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Determinants for Automation Levels in Port Containers Terminals at Antwerp and Rotterdam

by

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ABSTRACT

The role of seaports has been changed due to the rapid development of the global economy and maritime trade. The strong competition between ports and global terminal operators motivates ports and global terminal operators to improve port container terminals efficiency by investing in container terminal automation, among others by using the Internet of Things, digitization, and automation in the port business to improve port performance and the efficiency of cargo handling within terminal landscape. However, not all ports seem to move to certain levels of automation with the same pace or intensity, for various reasons. A divergence in automation levels used on terminals can be assumed based on different labour levels observed in the port of Rotterdam and Antwerp, whereas these ports are in fierce competition, have access to the same technology levels and are characterised by the same labour cost (Van den Driessche et. al., 2019) A pertinent question to investigate is therefore why fundamentally the capital-labour ratio divergence at port container terminals in those two ports persists.

Antwerp and Rotterdam, the main rivals' hubs in North-West Europe, have been pursuing differing levels of automation in PCTs for three decades, although having about the same scale, capital and labour costs, and degree of accessible technology. This thesis employs a qualitative analysis using a dual case-study analysis, and with data triangulation to deeper investigate the rationale behind the continued discrepancy in capital-labour ratios in both ports. The findings show that basic maritime economics reasoning using demand and supply of input factors to determine optimal productivity levels cannot solely be used to explain the divergence in capital-labour ratios in both ports. Port history, absorptive capacity, and strategic priorities may largely determine the intensity of labour and capital, and hence the extent of preferred automation level applied by the terminal management and investors.

List of Abbreviation

AGV	Automated Guided Vehicle
ARMG	Automated Rail Mounted Gantry Crane
ASC	Automated stacking crane
AShC	Automated shuttle carrier
BOT	Build–Operate–Transfer
CAPEX	Capital Expenditure
CT	Container Terminal
DEA	Date Envelopment Analysis
EC	European Commission
GHG	Greenhouse Gases
ITV	Internal Transport Vehicle
OCR	Optical Character Recognition
OPEX	Operating Expenses
PCT	Port Container Terminal
POA	Port of Antwerp
POR	Port of Rotterdam
QC	Quay Crane
RMG	Rail Mounted Gantry Crane
RTG	Rubber Tyred Gantry Crane
SC	Straddle Carrier
ShC	Shuttle Carrier
TEU	Twenty-foot Equivalent Unit
TGS	Total Ground Slots
TOS	Terminal Operating System
UNCTAD	United Nations Conference on Trade and Development

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CHAPTER ONE: INTRODUCTION

This chapter outlines the research outlook of the presented dissertation. section 1.1. defines the research, while section 1.2 sets out the research question and the methodology. Section 1.3 shows the contribution which this thesis would add to the body of knowledge currently available in this field. Finally, Chapter 1.4 lays out the structure of the thesis.

1.1 Problem Definition

In 1965, economic historiographer Robert Heilbroner stated that "as machines continue to invade society, duplicating greater and greater numbers of social tasks, it is human labour itself—at least, as we now think of 'labour'—that is gradually rendered redundant" (Akst 2014, p. 2 in Acemoglu & Restrepo, 2018). More than half century later, the debate continues regarding the fierce rivalry between human and machines armed with artificial intelligence.

According to David Ricardo (1817), the traditional driving reason behind international trade flows is technological differences between states. The premise of relative cost advantage theory is that cost advantage can be extracted by using the most abundant of production factors in the economy. The labour-capital ratio is affected by three factors: physical capital costs, technology level and costs of labour (Gomez Salvador et al., 2006; Felipe & Kumar, 2011). In accordance with, the labour-capital ratio is determined by labour cost, the cost of capital and the cost of accessible technology. The labour-capital ratio in port container terminals can be described by the level of automation. Automation was first implemented in container terminals to improve terminal efficiency and save operating costs. The purpose of this paper is to investigate the rationale behind changes in the labour-capital ratio in port container terminals, which can be observed in differences in the applicable level of automation.

1.2 Research Question

The main research question of this paper is "*Which factors influence the level of automation at port container terminals in Rotterdam versus Antwerp?*".

In order to answer the research question, a qualitative analysis based on cross-case study for PCTs at Rotterdam and Antwerp will be followed. Cross-case study relied on primary and secondary data sources. Where primary data were gathered via in-depth semi stature interviews with senior managers in deep-sea CTs at Rotterdam and Antwerp. In mean time, Secondary data were collected from technical paper, white papers, annual reports and literature analysis.

Firstly, a literature analysis is performed on the determinants of automation level in PCTs. The analysis aims to present the variables and the results that are used in available literature regarding research problem. The level of automation in Antwerp and Rotterdam was described in cross case study based on multiple data sources. Finally, expert interviews with top executives from worldwide terminal operators is conducted in order to gain insight into the factors that influence the extent of automation in both ports.

1.3 Thesis Contribution

Automation outlook shows that 3% of ports globally are currently automated to some degree, with 1% being fully automated and 2% being semi-automated (Vagellas, 2019). The Asia Pacific region dominates the automated PCTs, followed by Europe and North America (iContainers, 2018). The majority of automated PCTs in the Asia Pacific region are in "greenfield" development which are relatively new ports areas. Since the establishment of the first automated containers terminal, ECT delta, in Rotterdam in the late 1990s, automation has not grown exponentially in PCTs.

Despite the benefits of automated CTs in boosting efficiency, lowering operating costs, improving safety, and lowering GHG emissions, the delayed adoption of automation raises questions regarding automation's ability to meet expected goals. According to Navis' (2018) research, many terminals are taking a more moderate approach to automation, because of the obstacles they may face in successfully implementing automation (Port technology, 2018). According to the study, the key challenges are (1) the expenses of introducing automation, (2) the availability of skills and resources to implement and manage automation, (3) labour union challenges, and (4) the time it takes to deploy automation.

With 100 kilometres distance, the ports of Rotterdam and Antwerp are the primary container hubs in the Hamburg Le-Havre range. According to Van Den Driessche et al. (2019), Even though the value-added coefficients of container cargo are quite similar for both ports, the wage component in value added differs significantly for containers and between the two competing hubs. The two ports have been operating with divergent levels of automation since 1993, despite owing comparable levels of technology, labour, and capital costs. Accordingly, the purpose of this research is to determine what factors influence the level of automation in CTs at the ports of Rotterdam and Antwerp.

1.4 Thesis Structure

This paper's structure is as follows: The first chapter contains the background of the topic, the purpose for the topic, the problem to be investigated, and the methodology to tackle the problems are all covered in the introduction (above).

Chapter 2 contains the literature review which gives an overview of port performance and container terminal productivity measures explanation. Later, main port container terminal characteristics are defined.

In Chapter 3, an explanation of automation and a definition of the automation level in PCTs are explored. Chapter 3 will present classification for automation levels in deep-sea CTs at Rotterdam and Antwerp. Finally, automation trends in container terminals will be addressed.

In Chapter 4; the labour system in PCTs will be introduced, followed by the social impact of automation.

Chapter 5 contains the methodology of the thesis. The research is following qualitative analysis based on cross-case study for PCTs in Antwerp and Rotterdam. The case study relied on multiple data sources from primary and secondary data.

Chapter 6, which includes a literature analysis, presents a case study which classifies and defines the automation levels in Port of Antwerp and Rotterdam,

In Chapter 7, the results of an interviews conducted are presented, with an analysis of the empirical parts.

Chapter 8 provides the conclusions, research limitations, and recommendations for further researches.

CHAPTER TWO: LITERATURE REVIEW

In the next chapter the literature review is shown to qualitatively explain the subject of the research. the main topics in literature review are port performance, Container terminal productivity and automation in port container terminals.

1st section presents port performance concepts from several standpoints. The paper focus on cargo transfer products measurement (De Langen et al., 2017). Despite the fact that overall throughput is a common port performance measure, this chapter refers to technical efficiency as a method of measuring port performance.

The component of generalized port price rivals the contribution of handling time in determining port price (Tally, 2007). The terminal operating system would limit the handling time which has impact on port services price. Accordingly, productivity measurements for container terminals are presented in section 2.1.3.

Section 2.2 will outline port container terminal characteristics that would affect port performance in both Rotterdam and Antwerp such as port location, typology of terminal operator, greenfield and brownfield terminal.

2.1 Port Performance

Port performance might be evaluated from several standpoints. To the best of the author's knowledge, there is still no consensus on a unified model for ports performance measurement. UNCTAD has been referring to port performance indicators such berth occupancy, revenue per ton of cargo, and capital equipment investment per ton of cargo since 1976 (UNCTAD, 1976). Furthermore, ports' "societal success" is frequently measured in terms of the value added that ports as clusters generate for their respective regions. The value-added concept, in general, seeks to assess the value of port activities to a country's gross domestic product (Verbeke et al., 1995). Haezendonck (2000) established direct value-added analysis for different type of cargo in marine traffic based on labour costs, depreciations, and profit/losses. the concept enables to weigh nominal tonnes to value tonnes based on the differences in value contributed by each cargo kinds in port traffic data (Haezendonck and Moeremans, 2019).

According to De Langen et al., (2007), there are three different port products: cargo transfer product, the logistics product and port manufacturing product. For the use of this paper, we will emphasise on cargo transfer product measurement. The most of multi-port performance indicators of port technical efficiency rely on frontier statistical models that employ DEA methodologies. Ports used in the analysis are given relative efficiency ratings using DEA techniques. The efficiency scores may be deceiving if these ports are not equivalent. (See Cullinane (2002), for a description of these models) (Talley, 2007).

Talley (2006) outlined several decision variables that management should consider, to maximize performance. There are two crucial points: first, policymakers must clearly articulate the economic purpose, second, port managers have to choose variables that aligns with policy maker’s purpose. Finally, policymakers would have their own indicators to measure port successful in achieving its economic purpose. The success of policymakers decisions will be determined by how well these variables are managed by port managers (Talley, 2006). For example, policymakers can define social dimension as the port's potential to create additional employment and total compensation paid to port employees as the port's major mission. On other hands, the majority of port investors, whether private or public, will be looking for a return on investment, which could be measured in profit, revenue (concession revenues, port dues and terminal charges), or cargo volumes (Haezendonck and Moeremans, 2019).

2.1.1 Annual Throughput

Annual container throughput in 20-foot equivalent units (TEUs) is a common port performance indicator which used to rank world containers port. To develop an accurate index about port performance, annual throughput should be used as a relative to inputs rather than an absolute concept (Bichou, 2007). According to K. Talley (2007), ports have traditionally evaluated their performance by comparing their actual and optimal throughputs (measured in tonnage or number of TEUs handled). The term "optimal throughput" can refer to "engineering optimum capacity”. The maximum capacity of all the equipment installed at the port, which determines the operational container handling capacity, is also known as operational capacity. For example, Maasvlakte II's operational capacity in 2018 was 5,200,000 TEU (Van Hassel et al., 2020).

Technical efficiency refers to the ability to get the most output of a given set of inputs (output oriented) or to minimize the input to the minimum while maintaining the same output (input oriented) (Bichou, 2007). In port container terminals, this concept could be applied when comparing total production factors such as land space, quay side length, labour working hours, operating costs and etc, to throughputs volume in a certain period. The relationship between a port's maximum throughput and given levels of its producing resources is represented by the port's economic production function (Talley, 2007). A port's profit objective must be maximized for it to be profitable. As a result, it entails maximizing throughput with limited resources. Therefore, when a port maximizes its throughput to the optimal level, the average cost per unit in throughput will decrease.

2.1.2 Port Price

In a competitive environment such as ports in Hamburg Le Havre range, port performance shall be evaluated by comparing actual and economic optimum throughputs. The economic optimal throughput of a port is the throughput at which the port achieves an economic goal, such as maximizing port profits or minimizing port costs (Talley, 1988a). The shipper's demand for efficiency, the level of terminal competition, and the terminal operator's unit cost all influence terminal charges (Xie et al, 2021). According to Tally (2007), the component of generalized port price, are prices levied by the port for various port services plus ocean carrier port time price (the time-related costs incurred by ocean carriers while their ships are in port).

In addition, the price of inland carrier port time (the time-related costs incurred by inland carriers while their vehicles are in port). In addition, the price of the shipper's port time (represents the time-related costs incurred by shippers while their shipments are in port).

2.1.3 Container Terminals Productivity

Because of inter-port competition and intra-port competition among container terminals in the same port, port and terminal operators have developed a set of performance metrics to track their progress (Pallis and Notteboom, 2022). The performance dynamics of a modern port are measured using four strategic dimensions: finance, operations, human resources, and market (UNCTAD, 2016).

Container handling rates during a ship's call are related to the time it takes to service the vessel in the widest measures of ship productivity (De Langen, 2015). Ship productivity would be limited by the number of quay cranes deployed on the vessel and their relative hourly productivity, depending on the resources allocated to the ship. On the other hand, the number of cranes assigned to the vessel in the terminal are determined by the vessel's length and stowage plans for unloading and loading containers during port calls. Achieving high ship productivity handling rate is a key in reducing ship turnaround time. The overall time spent in port by a vessel during a given call is known as ship turn-around time, and it is impacted by a variety of services provided to the ship. Crane productivity is a measurement of a crane's handling rates (container moves per crane or container moves per hour). Crane productivity is also a factor in determining ship turnaround time (De Langen, 2015). In modern container ports, crane handling rates can range from 25 to 40 containers per hour on average. According to Saanen (2013), larger vessels may be the best option for lines looking to take advantage of economies of scale. In order to maintain the same operational expenses, container port handling rates must increase by 3–17 percent, depending on the increase in vessel size. The main forces behind the expansion in containership capacities have thus been port efficiency and productivity, particularly after 1995, when American President Lines introduced the post-Panamax vessels (Haralambides, 2014).

Several factors influence crane productivity, including the technical competence of ship to shore cranes, which includes spreader capacity and double lift options, trolley and hoist speed, which accelerating cranes capability to pick-up containers and place them. Crane operator's skills and training, as well as vessel stowage plans, include container locations on board also impact crane productivity.

Table 1:Container Terminal Key Performance Indicators.

Ship productivity	
Gross Moves per Hour (GMPH)	$\frac{Total\ Containers\ dischergerd\ \&\ loaded}{Hours\ between\ first\ and\ last\ lift}$
Net Moves per Hour (NMPH)	$\frac{Total\ Containers\ dischergerd\ \&\ loaded}{Hours\ between\ first\ and\ last\ lift\ Minues\ idle\ time}$
Ship turn-around time	TAT = TW + TB + TBER + TUNBER • TW = waiting time for free berth. • TB= service time at terminal • TBER= berthing time. • TUNBER= unberthing time.
Berth occupancy rate (%)	$\frac{Total\ time\ of\ ships\ at\ berths\ (in\ days)}{Total\ number\ of\ berth} \times \frac{100}{360}$
Crane productivity	
Gross Crane Rate	$\frac{Containers\ Moved\ per\ Carne}{Hours\ between\ first\ and\ last\ lift}$
Net Crane Rate	$\frac{Containers\ Moved\ per\ Carne}{Hours\ between\ first\ and\ last\ lift\ Minues\ idle\ time}$
Labour productivity	
Gross Labour Productivity	$\frac{Annual\ throughput(TEUs)Per\ FTE}{Annual\ labour\ per\ employee}$

Source : EU Terminal Productivity Indicator (De Langen, 2015).

2.2 Port Container Terminals Characteristics

Each port has different characteristics that affect its current and future performance. The ports of Antwerp and Rotterdam, despite their close vicinity, have distinct characteristics.

Natural geographic locations, physical infrastructure, or even management vision for port governing organizations in both ports could be among the port characteristics that differ between the two ports.

Felício et al., (2015) argue that most essential terminal performance criteria are location, marine access, and port dynamics. According to De Langen (2004), coordination between the active participants in both the hinterland network and the port is required. The major factors for ports when building new terminals are proximity to inland cargo and maritime routes, ability to accommodate large vessels with low costs per container, and strong support from port authorities and the port community (Felício et al., 2015). The performance of a terminal is significantly influenced by the port's and terminal's reputation (Cheon, 2007). Several terminal automation projects have been completed in countries or areas that desired to demonstrate their technological capabilities (Rodrigue and Notteboom, 2021). For example, since 1993, when the port of Rotterdam launched a fully automated container terminal, it has been eager to maintain its reputation as the port of the future.

We shall attempt to explore several terminal characteristics that may be determinants of automation level in PCTs at Rotterdam versus Antwerp.

2.2.1 Port Location and Port Accessibility

Apart from transhipment terminals, terminal performance is generally influenced by local economic trends, as manufacturing and consumption centres boost container traffic (Chang et al., 2008). Antwerp and Rotterdam connections to the central European hinterland play a crucial role in enhancing containers traffic in both ports. Access to vast hinterlands is critical for European ports' success (De Langen, 2004). On the other hand, some Mediterranean ports have grown in importance as transhipment hubs connecting Asia and North Africa to northern European ports (Notteboom, 2010). Furthermore, the major hubs have several characteristics including robust marine accessibility, proximity to large hinterlands, and nodes between North–South and East–West routes (Notteboom and Rodrigue, 2009, 2011). In addition, the quality of the inland connection to the port will help to reduce total transportation costs and improve demand on the port, especially in a competitive environment.

The size of a vessel and the capacity of a terminal are limited by maritime accessibility. According to Tongzon (2002) and Wiegmans (2003) marine accessibility is a decisive factor of terminal efficiency.

PCTs could provide a safe vessel berthing without restriction due to the quay length, permitted draught and the quality of vessel traffic management tools such as towage, pilotage, and data exchange system.

2.2.2 Greenfield and Brownfield Terminals

The process of commissioning a container terminal is divided into several phases, beginning with civil engineering, which includes berth dredging, construction of quay wall, railway and road access to the port's hinterlands, electricity, and information technology infrastructure setup, among others things. This phase is referred to as the infrastructure phase. The superstructure phase, which includes paving the terminal yard, designing the container storage area layout, and building terminal gates, warehouses, and administration buildings, is the second phase. Before beginning terminal operations, the last phase will entail commissioning of container handling equipment and the implementation of the terminal operating system. In the superstructure phase, a simulation study can be used to assess the various options of terminal layout and container handling equipment in terms of operational efficiency and running costs. The major goal of simulation is to choose a terminal layout and handling equipment that will provide higher performance while keeping prices reasonable (Steenken et al. 2004).

We can define container terminal which will start from phase one as greenfield terminal. For example, Rotterdam Ports extension projects in Maasvlakte 2 aim to increase port operational capacity by 12,000,000 TEU through a land reclamation project that would add 5000 acres to the port region and address land scarcity issues (NASA 2010; Van Hassel et al., 2020). The basic infrastructure was finished in 2013. In 2015, APM Terminals and Rotterdam World Gateway began operating the two new fully automated terminals (Notteboom et al., 2022). Meanwhile, the opening of the Deurganckdock as well as dredging the Western Scheldt resulted in an increase in capacity for Antwerp's port by 9 ,800 ,000 TEU since 2005 (Van Hassel, et al., 2020).

Brownfield terminals, on the other hand, are container terminals that are attempting to improve their superstructure in order to achieve a greater level of performance. Increased handling capacity, a renovated terminal layout, and/or an upgraded operating system could all be part of this development. For example, in 2018 DP World Antwerp proposed an almost 200-million-euro investment plan to boost the capacity of Antwerp Gateway's Deurganckdok terminal to 3.4 million TEUs by 2025 (DPWORLD, 2019).

2.2.3 Concession Agreement

Service ports, tool ports, landlord ports, and private service ports are examples of port management models. Landlord ports, which are primarily found in Rotterdam and Antwerp are ports where the port authority serves as the governance organization and landlord, while private corporations manage terminal operations through contract of lease or so-called concession agreement (Dooms, 2021).

The World Bank Group defines a concession as "(*A)n arrangement whereby a private party (concessionaire) leases assets from an authorized public entity (grantor) for a defined period and has responsibility for financing specified new fixed investments during the period and for providing specified services associated with the assets; in return, the concessionaire receives specified revenues from the operation of the assets; the assets revert to the public sector at expiration of the contract*" (Africa Transport Policy Program, 2017).

According to a study by the International Bank for Reconstruction and Development, the goals of a container terminal concession procedure, are to improve operational efficiency, promote innovative practices, reduce port expenses, and provide infrastructure finance choices (H. Juhel, 2017). For example, in 2016, the UAE-based ports operator DP World was awarded 50-year concessions to develop a greenfield multi-purpose port in Posorja, Ecuador. The concessions include funding the dredging of a new access channel, the construction of a 20-kilometer access road, and the construction of a 400-meter berth capable of handling containers and other cargos (ship-technology, 2016).

According to the OECD/ITF (2015), a site with a quay length of 950 meters is more likely to attract global operators, whereas smaller size terminals, such as those with a capacity of roughly 500 000 TEU, are more likely to attract local rather than global operators. A concession agreement could highlight a terminal's sustainable development plan in line with the vision of the port manging bodies. According to De Langen et al., (2012) in his study to the process of granting a Rotterdam World Gateway (RWG) container terminal in the Maasvlakte 2 to a consortium of terminal operator (DP World) and a several shipping lines (APL, MOL and HMM and CMA CGM); efficiency, modal split, and sustainability factors can all be agreed by both parties in concession contracts. However, the influence of port manging bodies would be limited after signing the agreement with the terminal operator (De Langen et al., 2012).

2.2.4 Global Container Terminals Operators

The strategic partnership among global terminal operators, port development companies and container shipping lines aim to achieve competitive advantage in port container terminals rivalry environment (Porter M. E., 1985). De-privatization in Latin America and Africa, as well as the opening of China and India's port sectors to private investment and new green-field development concessions through BOT programs, have all aided international container terminals operators in their transformation from national to international operators (Peters et al., 2001; Damas et al., 2002). Souza Junior et al., (2003) argue that terminal operators will carefully examine potential expansion options if the container terminal handling industry can provide sufficient returns to compensate for the significant investment required.

Mainly, there are three types of terminal operators' corporations.

I. Operators with no corporate's partnership with shipping lines or port authorities; The main activities for such enterprises are manging terminals and providing port services. Such as (Hutchison Ports Holdings Limited, YILPORT Holdings).
II. Operators' subsidiaries of shipping lines such as (APM Terminal, Terminal Investment Limited, CMA CGM Terminals).
III. Operators' subsidiaries of port authorities such as (Port of Singapore authority cooperation's, Dubai Ports World.

The container terminal operator's typology may have a significant impact on the operations mode selection (Acciaro & Serra, 2014). Below figure shows the throughput in million TEUs for the major international terminal operators around the globe.

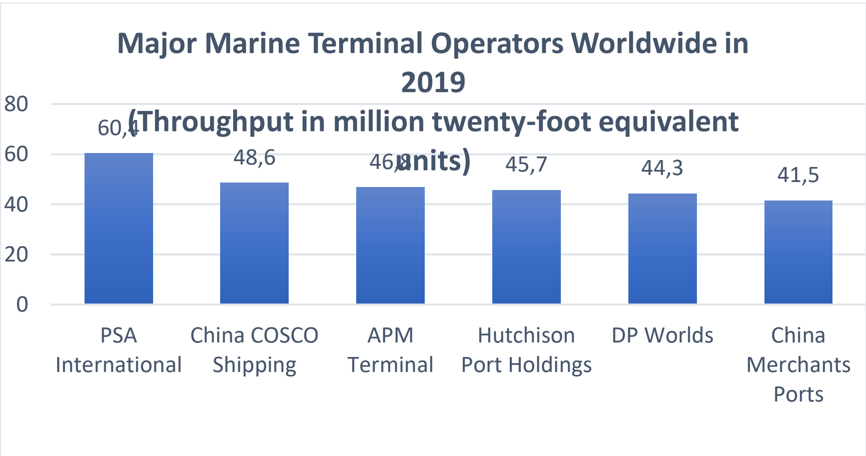

Figure 1:Major Containers Terminal Operators Throughput in 2019

Source: (Statista Research Department, 2021).

In the late 1990s, by acquiring 35% of Rotterdam's ECT terminal, HPH took a big step toward becoming Europe's second-largest container terminal operator in terms of TEU throughput.

However, the purchase was only allowed following a two-year inquiry by the European Commission (EC) into unfair competition, and it was conditional on ECT selling its one-third ownership in the Maersk Delta Terminal. The EC was concerned since ECT controlled over 70% of Rotterdam's container trade and HPH controlled Felixstowe and Thamesport, two of the UK's main container ports. Meanwhile, PSA was also keen to enter the container terminal industry in northern Europe. The merger of two of Antwerp's main stevedore companies, Hessenatie and Noord-Natie, was completed in early March 2002, and the united company was renamed Hesse-Noord Natie. But, as soon as the agreement was signed, PSA bought an 80% interest in the new firm, with Compagnie Maritime Belge owning the other 20%. (Containerisation International, 2001 ; Lloyd’s List, 2002 ; De Souza Junior et al., 2003).

CHAPTER THREE: PORT CONTAINER TERMINAL AUTOMATION

Chapter three will extensively explain automation in port containers terminal. The pros and cons of automation will be addressed in the first section. Followed by explanation to the scope of automation in PCTs which might lead to wide range of automation degree. According to most of literatures, broad classification of automation in PCTs ranges from semi-automated to fully automated and includes a wide range of procedures and applications. Section 3.3 defines the automation tendencies that may occur in Rotterdam and Antwerp for the purposes of this paper.

3.1 Advantages of Automation

Automation can result in increased terminal productivity and capacity, lower operational costs, improved worker safety, and reduced environmental impact (Martn-Soberón et al., 2014). In a survey by McKinsey in 2017, major port practitioners in China, Europe, the Middle East, Singapore, and the United States expect automation to reduce operational costs by 25 to 55 percent while increasing productivity by 10 to 35 percent (Chu et al., 2018). Furthermore, according to study conducted by Navis, a provider of operational technologies to terminal operators, 53 percent of respondents considered terminal automation as a strategy to improve operational productivity by 26% to 50%. Also 75% of PCTs operators believe automation (either Sami or fully) will give them a competitive advantage in the next 3 to 5 years (Port Strategy, 2018).

Better quay usage and yard density can be attributed to the rise in operating productivity and efficiency (Martn-Soberón et al., 2014). The usage of Automated Stacking Cranes (ASCs) also results in more cost-effective land utilization, which is a critical aspect in overcoming land scarcity challenges (A PEMA Information Paper, 2016). Combining automation systems with artificial intelligence applications would allow terminals to maximize benefits of automation and optimize operations process in the terminal (Saanen, 2014). When compared to conventional terminal, the main advantages of an automated terminal are the high productivity of horizontal transfer and lower labour cost (Acciaro and Serra, 2014). The most immediate cost savings from automation come from reducing in the number of operators required.

Only a few highly competent operators can handle fleets of dozens of straddle carriers (Alho et al., 2015). According to Saurí et al., (2014), AGV systems are preferable in ports with high labour costs and/or throughput of over 100,000 containers per QC-year.

Port-related shipping emissions account for 5% of overall shipping GHG emissions (ITF/OECD, 2018). Regarding adopting automation, terminal operating system, and integration with port community system to ease shipping decarbonization in ports containers terminal (See Chang and Jhang, 2016; IMO, 2020c; ITF/OECD, 2018; Poulsen et al., 2018; Alamoush et al., 2020; Alamoush et al., 2022). Also, statistics of UNCTAD (2018) referred to more than 50 ACTs around the world have been built until 2017, because of their significant advantages in reducing equipment energy consumption.

The Port of Rotterdam was used by Geerlings and Duin (2011) to showcase a system for quantifying CO2-emissions from container terminals. They demonstrated that switching from original straddle carriers (SCs) to electric straddle carriers (ESCs) reduced CO2-emissions from existing terminals by over 70%, even though it was costly (Wang et al., 2019).

Automation in PCTs could reduce human errors and delays, as well as the fact that completely automated terminals can operate 24 hours a day, seven days a week, in complete darkness, with no need for crew changes or operators' relief processes (icontainers, 2018). *The APM Terminals CEO, Kim Fejfer, spoke at the Maasvlakte II Port of Rotterdam's inauguration of The APM Terminal. "It operates on a zero-emissions, long-term economic model based on renewable energy, benefiting Rotterdam and Europe." Moreover, thanks to automation, our shipping line customers will see a 40 percent increase in productivity."* (iContainers, 2018).

3.1.1 Disadvantages of Automation

On the other hand, automated PCTs have a social impact that is almost always perceived as negative. The loss of jobs that a full automation entails create tensions with port workers who are at risk of losing their jobs as a result of automation (Soberón et al., 2014). The Port of Rotterdam experienced its first strike in 13 years in January 2016. The reason for this is a dispute between workers and terminals over the predicted loss of hundreds of jobs as a result of the opening of fully automated container terminals in Maasvlakte 2 (expatica.com, 2016). When deciding whether to automate a container terminal, the implementation time is still a critical issue to consider. The first two semi-automated terminals, which opened in the 1990s in Rotterdam and Hamburg, took ten years and $1 billion to create, requiring the invention of technology by a team of 100 IT specialists. Similar terminals can now be developed in as short as four years and for as low as half a billion dollars (Keefe, 2015). Also, one of the challenges that might be observed in brown field terminal when transition to automation is implementation time. An automation conversion project can take anywhere from 12 to 18 months to complete, and it will involve modifications to the terminal's whole infrastructure, considering the IT environment and wireless networks, fencing, safety infrastructure, and access control, among other things (Alho et al., 2015).

Automation of PCTs is well considered to have huge capital investments. The cost of equipment for automated terminals is projected to be three times that of a conventional terminal, while infrastructure costs are two times that of a regular terminal and information technology costs are five times that of a conventional terminal (Mongelluzzo, 2016). Furthermore, automated terminals require a constant supply of specialized and highly skilled labour, as compared to their conventional counterparts. Therefore, ports will be challenged to reconsider the fundamental skills and new capabilities required of port workers in order to efficiently operate an automated terminal (Vaggelas, 2019).

3.2 Level of Automations

Implementing automation solution requires huge capital investments that pose higher barriers to transforming from conventional operations which consider less capital intensive than automated operations. On the west cost of The United States, the automation of Long Beach Container Terminal costs around $1.4 billion in capital investments with an associated capacity of 3.3 million TEUs (Rodrigue and Notteboom, 2021). On other hands, Felício et al., (2015) argue that port geographic location, maritime access and port organization are the most important terminal performance factors. This might explain the slow pace in transition to automation until the date (ITF, 2021). Furthermore, fluctuating in containers volumes and uncertainties in global supply chain are two key challenges marine terminal operators continue encountering. A report by investment assessment organization Moody’s[1] reveals competitive advantages of PCTs might include lower operating costs, increase throughput capacity, improve service reliability, and reduce emission. Nevertheless, key risks accompanied PCTs are significant capital investment, uncertain productivity gains, potential disruptions to active operations and labour concerns (atlas-network.com, 2019).

[1] Moody’s is global integrated risk assessment firm [Moody's - credit ratings, research, tools and analysis for the global capital markets (moodys.com).](moodys.com)

Automation solutions in containers terminals might take place in three main scenarios; the first one when brownfield terminals aim to increase their service level and throughout. Meanwhile, terminal footprint remains constant. This scenario might exist due to land scarcity or when fierce rival occurs in intra-terminals level at same port. In this case, automation becomes an option for terminal operators to increase terminal capacity and achieve competitive advantage. Second scenario often occurs when terminal is planned to become a transhipment hub. In this case, terminals are handling huge volume of ship – to ship containers traffic. Almost all such terminals have cutting edge infrastructure and large capacity. These kinds of transhipment hubs are always owned and operated by carrier who is willing to secure stable demand for terminal services. The third scenario when a greenfield terminal facility is developed in a geographical region where recruiting skilled workforce are costly (Rodrigue and Notteboom, 2021).

It is crucial to take into consideration the needs of the container terminal in question with respect to the level of automation required (Martín-Soberón et al., 2014). Obviously, there are wide ranges of automation trends in containers terminals starting from retrofitting conventional equipment until reach to fully automated machines (Monfort et al., 2012).

3.2.1 Ports 4.0

The technological revolution known as internet of things (IoT) where digital and physical worlds come together has produced a new generation of smart ports or so-called Ports 4.0 (Seoane et al., 2019). Ports and terminals have evolved and from the 2010s have entered a fifth stage of evolution characterized by their digital transformation and alignment with Industry 4.0 practices (Zarzuelo et al., 2020). Adoption of devices and applications based on Internet of Things, Big Data, Artificial Intelligence, Cloud Computing, Robotics and Automation have been evolved in ports container terminals last decades. According to ITERMINAL 4.0[2] project, benefits derived from digitalisation of port container operations will boost operational efficiency, safety, and sustainability (iterminalsproject.eu). introducing smart port concept for the Port of Koper- Slovenia based on five pillars: 1) operational technological upgrades, 2) environment improvements, 3) energy savings, 4) information system improvements, 5) modal split shifting (Brank, 2013).

[2] ITERMINAL 4.0 an EU funding project awarded in mid-2018 by the Connecting Europe Facility Programme that will implement 4th Industrial Revolution concepts to the Port Container Terminal Industry

3.2.2 Terminal Operating System (TOS)

A Terminal Operating system (TOS) plays an important role in planning, monitoring, and updating containers movement within containers terminals. In addition to allocating and monitoring containers handling equipment while containers movement occur, new features in TOS support greater process automation through optimizing planning and scheduling decisions in terminal operations (Boer and Saanen, 2012). The subsystem of containers terminals includes berthing of vessels, discharging or loading containers by ship to shore cranes, horizontally transporting containers in between quayside and stacking yard by horizontal transportation devices., containers stowing in terminal stacking area by stacking cranes, loading, or unloading containers from road trucks, rails or barges and passing terminal gate from/to terminal hinterland.

Information technology, optimization techniques, and management enhancement are all considered cost-effective alternatives that do not involve a massive investment in physical infrastructure (Liu et al., 2002). Basically, automating the physical movements of containers cannot take place apart from TOS features. For example, the main decision problems in horizontal transportation are 1) selecting the type of vehicle (AGV, ITV, ALV, SC), 2) determining the number of vehicles required for operations, 3) routing and dispatching of Vehicles (Carlo et al., 2013). Trade-offs between CAPEX, OPEX, and operational efficiency will be considered during selection process that could be solved through in advance modelling process. In addition, optimising dispatching and allocating features in TOS would enable terminal to achieve operational efficiency while on time operations are going on.

3.2.3 Full and Semi-Automation

Terminal automation is either a fully or partial substitution of terminal operations through automated equipment and process (Rodrigue and Notteboom, 2021). The level of automation in containers terminals would be defined according to the level of employing automated machines and computer system instead of employing human resources. Broadly, two major types of automated containers terminals might exist; fully automated refers to terminal relays on automation machines, electronic devices, and computer system to handling containers from vessels to yard to terminals gate and visa-versa. By contrast, semi-automated terminal involves automation in certain equipment or process. Meanwhile, the rest of terminal operations and processes are performed by human resources. According to ITF[3] (2021), fully automated container terminals do not yet exist. 53 containers terminals around the globe are automated to certain degree. Most automated systems are installed in the container yard. Few terminals have automated the horizontal transportations between dockside and container yard. No terminal has completely automated quay cranes.

Generally, semi-automated and fully automated container terminals are the two types of automated container terminals that can be considered. The difference is that, while stacking processes are automated in both situations, transportation from/to yard to/from berth in semi-automated terminals is handled by manned vehicles, whereas in fully automated terminals it is done by automated guided vehicles (Saurí et al., 2014).

3.3 Trends in Containers Terminals Automation

Most of literature have investigated the automation in containers terminal by discussing automation of container handling equipment or automating physical follow of containers inside the terminal. In this research, the automation of information flow and automation of decision making as mediating and moderating variables are also addressed. Mediating variables can be defined as variables which are explained by independent variables while also explaining dependent variables (Bhattacherjee, 2012). On other hand, moderating variables are variables which influence the relationship between independent and dependent variables (Bhattacherjee, 2012).

Automation of information flow refers to eliminating human intervention in exchanging the information relevance to physical movement of containers within port containers terminal by using information management applications. On other hands, automation of decision-making process aims to optimizing operational decisions in strategic, tactical, and operational level by using simulations models in planning process and TOS in operational level. (Monfort et al., 2012). The level of automation of equipment can differ from level of automation in information flow and decision making (Martín-Soberón et al., 2014). According to Kalmar[4] White Paper which explained the wider approach of container terminal automation that build around an open, standardised platform. They defined open terminal automation platform by additional software integrated with terminal operating system to streamline decision making process,

[3] ITF: The International Transport Forum is an intergovernmental organisation with 63 member countries. www.itf-oecd.org .

[4] Kalmar, part of Cargotec, offers the widest range of cargo handling solutions and services to ports and terminals. www.kalmarglobal.com

through integrating information flow with control and monitoring into single solution (Myllarnemi and Hamalainen, 2021).

3.3.1 Quay side operations automation

Quayside operations in PCTs consists of loading and discharging containers from ship to shore. Mainly, quay side operations in PCTs consists of four subsystems: securing/unrecurring containers, operating quay cranes, twist-lock handling, transferring containers from quay to yard (ITF, 2021). In addition to former stated processes related to physical movement of containers; pre arrival information's consist of vessel arrival time and stowage plans for containers which will be loaded/unloaded in the port during vessel call.

This information is crucial for berth allocating and cranes scheduling. According to many literatures, the automating of ship to shore cranes and lashing process are less developed in port containers terminals (ITF 2021; Martín-Soberón et al., 2014).

3.3.2 Automated Horizontal Transportation

Automation in this area includes the use of unmanned automated terminal tractors, automated guided vehicles (AGVs), straddle carriers (SCs). The latest generation of AGVs is guided by GPS technology and is electrified to produce zero carbon dioxide emissions and noise reduction (Rodrigue & Notteboom, 2021). Horizontal-transport vehicles can be either loaded or unloaded by stacking cranes which so-called passive vehicles (AGVs) or vehicles (LAGVs) which equipped with built-in devices enable vehicles to load/unload containers by themselves without requiring cranes assistance which known as active vehicles (Kemme, 2013). The significant capital cost for acquiring AGVs, make it more for PCTs in countries where labour-costs are relatively high (Saanen, 2004).

3.3.3 Automated Stacking Cranes

Automated stacking cranes or Rail-Mounted Gantry cranes are used for stacking/retrieving containers in terminal stacking area. The RMGC system is most applicable in countries, where labour costs are restively high and where environmental aspects are rather important (Brinkmann, 2011). The decision-making process for automating stacking system in PCTs. based on several criteria such as equipment productivity, yard density, capital cost, operating cost, and labour cost. For more detailed comparison between different stacking yard system (See Saanen, 2006; Kalmar, 2011; Brinkmann 2011; A PEMA 2016).

3.3.4 Gate Automation

Many container ports have automated a significant part of these gate operations. Optical character recognition (OCR) systems and Radio-frequency identification (RFID) systems are used to check containers and truck data. Captured data will be transmitted to terminal operating system (ITF, 2021). In most terminals, delivering or receiving containers from road truck handled by robotics cranes and under certain level of human supervision. Human intervention by PCTs in this process aims to reduce the potentials risks for interacting between terminal equipment and manned road trucks.

The following table will summarise the feasibility of automation for containers handling activities.

Table 2:Feasibility of automation for handling activates

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

Source: Container Port Automations: Impacts and Implications, OECD/ITF (2021).

CHAPTER FOUR: THE SOCIAL COST OF AUTOMATION

This chapter will introduce port labour system, starting with defining port labour productivity concepts. Later, will address the labour concerns about automation. Labour safety issues in PCTs and skills required for PCTs will be addressed in last section.

4.1 Port Labour Productivity

In the port and terminal ecosystem, port labour is a crucial production factor that can be compared to other production factors such as land and capital (Notteboom, 2018). The choice of which system to implement in relation to the degree of automation is a strategic decision based on factors such as land costs, available technology, experience economies, and labour productivity (Acciaro and Patrizia, 2014). The competitiveness of a port can be harmed by unfortunate labour organization. Terminal productivity and reliability are hampered by harsh working conditions, particularly in the container stevedoring industry (Notteboom & Vitellaro, 2019).

The substantial amount of volatility and seasonality in the cargo volumes to be handled at seaport terminals is a significant aspect of maritime traffic (Stopford, 2009). Given the fluctuating demand for stevedoring services, labour flexibility is critical to port competitiveness, as it avoids times of overstaffing or understaffing (Notteboom, 2010). To deal with market peaks, terminal operators are more likely to employ a core workforce and hire additional (temporary) dockworkers (Naniopoulos, 2000). According to current regulations on labour port schemes, additional workers is given through job agencies or formal labour pools directly administered by the port (Satta et al., 2019). Adoption of automation aims to increasing port labour performance (Notteboom & Vitellaro, 2019). Automation of container handling equipment can also be used to mitigate some of the challenges those conventional terminals face due to the human resources shortages. Obviously, it is no longer necessary for terminal management to plan and book labour to handle peak periods. Automated container handling equipment might run continuously, irrespective of weather conditions (Johansen, 2011).

The number and size of gangs, as well as the quantity and kind of cranes and other equipment deployed to handle the vessel, including their level of automation, all affect dockworker productivity (measured as tonnage loaded and discharged per dockworker/shift) (Notteboom & Vitellaro, 2019). The key predictor of port competitiveness and performance is still labour productivity (Haezendonck, 2001).

When comparing the value added of containers in the ports of Antwerp and Rotterdam, wages in the port of Antwerp are much higher (nearly 10% difference) than in the port of Rotterdam, which has a profit share of 16 percent more than the port of Antwerp (Van den Driessche et al., 2019). This is likely explained in part by the port of Rotterdam's higher level of automation on container terminals (Eurosport, 2017).The comparison, on the other hand, reveals trade-offs between value-added components in the container value chain. Because the Port of Rotterdam has a bigger profit share, the Port of Antwerp might keep creating jobs.

Acciaro and Patrizia (2014) argue that labour cost has a great influence on container terminal structure. The increase in labour costs favours SC-operated CTs over RMG, RTG, and semi-automated CTs. In fact, SC-operated CTs require less labour than RTG or RMG CTs. The influence of labour unionization in countries with high labour costs will impede the adoption of fully automated systems, according to this research.

4.1.1 Demographic Challenges

In several parts of the world, automation is frequently used as a solution to tackle demographic concerns. In Europe, an aging workforce has produced a labour supply and demand imbalance (International Transport Workers' Federation (ITF), 2019). For instance, in Belgium and the Netherlands, the population aged 25 to 54 years old accounts for 39.23% and 38.47% of the population, respectively (indexmundi.com, 2021). When labour is in limited supply, automation can help increase the number of workers available for other jobs. If the wages and working conditions of the jobs are better than those of their prior jobs, automation may give social benefits (OECD/ITF, 2021).

4.1.2 Labour Conflicts

Dockworkers continue to play a vital part in operational tasks, even as port terminals become more automated, and the industry becomes more capital-intensive. According to terminal data, human capacity will always be at a minimum on every container terminal since the final handling process, placing the container on the vessel, will always require operational leadership from well-trained people, according to experts (Van den Driessche et al., 2019). Consequently, labour cost efficiency is a vital goal for terminal operators, as it has a considerable impact on their ability to generate profit margins (Notteboom & Vitellaro, 2019). A conventional container terminal's labour costs account for more than half of its total cost, whereas "automated terminals require 40 percent to 70 percent less labour." (Atlas-network.com, 2021).

Salary cuts or a reduction in the number of employees may not immediately mean better profit margins, as these measures can result in labour shortages, strikes, or other organizational and operational inefficiencies, all of which lower overall labour performance (Notteboom, 2018). Around ports, port automation projects frequently cause major societal tension.

Port automation announcements have sparked criticism from trade unions, blockades, and strikes in the United States and Australia (ITF, 2021). According to a report by the investment rating agency Moody's, the prohibition on fully automated container terminals at ports on the East Coast and Gulf Coast was a crucial part of the 2018 International Longshoremen's Association (ILA) contract. *'It further said that a strike in Canada was almost avoided last month due to the ILWU Canada's objection to automation in Vancouver, British Columbia''* (atlas-network, 2021).

As per European dockworker unions, the inauguration of the automated container terminal, APMT Maasvlakte 2 resulted in a loss of 1,000 jobs, or about 20 percent of the existing unionized labour force (Patricia, 2015). The Rotterdam port workers went on strike in January 2016. Unions worry that the introduction of fully automated terminals on the Maasvlakte 2 would result in the loss of hundreds of jobs in the container industry (Nltimes.nl, 2016). In line with the results of a survey on the constraint factors of automation implementation in Indonesia container terminals, 25% of practitioners believe that applying automation will result in labour conflicts (Pamungkas and Gurning, 2020).

Complete automation will only be possible through dialogue and communication with trade unions, involving them in the project, and providing them with the information and training necessary for their retraining, so that workers acquire the necessary skills according to their capabilities (Orive et al., 2020). Furthermore, the social costs of port automation include social security costs (redundancies) and lost tax income as a result of machines replacing port labour. In many circumstances, the personal tax revenue lost because of a machine substituting a labour is not reimbursed by increasing corporate tax income (OECD/ITF, 2021).

4.2 Automation and Labours Safety

According to several port safety authorities, such as the Hong Kong Marine Department and the Health and Safety Executive UK; cargo handling activities are one of the highest potential accident risks in container ports. Human error, equipment maintenance, and the environment are the underlying causes of potential accidents (Sunaryoa and Mohamad Hamka, 2017). Workplace accidents reduce terminal efficiency by causing work delays and a significant increase of the operational time (Notteboom & Vitellaro, 2019). Meanwhile, safer containers terminals can benefit from the lower insurance premiums and lower compensation costs because of the lower accident rates (Kaunonen, 2017).

Trade unions are particularly active, exerting significant pressure on government management bodies to draw attention to the serious hazards that stevedores face (Turnbull and Wass, 2000). In addition to improving productivity and lowering operating costs, PCT automation also improves the safety and security of workers and port facilities. Accident rates are significantly reduced by automation (Kalmar, 2014). According to Grau's (2014) analysis, converting to an ASC/shuttle-type (i.e., semi-automated) terminal might reduce injuries by 25%, while converting to full automation (including AGVs) could reduce injuries by around 40%. (Den Driessche et al., 2019). Workers in automated container ports are less likely to be exposed to hazards. According to Ceci, John Nardi, president of the New York Shipping Association, and Joe Harris, spokesman for the Port of Virginia, PCTs employees can expect healthier working conditions as a result of the transition to autonomous and remotely controlled equipment, as well as increased safety and career longevity (Keefe Patricia, 2015).

Although automation in container terminals may reduce human errors, it may also lead to new types of human errors. (Walters and Wadsworth, 2021). Accidents involving automated straddle carriers have been reported in Auckland's ports (Maritime Union of New Zealand, 2021). In 2021, the Auckland Port Authority in New Zealand temporarily suspend the use of automated straddle carriers due to safety concerns. (Ports of Auckland, 2021; OECD/ITF 2021).

4.2.1 Dockworkers Skills

Structural changes in maritime and logistics market have transformed the port industry and as a result, labour requirements (Notteboom, 2018; Vonck, 2017). According to Arntz et al. (2016), 14% of existing employment in 21 OECD nations are at risk of being automated. When compared to their high-skilled counterparts, where technology is frequently introduced to complement their activities, low- and middle-skilled professions in the transportation sector stand a greater risk of unemployment by 2040 (International Transport Workers’ Federation (ITF), 2019). Concentrating on the marine cluster in the Netherlands, it is concluded that with the arrival of automation, the number of jobs in the maritime cluster will decline by at least 25%. The port sector is expected to lose 8.2% of its jobs (Vonck, 2017; UNCTAD, 2018).

According to Frey and Osborne (2017), 27% of dock work is currently automated, and approximately 85 % of their duties will be automated by 2040 in the port industry. As a result, dockworkers are faced with the challenge of learning specific technical skills in fulfil present and future labour market demands.

To take advantage of the potential benefits from automations, retraining and employing personnel with relatively higher skills than those employed in conventional PCTs is required. Retraining is required, particularly in semi-automated terminals where labours are still demanded (International Transport Workers' Federation (ITF), 2019).

CHAPTER FIVE: RESEARCH METHODOLOGY

5.1 Introduction

Extensive studies have been undertaken on container terminal automation and the determinants for the appropriate level of automation. Most of this research have been built on solving simulation researches on several types of automated scenarios accompanied by various terminal layouts using quantitative analysis to determine the optimal economic, operational, and environmental scenario for each PCT. However, little qualitative researches have been done in this area. There has been little investigation into how the degree of automation in PCT is determined, and what the rationale is for determining varying automation levels even within the same port. The focus of this research is to explore the rationale beyond the labour-capital ratio discrepancies among deep-sea CTs at Rotterdam and Antwerp, through exploring the factors that would determine the applicable automation level in deep-sea CTs at Antwerp and Rotterdam. The favourable level of automation highlighted the divergence in the labour-capital ratio in CTs at both ports.

To solve research problem author relied on cross – case study approach. A case study is an empirical research method for investigating a current phenomenon by focusing on the dynamics of the case in its real-world context (Yin, 2009; Roth, 1999) An exploratory, descriptive, or explanatory case study is possible. According to Welch et al. (2011), case studies can be used to develop inductive hypotheses, interpretive sensemaking, natural experiments, and contextualized explanations. The ability to construct new theory from empirical evidence is a significant strength of the case study (Eisenhardt, 1989).

The research employs a variety of data collection methods, including primary and secondary data. The primary data were gathered through semi-structured interviews with top managers at container terminals in both Rotterdam and Antwerp ports. Meanwhile, secondary data were gathered through annual reports, white papers, technical reports, and a review of the literature. literature analysis might be viewed as a less biased evidence-based conclusions review approach that would eventually lead to the adoption and approval of theoretical frameworks (Munn et al., 2018).

The focus of the cross-case study for PCTs in Rotterdam and Antwerp was on data triangulation to reduce bias in case study research (Yin, 2009).

For the following reasons, the investigation was limited to the main rival ports in Hamburg-Le Havre range; (1) The availability of the data for researcher, (2) Antwerp and Rotterdam have some labour cost, capital cost and same level of accessible technology, and (3) All deep-sea CTs at both ports have relative same scale with capacity exceeding 1 million TEU.

5.2 Cross-Case study Process

Cross-case patterns apply different techniques. As a result, the divergent approaches in data analysis forces researcher to consider ahead of initial notions and see evidence thru numerous perspective (Eisenhardt, 1989). Inductive case study research can be deployed in theory generation (Eisenhardt, 1989). The defining of main research question in this research helps the researcher to be focus on research problem and avoid overwhelming by volume of data. A prior design of concepts in literature would help to shape the initial design of theory-building research (Eisenhardt, 1989). In a literature review, the author formulates the research problem, which is the determinants of the automation level in CTs in Antwerp and Rotterdam and specifies potential variables from extant references.

The study combines data collection methods from primary sources (expert interview) and secondary sources (literature and desktop research). Multiple data gathering methods enable triangulation, which strengthens the substantiation of constructs and hypotheses (Eisenhardt, 1989). The research of a case study can be qualitative, quantitative, or both (Yin, 2009). Quantitative evidence can reveal relationships that the researcher may not be aware of (Eisenhardt, 1989). Cross-case analysis for Antwerp and Rotterdam enable researcher to avoid building conclusion based on limited data (Kahneman & Tversky, 1973). Mitigating biases by looking at data in a variety of ways is the key to good cross-case comparison. (Eisenhardt, 1989). The researcher applies this approach by selecting variables based on existing literature and then to explore within-ports similarities combined with inter-ports differences. Furthermore, when a model from one data source is supported by evidence from another, the conclusion is more solid and well-founded. In case study research, theoretical saturation is the point at which incremental learning is limited (Glaser and Strauss, 1967.)

5.2.1 Pros of Cross-Case Study Research

Overlapping data gathering and analysis enables researchers to take use of flexible data collecting (Eisenhardt, 1989). Furthermore, the potential of generating new theory from cross-case analysis is significant.

The likelihood of a viable theory is high because the theory-building process is so closely linked to evidence that the resulting theory is very likely to be consistent with empirical observation. (Eisenhardt, 1989).

5.2.2 Cons of Cross-Case Study Research

The findings of research would be more robust if researcher has the authority to capture data through field observation. This could happen if the research combined with internship in terminal operator headquarters. According to Glaser and Strauss (1967), developing a testable, relevant, and valid theory requires an intimate link with empirical reality. However, to compensate for the lack of observations and avoid bias in the results, the author used triangulation data sources. Furthermore, absence of statistical measures such as correlation coefficients, F values, or T-test effect the measurement of the findings significance (Eisenhardt, 1989). Statistical generalization, or inferring generalizations about a population, is impossible with single or many case studies (Yin, 1994; Numagami 1998).

5.3 Expert Interview

The objective of the expert interviews is to gather primary data about port container terminal automation from the standpoint of terminal operators. The expert interview is a survey research tool that allows researcher to acquire a wide range of non-observable data (Bhattacherjee, 2012). In order to achieve this, expert interviews were conducted with senior managers in terminal operators, terminal directors and port digital solutions consultant.

Senior executives from corporate terminal operators at locations in Antwerp and Rotterdam. 2 container terminal directors having extensive expertise in both automated and conventional terminals in both ports. In each port, there are two managers in CTs. Finally, an interview is also conducted with a digital solutions consultant in the Port of Rotterdam, with. The interviewees have a wide range of experience in the container terminal business, including operations, planning, technical, and managing large-scale facilities. Three of the interviewees have more than 30 years of CTs experience. Two of the interviewees work in headquarters of a corporate terminal operator based in Europe. An oral interview was done with the majority of the managers, however one of them preferred a questionnaire style. The interviews were conducted using a question semi-structure that had been created. The personnel who chose a questionnaire were given the same questions.

Three different sets of questions were created. The first set of questions, which were shared with one manager and a digitalization consultant, were regarding automation level and determinants of automation degree.

The second set of questions was distributed to executives at the global terminal operator's headquarters. The final set of questions was distributed to the directors and managers of the CTs at the ports of Antwerp and Rotterdam. Two rounds of interviews with one of the experts were undertaken in order to generate a comprehensive discussion of the issues at hand. In addition, follow-up questions prompted by a discussion with one individual were shared with other experts to obtain the perspective and input of the interviewee. The following are the questions:

Questions for digitalization consultant and automation transformation personnel

- How do you categorize the level of automation in a container terminal in terms of human intervention in the terminal operations process?
- Will the level of automation within a port standardize in the future to provide the optimal solution, or will it continue to vary from one terminal to the next?
- How crucial is it to automate both the flow of information and the decision-making process for automating container movement (handling equipment automation)?
- Are you satisfied with the existing level of innovation in the container terminal business for automating handling equipment, decision-making, and information flow?
- Does the terminal operating system (TOS) in automates/semi-automated terminals provide (in)efficient scheduling and planning features?

Questions for executives at the global terminal operator's headquarters

- From the standpoint of terminal operators, how are automation decisions made and what are the measures of automation efficiency? In both brownfield and greenfield terminals
- Who makes the decision about the terminal investment and automation level?
- Is the investment choice made at the global terminal operator's headquarters?
- Is the level of automation decided by the local management?
- Does the consortium interfere in the automation choice if it includes carriers or local shareholders?
- How may invest in automation make financial sense in order to pay back a large initial investment?

- How can a terminal operator ensure that its operating system (conventional/semi-automated/fully automated) is effective in achieving the terminal's goal?
- What factors/characteristics will make the transition to a fully automated operation more straightforward?
- What aspects or characteristics will make the shift to completely automated more difficult?
- Will container terminals adopt automation as a standard strategy in the future?

Questions for individuals in the CTs at the ports of Antwerp and Rotterdam

- The operating system is designed to promote annual throughput, decrease vessel turnaround time, increase yard density, lower cost per handled unit, and improve terminal safety. Is the existing operating system capable of mirroring the terminal's objectives?
- Does the length of time it takes to implement automation in a greenfield or brownfield terminals affect the decision?
- How may the size of a terminal or the layout of a yard influence an operator's choice of automation level? In a greenfield/brownfield situation.
- How does the amount of service (vessel service duration, gross berth productivity, vessel crane density) affect the level of automation in PCTs?
- How does container flow through the terminal (vessel arrival pattern, Dwell duration, Modal split) affect the degree of automation?
- What effect might the ratio of transhipment, origin, and destination containers have on the level of automation?
- Does the terminal operating system (TOS) in automated/semi-automated terminals provide (in)efficient scheduling and planning features?
- How can port labour skills be harnessed in favour of implemented operating system?
- How will the terminal operator deal with the uncertainty surrounding experienced dockers' availability?
- How does terminal operator sustain labour Performance in port organization?
- Is the port labour union strength an impediment to automation adoption?
- How can terminal operators deal with port workers' reluctance to change as part of automation projects?

The purpose of interviewing digitalization and automation transformation projects individuals is to learn about the innovation and outlook of automation markets from the perspective of providers. Furthermore, we perceive the extent of automation in the business through automating decision-making and information flow.

The goal of interviewing executives at global terminal operator headquarters is to learn more about the strategic decision-making process. Global terminal operators manage all deep-sea container terminals in Antwerp and Rotterdam. As a result, the importance of gaining insight into the reasons for investment decisions, as well as how corporate strategy may influence investment decisions, was at the core of the questioning line.

Finally, an interview with C-level and senior management in CTs in Rotterdam and Antwerp was conducted to get insight on automation deployment and the problems that brownfield terminals face when deciding to automate to a larger degree. Furthermore, we concentrate on the various aspects of each terminal that may influence the level of automation. Specifically, we concentrate on labour management in the port organization.

CHAPTER 6: LITERATURE ANALYSIS AND CASE STUDY

6.1 Ports Containers Terminals Challenges

Recently, the port landscape has been characterized by fierce competition. Particularly in the container market segment, where the decisions of shipping alliances regarding the capacities used, the ports called at and the network structure can decide the future of a port container terminal (UNCTAD/RTM, 2018). The significant growth of container ships size, combined with the mergers and alliances between powerful carriers, are putting pressure on ports to continuously improve their efficiency and productivity (Bastug et al., 2021). Global terminals operators are gradually establishing dedicated terminal joint ventures in collaboration with carriers and powerful shipping alliances to ensure stable demand for terminal services (Notteboom and Neyens, 2017). Few port authorities now operate their own CTs, but an increasing number of them act as landlord ports, which means that CTs are given to other terminal operators on a concession basis (Talley, 2009: Van Hooydonk, 2013). Obviously, Port infrastructure has ended up not as it were the facilitator of world trade, but more over a profitable resource for private investment. Hence, global terminal operators developing port terminal portfolio around the globe (Haralambides, 2021). When dealers are Global Terminal Operators, corporate policies and investment availability may play a key role in determining the extent of automation, as objectives and incentives may differ depending on corporate business plans (Notteboom and Rodrigue, 2012).

Ports and container terminals are chosen by container cargo shippers and logistics businesses based on their location, accessibility to markets, port costs, freight rates, turnaround time, cargo value and volume, frequency of liner service, and trade routes (Felício et al., 2015). Clearly, demand for port container terminal services is influenced by a variety of factors and is not only dependent on terminal operators' capacity to deliver cutting-edge cargo handling technologies. Yet rather than the port or terminal itself, the choice is constantly made by the whole network service organization (Yap and Notteboom, 2011). The network is shaped by strategic relationships between shipping corporations and global logistics networks include maritime shipping services, which determine which container terminals to call at (Tongzon & Heng, 2005).

6.1.1 Terminal Efficiency and Automation

As economic globalization deepens, the status of automated container terminal is becoming progressively important. Rational planning of handling equipment has become the key to improving the efficiency of terminal operations (Zhao et al., 2019). ACTs are proving to be a significant benefit in saving terminal labour costs, improving port capacity, reducing equipment energy consumption, and improving port image (Wang et al., 2019). Ports must make the best use of available space, time, and resources while minimising negative externalities to port community. In this sense, robotics and automation for port operations, Big Data analytics and the Internet of Things are important prerequisites in this context (Notteboom and Neyens, 2017). In line with the European Sea Ports Organization (ESPO) has created the "Connect Europe" program (2021-2028) to fund new port expansions. Between 2018 and 2027, it is anticipated that European ports will require around 48,000 million euros in investment, due to external reasons such as increased trade flows, new maritime sector trends, decarbonization, digitization, automation, urban development, and security (O'Reilly; ESPO, 2018).

According to NAVIS survey, most terminal operators consider (either semi or full) automation will be crucial to remain competitive in the next three to five years. The survey also refers to that most PCT operators predict automation may increase productivity by 26 to 50% (Port Technology, 2018). In addition to automating cranes and transport equipment in port container terminals, the application of intelligent routing and scheduling for handling equipment is critical to terminal efficiency. The optimization of CHEs planning and allocation processes enables an economical use of terminal resources (Stahlbock & Voss, 2008).

Wiśnicki et al. (2017) argue that efficiency of container terminals is not closely related to their level of automation; conventional terminals can be quite effective. This conclusion is based on the application of data envelopment analysis to evaluate terminal efficiency for nine container terminals in European ports with different levels of automation. The input parameters for the DEA model were quay length, maximum allowable ship draught, number of ship-to-shore gantry cranes, number of container yard gantry cranes, and container yard capacity. The output parameters of the DEA model were the annual throughput of the terminal.

However, the DEA model relies on a limited number of input parameters. All parameters were related to terminal infrastructure and equipment capacity. Macroeconomic factors such as labour costs, land costs, and economic development of the port area are not considered in this model. In addition, the limited number of entities could affect the results. For more information on measuring efficiency using data envelopment analysis, (See Charnes, et al. (1978); Wiśnicki et al., (2017)). According to Felício et al (2015); the most successful container terminals are in northern Europe and the Mediterranean coast.

Because they are close to significant consumer and producer markets, have good rail and road connections, are in dynamic ports with deep-sea access and frequent shipping lines services available. As a result, the growth of automated and semi-automated container terminals in northern Europe and along the Mediterranean coast might be explained.

6.2 Automated Container Terminal Layout

The key determinants of automation level selection at the micro level have traditionally been space availability, stacking capacity, and equipment costs (Stahlbock and Voß, 2008). The decision between automated and semi-automated CTs is influenced by throughput. Larger CTs are more likely to favour automation (Acciaro & Patrizia, 2014). According to Saanen et al. (2003); robotization of terminal equipment, or the construction of automated container terminals, is a cost-effective solution for high-density terminals with a capacity exceeding 1 million TEU in countries with high wages.

Although the average container terminal size is 51.7 hectares, fully automated terminals have an average size of 85.5 hectares and semiautomated terminals have an average size of 69.9 hectares, illustrating the scale preference for automation (Notteboom & Rodrigue, 2021). Furthermore, automated terminals allow for increasing quay and yard density, resulting in more efficient use of space and improved terminal capacity (Montfort et al., 2011).

Layout design is the foundation of ACT construction, which has an at least 50-year impact on the terminal (Wang et al., 2019). Furthermore, strategic layout decisions interact directly with tactical configuration decisions and terminal operational complexity, which entails a variety of unpredictable and dynamic terminal activities, as well as scheduling restrictions and operating limits (Li et al., 2021). Generally, a common automated container terminal layout uses block designs perpendicular to the piers to reduce horizontal ground motions and to ease traffic control (Notteboom & Rodrigue, 2021). For example, APM Terminals' Maasvlakte II, an automated terminal in the Port of Rotterdam, used ARMG and lift AGVs in a perpendicular yard configuration (PEMA Information Paper, 2016).

Meanwhile, most conventional terminals have parallel layouts. In a parallel yard configuration, rubber tyred gantry cranes or rail mounted gantry cranes and manned ITVs are commonly used (Lee and Kim, 2013). When comparing the overall cost of parallel and perpendicular layouts, Lee and Kim (2013) argue that the parallel plan is preferable to the perpendicular layout. The parallel layout used quite fewer yard cranes and had lower expenses for purchasing and operating YCs and horizontal transporters than the perpendicular configuration.

Gharehgozli et al., (2017); Wang et al., (2019) have concentrated on resolving layout optimization problems under perpendicular layout, i.e., block length and width, to achieve emission reduction and efficiency enhancement.

X. Li et al. (2021) conduct a simulation study on ACT layout design. Embedded with cycle-time models that are used to calculate the time it takes for various terminal services to operate. For evaluating layout design, key performance measures are proposed. Furthermore, a simulation-based energy consumption and cost model is developed and used to provide a more exact and practical reference for terminal operators when making layout design decisions throughout the development phases of ACTs.

The design of individual yard blocks and the operational type of the RMGs system define the design of automated RMGC storage yards (Kemme, 2013). Studies investigate different types of RMGC systems for a particular yard-block layout (e.g., Valkengoed 2004; Saanen and Valkengoed 2005; Saanen 2007).

6.2.1 Brownfield Terminal Automation

The decision to automate a port container terminal varies depending on whether the terminal is being built from the ground up (greenfield) or is already operational (brownfield) (Martín-Soberón et al., 2014). Automation becomes a technique to boost throughput, manage higher operating expenses, and remain competitive when an existing terminal facility's size is difficult to expand (Notteboom, Pallis and Rodrigue, 2022). For example, Antwerp Gateway Terminal (Port of Antwerp, Belgium), converted its yard straddle carriers to RMGs (Port Technology, 2012). According to a PEMA information paper, upgrading from a Straddle carrier to an ARMG and horizontal transfer (ShCs) system would improve yard density from 700 to 1400 TEU/ha (PEMA Information Paper, 2016).

Table 3:Challenges to Automating Equipment in Brownfield Terminal

• Operational disruption and the possibility to retrofit existing fleet	• More extensive examination and training of operational employees will be possible with a gradual transition. However, consider the possibility of losing a customer.
• Existing terminal layouts may make installing new layouts and routines more challenging.	• It may be difficult to assign specific blocks inside the terminal yard to test automated equipment due to the terminal's limited space and land scarcity.
• A large percentage of existing equipment is nearing the end of its lifespan - current machine book value	• Electrical capacity sufficient to power E-RTGs.
• Changes in essential skill sets; modifications to present contracts and labour agreements	• Ability to adapt of the terminal operating system to automated handling equipment
• Installation of IT infrastructure, as well as infrastructure capability and yard design	• Information on the concession agreement's expiration date and the potential of renewing the concession contract.

Source: Author elaboration based on PEMA-Brownfield paper, (2019).

6.2.2 Horizontal transportation selection

To ensure the greatest possible coordination between stacking and quay cranes, terminal operators should decide whether horizontal handling equipment should be manned or automated in terms of productivity and operational costs. To assure that processes are carried out quickly and efficiently, both at the terminal quay and at the terminal yard, sufficient vehicles, either automated or manned, must be available to move all containers from/to the shore to/from the yard (Saurí et al., 2014). Saanen et al., (2003) argue that that AGVs are less costly than ALVs because of the decoupling between RMGs (YC) and ALVs and even though it requires fewer vehicles to achieve the same QC productivity. Furthermore, automated options are shown to be less costly than shuttle carriers. Despite, automation remains a risky solution due to its limited flexibility (Saanen et al., 2003). On the other hand, Vis and Harika, (2004) simulated the effects of using AGVs and ALVs on vessel unloading performance in a similar way. They compared unloading times, crane waiting times, QC occupancy levels, and the required vehicle fleet. They concluded that the AGV fleet needs to be 38 percent greater than the ALV fleet. Then, in terms of cost, ALVs are a better choice than AGVs. Furthermore, Duinkerken et al., (2006) used the Maasvlakte container terminals to compare transportation systems for inter-terminal movement. This time, the cost of multi-trailers (MTS), AGVs, and ALVs was compared. The study concluded that the MTS option requires a tremendous work in vehicle control and planning, however MTSs are idle roughly 50% of the time. In comparison, the number of ALVs required is less than half that of AGVs, and they are idle only 15% and (ALVs) 30% of the time.

Saurí et al., (2014), investigate the economic cost of a manned system operated (SCs) versus an automated one consisting of automated guided vehicles (AGVs). Simulation model was built based on data retrieved from the new semi-automated container terminal at Port of Barcelona. Simulation study concluded that AGV systems are preferred in ports with high labour costs and/or a throughput of over 100,000 containers per QC-year. On the other hand, SCs systems are recommended for terminals with low yearly throughput (less than 100,000 containers per QC) and/or low labour costs. During a wide range of yearly throughput (80,000-170,000 containers/QC-year for the 40 mov/h scenario and 50,000-80,000 containers/QC-year for the 30 mov/QC scenario), both horizontal transporting systems record comparable total costs (Saurí et al., 2014).

According to Sauri et al., (2014); SCs are deemed to be less risky in this scenario since they are less capital intensive and are more flexible to operational changes. Furthermore, SC systems achieve better performance at the terminals with higher productivity (40 mov/QC-h). Labour is the most expensive component of the SC system, accounting for over 50 % of all costs. Investment costs, including financing charges, are the second most expensive part of the manned system. Meanwhile, investment cost is the most expensive part of the automated system which accounting for 43% of the overall average cost (Sauri et al., 2014).

For more simulation studies comparing the different option of horizontal transportation, (See Bae et al., 2002; Zhen et al., 2012; Yang et al., 2004; Liu et al., 2002).

According to Van Hassel et al. (2020), the cost structure of container terminals in Antwerp, Hamburg, and Bremerhaven demonstrates that capital costs account for more than 55 percent of the average cost of a container terminal. The financial cost of all terminal equipment, as well as the cost of land lease, determine capital costs (Vanelslander, 2005). Meanwhile, labour costs account for 33% of the average cost of a container port, while maintenance costs account for 5% and operating costs account for 7% of the total.

6.3 Case Study

6.3.1 Market Outlook

In 2021, the top 15 EU containers ports jointly handled 78 million TEU, a 5% increase over 2020. The ports of Rotterdam and Antwerp handled 15,300,000 and 12,020,000 TEU, respectively. In 2021, most of the top 15 ports experienced growth. Looking at the top of the list, Rotterdam maintained its position as Europe's largest container port with a robust 7.8% increase in 2021, after experiencing a 3.2 percent decline in 2020 (year of the pandemic). On other hand, Antwerp was Europe's only significant gateway port to record growth rates (+1.4 percent) in 2020. Its container volume stayed constant at 12 million TEU in 2021. In April of this year, the port authorities of Antwerp and Zeebrugge will merge to establish the Port of Antwerp-Bruges. In 2021, their total volume was 14.1 million TEU (+1.9 percent), 1.2 million TEU less than Rotterdam's (Notteboom, 2022).

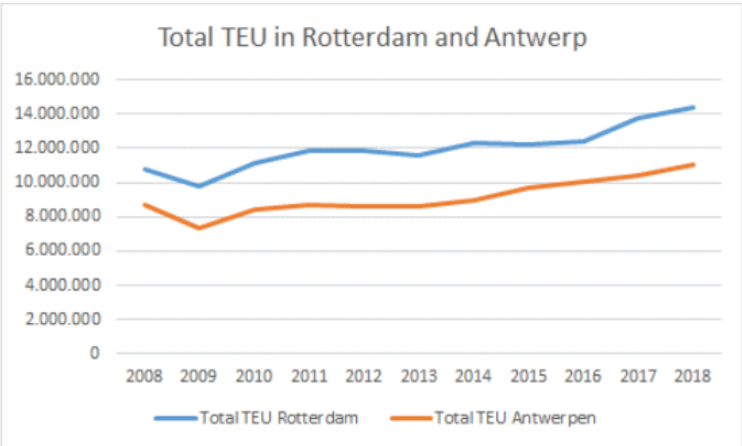

Figure 2:Container Traffic in the Ports of Rotterdam and Antwerp from 2008 to 2018 in TEU

Source: Port of Rotterdam Authority (2018) and Antwerp Port Authority (2018).

In 2021, both Rotterdam and Antwerp handled more volume than in 2019, and much more containers than in 2007 (+42 percent and 47 percent, respectively). Both ports handle nearly 35.2 percent of the total amount of containers handled by the top 15 EU ports. The Port of Rotterdam's throughput increased by 143% from 6,280,000 TEU in 2000 to 15,300,000 TEU in 2021, whereas the port of Antwerp's throughput increased by 190 percent from 4,080,000 TEU to 12,020,000 TEU during the same period (Clarksons, 2019; CEMIL, 2022).

The expansion of Maasvlakte II in Rotterdam's port has a projected maximum capacity of 12,000,000 TEU as from 2013. Meanwhile, since 2005, the expansion of Deurganckdock and dredging of the Western Scheldt have added more than 9,800,00 TEU potential capacity to the Port of Antwerp (E. Van Hassel, et al., 2020).

6.3.2 Port of Rotterdam

Rotterdam Port has excellent accessibility due to its location on the North Sea and at the Rhine's river mouth. The terminals are situated close to deep water and can be reached easily and safely from the open sea without the use of sea locks. This permits vessels to be unloaded and loaded fast, allowing them sail to their next destination as soon as possible. Rotterdam Port's geographic location, combined with 100 direct Deepsea connections to more than 200 ports around the world, allows the port to maintain its position as Europe's major transhipment hub. Transhipment container volume movement accounted for 36% of overall container volume throughput in 2020. The modal split for moving containers from the port to the hinterland in the same year was 52 percent road truck, 38 percent barges, and 10% railroads. The Port of Rotterdam generates around 45.6 billion euros in direct and indirect added value. This amounts to 6.2 percent of the gross domestic output of the Netherlands (GDP) (portofrotterdam.com).

6.3.3. Port of Antwerp

Due to its inland location 80 kilometres inner from the North Sea, the Port of Antwerp provides a more central location in Europe than most North Sea ports. Container ships can now sail upriver with a maximum draught of 15.6 metres and downriver with a maximum draught of 15.2 metres in the Western Scheldt navigation channel. Antwerp is noted for its high container handling productivity, with 40 moves per crane per hour.

Table 4:Deepsea Container Terminals at Port of Rotterdam

Deepsea Container terminals at Port of Rotterdam					
Terminal	**Operator**	**Quay length (M)**	**Plot (ha)**	**TEU Cap. (‘000 TEUs)**	**Draught (M)**
ECT Delta	HPH	3 600	272	6200	16.65 - 17.45
Euromax	HPH	1500	84	5.000	17.65
DELTA 2	HPH	1600	100	3,350,000	16.65
APMT-MAASVLAKTE 2	APM	1500	86	2,700,000	20
Rotterdam World Gateway	RWG	1700	108	2,350,000	20

Source: Author creation based on Port of Rotterdam Authority (2021).

Table 5:Deepsea Container Terminals at Port of Antwerp

Deep Container terminal Port of Antwerp					
Terminal	**Operator**	**Quay length (M)**	**Plot (ha)**	**TEU Cap. (‘000 TEUs)**	**Draught (M)**
MSC PSA European Terminal (MPET)	PSA-TIL	3700	242	9000	17
PSA Noordzee Terminal	PSA	1265	79	2600	17
PSA Europa Terminal	PSA	1180	72	1800	14.5
Antwerp Gateway Terminal	DPW-COSCO	1660	107	2800	17

Source: Author creation based on Antwerp Port Authority (2021).

Table 6:Yard Storage System and Horizontal Transportation in CTs at Rotterdam and Antwerp

Terminal	Yard storage system	Quay-yard transfer system
ECT Delta	ARMG	AGV
Euromax	ARMG	AGV
Delta 2	Manned ShC	Manned ShC
APMT-MAASVLAKTE 2	ARMG	Lift AGV
Rotterdam World Gateway	ARMG	AGV
MSC PSA European Terminal (MPET)	Manned ShC	Manned ShC
PSA Noordzee Terminal	Manned ShC	Manned ShC
PSA Europa Terminal	Manned ShC	Manned ShC
Antwerp Gateway Terminal	ARMG	Manned ShC

Source: Author creation based on PEMA 2016 and Terminal Operators websites

Table 7:Maximum Capacity and Automation Level in PCTs at Port of Antwerp and Port of Rotterdam.

Maximum capacity and automation level at PCTs in the Port of Antwerp and Port of Rotterdam				
Terminals	**No automation**	**Semi-automation**	**Full automation**	**Total Cap. TEU**
Rotterdam				
ECT Delta			6200000	
Euromax			5000000	
Delta 2	3.350.000			
APMT-MV2			2700000	
RWG			2350000	
Total Rotterdam	3500000	0	16250000	19750000
Antwerp				
MSC PSA European Terminal (MPET	9000000			
PSA Noordzee Terminal	2600000			
PSA Europa Terminal	1800000			
Antwerp Gateway Terminal		2800000		
Total Antwerp	13400000	2800000		16200000

Source: Port of Rotterdam and Port of Antwerp Data (2021)

CHAPTER 7: RESULTS AND ANALYSIS

This chapter presents the methodology's findings, broken down by each factor that was tested and evaluated. This is clearly prefaced where the results were acquired by literature analysis or observation from a case study. This is also stated when the result was obtained through expert interviews.

7.1 Capital Costs

Automation on PCTs is well recognized to have huge capital investments. The automation of the Long Beach Container Terminal on the west coast of the United States cost around $1.4 billion in capital investments, with a capacity of 3.3 million TEUs (Rodrigue and Notteboom, 2021). The cost of equipment for automated terminals is projected to be three times that of a non-automated terminal, while infrastructure costs are two times that of a conventional terminal and information technology expenses are five times that of a conventional terminal (Mongelluzzo, 2016). According to all interviewees, the total investment cost, plus the impact of automation on reducing operational costs are the most important considerations in choosing automation degree. Expert number 7 also stated that the implementation of automation must improve terminal efficiency, which should be reflected in increased productivity and throughput. The increase in terminal efficiency will increase terminal profits, making investing in automation more financially viable. Furthermore, Expert number 6 stated the decision to invest in automation would be made by the business unit based on the results of the economic simulation in the first stage. In most circumstances the headquarters will not make an investment decision on automation. Expert number three clarifies that the headquarters' role in automation investment decisions is primarily consultative. Though, in certain cases where there is a desire to exhibit the level of innovation achieved by the worldwide terminal operator, the headquarters have the authority to decide whether to invest in automation.

7.1.1 Terminal Scale

Due to the high cost of implementing automated CTs, automation appears to make economic sense only when ports handle at least 1 million TEUS per year to benefit from economies of scale. (Petersen, 2015). In Rotterdam and Antwerp, all deep-sea container terminal sizes exceed 1 million TEU handling per year. According to expert number 7, Annual throughput would make financial sense if automation was combined with a higher level of productivity.

Hutchison Ports Brisbane, for example, is a semi-automated port with a capacity of no more than 500,000 TEU per year on a 26-hectare property (hutchisonports.com.au, 2017). Although the average container terminal size was 51.7 hectares, fully automated terminals had an average size of 85.5 hectares and semiautomated terminals had an average size of 69.9 hectares, demonstrating the scale tendency for automation (P. Rodrigue &T. Notteboom, 2021). Expert number three stated that larger automated and semi-automated container terminals require the installation of automation hardware such as yard fences, AGVs pathways, and interchange zones. Expert number 6 also stated that increasing the number of blocks in an automated yard plan is necessary to increase efficiency and minimize AGVs deadlocks and bottlenecks. This is what underlies the automated system's rigor.

7.1.2 Yard Capacity

According to Acciaro and Serra (2014), in the first stage, port space availability or stacking capacity has a significant impact on ports' desire to automate or not. This is debatable, considering that electric vehicles and automation hardware require more space for their operations, which could negate the space advantage from stacking, Expert number four stated that automating yard cranes would result in increased yard density due to ARMGs' greater ability to vertically stack containers. The below table shows the impact of different type of equipment type in yard stacking density:

Table 8:Yard Density for Containers Handling Equipment

Yard equipment type	Horizontal transfer method	TEU/ha[5]
ARMG (1 over 5)[6]	ShC	1400
CARMG (1 over 5	ITV	1350
ARMG (1 over 5)	AGV	1250
RTG (1 over 5)	ITV	1100
Straddle carrier (1 over 3)	n/a	700

Source: A PEMA Information Paper, 2016

The entire plot size for deep sea container terminals in Rotterdam and Antwerp is 650 ha and 500 ha, respectively.

[5] These numbers include access roads and the area between quay and blocks.
[6] (1 over 5): Refers to containers stacking height.

Obviously, there is a greater demand for yard in higher automated systems. When compared to Antwerp, the Port of Rotterdam has a higher container throughput POR (15,300,000 in 2021), POA (12,020,000 in 2021).

Expert 4 distinguish between 2 concepts in his respond to the correlation between boost yard capacity and level of automation.

- The capability of automated stacking cranes to stack more containers vertically would increase yard density.
- Yard Capacity which can be calculated by using following formula, include height as a factor in this formula

$$\text{Yard Capacity} = \frac{TGS\ x\ Max\ Stacking\ Height\ x\ Average\ Stack\ Height\ Utilisation\ x\ Days\ in\ Period}{\text{Surge Factor x Peaking Factor x Average Dwell Time}}$$

Optimising yard operations normally requires a multi-faceted approach (Notteboom et al., 2022). The above formula includes multivariate components reveal that stacking height is one factor in improving yard capacity. Expert four refers to TOS features in optimizing operations in automated yard. The most efficient container positioning in the terminal yard allows the terminal to maximize yard capacity, eliminate unproductive movements, and improve yard efficiency. Expert four emphasizes the significance of integrating the port community system with TOS to provide terminal with full container data in advance, which would facilitate terminals process in organizing stowing containers in terminal yards. Expert six stresses the importance of dwell time when it comes to increasing yard capacity.

This could explain why the MPET container terminal in Antwerp, which has a capacity of up to 9 million TEUs, uses manned straddle carriers and achieves high productivity.

7.1.3 Productivity Level

The ultimate purpose of PCTs is to reduce vessel turnaround time. The higher handling rate for ship to shore cranes isn't the sole reason for reducing vessel port stays. It also reflects the efficiency of other PCT subsystem parts like yard cranes, horizontal transportation, and TOS features in terms of optimizing planning and monitoring. Without several years of testing and observing real operations in ACTs, expert number five believes it is unlikely to achieve world-class handling rates in fully automated terminals. Automations, according to most interviewees, might not be the silver bullet for increasing handling rates at PCTs, particularly in fully automated terminals.

Although terminal handling rates data are difficult to obtain due to container terminals' high level of confidentiality. We noticed that POA, with a lower level of automation, claimed on their official website that Antwerp container terminals could achieve 40 moves per hour while handling container vessels. According to expert number four, the higher handling rate in non-automated terminals in POA outperforms their automated counterparts. Expert number six mentioned that terminal management must analyse the service level (vessel service time, gross berth productivities, and crane density on vessels, call size. etc) under varying terminal configurations (i.e., number of quay cranes, gross quay crane productivity, number of horizontal transfers, number of yard cranes and yard blocks) in terms of operating speed, automated equipment is more sensitive to the density of the operation. Following that, terminal must compare the CAPEX and OPEX requirements for each system (Saanen, 2015). Expert five, on the other hand, noted that in order to increase productivity in no automation terminal, more experienced operators and skilled dockers are required. In the meantime, increasing level of productivity in automated terminal requires more equipment, more land, advanced TOS and long rump up time.

7.1.4 Labour Skills

Automation in PCTs results in the employment of labour with completely differ competencies than their counterparts in non-automated terminals. Engineers, technicians, and even remote crane operators with specialized qualifications are required for automation terminals. On the other hand, a conventional terminal demands the employment of operators, dispatchers, and supervisors who are either low or medium skilled profile. Meanwhile, due to the lack of automation in the lashing and unlashing process, dockers with extensive experience in container securing (lashing) on vessel board continue to be employed in both automated and conventional types. All respondents agreed that securing a steady supply of specialized labour with high technical skills in small numbers will not be a challenge in Northern-West Europe.

Expert one mentioned that availability of technical universities in port neighbourhood might have great impact in research and development plus supplying ports with engineers and IT specialised who are willing to adopt with new technology. The innovative Delta Sea terminal in Rotterdam, for example, was built in collaboration with Delft University of Technology, a major technological and engineering university nearby port of Rotterdam (Rodrigue and Notteboom, 2021). Automation would be preferred in ports outside of urban areas, such as Maasvlakte 2, because it would eliminate the need to hire labour from another city ([Expert six)].

Expert two went on to say that new 5G technology would allow remote crane operators to direct their cranes from a control centre that could be in another region which could mitigate high labour cost and labour scarcity in North-West Europe. According to Expert six, automation could lower training costs. Quay cranes could be operated remotely from offices in a safer environment by operators with less experience. He added this could make automation more sustainable since we can hire and train new staff in few weeks.

Expert number five shows a variety of processes in a conventional terminal. Operators must be highly trained in order to meet company requirements for increased handling rates, which may involve more training, coaching, and practice. In Antwerp PCTs, senior dockers pass on their experience from past years to junior dockers. Continuous recruiting and on-the-job training in conventional terminals are needed to sustain a skilled docker supply. Expert number seven discussed the importance of the Antwerp port labour pool system, or CEPA, in supplying recognized dockers who are legally eligible to work in Antwerp port's container terminals.

7.1.5 Labour Union

The labour regime is one of the most critical elements in determining the level of automation. According to Acciaro et al. (2014), labour regime includes labour cost and labour regulation. All respondents agreed that high labour costs, may lead to automation. The rigors of North-West Europe's labour regime in favour of labour led to a re-evaluation of the societal cost of automation. Regardless, automation could be a strategy used by a multinational terminal operator to avoid labour union pressure. As a result, the choice to automate may escalate tensions between terminal operators and labour unions. In 2016, a labour strike occurred in Rotterdam Port because of the installation of a fully automated terminal in Maasvlakte 2. Expert number seven stated that if CTs in Antwerp consider automation, redundancy compensation for employees must be addressed. The introduction of automation in Rotterdam port since the 1990s has resulted in decreased labour commitment in collaboration with a worldwide terminal operator, according to expert number four.

In Antwerp, dockers have been legally protected by force of law. In addition to preventing unlicensed labour from participating in stevedoring activities, the protection provides unemployment compensation for nonworking days. Expert number five indicated that maintaining a high level of production in CTs in Antwerp requires a strong commitment of labour.

7.1.6 Ownership Structure

There appears to be a lot of disagreement regarding who will decide on the degree of automation in PCTs. Respondents from global terminal operators acknowledged that global terminal operators have the brightest minds in regard of automation, at least to some extent or for subsystems in the terminal process. PCTs are managed by a variety of investors, including a worldwide terminal operator, a local company, or a consortium of terminal operators and shipping lines. Even the profile of a terminal operator varies depending on whether it is a port government subsidiary or a joint venture with a carrier. Drawing a general strategy for a worldwide terminal operator is difficult. Terminal operators' strong competitiveness, surrounded by port inter and intra-competition in a fast-paced business landscape, causes terminal operators to vary tactics even within the same port. APM Terminals operated two terminals in Rotterdam, each with a different level of automation. DPW also operates semi-automated terminals in Antwerp. In the meantime, the same company is a consortium member so-called RWG who operates fully automated terminal in Maasvlakte 2.

In this context, some respondents agreed that when deciding on automation, terminal management should consider the port's image, community, and stakeholders. The reputation of the ports for social responsibility and the power of the trade unions in Antwerp may lead to a lower level of automation. The social impact of automations may influence decision-makers' willingness to fully automate. Meanwhile, Rotterdam's reputation as the port that pioneered fully automated container terminals in the early 1990s may motivate investors to place a greater emphasis on automation. Furthermore, representing a shipping line in Maasvlakte 2 was associated with a higher level of automation, which might be explained by the shipping company's ability to meet consistent demands for port services while working in collaboration with terminal operators. On the other hand, the presence of shipping lines with a relatively modest percentage in Antwerp, such as MSC at the MPET terminal and COSCO in the Antwerp gateway, has little effect on the degree of automation.

7.1.7 Implementation Time

Since the launch of the first fully automated container terminal in the Port of Rotterdam in 1993, automation in container terminals has not grown exponentially. In both greenfield and brownfield projects, ramp up time is crucial factor that may influence automation decisions. In a greenfield project, a medium-sized terminal automation system might be built in four years for half a billion dollars (Keefe, 2015).

It appears that automating greenfield terminals is easier than retrofitting brownfield terminals, which may explain why the Maasvlakte 2 greenfield terminal chose a completely automated system. In mean time, automating brownfield terminal might be a financially painful ramp up (Saanen, 2019). It might cause a lot of disruption to operations and confront with customer unsatisfaction. All respondent agreed that roadmap to automation should be planned according to terminal condition. Expert number four stated retrofitting mature technology in brownfield terminal would start with process optimization and identifying automation control features in TOS, 2nd step is automating yard cranes, 3rd include retrofitting quay cranes to remotely operated cranes. Finally, include automating horizontal transportation. Expert six emphasized that live terminal operations, even in greenfield terminals, may face numerous obstacles. It will take time to achieve an acceptable level of productivity by implementing a rigorous automation system in a dynamic environment. Expert number seven mentioned that brownfield terminals in their automation retrofitting journey have to be willing to lose volume in favour of their competitors. In first stage terminal are willing to lose transhipment share since it might be considered as vulnerable demands with low margin. Furthermore, when a single global terminal operator handles numerous terminals in the same port, such as PSA in Antwerp, the impact of implantation time interruption can be mitigated since a terminal with free capacity can be used as a backup during the implantation period [(Expert number three)].

7.2 Analysis

Regardless of the benefits and costs of automation on PTCs as determined by a literature review and elaborated on by experts and terminal directors through in-depth interviews. We don't seem to be able to explain the considerable difference in automation versus labour intensity on PTCs in seaports like Antwerp and Rotterdam, which are severe competitors for the same segment of containers flow and have similar levels of technology, capital, and labour costs.

The results of the interviews demonstrate that none of the recommended variables that might lead to different level of automation are adopted to great extent. Since the explanation for the determinants of automation level in Antwerp versus Rotterdam couldn’t be built based on maritime logistics scope. We might explain this phenomenon by strategic management theories on absorptive capacity. The ability of a company to detect, acquire, adapt, and utilize relevant external knowledge is known as absorptive capacity. In other words, absorptive capacity refers to a company's ability to absorb a certain rate or quantity of scientific or technological information. Cohen and Levinthal coined "absorptive capacity" in 1990 (Lane et al., 2006).

The port's capacity to perceive and extract value from new technology, information, or innovation is strongly dependent on the port's prior associated information and specialized diversity. As a result, corporate history can be used to forecast the extent of automation in PCTs. The port of Antwerp's slower adoption of automation may be attributed to a lesser R&D expenditure for this precise industry development.

Antwerp port's strategic vision might include establishing a strong port labour organization, which would result in greater commitment and performance from port workers. CTs have a competitive advantage in the port of Antwerp due to the higher productivity of port dockers. In mean time, the port of Rotterdam was a pioneer in automation on its terminals beginning in the early 1990s. According to Lieberman and Montgomery (1990), the first company to adopt a new technique is thought to gain a competitive advantage over time.

CHAPTER EIGHT: CONCLUSION

This thesis focuses on the level of automation in port container terminals and the factors that influenced the degree of automation in Rotterdam and Antwerp ports. The main research question of this research was "*Which factors influence the level of automation at port container terminals in Rotterdam versus Antwerp?*"

The opening section of this paper focuses on quantifying the research problem by outlining the various factors that could influence the level of automation based on recent literature on the subject. An overview on terminal characteristics, labour, and port performance have been explained. Furthermore, the advantages and disadvantages of automation are presented, as well as defining the various levels and trends of automation in PCTs.

In empirical part, qualitative analysis has been carried using a cross-case study analysis and with data triangulation from primary and secondary sources. Data sources include literature, annual reports, white papers, and technical papers. Finally, in-depth interviews with experts were conducted to gain practical insight from PCTs professionals on factors that may influence the degree of automation in both ports.

Considering the relatively similar current scale of PCTs in both evaluated ports, the best performance standards demanded by global operators and carriers, the level of expertise and development of both ports in container throughput, there is no substantial evidence for consistent automation differences at first glance. The concept of absorptive capacity and Rotterdam Port's first mover advantage could provide a viable explanation for sustainable deploying of automation in CTs at Rotterdam port (Van den Driessche et. al., 2019). The port of Antwerp's social vision has resulted in sustained labour productivity and a robust labour organization, enabling the port to rely on a higher labour-intensive ratio. The productivity of the Antwerp port, which has been a competitive advantage for decades, has shown to be sustainable, encouraging a gradual move to automation to replace labour (Haezendonck and Langenus, 2019).

Despite the scale similarities and proximity of two competitors, there is a significant difference in PCTs characteristics at both ports. The location of Maasvlakte 2 in Rotterdam, which is directly situated at the North Sea, permissible draught, geographical location, land availability, and ease of maritime access to the ports have given terminal operators in joint venture with carriers the feasibility of developing fully automated facility in greenfield terminals. Adopting automation in Maasvlakte 2 is appropriate for transhipment traffic, which is more likely to be compatible with a rigorous automation system and benefit from efficient and non- stoppable operation.

Meanwhile, Antwerp port is closer to the hinterlands, making it ideal for operate as a gateway port with sophisticated inland connectivity. Furthermore, ports face land expansion constraints, which may result in brownfield development for future expansion. Thus, Antwerp is more fit for a less degree of automation.

8.2 Research Limitations

This thesis was mainly reliant on expert interviews as a source of primary data, where the main limitation was the small sample size of interviewees. This sample size limitation is particularly relevant to terminal operators' managers. Due to the sensitivity of the subject, some interviews attempt to justify corporate decisions, and most terminal operators refuse to state quantitative data about productivity, costs, and benefits of automation due to the sensitivity of the topic. Furthermore, most of PMBs managers and terminal performance managers in shipping lines denied participating and advised to obtain information from terminal operators. The adoption of the triangulation data sources which combines evidence acquired from terminal operators questioned with secondary sources of data and literature analysis, was one way to mitigate this.

8.2.1 Future Research Recommendations

Further research in PCTs automations may include data envelopment analysis (DEA) and estimations of production frontiers of container terminals in the Hamburg Le-Havre Range could be used to quantify the efficiency of this sample and assess the influence of automation on utilizing terminal resources. Further research could also include a diamond framework analysis of competitive advantage for the ports of Antwerp and Rotterdam. It is, however, critical to use reliable data.

To summarize, there are numerous options for conducting research on this topic. because the number of studies currently available is quite small.

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Appendix

Appendix A

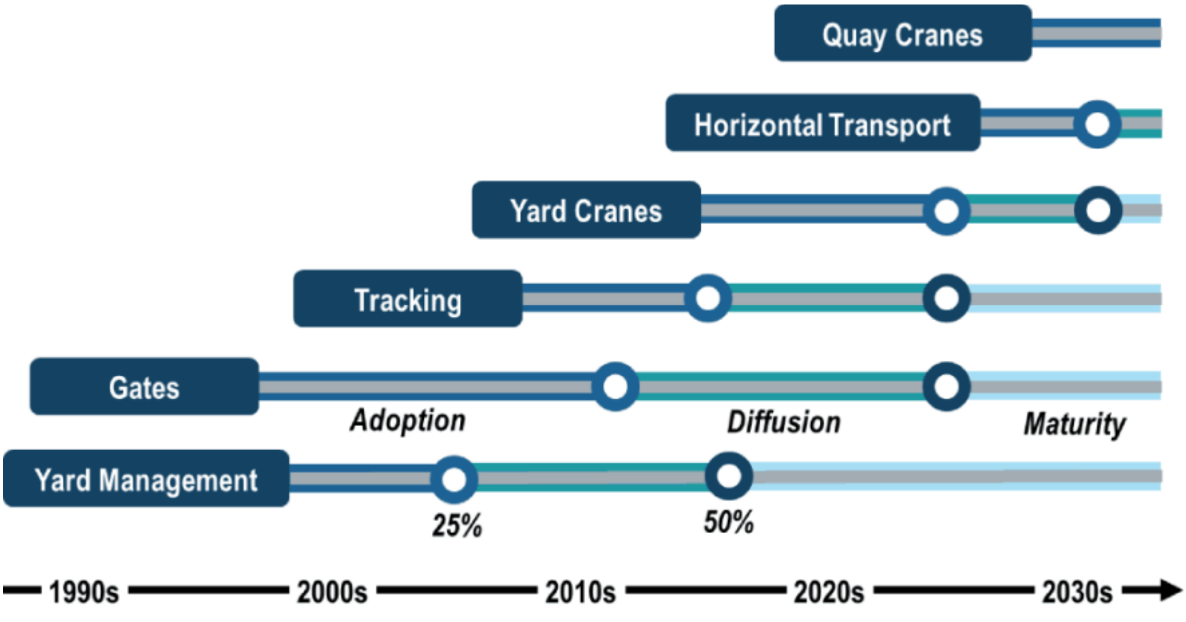

Figure C:Diffusion of Key Port Terminal Automation Technologies

Source: Notteboom, Pallis and Rodrigue, (2022)

Appendix B

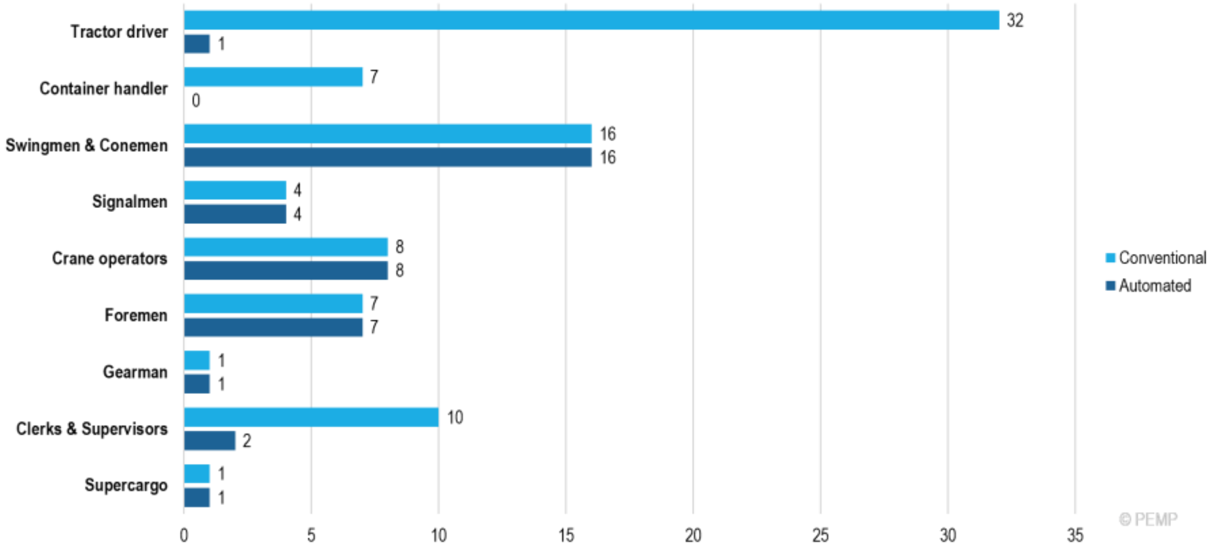

Figure D:Labor Requirement in Conventional versus Fully Automated Terminals

Sources: Journal of Commerce; Moffat & Nichol; Moody's Investors Service; Notteboom, Pallis and Rodrigue, (2022)

Appendix C

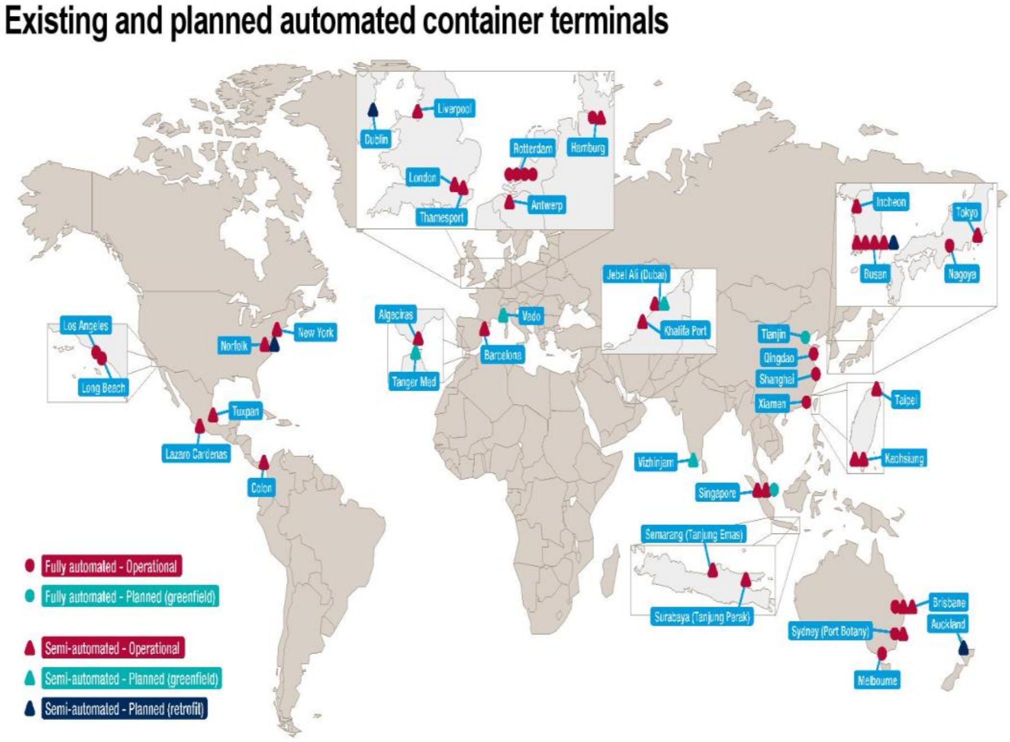

Figure E:Existing and planned container terminals

Source: porttechnology.org

Appendix D

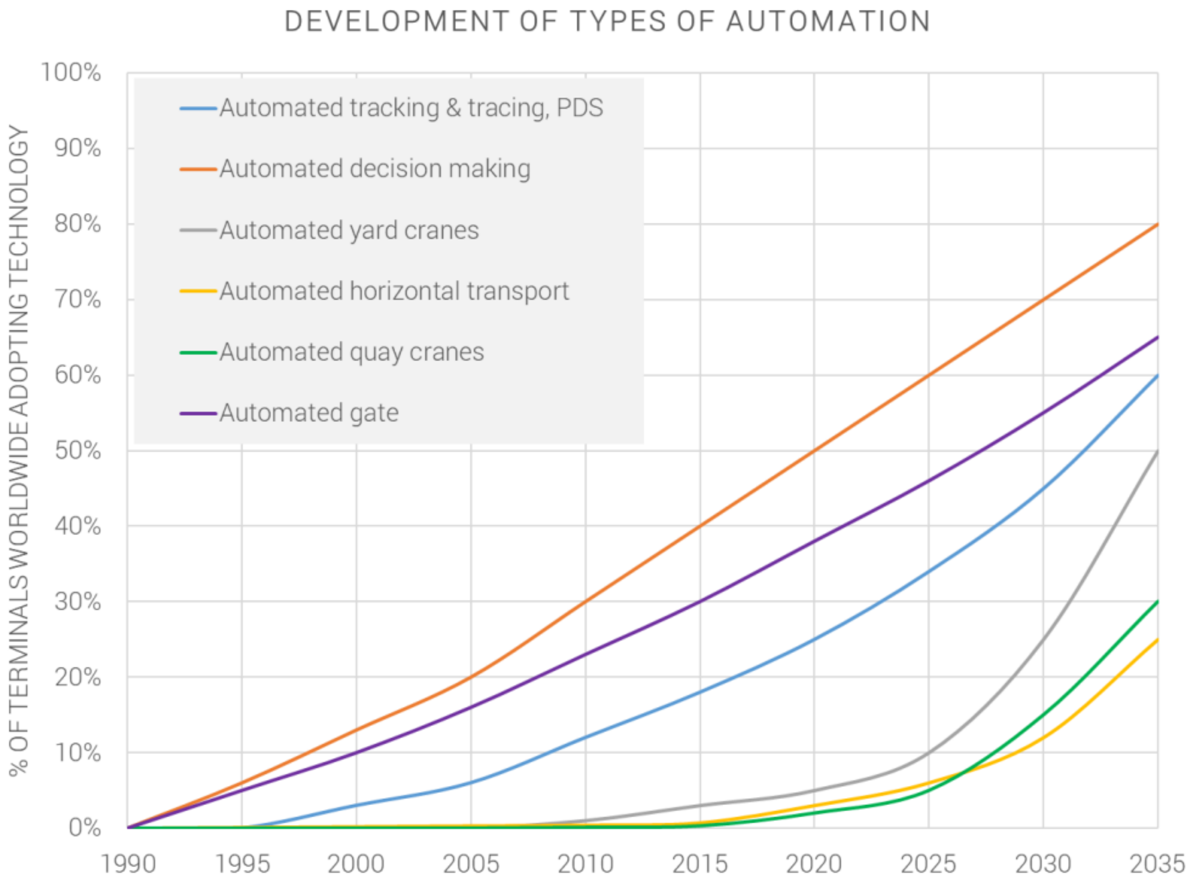

Figure F:Development of type of Automation

Source: Saanen Y. (2021). Maritime Logistics -3 Lecture slides presented during completion of MSc. course in Maritime Economics and Logistics at Erasmus University, Rotterdam.

Appendix E

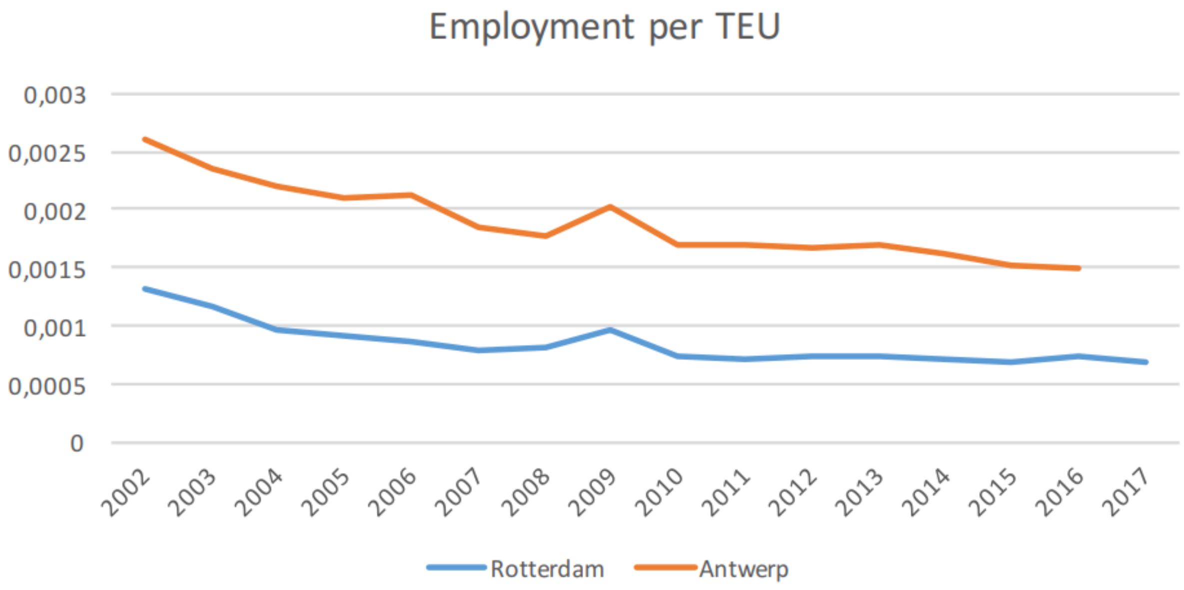

Figure G:FTE per TEU for both the ports of Rotterdam and Antwerp from 2002 to 2017

Source: Van der Lugt et al., (2018), Port of Rotterdam (2018), Port of Antwerp (2018) and various annual versions of working papers of the National Bank of Belgium (from 2007 until 2018).