presented as follows.

6.3. Conclusions

The research question of this thesis, **what information from the experience of past container terminal conversions to automated operations should be gathered and used to build an overview for future reference?** has been answered by going through 6 sub-questions. A discussion per sub-question is presented as follows.

1. What are the main automatable processes in a container terminal?

Based on questionnaire results with a limited number of respondents and a desk study, it was found that the main automatable processes are:

- **Yard processes**: completely automated alternatives exist, with remote operators only required for handling exceptions. In practice, brownfield conversions have generally adopted automatic movements in the stacks, but remote manual operations with OTR trucks. Sometimes operation on manned ITVs is also manual. Reasons for this are the variety of trailer designs or mandatory manual operation over manned equipment by law, as in Japan, probably due to safety reasons. Fully automated terminals serve ITV's automatically, and can serve OTR trucks with remote operation or automatically (PIANC, 2021).

- **Horizontal transport processes**: they are either automated for fully automated terminals or manned for semi-automated ones.

Other processes that have incorporated automated operations occur at the gate and the quay. However, manned operations are still required on both. In the case of gates, some tasks like seal checking or empty container inspection are still required to be manual (Chao, 2017). In the case of quay cranes, some movements of the trolley have been automated, however many operations such as gantrying or handling hatch covers require manual operations, potentially remote. Twist lock handling, mooring processes, and (un) lashing operations still largely require manned operations as well. Efforts to automate the first one has been made, but little practical use has been observed yet. Some automation level has also been tried for mooring, where ropes are replaced by a system using vacuum pads, but these systems are not currently widely used. Lashing operations are completely manual. Automating these would require completely redesigning the way containers are secured on a vessel, establishing a new standard.

A summary of all these processes is presented in Table 2-1.

2. How can the information on past conversions be systematically gathered and analysed?

To gather and analyse information on past conversions, an empirical research systematic approach was adapted from Flynn et al (1990). Within this method, a theory-building approach was chosen, which means no hypothesis is required. The subject was studied through multiple case studies, for which purpose a list of brownfield automated terminals was elaborated. Then, two data collection methods were used. A questionnaire was directed to personnel in managerial positions within each terminal, to gather data on drivers, challenges, benefits, and drawbacks. Also, a justification on the type of solution adopted was asked. On the other hand, data on terminal equipment, throughput, and size before and after conversion was gathered from terminal websites and specialised publications. Satellite imagery was used to roughly identify implementation strategies.

Questionnaire answers were categorised and reduced through thematic analysis. Results regarding these categories, plus terminal characteristics and implementation approaches were aggregated and discussed. Terminal characteristics gathered from the desk study were classified and used to identify trends regarding the type of conversion and type of yard equipment used.

As discussed in §6.2, questionnaires and the analysis of satellite imagery present limitations. Biases from the researcher may be introduced in the questions, and biases from the respondents may be introduced in the answers. Satellite images only offer a high-level overview of the conversion process where civil works are executed, limited by the availability of images. Despite these limitations, the methods are considered adequate for the purposes of this work, since they allow to gather data from historic conversions, including practical views from terminal operators, in an inexpensive and fast manner. To consider the limitations, results cannot be observed as exhaustive, but as a limited overview of the main aspects of past historic brownfield conversions of container terminals to automated operations.

3. What are the main drivers for automating existing terminals?

Based on questionnaire results with a limited number of respondents and a desk study, it was found that the main drivers observed for brownfield automation in container terminals are:

- **OPEX reduction per container handled**: mostly achieved from reducing labour costs. The materialization of it depends on the local labour market. The financial benefit may be high in countries with high salaries, but not in countries with low salaries. Terminals that reported OPEX reductions are from high income countries. The availability and costs of the new more qualified staff required for automated operations may also affect the OPEX result. Most terminals, but not all of them, included OPEX reduction as a driver.
- **Labour shortage:** addressed by a lower number of operators required and by improving working conditions. The lower number of operators is achieved due to fewer tasks required to be handled manually and by decoupling operators and equipment thanks to remote operation. The improvement in working conditions is achieved by moving operators from the yard into an office environment.
- **Higher productivity:** terminals presenting higher average productivity from automating seemed to have achieved it from changing to more productive yard equipment or from seamless transfer and just-in-time operation, as discussed in §5.2. But some terminals also reported lower average productivity, although none of them lost capacity. In those cases, more stacking area, and more cranes, helped maintain or increase the terminal capacity.
- **Higher capacity:** terminals mentioning higher capacity always migrated to aRMG, which is the equipment with the higher potential productivity per area.
- **Others:** reliability/safety, sustainability, predictability, and marketing.

Properly planned and implemented container terminals, i.e., with an adequate safety design, properly tested before going live, and with adequate personnel training, could achieve improved working conditions, a reduction of operators required per crane in the long term, safer, more reliable, and more sustainable operations with a more stable performance. But achieving higher productivity, capacity, or reducing OPEX, cannot be assumed a priori as a direct result of automating. They depend on the terminal conditions and the solutions adopted. Thus, terminals evaluating the incorporation of automated operations should set their main objective during the initial business case planning. Then, automated solutions targeted to achieve these objectives will be chosen. Finally, the effects of these solutions on other KPIs can be studied during the planning stage.

4. What are the main challenges, and how have these been addressed during the conversion process?

Based on questionnaire results with a limited number of respondents and a desk study, it was found that the main challenges observed for brownfield automation in container terminals are:

- **Continuity of operations**: especially challenging for terminals with yards operating close to full capacity and remaining within the same terminal footprint. Terminals in this condition mostly followed a phased implementation approach since this allows the terminal to comply with its commercial commitments. Terminals increasing the physical footprint followed a greenfield-like approach, i.e., the first implementation of automated technologies took place on previously unused land, not affecting the existing yard. For both phased and greenfield-like approaches, it was sometimes observed that land was vacated within the terminal footprint. The following strategies were observed to achieve this: relocating or removing empties and warehouses, relocating the rail terminal, rearranging container handling equipment operations. Finally, big bang approaches were observed on SC terminals, i.e., the solution would be tested in a small test bed, and then rolled out into the entire yard, or a large part of it, by closing the terminal for 2-3 days.

- **Adaptation to new operations:** this issue is intrinsic to converting terminals. A retraining strategy is fundamental for converting terminals (PIANC, 2021). An evaluation strategy should also be defined to check retraining has been successful. For terminals operating both manned and automated yards, dedicated personnel for each yard would help avoid misunderstandings.
- **Labour relations**: only a challenge for terminals reducing the number of workers, mainly fully automated ones. Most terminals converting to semi-automation did not require to reduce staff. When a staff reduction was necessary, redundancy packages, retraining and relocations were considered. In any case, open communication about the project goals, its benefits, and the role of each stakeholder is advised. A stakeholder management strategy would help in this process.
- **Communication systems**: a reliable communication system to perform automated operations must be installed. A robust design and commissioning testing should prevent problems after the go-live.
- **Others**: infrastructure, suppliers, system development, integration of systems, local market, variation and gaps in scope, optimization for higher productivity.

A referential commissioning period of 12 months and a ramp-up period of 6-12 months are expected for semi-automated conversion based on questionnaire answers. Up to 12 months longer ramp-up period is expected for fully automated conversions, based on the PIANC (2021) and answers from Patrick Terminals Brisbane. These numbers could be considered referential for the early planning stages, but a more definitive number should be established during later stages, with the help of vendors.

5. What are the benefits and drawbacks observed from past brownfield automation projects?

Based on questionnaire results with a limited number of respondents and a desk study, it was found that the main benefits from brownfield automation in container terminals are mostly the same as the drivers for automation, discussed in §5.2, and which conclusions were presented under SQ5. New concepts mentioned from questionnaire answers were reduced footprint, standardisation/ Integration with stakeholders and moving to an AI terminal.

Based on questionnaire results with a limited number of respondents and a desk study, it was found that the main drawbacks observed for brownfield automation in container terminals are:

- **Unpredicted technical issues and high impact of failures**: fallback solutions should be planned, and redundancy and resilience should be built. Redundancy is achieved with spare equipment and installations, while resiliency is achieved from identifying potential disruptions in advance and planning for fast recovery.
- **Lower average performance:** reported by some terminals, while others reported higher performances as discussed on SQ3. Other related drawback reported was the loss of expert performers, i.e., skilled staff with a higher performance than the average. Automated operations present a more stable

performance, so the higher performance is indeed lost. But a stable performance allows for fewer risks when planning future operations.

- **New staff requirements:** staff with different skills are required. Retraining or hiring are the solutions. The first one, when possible, would reduce labour issues. Regarding the second one, new personnel may not be available in the local market, expatriate workers may be required (PIANC, 2021).
- **High maintenance cost**: maintenance costs are expected to be higher for scheduled maintenance, but lower for unscheduled maintenance. Infrastructure maintenance may be more expensive for automated terminals (PIANC, 2021). The overall result is not clear a priori and should be analysed for each case.
- **Exception handling**: a long time to handle exceptions was reported as a drawback. A simplification of operations to reduce the number of exceptions as suggested by Chu et al. (2018) would help reduce the number of exceptions, but there will always be exceptions. Planning for exceptions and testing exception scenarios will allow putting in place procedures to handle them.

New skills for the staff, planning for unpredicted technical issues and planning for exception handling, are drawbacks that should be addressed by any terminal converting to automation. Regarding final performance or maintenance costs, no outcomes can be assumed a priori, and they should be evaluated during the planning stage, with the help of vendors.

6. What are the main trends observed regarding the type of automated technologies chosen?

Based on questionnaire results with a limited number of respondents and a desk study, it was found that the main trends of brownfield automation are:

- **Converted terminals mainly opted for semi-automated solutions**: 23/29 terminals opted for semi-automation, even if fully automated solutions present a potentially lower OPEX. Reasons given were fewer labour issues, higher vessel productivity, less required space, better agility in dealing with disruptions, and lack of maturity in the control systems for full automation. It was observed that terminals converting to full automation either increased their physical footprint or had spare capacity. Conversion to full automation in other conditions are less likely, since stacking area and horizontal transport area should be closed for testing and commissioning, which is expected to take longer for fully automated conversions than semi-automated ones.
- **Fully automated solutions opted for ASCs or auto SC**: terminals converting to fully automated auto SC were originally SC terminals. The difficulty for segregating manned OTR trucks and automated ITVs with aRTG or CARMG solutions, may be one of the reasons why these have not been considered.
- **Yard equipment**: it was observed that the 3 terminals with yard areas below 10 ha chose aRTG with semi-automated yards. For terminals with yard areas above 10 ha, the solution for the yard was either the automated version of the yard equipment before automating or a version of aRMG (ASC or CARMG). This may be explained because aRMGs are the equipment that would yield the highest productivity and capacity from a yard, but the conversion process is highly disruptive (unless aRMGs are being retrofitted). Yards smaller than 10 [ha] may be too small to install aRMGs, so the next equipment that would yield the higher productivity are aRTGs. Finally, if high disruptions are not an option, converting to the automated version of the existing equipment would result in the less disruptive procedure.

Finally, the conclusions to the main research question are presented.

What information can be extracted from historic automation projects on brownfield container terminals to inform the initial planning stage of future container terminal conversions to automation?

This desktop study of brownfield automation projects produced a high-level characterisation of historic brownfield automated container terminals. This characterisation includes the automated solutions adopted per terminal, drivers and benefits, challenges and solutions, and drawbacks from automation, including practical views from people with field experience. Also, trends regarding the type of automation and automated equipment were discussed. Results, although not exhaustive, are expected to cover the most important aspects of the topics mentioned above. This way, a broad overview is presented to the reader who wants to be informed on historic applications of brownfield container terminal automation worldwide up to date.

This research used with the PIANC report WG208 "Planning for automation of container terminals", is expected to be a starting point for port professionals looking for knowledge about brownfield terminal automation projects. Drivers, benefits, challenges, and potential ways to overcome them, and drawbacks from automation presented may be used in early planning stages as a referential inventory of potential outcomes from an automation project. However, none of them can be assumed as a general consequence of automation only. The expected results for a future automation project will depend on the conditions of the terminal before automating and on the type of solution adopted. Also, the best automated solution for a certain terminal cannot be determined based on the terminal's characteristics only. The solution must be devised based on the goals established by the terminal owner. Only after the solution has been determined, potential expected benefits, challenges, and drawbacks can be evaluated.

6.4. Next steps

As a result of this work, a characterisation of the experiences and solutions of brownfield automated terminals up to date is presented. This is expected to give the reader an indication of potential outcomes of automation. Further research is proposed to enrich this overview by including a wider range of challenges and drawbacks, by further diving into the main results, and by expanding results to other processes in the terminal, not analysed in this work. Additionally, it is proposed to use these results in developing a planning process fit for brownfield conversions. Finally, in the medium term, it is proposed to update the results by incorporating new terminals.

- **Present a more exhaustive inventory of challenges and drawbacks:** challenges and drawbacks are interesting findings, since they give an idea of the issues that could be faced in a conversion process to automation followed by container terminals. They could also help raise red flags in early planning stages. As discussed in §6.2, results presented in this document cover the main challenges according to a limited number of respondents, but the list is not exhaustive. More challenges, and the way terminals have dealt with them, could be included in further research. A new questionnaire including potential challenges not discussed here, such as those left out of the questionnaire presented in Appendix A, or other challenges such as adopting a new TOS, or relations with stakeholders other than labour could be included. The definitive list of challenges to include in a new questionnaire could be identified with a procedure like the one applied in this work, i.e., by interviewing experts on the field, but including more experts from different backgrounds, to cover a wider range of possibilities.

- **Further dive into the main challenges and drawbacks**: a high-level identification of challenges and drawbacks from brownfield conversions was performed. Further information regarding these challenges and solutions adopted may be requested and analysed, to understand in a more detailed level these difficulties and their effects. For example, a further study of the adaptation to new operations challenges could be conducted. To do so, a questionnaire related to it may be elaborated. Questions like “can you explain the training strategy?”, “how were people evaluated to check if they were ready to operate in automated mode?”, or “how were relocations within the terminal planned?”, would dive further into the problem.
- **Incorporate trends on other automated processes**: most findings are focused on yard equipment and horizontal transport equipment. Information about STS cranes, or automated gates could be incorporated to expand this overview to cover the entire range of processes in a container terminal. This could be done following the same methodology but including questions directly about these processes.
- **Devise a planning process fit for brownfield converted terminals**: the current version of the PIANC guidelines briefly mention some issues related to brownfield automation, though the focus is on greenfield conversions. A planning process fit to brownfield conversions could also be presented. The challenges and drawbacks identified in this work, or with potential further work, could be included in this process. Since the current PIANC guidelines also allow for the use of empirical data in the early planning stages for technology and sizing, empirical information for identifying challenges and solutions may also be used in these early stages.
- **Update the results**: the results presented in this document are representative of the situation of brownfield terminals until May 2021. Between the end date of collecting questionnaire results and the publication date of this report, at least 4 new terminals have been identified. Since brownfield automation projects are expected to increase in the next years, this analysis could be repeated with more terminals in the medium term to update the results. By doing this, new technologies would be incorporated, and more robust trends could be identified.

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APPENDIX A | PRELIMINARY CHALLENGES OF BROWNFIELD AUTOMATION OF CONTAINER TERMINALS

The preliminary list of challenges developed to build the questionnaire, is presented in Table A-1. Comments on each challenge were included.

Table A-1: inventory of challenges in designing and implementing automated terminals.

Category	N°	Challenge	Green/ Brown	Comments
Design and implementation	1	Give continuity to operations during the conversion process.	Brownfield	This is a relevant challenge. It might determine which solution is preferred for a certain terminal.
	2	Exception handling.	Both	This is one of the operational challenges that must be solved in the planning stages.
	3	Adapt existing equipment to the automated solution.	Brownfield	There is usually one supplier for automated solutions. If the terminal has old equipment from another supplier, then the automation supplier will update the old equipment with his electronics and software.
	4	Adapt existing infrastructure to the automated solution.	Brownfield	This challenge is related to continuity.
	5	Find skilled personnel.	Both	This is solved either by bringing people in or by training existing workers.
Commercial	6	Maintain service levels to keep the customers satisfied.	Brownfield	This challenge is related to continuity.
	7	Deal with temporary closures.	Brownfield	This challenge is related to continuity.
Social	8	Digitalization of processes, involving other stakeholders.	Brownfield	This is more related to port community systems, subject not directly addressed in this thesis.
	9	Dealing with unions.	Brownfield	This is one of the main challenges, according to literature and interviews.
Business case	10	High CAPEX must be justified by high confidence in projected revenues. This is challenging for independent terminals.	Both	This is addressed in a financial analysis. High risk can be addressed by a higher discount rate.
	11	Deal with reduced productivity during the conversion and ramp-up periods.	Brownfield	This challenge is related to continuity and can be addressed in a financial analysis.
	12	Concession periods long enough.	Both	This is addressed in a financial analysis. Related to ROI.

From the table above, the following observations can be made:

- Continuity is an important challenge, since it could determine the type of solution chosen for a certain terminal. Also, many other challenges are related to the continuity strategies. Therefore, the question "**How were the automation works planned to give continuity to the terminal operations and services?**" was included in the questionnaire.

- Dealing with unions is one of the main challenges, according to interviewees and literature. Therefore, the question "**How were labour relations managed facing the possible loss of jobs?**" was included in the questionnaire.
- Many terminals find that exception handlings are the greatest single challenge for raising productivity (Chu et al., 2018). Since vessel productivities expected have not been achieved by many automated terminals (PIANC, 2021), the problem of handling exceptions was also included in the questionnaire. The question is "**How was considered the handling of exceptions? Where there any exceptions that were not considered originally?**".
- Finally, the development of a business case is a relevant step in the planning process. Current OPEX are well known by terminal operators. Future CAPEX and OPEX and expected performances can be well established during the new terminal planning stage. But there seem to be uncertainty on how long it will take for a terminal to achieve theoretical productivities, if they even are able to achieve it (White, 2018). A question related to the ramp-up period, i.e., the period between the go-live of the new terminal and the moment when productivities achieve their target. The question is "**How long was the commissioning period and how long was the ramp up period?**".

Other challenges listed in Table A-1 are left out of the scope of this thesis.

APPENDIX B | QUESTIONNAIRE

1. What is the design throughput of your terminal in [TEU/year] before and after automating?

2. What were the main drivers to automate the operation of your terminal?

3. What is the automation level selected and why? Is further automation being considered in the future?

4. From your experience, what are the main challenges of developing and implementing new automated operations?

5. How were the automation works planned to give continuity to the terminal operations and services?

6. How were labour relations managed to face the possible loss of jobs?

7. How long was the commissioning period and how long was the ramp-up period?

8. What benefits and drawbacks are observed from the automated operation?

9. How was the handling of exceptions considered? Were there any exceptions that were not considered initially?

10. Any additional comments?

APPENDIX C | LIST OF CONVERTED TERMINALS

N°	Country/ Region	Port	Terminal	Operator/ Owner	Year of automation	Status	Respondent	Before automation					After conversion						Type of automation	Implementation strategy	Old yard
								Yard area	Capacity [MM TEU/yea	Quay length [m]	Horizontal transport e	Stacking areas	Yard area	Capacity [MM TEU/yea	Quay length [m]	Horizontal eq.	Stacking areas				
																	System	N° of automated e			
1	Australia	Brisbane	Fisherman Islands Terminal	Patrick Terminals	2005	Current	Terminal Manager	7	0.4 [1]	670	SC	SC	20	1.1 [2]	933	auto SC	auto SC	28 auto SC	Fully automated	Greenfield-like	Vacated
2	Australia	Brisbane	Fisherman Islands Terminal	DPW	2014	Current	-	15	0.6 [3]	902	TT	RS/CRMG	19	1.0 [3]	902	ShC	ASC	16 ASC	Semi-automated	Greenfield-like	Vacated
3	Australia	Port Botany	Sydney Autostrad Terminal	Patrick Terminals	2014	Current	Terminal Manager	20	0.6 [1]	1000	SC	SC	30	1.6 [4]	1400	auto SC	auto SC	44 auto SC	Fully automated	Big bang	Complete conv.
4	Belgium	Antwerp	Antwerp Gateway (AGW)	DPW	2007	Current	-	26	1.4 [5]	1320	SC	SC	44	2.8 [8]	1660	SC	ASC/SC	20 ASC	Semi-automated	Greenfield-like	Kept manned
5	Germany	Hamburg	Burchardkai	HHLA	2010	Current	Managing director	74	2.8 [7]	2850	SC	SC	78	5.2 [7]	2850	SC	ASC/SC	36 ASC	Semi-automated	Phased	Mixed
6	Greece	Piraeus	Pier II West	PCT (COSCO)	2012	Current	-	19	0.7 [8]	698	SC	SC	19	1.4 [9]	698	TT	CARMG	16 CARMG	Semi-automated	Phased	Complete conv.
7	Indonesia	Semarang	Petikemas (TPKS)	Pelindo III	2016	Current	-	15	0.5 [10]	525	TT	RTG	21	0.8 [11]	630	TT	aRTG/RTG	20 aRTG (+5 old)	Semi-automated	Greenfield-like	Mixed
8	Ireland	Dublin	CT N°50 berth	Dublin Ferryport T.	2017	Current	General Manager	9	0.3 [12]	550	TT	RTG	9	0.4 [13]	550	TT	aRTG/RTG	4 aRTG	Semi-automated	Phased	Mixed
9	Japan	Kobe	Kamigumi Kobe CT	Kamigumi	2027	Under dev.	-	12	unknown	780	TT	RTG	12	unknown	780	TT	aRTG	-	Semi-automated	Unknown	Unknown
10	Japan	Nagoya	Nabeta	Nagoya United	2023	Under dev.	Automation project leader	52	1.1 [1]	985	TT	RTG	52	1.3 [1]	985	TT	aRTG	40 aRTG	Semi-automated	Phased	Complete conv.
11	Japan	X	X	X	2025	Under dev.	Corporate Planning dep.	16	unknown	760	TT	RTG	16	unknown	760	TT	aRTG	15 aRTG	Semi-automated	Phased	Complete conv.
12	Netherlands	Vlissingen	Blijeveldhaven	Kloosterboer CT	2020	Current	General Manager	-	0.14 [14]	1700	TT	RS	-	0.25 [15]	820	TT	aRTG	4 aRTG	Semi-automated	Phased	Mixed
13	New Zealand	Auckland	Ferguson	POAL	2021	Under dev.	-	11	0.9 [16]	625	SC	SC	14	1.4 [17]	920	SC	auto SC	27 auto SC	Semi-automated	Big bang	Complete conv.
14	Norway	Oslo	Sjursøya	Yilport	2016	Current	-	3	0.3 [18]	305	SC	SC	5	0.5 [19]	665	TT	aRTG	8 aRTG	Semi-automated	Phased	Complete conv.
15	ME	X	X	X	2017	Current	Head of Operations	16	1.5 [20]	970	TT	RTG	48	1.8 [21]	970	TT	aRTG/RTG	8 aRTG	Semi-automated	Greenfield-like	Kept manned
16	Panama	Colon	Manzanillo	MIT	2015	Current	Terminal design manager	40	2.2 [22]	1640	TT	RTG	40	3.5 [23]	2035	TT	CARMG/RTG	6 CARMG	Semi-automated	Phased	Mixed
17	PRC	Hong Kong	Terminal 9 North	HIT	2018	Current	-	12	0.9 [24]	690	TT	RTG	12	unknown	690	TT	aRTG	29 aRTG	Semi-automated	Phased	Complete conv.
18	PRC	Tianjin	(former) FICT	Tianjin Port Group	2019	Current	-	28	2.5 [25]	1250	TT	CRMG	28	2.8 [25]	1250	TT	CARMG	31 aRMG	Semi-automated	Phased	Complete conv.
19	PRC	Xiamen	Xiamen Ocean Gate CT	COSCO	2014	Current	-	44	1.4 [26]	1500	TT	RTG	66	2.6 [27]	1800	AGV/TT	ASC/RTG	16 ASC	Fully automated	Greenfield-like	Kept manned
20	Taiwan	Kaohsiung	Evergreen Marine Terminal	EMC	2016	Current	-	23	1.5 [28]	900	TT	RTG	23	1.8 [28]	900	TT	CARMG/RTG	4 CARMG	Semi-automated	Phased	Mixed
21	Turkey	Yarımca	Yarımca	DPW	2018	Current	Automation manager	26	1.3 [29]	895	TT	RTG	26	1.3 [30]	895	TT	aRTG/RTG	2 aRTG	Semi-automated	Phased	Mixed
22	UAE	Jebel Ali	Terminal 2	DPW	2015	Current	-	120	6.0 [31,32]	2980	TT	CRMG	120	6.5 [33]	2980	TT	CARMG	-	Semi-automated	Unknown	Unknown
23	UK	Belfast	Victoria Terminal 3	Belfast CT (ICG)	2020	Under dev.	Temrinal director	7	0.3 [34]	375	TT	CRMG/SC	7	0.4 [34]	375	TT	aRTG	8 aRTG	Semi-automated	Phased	Complete conv.
24	UK	Felixstowe	Berth 8/9	HPH	2019	Current	-	16	unknown	730	TT	RTG	26	unknown	920	TT	aRTG/RTG	8 aRTG	Semi-automated	Greenfield-like	Kept manned
25	USA	Long Beach	LBCT (Long Beach)	OOCL	2016	Current	-	-	-	-	TT	RTG/chassis	53	3.5 [35]	1300	AGV	ASC	47 ASC	Fully automated	Greenfield-like	Complete conv.
26	USA	Los Angeles	MOL	TraPac	2014	Current	-	44	1.7 [36]	1520	TT	RTG/chassis	46	2.4 [36]	1650	aShC	ASC/RTG/FL/chassis	29 ASC	Fully automated	Phased	Mixed
27	USA	Los Angeles	Pier 400	APM Pacific	2021	Under dev.	-	120	4.4 [37]	2190	TT	RTG/chassis	120	4.4 [38]	2190	auto SC	autoSC/RTG/chassis	70 auto SC	Fully automated	Phased	Mixed
28	USA	NY/NJ	GCT Bayonne	GCT	2014	Current	-	30	unknown	550	TT	RTG	43	1.7 [39]	823	ShC	ASC/RTG	20 ASC	Semi-automated	Greenfield-like	Kept manned
29	USA	Virginia	Norfolk Int. Terminals South	VIT	2018	Current	Sr. vicepresident technology	36	0.7 [1]	1290	SC	SC	36	1.4 [1]	1290	SC	ASC	24 ASC	Semi-automated	Phased	Complete conv.

[1] From questionnaire answers
[2] https://patrick.com.au/locations/brisbane/
[3] https://www.kalmarglobal.com/customer-cases/all-customer-cases/dpw-brisbane/
[4] https://patrick.com.au/locations/sydney/
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[7] Feldt (2009)
[8] Piraeus Port Authority S.A. (2014) for Pier II. West Pier capacity estimated by relating quay lengths.
[9] https://www.pct.com.gr/content.php?id=26 for Pier II. West Pier capacity estimated by relating quay lengths.
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[13] https://www.cargotec.com/en/nasdaq/trade-press-release-kalmar/2021/kalmar-receives-repeat-order-of-five-autortgs-to-extend-the-system-at-dublin-ferryport-terminals/
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[15] https://global.royalhaskoningdhv.com/projects/delivering-automated-terminal-operations-for-kloosterboer
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[19] https://www.yilport.com/en/ports/default/Oslo-Norway-%7C-Nordic-Terminals/86/0/0
[20] https://www.soharportandfreezone.com/en/media/news-events/52
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[22] https://anpanama.com/47-MIT-de-Panama-amplia-su-capacidad-.note.aspx
[23] https://logistics.gatech.pa/en/assets/seaports/manzanillo-international-terminal
[24] Hong Kong South China Historical Research Programme & Hong Kong Marine Department (2017)
[25] Henriksson et al. (2020)
[26] Cosco Pacific Limited (2012)
[27] Cosco Shipping Ports Limited (2017)
[28] Taiwan International Ports Corporation Ltd. (2014)
[29] https://www.dpworld.com/en/yarimca/about-us/terminal-overview/capacity
[30] In the questionnaire it was indicated that, at least for now, productivity was the same for automated equipment as before.
[31] https://gulfnews.com/business/work-on-new-jebel-ali-port-terminal-starts-1.298155
[32] https://www.porttechnology.org/news/first_cranes_for_dp_worlds_new_jebel_ali_terminal/
[33] https://www.dpworld.com/en/uae/services/ports-and-terminals/jebel-ali-port
[34] Capacity informed as lifts before and after conversion from Irish Continental Group (2021). Converted to TEU by assuming the TEU factor from DFT, estimated by computing number of lifts informed for DFT in the same reference and capacity in TEU informed.
[35] https://www.lbct.com/AboutUs/CorporateMessages
[36] USACE (2007)
[37] https://www.apmterminals.com/en/los-angeles/about/our-terminal
[38] The port of LA Executive Director (2019)
[39] https://www.portstrategy.com/us-gateway-for-global-commerce/195025.article?adredir=1

APPENDIX D | QUESTIONNAIRE RESULTS ANALYSIS

D.1. General

Twelve terminals answered the questionnaire. The data gathered was analysed using a thematic analysis approach, to reduce and classify the data. The process is presented in this appendix with the resulting tables. A discussion on results is presented in chapter 4.

D.2. Drivers for automation

Answers to the questions "**Why did you decide to automate? What were the main drivers?**" were coded to identify drivers. The first set of codes is: reduce cost, efficiency, capacity, productivity, reliability, safety, cost ratio operator to crane, hygiene factors, gender balance, appeal to younger workforce, more predictable and consistent performance, safer, sustainability, working conditions, 24x7 operation, labour shortage, marketing, government subsidy and minimizes human-related disruptions. These codes were then reduced into themes.

Three port operators mentioned Efficiency as one of the drivers. According to the online Cambridge dictionary, efficiency means "to use resources… without wasting any". Therefore, in this context efficiency can also be understood as the reduction of unitary operating costs. Efficiency and cost reduction are then grouped in the same category.

Capacity refers to the projected volume to be transferred over a certain period, usually a year. The capacity of the terminal might be governed by the quay, yard, or gate capacities, although gate is not usually the constraint, since it is relatively inexpensive to expand them (PIANC, 2021). Productivity is related to the flow rate of containers per a certain period, usually an hour or a day, through each of the components of the process (PIANC, 2021). Even though productivity and capacity are related, capacity and productivity are kept separate to keep in mind their differences when analysing the results.

The codes "24x7 operation" and "minimizes human-related disruptions" were put together with productivity since more hours per day would yield a higher daily productivity.

One of the drivers most frequently mentioned is labour shortage. The labels hygiene factors, gender balance, appeal to younger workforce, better working conditions, and labour shortage are grouped in one category, "labour shortage".

Reliability and safety/safer were put into the same theme since both refer to the quality of operations. It is expected that more reliable operations are also safer.

"More predictable and consistent performance" is renamed as "Predictability".

The respondent from DP World Yarımca did not mention any drivers. They indicated this was a proof of concept (PoC) offered by their headquarters, to test automation and evaluate its benefits. They mentioned it was a good opportunity since they already used electric RTG (eRTG), and they only needed to set up the communication system. This proved to be challenging though, as discussed in §D.1.2.3.

Resulting themes are presented in Table D-1.

Table D-1: drivers indicated by respondents for converting to automated operations.

Terminal name	Operating cost reduction	Higher capacity	Higher productivity	Reliability/ Safety	Sustainability	Predictability	Labour shortage	Marketing	Government subsidy
Fisherman Island (Patrick)	X								
Sydney AutoStrad (Patrick)	X								
CTB Hamburg	X		X	X					
CT N°50, Dublin	X						X		
Nabeta			X				X		X
Japan, X							X		
Blijeveldhaven (Kloosterboer)			X		X		X		
ME, X			X	X		X			
Manzanillo	X	X						X	
Yarımca	*PoC proposed by HQ. No clear drivers. Opportunity to evaluate the benefits.*								
Belfast CT	X						X		
Norfolk International	X	X		X					

D.3. Challenges

Answers to the question "**From your experience, what are the main challenges of developing and implementing an automated container terminal?**" were coded. The first set of codes is: labour relations, continuity, suppliers, system development, communication system, adaptation to new operations, integration of systems, infrastructure and local market, variation and gaps in scope, optimization for higher productivity, coexistence of different operating strategies, and high CAPEX. These codes were then reduced into themes.

"Coexistence of different operating strategies" was merged with "Adaptation to new operations" since both refer to the capacity of stakeholders to adapt to the new way of operating.

All other codes were kept as separate themes. "System development" refers to the design of the automated solution. "Integration of systems" and "Communication systems" may also be related to it, but they were maintained as separate themes given the different connotations of these 3.

Resulting themes are presented in Table D-2.

Table D-2: challenges indicated by respondents to convert to automated operations.

Terminal name	Continuity	Labour relations	Suppliers	System development	Integration of systems	Adaptation to new operations	Communication System	Infrastructure	Local market	Variation and gaps in scope	Optimization for higher productivity
Fisherman Island (Patrick)		X									
Sydney AutoStrad (Patrick)	X	X									
CTB Hamburg	X										
CT N°50, Dublin							X			X	
Nabeta											X
Japan, X			X	X							
Blijeveldhaven (Kloosterboer)					X						
ME, X								X	X		
Manzanillo						X					
Yarımca						X	X				
Belfast CT											
Norfolk International	X					X					

D.4. Continuity

Answers to the question "**How were the automation works planned to give continuity to the terminal operations and services?"**, were coded. The following codes were identified: greenfield-like, adjacent berth for trials, terminal shut, fall-back solutions, introduction in steps, strategic partners, test bed, one by one module, step by step, sufficient place, phases, terminal under-capacity, and communication. These codes were then reduced into themes.

The codes, "introduction in steps", "one by one module", "step by step", and "phases", all correspond to a phased approach. Therefore, these terminals are qualified under the theme "Phased approach".

"Sufficient space" and "terminal under-capacity" also refer to the same condition, therefore they are grouped under the theme "Under-capacity operation".

"Adjacent berth for trials" and "test bed" remained as separate themes. The first one refers to the construction of a new adjacent berth for trials, while the other considers the construction of a test yard within the terminal footprint. Moreover, when looking at the entire answer from the respondent who mentioned "Adjacent berth for trials", it is indicated that this is the first part of the strategy. The second part is "shut the manual terminal for 72 hours and rolled the automated gear from the adjacent berth into the terminal proper". Then the strategy is relabelled as "Adjacent berth for trials + fast roll out".

No other codes were merged. Resulting themes are presented in Table D-3.

Table D-3: strategies to overcome the challenge of continuity indicated by respondents.

Terminal name	Phased approach	Under-capacity operation	Adjacent berth for trials + fast rollout	Test bed within the footprint	Greenfield-like	Fall back solutions	Strategic partners	Communication
Fisherman Island (Patrick)					X			
Sydney AutoStrad (Patrick)			X					
CTB Hamburg	X					X		
CT N°50, Dublin				X				
Nabeta	X							
Japan, X	X							
Blijeveldhaven (Kloosterboer)		X						
ME, X	X							
Manzanillo	X							
Yarımca		X						
Belfast CT	X							
Norfolk International								X

D.5. Labour relations

Answers to the question "**How were labour relations managed facing the possible loss of jobs?**", were coded. The following codes were identified: No union, negotiations, union did not oppose, redundancy packages, retirement programs, open books, benefits for employees, improving work safety, qualification to new jobs, open communication, explained opportunities, maintaining current staffing levels, guaranteed another work, agreement with port labour union, terminal growing, transfer those affected to other job, personnel not member of a syndicate, and no loss of jobs. Codes were then collated into themes.

The word "Union" is repeatedly mentioned. Most respondents mentioned that negotiations with unions were required. Some respondents indicated that there were no unions or that unions did not oppose, either because they did not see automation as a threat or because there were no staff reductions required. So, a category indicating if there were negotiations is proposed. Then, the strategies followed during those negotiations are grouped together.

Regarding the strategies followed when negotiating with unions, "redundancy packages" and "retirement programs" are both grouped within the theme "Compensations". Although they are different, given the context of someone retiring for the second one, in essence both are a compensation.

"Guaranteed another work", "transfer those affected to other job", and "qualification to new jobs" were all grouped under "Relocations". It was not always specified whether these relocations would take place within the terminal or in other companies. Terminals applying relocations may have done it partially, meaning that some people were relocated, while some others were laid off.

"Open books" and "open communication" are grouped under "Communication strategies". "Benefits for employees", "improving work safety", and "explained opportunities" are also grouped under the "Communication strategies" theme. Terminals indicating these as a strategy, indicate they mainly explained their people why automation is a necessary step, regardless of the costs.

One respondent indicated they "use personnel not member of a syndicate" for remote operation. It is implied that workers in syndicates kept operating with manned equipment, which that specific terminal corresponded to most of the terminal's operations, while new workers were hired for the remote operations of the automated equipment, which represent a minority of yard operations. It must be noted that in this case it was not clarified whether there were staff reductions took place or not.

"Maintaining current staffing levels", "no loss of jobs" and "terminal growing" were grouped under "Staff retained, growing terminal". Here it is implied that the people kept working in their previous roles. This is different from "relocations", where people would take a new role within or outside the terminal.

The themes regarding labour are summarised in the following table.

Table D-4: labour strategies.

Terminal name	**Negotiation with unions**				**Unions did not oppose**	**No union**	**Staff retained, growing terminal**	**Personnel not member of a syndicate**
	Compensations	**Relocations**	**Communication strategies**	**No details**				
Fisherman Island (Patrick)					X			
Sydney AutoStrad (Patrick)	X							
CTB Hamburg	X	X	X					
CT N°50, Dublin			X				X	
Nabeta		X						
Japan, X				X				
Blijeveldhaven (Kloosterboer)							X	
ME, X		X						
Manzanillo								X
Yarımca						X		
Belfast CT			X				X	
Norfolk International							X	

D.6. Benefits and drawbacks

Answers to "**What benefits and drawbacks are you seeing from your automation?**" were coded. Benefits and drawbacks were studied separately.

D.6.1. Benefits

The following codes were identified for benefits: cost efficiencies in labour, cost efficiencies in maintenance, cost efficiencies in pavement design, health, safety, cost reduction, increased productivity, as per drivers, better working conditions, decrease in footprint, flexible hours, standardisation, moving forward to an AI terminal, integration of processes with external stakeholders, faster shift change, no back problems, and pregnant women can operate. Codes were then collated into themes.

DFT in Dublin and terminal X from the ME indicated benefits were “as per drivers”. Codes identified for those drivers were: minimizes human-related disruptions, more predictable and consistent performance, safer/safety, cost ratio operator to crane, hygiene factors, gender balance, and appeal to a younger workforce. Norfolk International answered “promises related to the business case that drove the decision were fulfilled”. No details about the business case were given, therefore this answer is discarded from the analysis.

Different cost efficiencies, “cost reduction”, and “cost ratio operator to crane” were merged into “cost reduction”. Even if cost efficiencies can be achieved in different categories, only one terminal provided this level of detail.

“Health”, “better working conditions”, “no back problems”, “flexible hours”, “hygiene factors”, “gender balance”, and “appeal to younger workforce” were grouped into “better working conditions”. “Pregnant women can operate” is also included here, since it is a consequence of the improved working conditions.

“Increased productivity” and “faster shift change” are not merged. It is interpreted that faster shift changes would result in higher productivity, but it might not be the only factor.

“Standardisation” and “Integration of processes with stakeholders” are grouped together since standardization allows the integration of processes with other stakeholders.

Other codes were kept as separate themes. Resulting themes are summarised in Table D-5.

Table D-5: benefits from automation as indicated by respondents.

Terminal name	**Operating cost reduction**	**Better working conditions**	**Increased productivity**	**Faster shift changes**	**Reliability / Safety**	**Decrease on footprint**	**Standardisation/ Integration with stakeholders**	**Moving to an AI terminal**	**Predictability**
Fisherman Island (Patrick)	X	X			X				
Sydney AutoStrad (Patrick)	X	X			X				
CTB Hamburg	X								
CT N°50, Dublin	X	X							
Nabeta	X		X		X				
Japan, X							X	X	
Blijeveldhaven (Kloosterboer)		X				X			
ME, X					X				X
Manzanillo							X		
Yarımca		X		X					
Belfast CT	X	X							
Norfolk International	*Unable to process answer.*								

D.6.2. Drawbacks

Four out of the 12 respondents did not respond about drawbacks. From respondents, the following codes were identified: non-existent, removal of expert performance, lower average performance, high impact of failures, higher maintenance cost, possible lower productivity, unpredicted technical issues, long time for exception handling, long time for breakdown handling, people with electronic skills, lower performance, retraining existing staff and discipline demands for semi-automated facilities. These codes were collated into themes.

Codes regarding lower productivity and performance are grouped together, the same for technical issues and impact of failures. Also, “people with electronic skills”, “retraining existing staff”, and “discipline demands for semi-automated facilities” are grouped under the theme “New skills for staff”.

Results are presented in Table D-6.

Table D-6: drawbacks from automation as indicated by respondents.

Terminal name	Non-existent	Removal of expert performance	Lower average productivity	Unpredicted technical issues/ High impact of failures	Higher maintenance cost	Long time for exception and breakdown handling	New skills for staff
Fisherman Island (Patrick)	X						
Sydney AutoStrad (Patrick)	X						
CTB Hamburg	NI						
CT N°50, Dublin		X	X	X			
Nabeta					X		
Japan, X			X	X			
Blijeveldhaven (Kloosterboer)	NI						
ME, X						X	
Manzanillo	NI						
Yarımca							X
Belfast CT	NI						
Norfolk International							X

NI: not informed

D.7. Handling of exceptions

Answers to “**How did you consider the handling of exceptions in your planning? Were there any exceptions that were not considered originally?**” were coded, although respondents answered only the first question. The following codes were identified: forklift and terminal tractors, defined manned processes, remote operator, conventional operation, manual mode, and manual yard.

It is observed that all codes can be grouped in one theme, i.e., exceptions were always handled with a manned crew. “Forklift and terminal tractors” is the answer for both fully automated auto SC terminals. Other terminals would use the automated equipment with remote operation.

APPENDIX E | TERMINAL AUTOMATION DATASHEETS

Patrick terminals
Fisherman Island terminal
Port of Brisbane

General

Parameter	Before conversion	After conversion
Country	Australia	
Yard equipment	SC	auto SC
Horrizontal transport eq.	SC	auto SC
Type of conversion	Full automation	
Yard area [ha]	7	20
Capacity [MM TEU/year]	0.4	1.1
Quay length [m]	670	930

Implementation approach

Greenfield-like

- The new automated terminal was built in a new location within the same port. Construction and testing would take place in the new location without disturbing the operations of the old terminal. Then operations were gradually moved to the new terminal.
- The old yard was vacated.

Implementation images

- Nov/2003: old terminal under operation.
- Nov/2004: old terminal under operation, new terminal under construction.
- Jul/2006: operations moved to new terminal
- Jun/2009: new terminal expanded.

DP World
Fisherman Island terminal
Port of Brisbane

General

Parameter	Before conversion	After conversion
Country	Australia	
Yard equipment	ReachS/CRMG	ASC
Horrizontal transport eq.	TT	ShC
Type of conversion	Semi-automation	
Yard area [ha]	15	19
Capacity [MM TEU/year]	0.6	1.0
Quay length [m]	900	900

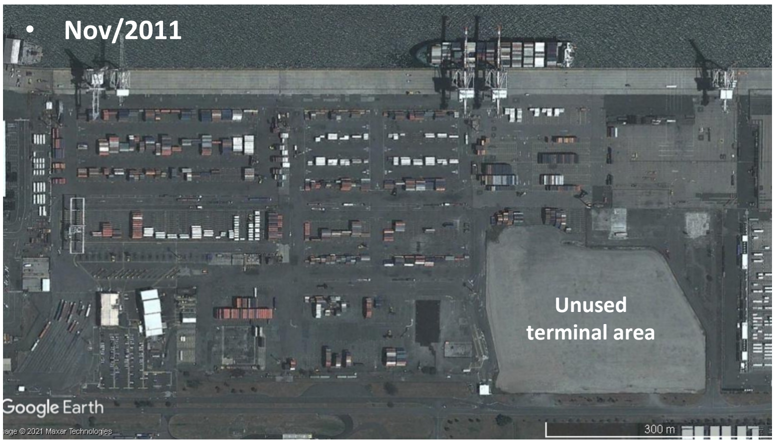
Implementation approach

Greenfield-like

- New automated yard was built next to the old yard, mainly on previously unused land plus a small area previously used by empties.
- The old yard was mostly vacated after ASCs started operating.

Implementation images

- Nov/2011: old yard under operation.
- Mar/2013: old yard operational, new yard being built on previously unused land plus land previously used for empties.
- Mar/2014: some cargo operated in ASC yard, some cargo in the old yard.
- Nov/2014: most cargo handled in the new ASC yard.



Patrick Terminals
Sydney AutoStrad™ terminal
Port Botany

General

Parameter	Before conversion	After conversion
Country	Australia	
Yard equipment	SC	auto SC
Horrizontal transport eq.	SC	auto SC
Type of conversion	Full automation	
Yard area [ha]	20	30
Capacity [MM TEU/year]	0.6	1.6
Quay length [m]	1,000	1,400

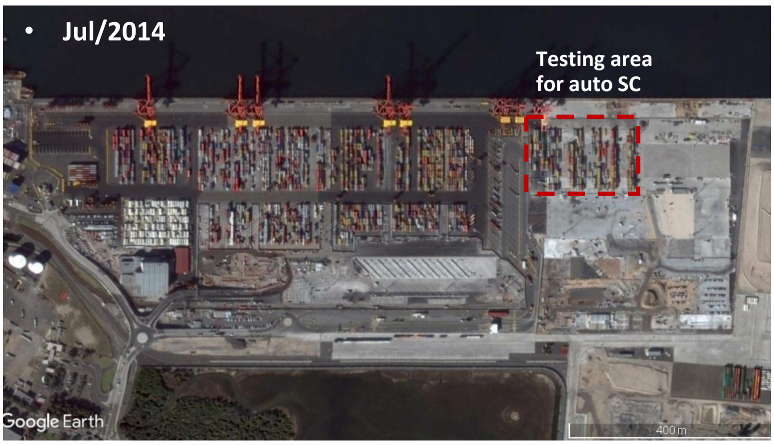
Implementation approach

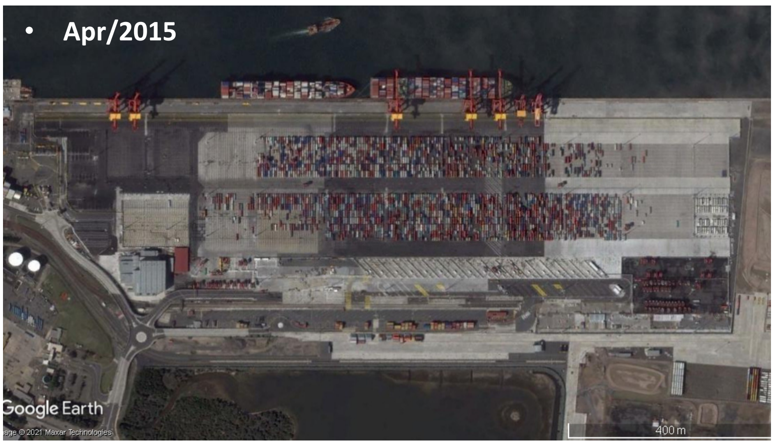
Big bang

- Increased yard area into new land. An adjacent berth plus stacks were built and fenced. Once equipment had been tested and people trained, the terminal was shut down and the auto SC rolled out into the entire yard.
- The old yard was fully converted.

Implementation images

- Jun/2009: manned terminal before conversion.
- Nov/2013: old yard operating, terminal expansion under construction.
- Jul/2014: fenced automated test bed can be observed in the right hand side of the yard.
- Apr/2015: the terminal was shut down in March 2015. In April the auto SC had been rolled out onto the entire yard.

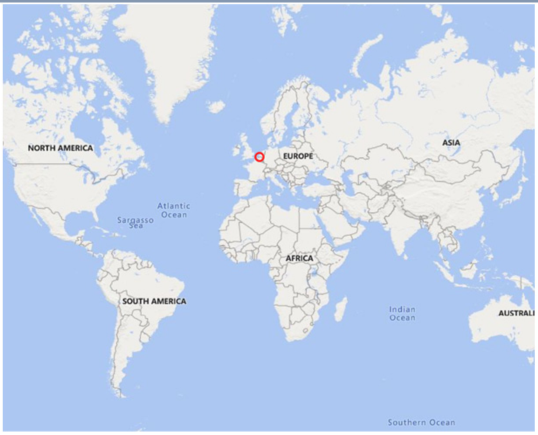




DP World
Antwerp Gateway terminal
Port of Antwerp

General

Parameter	Before conversion	After conversion
Country	Belgium	
Yard equipment	SC	ASC/SC
Horrizontal transport eq.	SC	SC
Type of conversion	Semi-automation	
Yard area [ha]	26	44
Capacity [MM TEU/year]	1.4	2.8
Quay length [m]	1,320	1,660



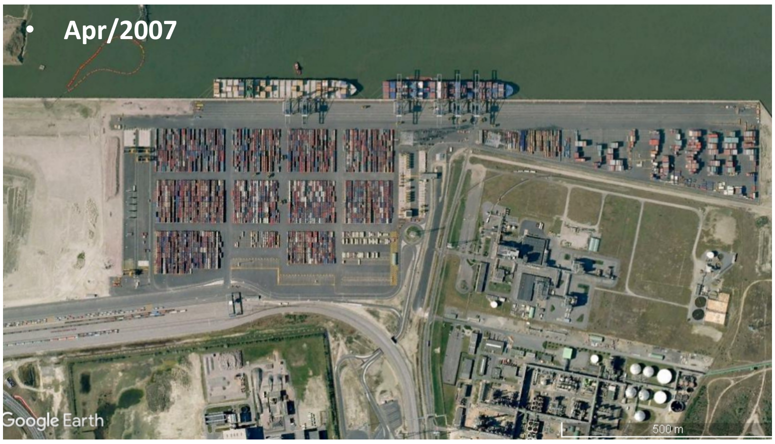
Implementation approach

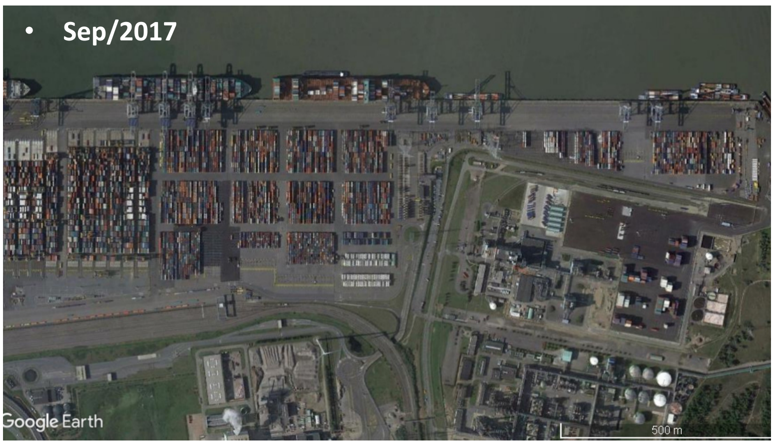
Greenfield-like

- Terminal opened in 2005 with manned straddles. It started operating the first 2 ASC blocks next to the manned straddle yard in 2007. By 2009 7 blocks were operating. In 2016 the current configuration with 10 ASC blocks was achieved.
- The manned yard has been kept manned so far resulting in a mixed yard. Plans to convert the manned SC yard to ASCs netween 2022 and 2026 have been informed by DP World.

Implementation images

- Apr/2007: manned yard operational for 2 years. 2 ASC blocks being added on the left side of the photo.
- Aug/2009: ASC blocks increased to 7. Manned SC yard not modified.
- Aug/2016: latest 3 ASC blocks were added.
- Sep/2017: all 10 ASC blocks operational.

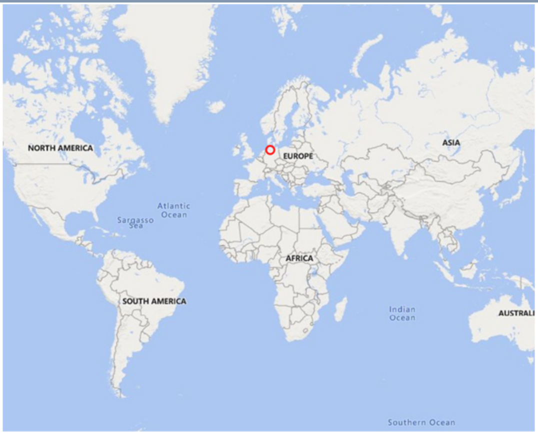




HHLA
Container Terminal Burchardkai
Port of Hamburg

General

Parameter	Before conversion	After conversion
Country	Germany	
Yard equipment	SC	ASC/SC
Horrizontal transport eq.	SC	SC
Type of conversion	Semi-automation	
Yard area [ha]	74	78
Capacity [MM TEU/year]	2.6	5.6
Quay length [m]	2,850	2,850



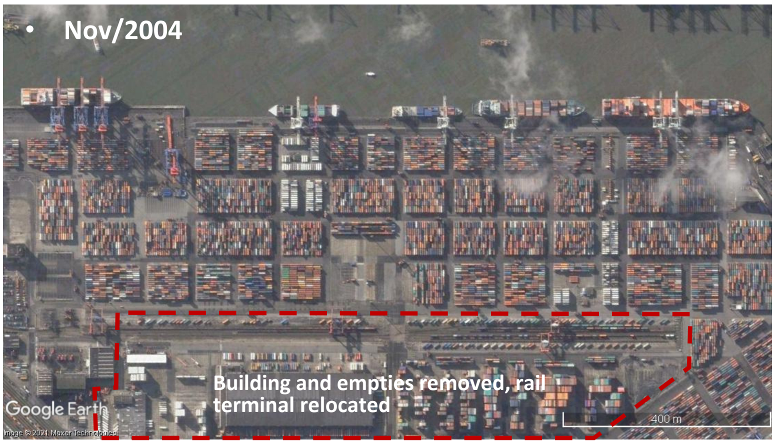
Implementation approach

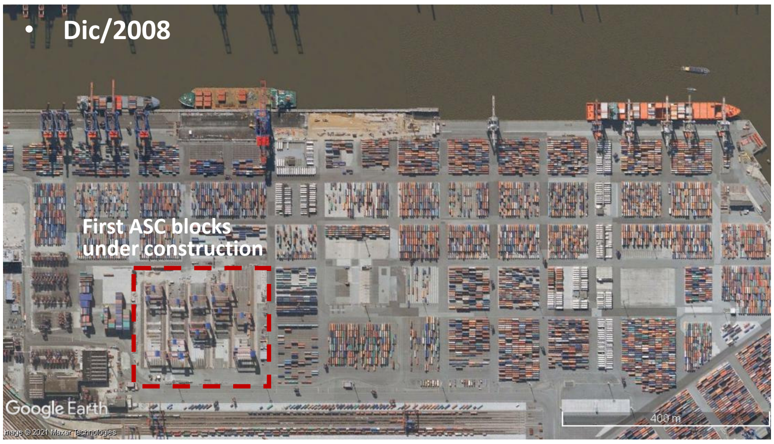
Phased

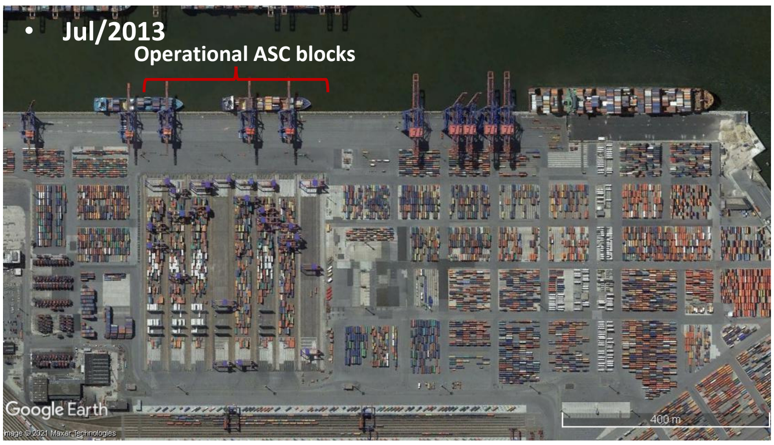
- Works started in 2005 by removing a building, an empties yard and relocating tha rail terminal. By 2008 the first 5 ASC blocks were under construction. The number of ASC blocks has been increasing steadily up to date.
- The manned yard has been reduced progressively to make room for new ASC blocks, but up to the date of this document it remains a mixed yard.

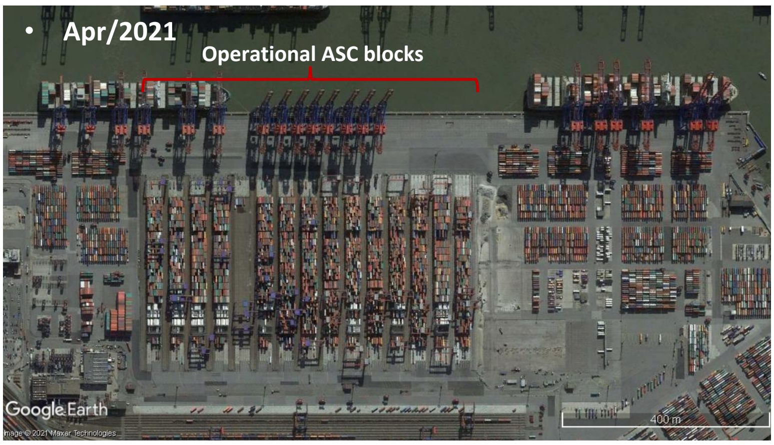
Implementation images

- Nov/2004: manned yard operational.
- Dic/2008: rail terminal relocated to increase yard. 5 ASC blocks under development.
- Jul/2013: 8 ASC blocks operational.
- Apr/2021: 15 ASC blocks operational.









PCT (COSCO)
Pier II West terminal
Port of Piraeus

General

Parameter	Before conversion	After conversion
Country	Greece	
Yard equipment	SC	CARMG
Horrizontal transport eq.	SC	TT
Type of conversion	Semi-automation	
Yard area [ha]	19	19
Capacity [MM TEU/year]	0.7*	1.4*
Quay length [m]	700	700

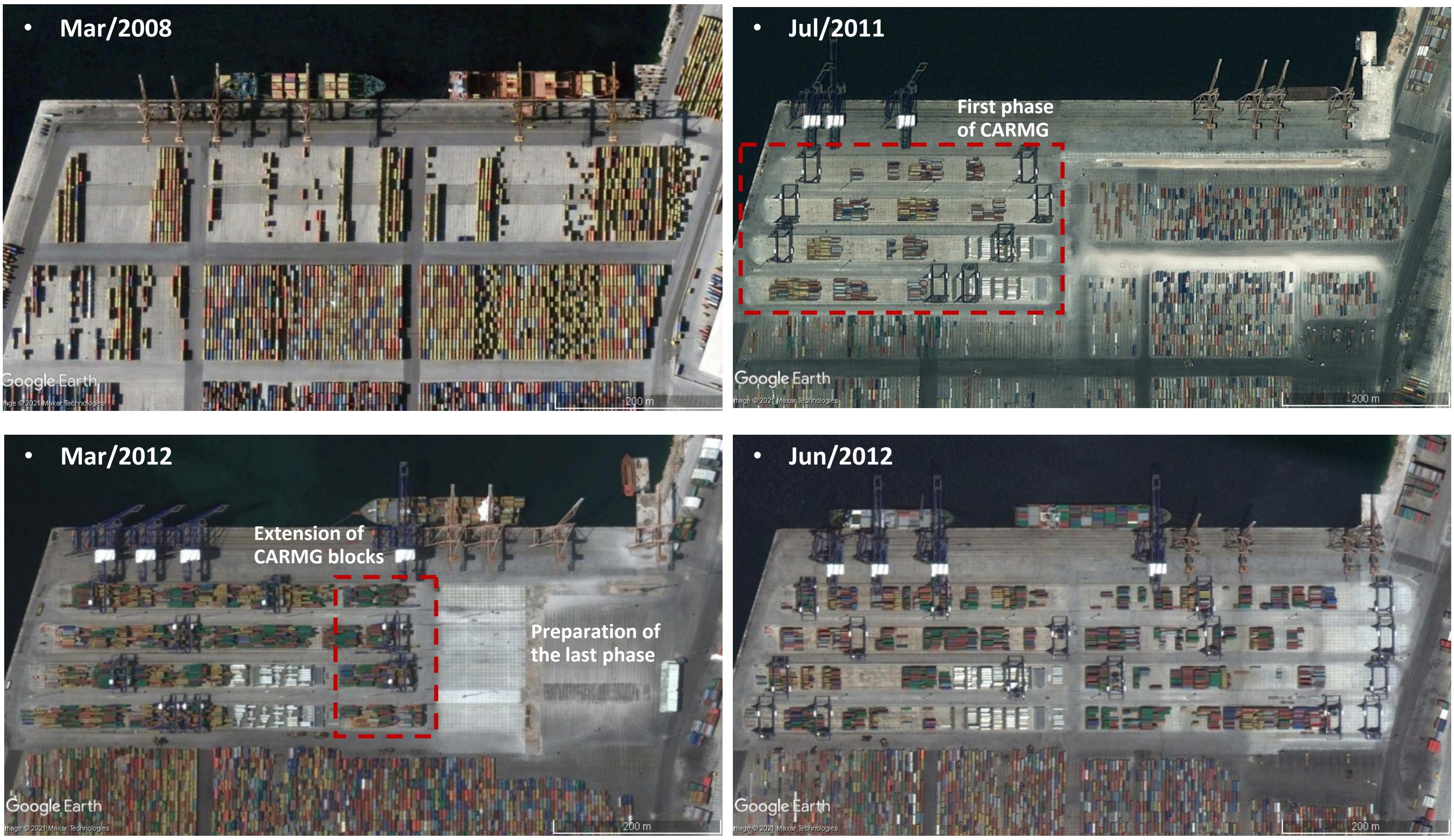
Implementation approach

Phased

- In 2011 half of the west yard had been converted to a CARMG yard. During 2012 the blocks were extended to complete the yard.
- The yard was fully converted to CARMG.

Implementation images

- Mar/2008: manned SC yard operational.
- Jul/2011: Half the yard of the west terminal in Pier II was converted. The east terminal remained as an SC yard.
- Mar/2012: CARMG blocks were extended, SCs were completely removed.
- Jun/2012: CARMG yard completed.

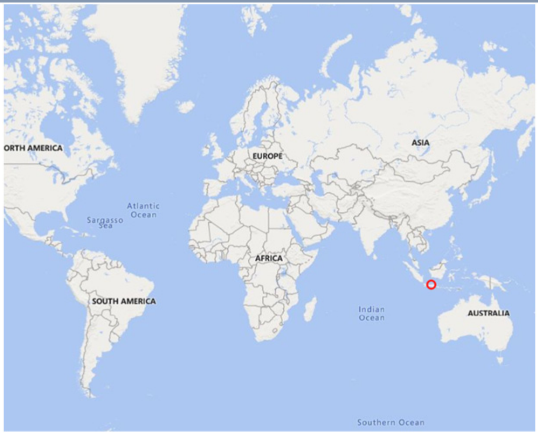


*capacity estimated proportionally to quay lengths from the total capacity of Pier II

Pelindo III
Terminal Petikemas (TPKS)
Port of Semarang

General

Parameter	Before conversion	After conversion
Country	Indonesia	
Yard equipment	RTG	aRTG
Horrizontal transport eq.	TT	TT
Type of conversion	Semi-automation	
Yard area [ha]	15	21
Capacity [MM TEU/year]	0.5	0.8
Quay length [m]	525	630



Implementation approach

Greenfield-like

- Land reclamation started in 2013. Newly reclaimed land was paved in 2015, first aRTGs are mounted, tested and started operation in 2016. At the end of 2016, the 2 blocks furthest from the quay in the old yard were closed. They were repaved in 2017, a third block was added and repaved. In 2018 the first aRTG cranes were mounted on those 3 blocks. In 2019 a fourth block was finished.
- The terminal has a mixed yard with 3 RTG blocks and 11 aRTG blocks.

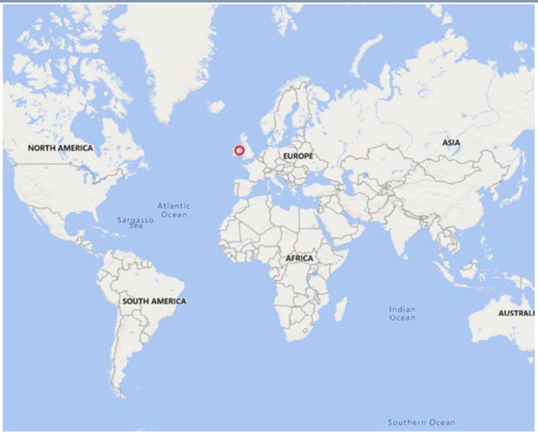
Implementation images

- Jul/2013: new land is reclaimed next to the old terminal.
- Aug/2017: a new aRTG yard is built in the newly reclaimed land. Quay was also extended. First old blocks are closed and repaved.
- Aug/2018 : New automated yard finished. 3 old blocks converted. A fourth one is repaved.
- May/2019: automated yard is ready and fenced. 3 blocks remained manned outside the fenced automated yard.

Dublin Ferryport Terminal
CT berth N°50
Port of Dublin

General

Parameter	Before conversion	After conversion
Country	Ireland	
Yard equipment	RTG	aRTG
Horrizontal transport eq.	TT	TT
Type of conversion	Semi-automation	
Yard area [ha]	9	9
Capacity [MM TEU/year]	0.3	0.4
Quay length [m]	550	550



Implementation approach

Phased

- Terminal footprint remained the same, but RTG stacking area was increased for the southernmost 2 blocks into an area mainly previously used for empties. New staking area and RTG paths were repaved in 2016. The first 2 aRTG cranes were delivered in 2017, and are operational since 2018 in one block. In 2020, 2 more aRTG were delivered completing 2 automated blocks.
- The terminal has a mixed yard, with 8 manned RTGs and 4 aRTG.

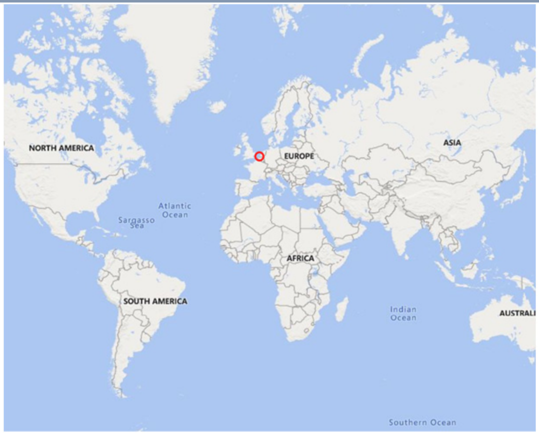
Implementation images

- Jun/2016: old yard. Blocks are 7+1 wide. Right side of the picture mainly corresponds to an area for empties.
- May/2017: 2 blocks extended into the empties area to the right. The aRTG paths were repaved for the new crane width, i.e. 8+1.
- Jun/2018: first 2 aRTG are installed and operating in the block closer to the quay.
- Apr/2021: 2 new aRTG are installed and operating in the remaining block.

Kloosterboer CT
Blijeveldhaven
Port of Vlissingen

General

Parameter	Before conversion	After conversion
Country	The Netherlands	
Yard equipment	RS	aRTG
Horrizontal transport eq.	RS	TT
Type of conversion	Semi-automation	
Yard area [ha]	-	-
Capacity [MM TEU/year]	0.1	0.3
Quay length [m]	1700	1700



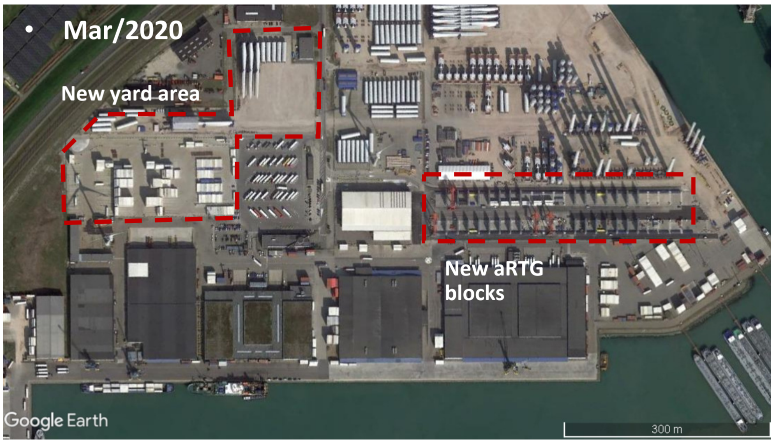
Implementation approach

Phased

- This is not the typical container terminal. They handle temperature controlled food products in reefer container and in other ways.
- 2 aRTG blocks for reefers were built on a piece of yard previously used to stack containers, which fits the definition of a phased approach. The terminal reported continuity not to be a problem due to idle capacity in the yard.
- The terminal has a mixed yard, with RS and 4 aRTG.

Implementation images

- Jul/2016: old multipurpose yards.
- Mar/2020: 2 blocks built on the right side of the image. The yard area also increased.
- No more images were available.



POAL
Fergusson terminal
Port of Auckland

General

Parameter	Before conversion	After conversion
Country	New Zealand	
Yard equipment	SC	auto SC
Horrizontal transport eq.	SC	SC
Type of conversion	Semi-automation	
Yard area [ha]	11	14
Capacity [MM TEU/year]	0.9	1.4
Quay length [m]	625	920

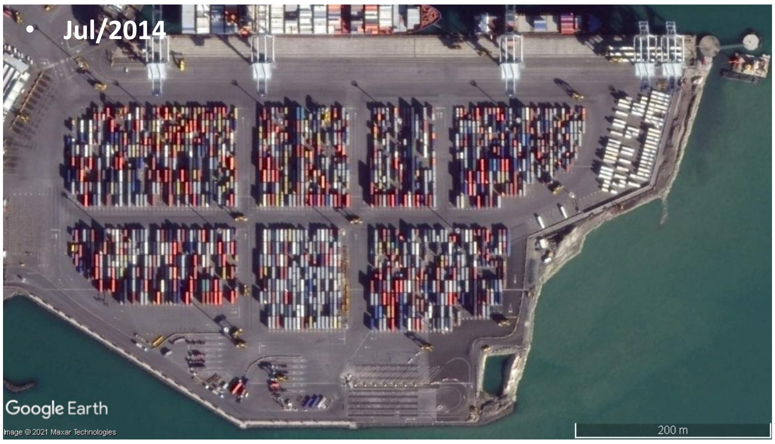
Implementation approach

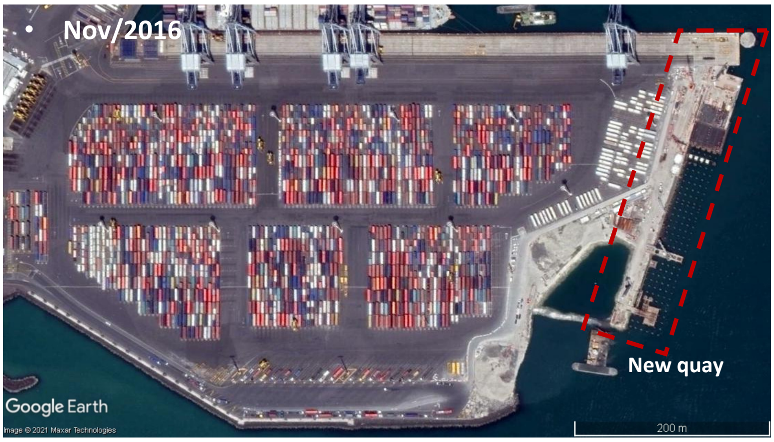
Big bang

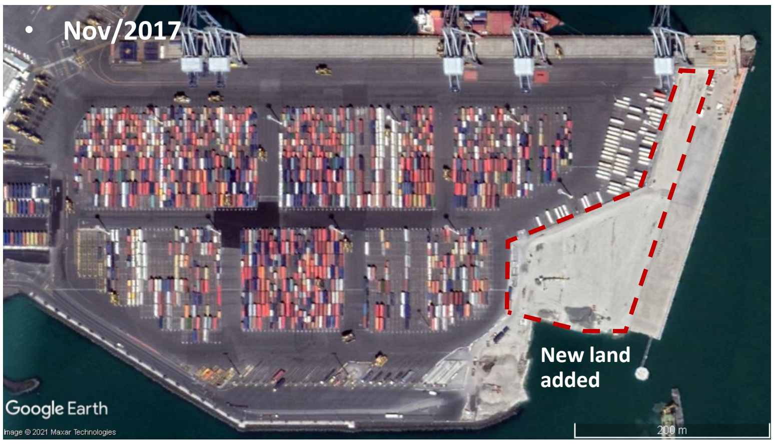
- In 2014 works to extend the existing quay started. In 2015 the construction of the new north quay started. In 2016 the land reclamation started. A test bed was built in 2018 mainly on the newly reclaimed land. The same year the auto SC were delivered to Auckland. Original expansion to the entire north quay was planned for February 2020, but it has been delayed until 2022.
- The old yard will be fully converted.

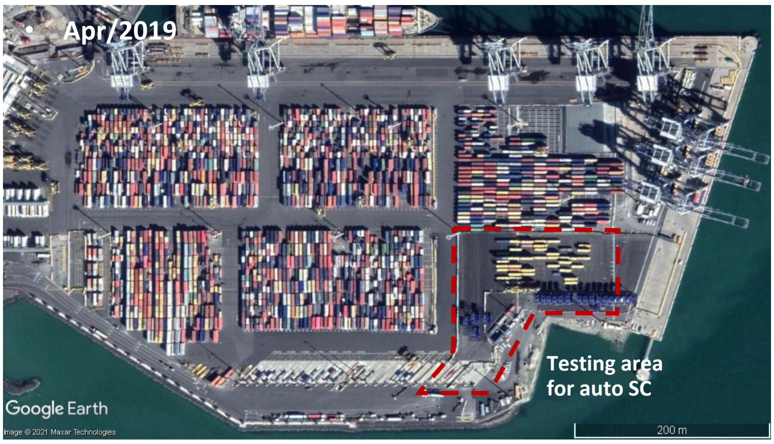
Implementation images

- Jul/2014: old manned terminal.
- Nov/2016: existing quay was extended, a new quay is under construction on the northern edge of the pier.
- Nov/2017: quays are ready, land reclamation is being finished.
- Apr/2019: a test bed for the new auto SC was prepared mainly on the newly reclaimed land.





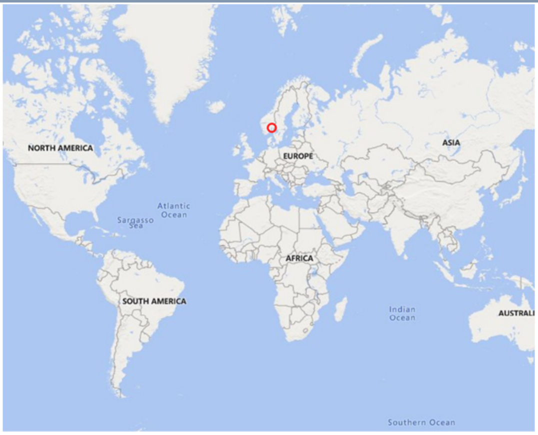




Yilport
Sjursøya CT
Port of Oslo

General

Parameter	Before conversion	After conversion
Country	Norway	
Yard equipment	SC	aRTG
Horrizontal transport eq.	SC	TT
Type of conversion	Semi-automation	
Yard area [ha]	3	5
Capacity [MM TEU/year]	0.3	0.4
Quay length [m]	300	665



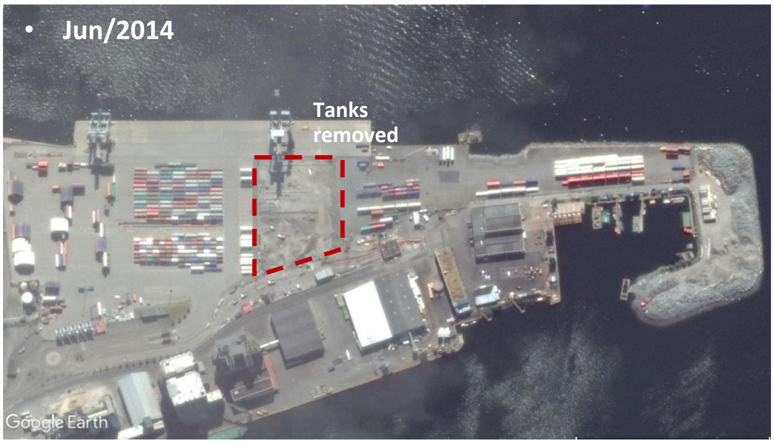
Implementation approach

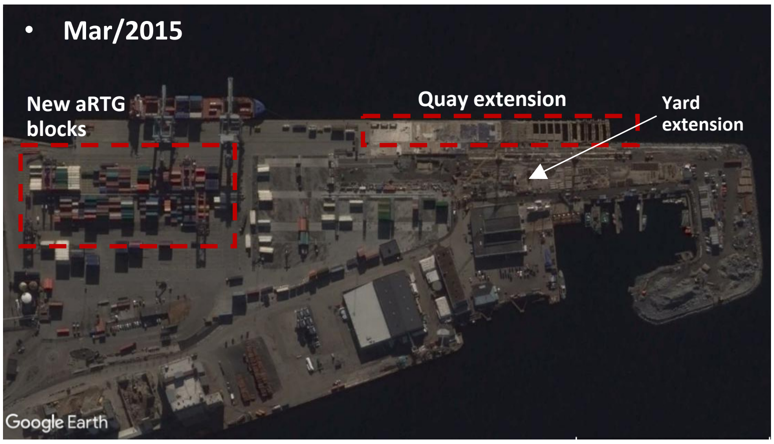
Phased approach

- Tanks were removed between 2013 and 2014 to extend the yard. The construction of new yard and quay started in 2014. Between 2014 and 2015 SC stacks were replaced by 2 aRTG blocks, 2 more blocks were added in 2015.
- The old yard was fully converted.

Implementation images

- Aug/2013: manned terminal before conversion.
- Jun/2014: tanks were removed to extend the yard.
- Mar/2015: SC stacks were replaced by 2 aRTG blocks (4 cranes). Yard and quay extensions are under construction.
- Aug/2018: final terminal with 8 aRTGs.

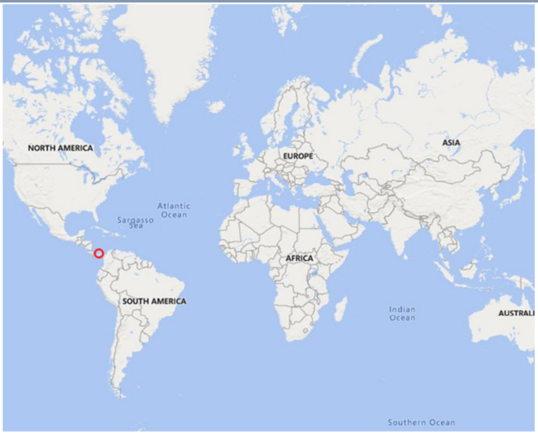




MIT
Manzanillo CT
Port of Colon

General

Parameter	Before conversion	After conversion
Country	Panama	
Yard equipment	RTG	CARMG/RTG
Horrizontal transport eq.	TT	TT
Type of conversion	Semi-automation	
Yard area [ha]	40	40
Capacity [MM TEU/year]	2.2	3.5
Quay length [m]	1640	2035



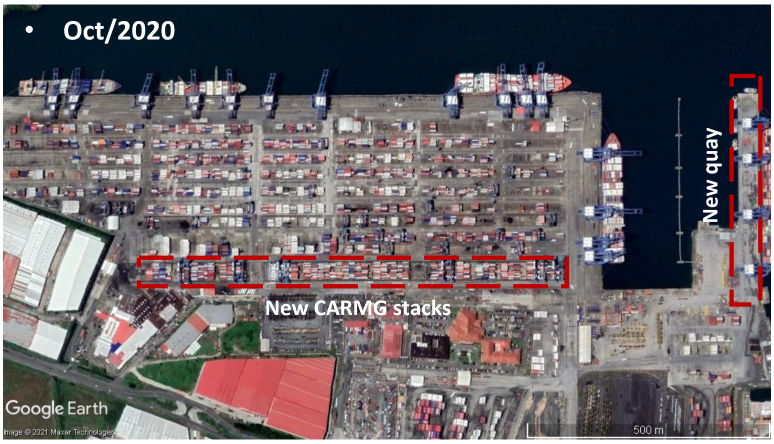
Implementation approach

Phased approach

- An area previously used for RTG stacks and empties was destined for the installation of 6 CARMG. The project also considered the construction of 400m of new quay. The installation of the CARMG was done in 4 phases (Ozolin, 2016) during 2014. The yard and the new quay were operational in 2015.
- The terminal has a mixed yard, with 6 CARMG and 24 manned RTGs.

Implementation images

- Apr/2011: manned terminal before conversion.
- Jan/2015: CARMG were already installed, but not fully operational yet. New quay was under construction.
- Apr/2016: CARMG stacks and the new quay were operational.
- Oct/2020: Latest available image of the terminal.



HIT
Terminal 9 North
Port Hong Kong

General

Parameter	Before conversion	After conversion
Country	China	
Yard equipment	RTG	aRTG
Horrizontal transport eq.	TT	TT
Type of conversion	Semi-automation	
Yard area [ha]	11	11
Capacity [MM TEU/year]	0.9*	0.9*
Quay length [m]	690	690

Implementation approach

Phased approach

- A retrofitting project was launched in 2013. In 2016, 9 cranes had been converted. The conversion of all 29 cranes was officially announced in January 2019.
- The yard was fully converted to remotely operated aRTGs.

Implementation images

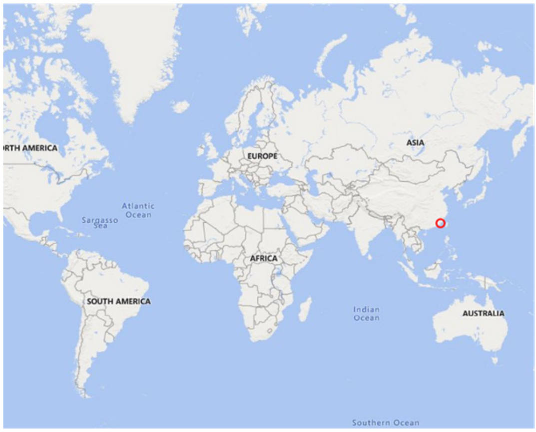
- Jan/2015: no evident changes from pre-conversion condition.
- Nov/2015: supporting pedestals were installed in the RTG blocks at the bottom of the image.
- Aug/2016: more supporting pedestals are installed. Also, structures aligned with the RTG orientation are observed.
- Feb/2018: Project was completed. Zoomed area presented in previous images is shown.

*estimated from T9 capacity of 2.6 million TEU/year and a relation with the quay lengths between T9 north and T9 south.

COSCO
Xiamen Ocean Gate CT
Port of Xiamen

General

Parameter	Before conversion	After conversion
Country	China	
Yard equipment	RTG	RTG/ASC
Horrizontal transport eq.	TT	TT/AGV
Type of conversion	Full-automation	
Yard area [ha]	44	66
Capacity [MM TEU/year]	1.4	2.1
Quay length [m]	1500	920



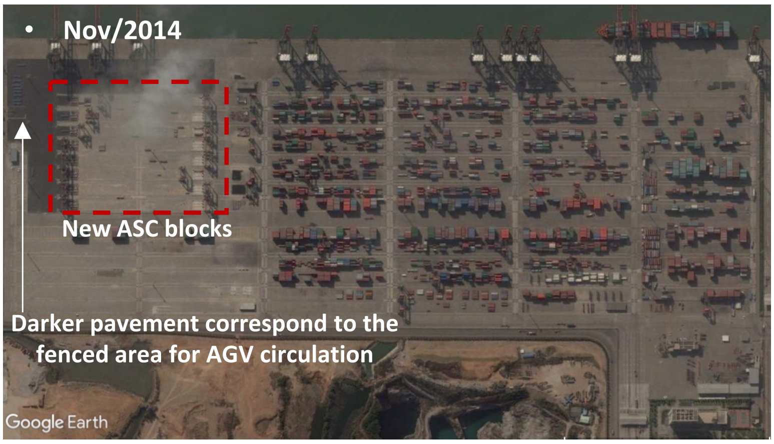
Implementation approach

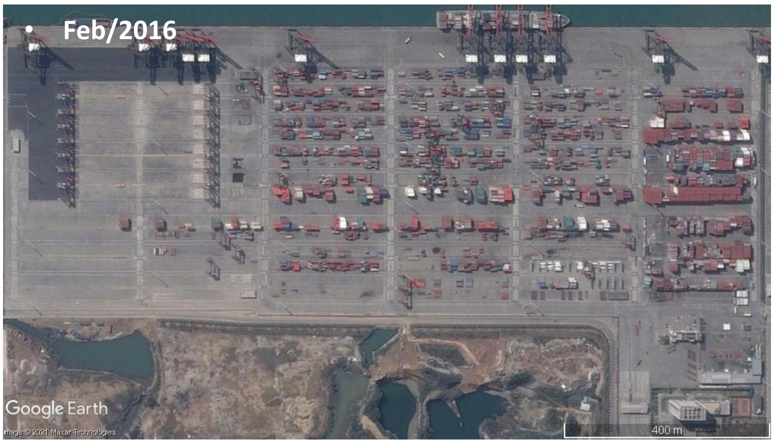
Greenfield like

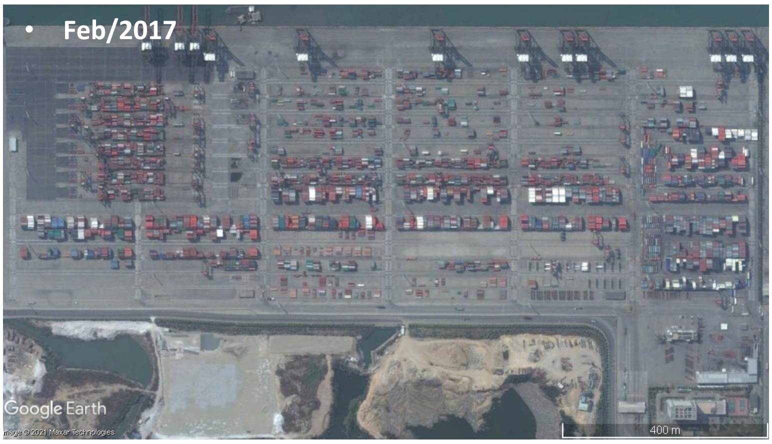
- Terminal started operations in 2011. Part of the yard remained unused. In 2014 ASC blocks were installed on the unused yard and AGV area was paved. The automated terminal became operational in 2016.
- The old yard was kept with manned RTGs.

Implementation images

- Apr/2014: manned RTG terminal on the right side of the image. Left side was not used.
- Nov/2014: ASC blocks had been installed and AGV area paved and fenced.
- Feb/2016: automated blocks still do not go operational.
- Feb/2017: terminal operational with 2 yards, a fully automated one (ASC+AGV) and a manned one (RTG+TT).



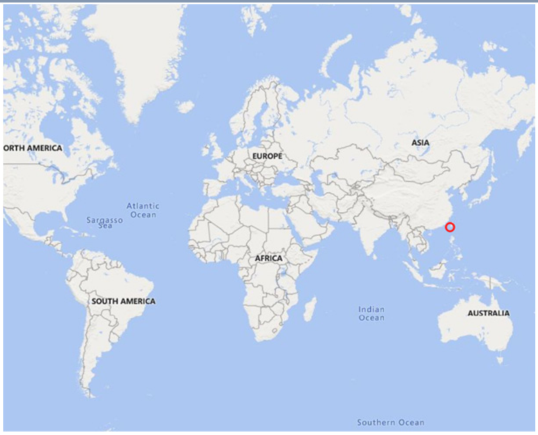




EMC
Evergreen Marine Terminal 4
Port of Kaohsiung

General

Parameter	Before conversion	After conversion
Country	Taiwan	
Yard equipment	RTG	CARMG/RTG
Horrizontal transport eq.	TT	TT
Type of conversion	Semi-automation	
Yard area [ha]	23	23
Capacity [MM TEU/year]	1.5	1.8
Quay length [m]	900	900



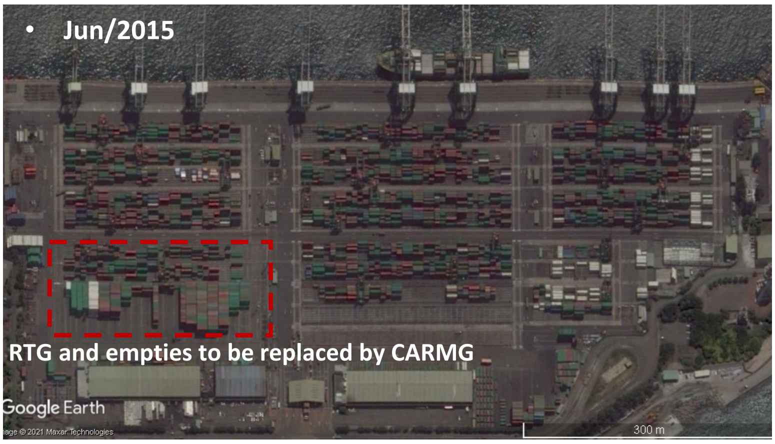
Implementation approach

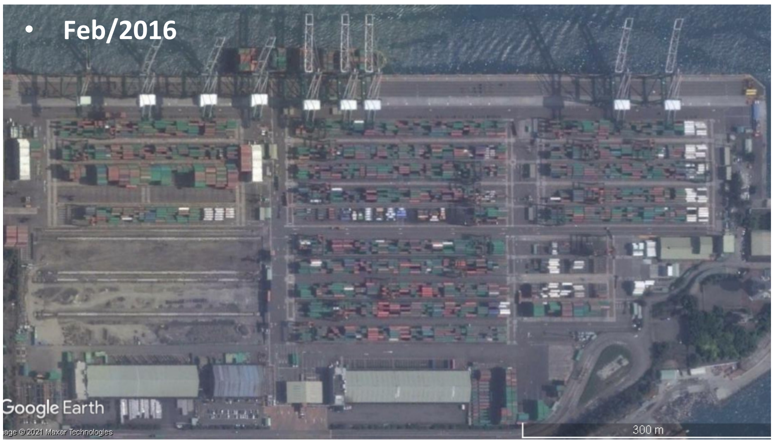
Phased

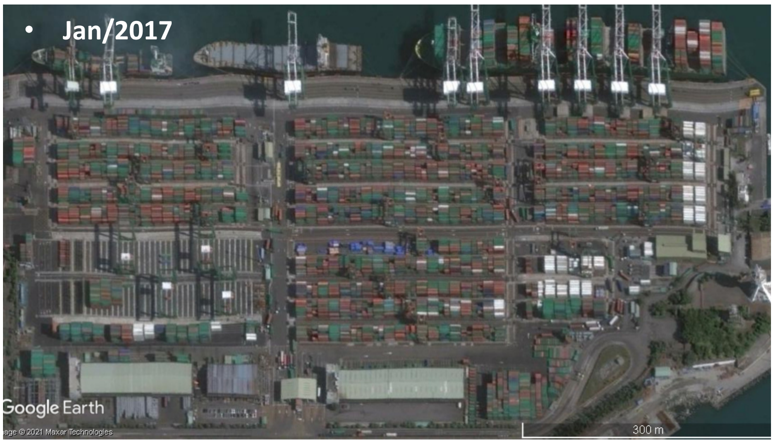
- A first phase with 2 blocks and 4 CARMG were located in an area previously used for empties and 2 RTG blocks. No other phases have been observed. Previously, the terminal had also deepened the berths and acquired 5 new larger quay cranes (Evergreen Marine Corp. (Taiwan) Ltd., 2015).
- The terminal has a mixed yard, with 23 manned RTGs and 4 CARMG.

Implementation images

- Jun/2015: old RTG yard. An area with 2 RTG blocks and empties is observed in the bottom left side of the image.
- Feb/2016: the mentioned area is vacated. Empties were temporarily relocated closer to the quay, where there used to be RTGs.
- Jan/2017: 4 CARMG were installed and are being tested. Temporary empties are relocated around the terminal.
- Apr/2017: the new CARMG are operational.



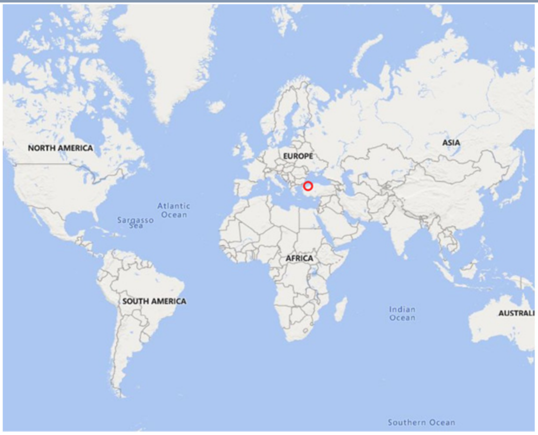




DP World
Yarımca Terminal
Port of Yarımca

General

Parameter	Before conversion	After conversion
Country	Turkey	
Yard equipment	RTG	aRTG/RTG
Horrizontal transport eq.	TT	TT
Type of conversion	Semi-automation	
Yard area [ha]	26	26
Capacity [MM TEU/year]	2.2	2.2
Quay length [m]	900	900



Implementation approach

Phased

- A first phase with 2 blocks and 4 CARMG were located in an area previously used for empties and 2 RTG blocks. No other phases have been observed. Previously, the terminal had also deepened the berths and acquired 5 new larger quay cranes (Evergreen Marine Corp. (Taiwan) Ltd., 2015).
- The terminal has a mixed yard, with 23 manned RTGs and 4 CARMG.

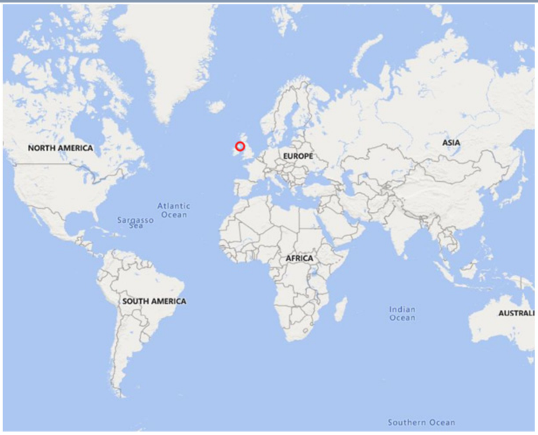
Implementation images

- Jun/2015: old RTG yard. An area with 2 RTG blocks and empties is observed in the bottom left side of the image.
- Feb/2016: the mentioned area is vacated. Empties were temporarily relocated closer to the quay, where there used to be RTGs.
- Jan/2017: 4 CARMG were installed and are being tested. Temporary empties are relocated around the terminal.
- Apr/2017: the new CARMG are operational.

BCT
Victoria Terminal 3
Port of Belfast

General

Parameter	Before conversion	After conversion
Country	Northern Ireland (UK)	
Yard equipment	RMG/SC	aRTG
Horrizontal transport eq.	TT	TT
Type of conversion	Semi-automation	
Yard area [ha]	7	7
Capacity [MM TEU/year]	0.2	0.3
Quay length [m]	375	375



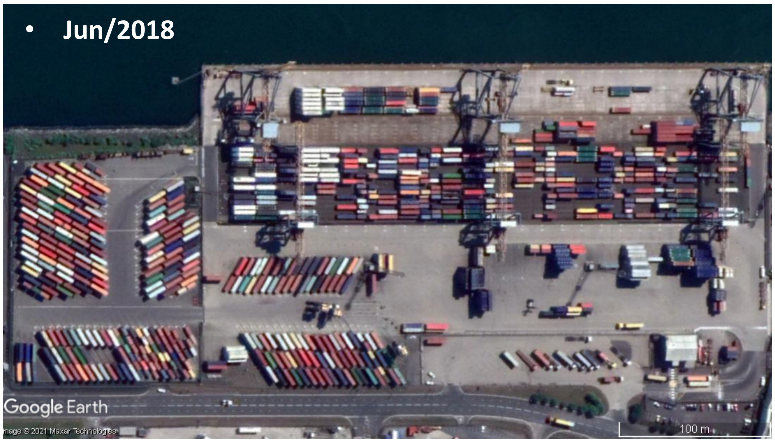
Implementation approach

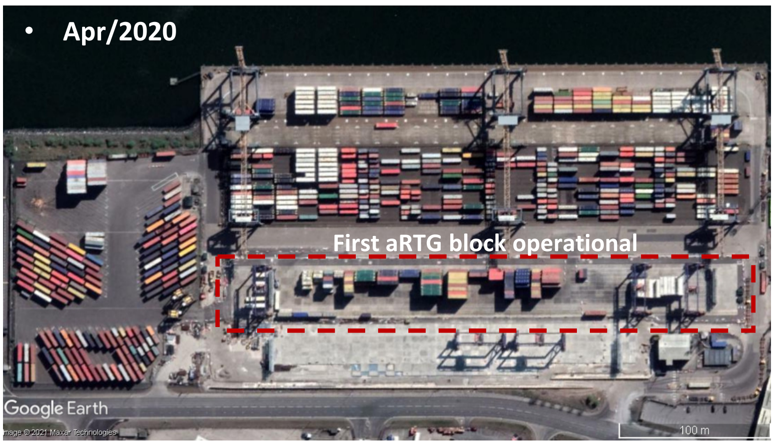
Phased

- 3 phases were considered. The first phase was completed with one block and 3 aRTGs. The second phase was completed with a second block and 2 aRTGs. Phase 3 is ongoing with the last 2 blocks and 3 aRTGs. In this phase the old equipment will be decommissioned.
- The old yard is being fully converted.

Implementation images

- Jun/2018: old RMG and SC yard.
- Feb/2019: empties relocated to start building the first aRTG block.
- Apr /2020: first block with 3 aRTG operational, second block under construction.
- Apr/2021: second block with 2 aRTG operational (5 aRTG in total), 3 last new cranes arrived.

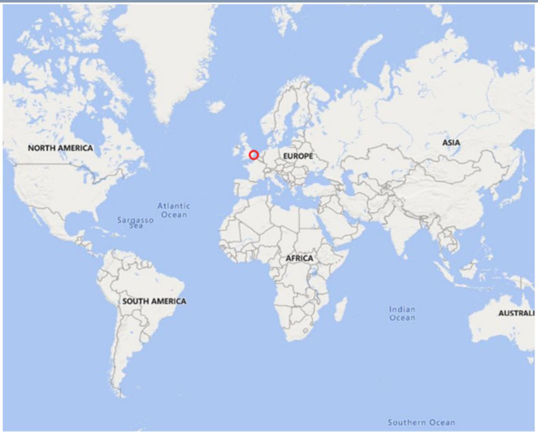




Hutchison Ports
Berth 8/9
Port of Felixstowe

General

Parameter	Before conversion	After conversion
Country	UK	
Yard equipment	RTG	aRTG/RTG
Horrizontal transport eq.	TT	TT
Type of conversion	Semi-automation	
Yard area [ha]	16	26
Capacity [MM TEU/year]	1.2	1.5
Quay length [m]	730	920



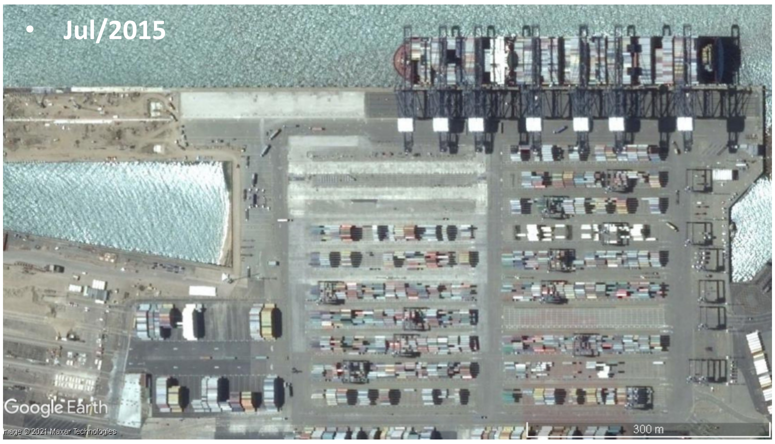
Implementation approach

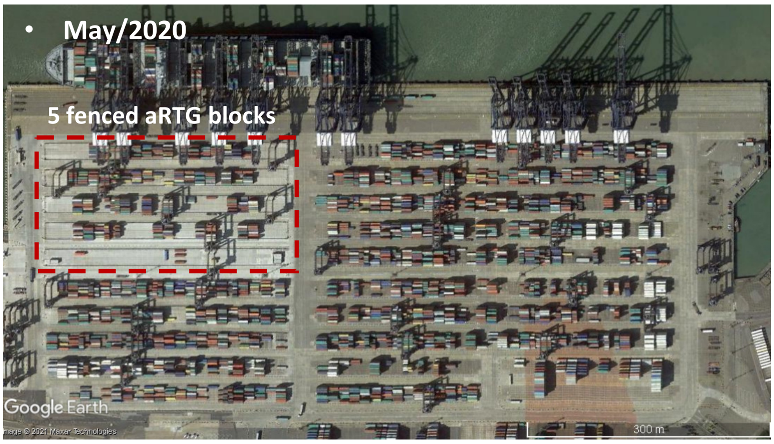
Greenfield-like

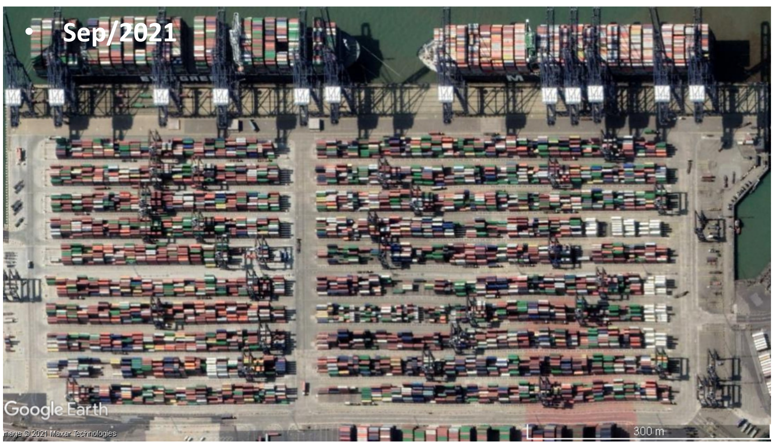
- New 5 aRTG blocks with 8 cranes were deployed in a new piece of yard.
- New manned RTG blocks were also added. The old yard remained manned.

Implementation images

- Jul/2015: old RTG yard.
- May/2020: yard and quay increased. Mostly manned RTGs, 5 aRTG fenced blocks in the upper left side of the image.
- Sep/2021: yard fully operational.
- No more images were available.







OOCL
Lond Beach Container Terminal
Port of Long Beach

General

Parameter	Before conversion	After conversion
Country	USA	
Yard equipment	RTG/chassis	ASC
Horrizontal transport eq.	TT	AGV
Type of conversion	Full automation	
Yard area [ha]		53
Capacity [MM TEU/year]	1.2	3.3
Quay length [m]	730	1300

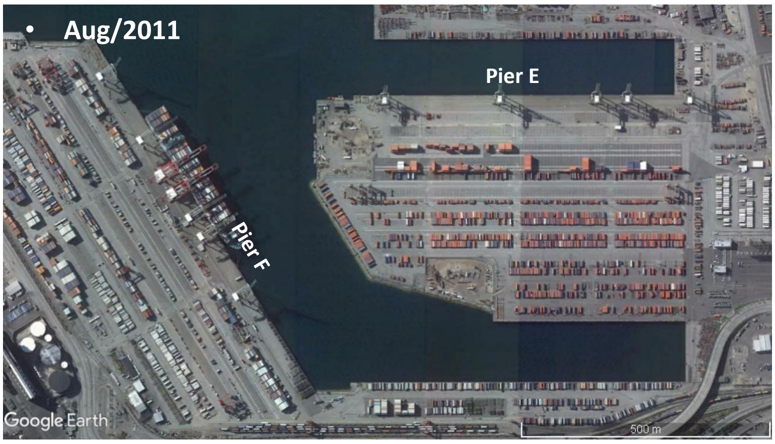
Implementation approach

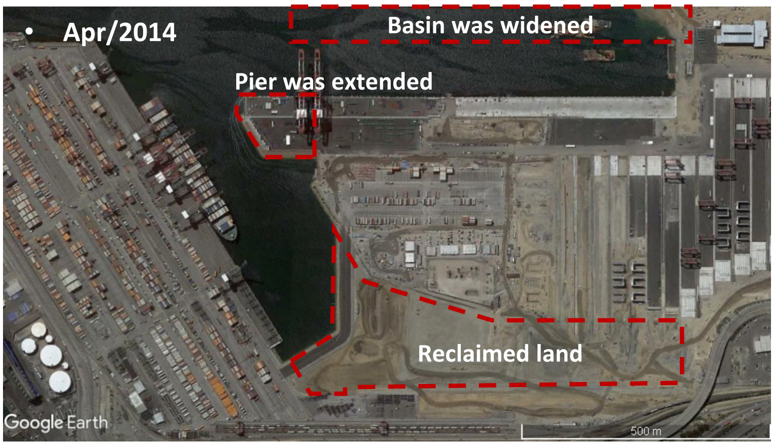
Greenfield-like

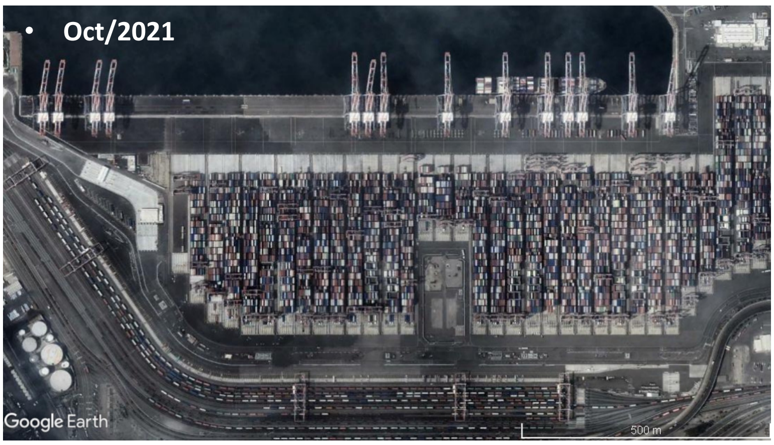
- Two old terminals were merged into one. Opportunity given because terminal of Pier E was vacated by operator, who move its operations to the port of LA. Pier E was redeveloped while the terminal in Pier F kept operating. Once the new terminal in the Pier E side was ready, the Pier F terminal was closed and redeveloped.
- Old yards were completely converted.

Implementation images

- Aug/2011: 2 old terminals. Pier E on the right side and Pier F on the left side.
- Apr/2014: terminal in Pier E abandoned the port. A new ASC yard started to be built on it. Basin was widened.
- Dic/2017: new terminal operational. Pier F terminal was vacated to redevelop.
- Oct/2021: final terminal is completely operational.







TraPac Inc.
TraPac Container Terminal
Port of LA

General

Parameter	Before conversion	After conversion
Country	USA	
Yard equipment	RTG/chassis	ASC/RTG/FL/chassis
Horrizontal transport eq.	TT	aShC
Type of conversion	Full automation	
Yard area [ha]	44	46
Capacity [MM TEU/year]	1.7	2.4
Quay length [m]	1390	1640

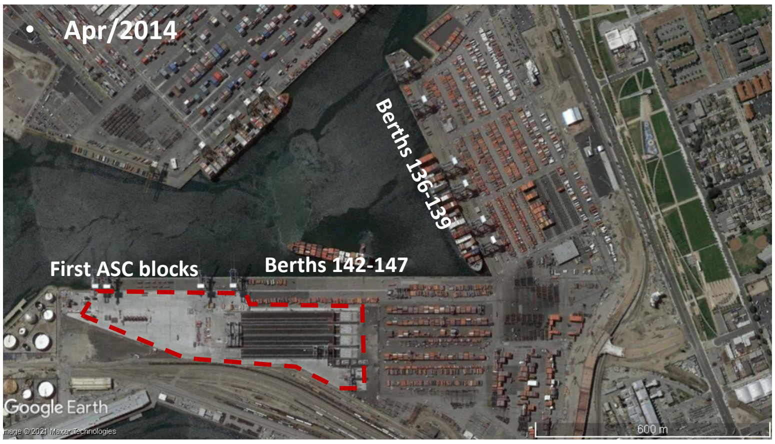
Implementation approach

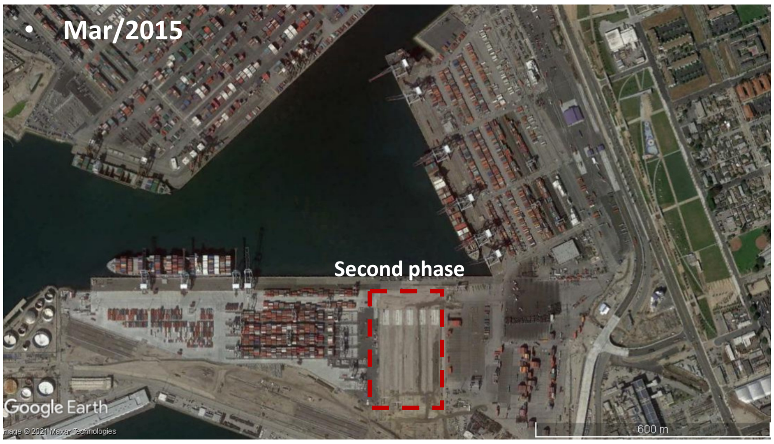
Greenfield-like

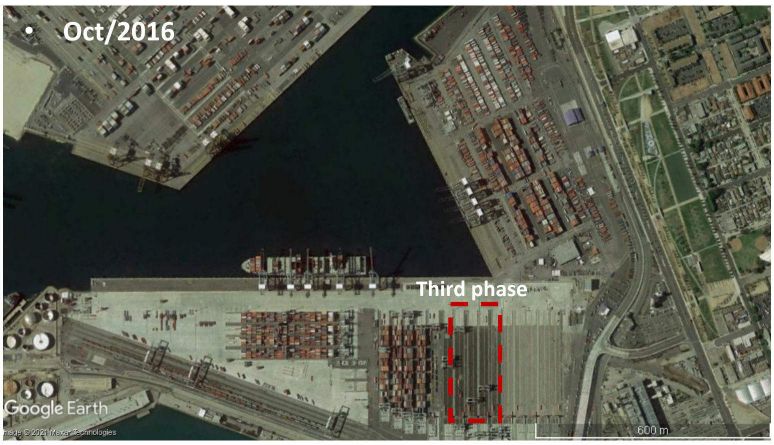
- The project also considered building 130m of new quay and rebuilding 500m of old quay in 2009-2010 (not in the images). In 2013-2014 the first stage of the new ASC blocks (parallel to the quay) were built. A second stage with 5 blocks perpendicular to the quay followed. A third stage with 10 more blocks was built. Four of them have not been implemented with cranes up to the date of this report.
- The old yard behind berths 142-147 was completely converted, but the yard behind berths 136-139 remains manned.

Implementation images

- Apr/2014: first construction phase of ASC blocks.
- Mar/2015: first phase operational, second phase under construction.
- Oct/2016: second phase operational, third phase under construction.
- Dic/2017: final terminal operational. A fourth phase was built, but remains unused (no cranes yet).







APM Pacific
Pier 400
Port of LA

General

Parameter	Before conversion	After conversion
Country	USA	
Yard equipment	RTG/chassis	auto SC/RTG/chassis
Horrizontal transport eq.	TT	auto SC/TT
Type of conversion	Full automation	
Yard area [ha]	44	46
Capacity [MM TEU/year]	4.4	4.4
Quay length [m]	2190	2190

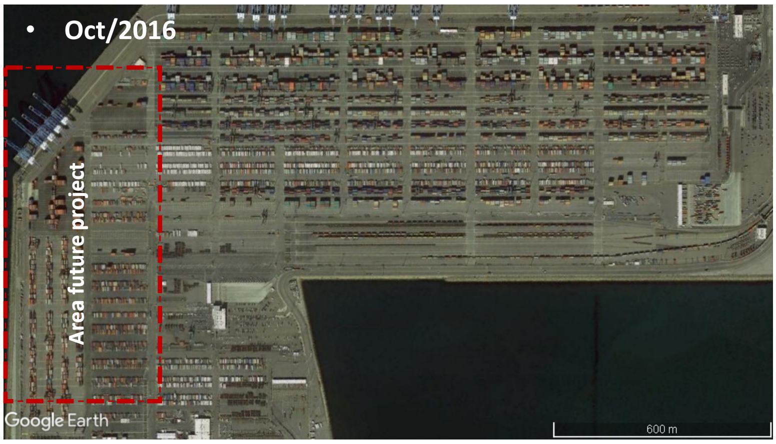
Implementation approach

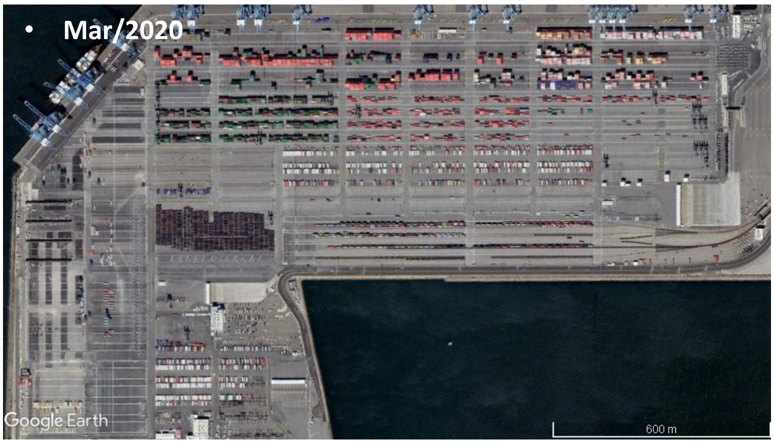
Phased

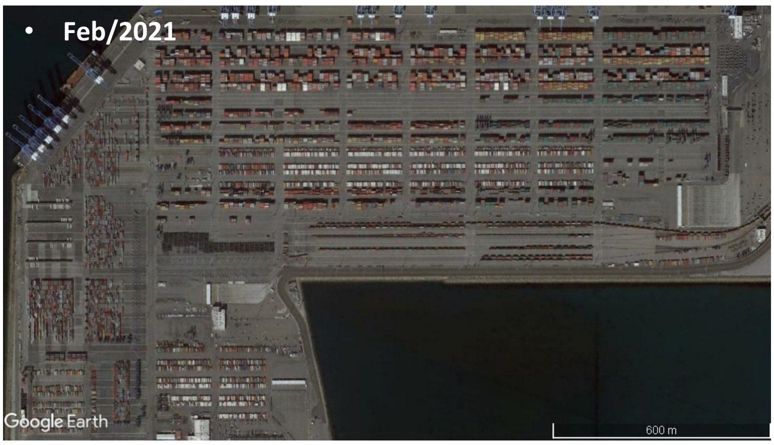
- Part of the old RTG/chassis stacking yard was vacated and fenced, to deploy auto SC. A berth was also fenced. Operational in 2020. In 2021 auto SC yard was expanded.
- The old yard is mixed, with an area for fully automated operations and an area for TT+RTG or chassis stacking.

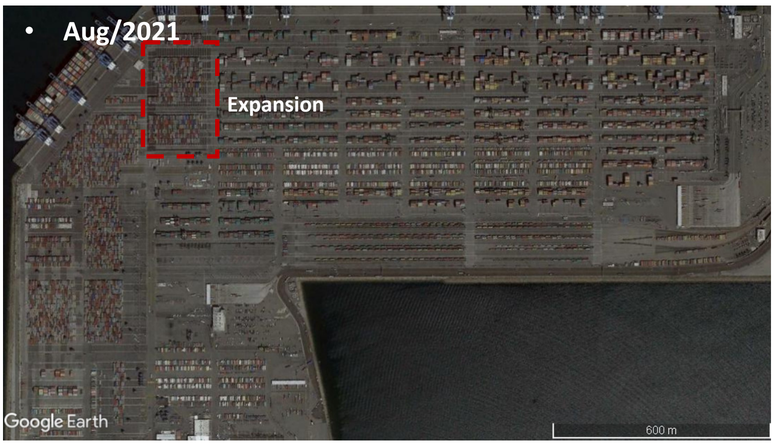
Implementation images

- Oct/2016: old RTG/chassis stacking yard. Area of future project indicated.
- Mar/2015: area to install auto SC vacated. Fencing, reefer stations, and areas to exchange with truck being built. Auto SC being tested.
- Oct/2016: auto SC mostly operational with dedicated berth to segregate automated equipment from manned operations.
- Dic/2017: auto SC yard expanded.









Global Container Terminals
GCT Bayonne
Port of NY/NJ

General

Parameter	Before conversion	After conversion
Country	USA	
Yard equipment	RTG	ASC/RTG
Horrizontal transport eq.	TT	ShC/TT
Type of conversion	Semi-automation	
Yard area [ha]	30	43
Capacity [MM TEU/year]	1.0	1.7
Quay length [m]	550	823

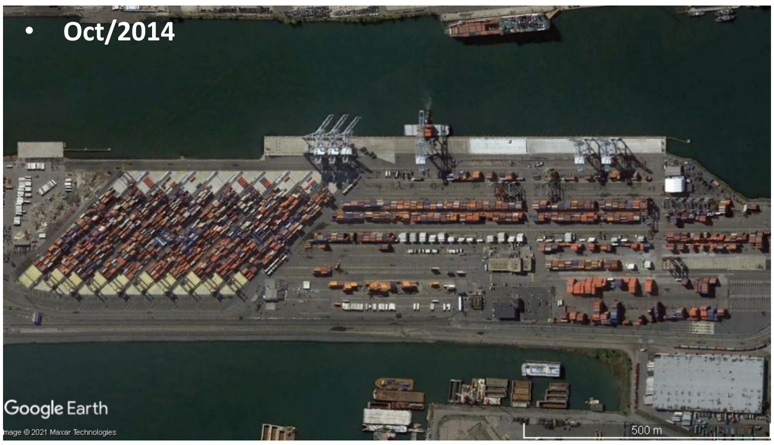
Implementation approach

Greenfield-like

- The new ASC blocks were built mostly on new area, although a small part of the old yard was affected by the construction.
- The old yard was kept manned.

Implementation images

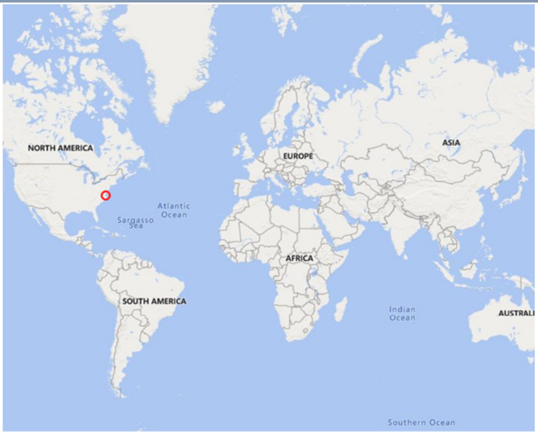
- Feb/2012: old RTG yard. Quay expansion was starting.
- May/2013: ASC stacks under construction. Quay expansion almost finished.
- Apr/2014: first ASC blocks operating (closer to the old yard). Blocks further away being finished.
- Dic/2017: new yard operational.



Virginia International Terminals
Norfolk International Terminals
Port of Virginia

General

Parameter	Before conversion	After conversion
Country	USA	
Yard equipment	SC	ASC
Horrizontal transport eq.	SC	SC
Type of conversion	Semi-automation	
Yard area [ha]	36	36
Capacity [MM TEU/year]	0.7	1.4
Quay length [m]	1290	1290



Implementation approach

Phased

- The conversion of the yard took place in 3 phases.
- The old yard was completely converted.

Implementation images

- Nov/2016: old SC yard.
- May/2018: area for first phase of ASC construction cleared.
- Apr/2019: first phased operational, second phase under construction.
- Aug/2021: all 3 phases operational.