ERASMUS UNIVERSITY ROTTERDAM

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MASTER THESIS

Urban, Port and Transport Economics

IMPACT OF AUTOMATION ON PORT CONTAINER TERMINALS
A CASE STUDY ON TRANSHIPMENT PORTS

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Abstract

Today, in a number of industries automation has many roles. The same is present within the maritime industry. Automated vehicles, sensors, lasers, terminal operating systems, and many other innovations have started to arise in container terminals worldwide. Thus, this paper examined the impact of automation on port performance, the determinants of port performance, and the effect of automation on greenhouse emissions.

A literature review provided an outlook on automation and port performance. Additionally, different determinants of port performance were explained, including location, economic factors and port productivity. Following, the quantitative analysis was conducted on four selected transhipment ports: Algeciras, Valencia, Barcelona and Gioia Tauro from 2008 until 2017. The analysis was performed using linear regression. Furthermore, the qualitative analysis provided a broader overview on port automation and port productivity on the four selected ports. Three indicators were used for port productivity: berth productivity based on the vessel capacity, productivity based on crane movements per hour per vessel capacity, and the *combination* indicator.

The main findings indicate that automation within transhipment ports does not lead to positive port performance. Additionally, the use of automated equipment provides higher levels of greenhouse emissions in the regions where the ports are located. However, qualitative analysis shows that port productivity impacts port performance, and the use of the right equipment plays an important role in it. On the other hand, the variables from the quantitative analysis indicate that the national level of gross domestic product proves an increase in port throughput and port performance. Principally, when it comes to transhipment ports automation does not provide any considerable increases in port performance.

Keywords: maritime industry, port container terminals, transhipment ports, terminal automation, automated equipment, port performance indicators, port productivity, throughput

Acknowledgment

The paper ahead of you is the final step towards one of my bravest accomplishments yet - the Master degree in Urban, Port and Transport Economics from Erasmus University in Rotterdam. Two years ago I decided to pursue my dreams and move to another country. Finally, I decided to go to the Netherlands and finish my Master education at Erasmus University. With this paper the student chapter of my life ends and new brave ventures start.

I would like to use this opportunity to express my gratitude to everyone who made it possible for me to succeed in this accomplishment.

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Thank you all for making this final step in my educational life possible!

Sincerely,

Daniela Raimund

Rotterdam, April, 2020

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List of abbreviations

AGV - automated guided vehicle

ALV - automated lifting vehicle

AQC - automated quay crane

ARMG - automated rail-mounted gantry crane

ASC - automated stacking cranes

BEST - Barcelona Europe South Terminal

CARMG - cantilever automated rail mounted stacking crane

CATOS - computer automated terminal operation system

CFS - container freight station

CIMS - crane information management system

CO_2 - carbon dioxide

CSP - Cosco Shipping Ports

DGPS - Differential Global Positioning System

FCL - full container load

FICT - Five Continents International Container Terminal

GDP - gross domestic product

ISO - International Organisation for Standardisation

ITV - inter-terminal vehicle

LCL - less than container load

LCS - load control system

MSC - Mediterranean Shipping Company

nGEN - next Generation Terminal Management

NO_X – nitrous oxide

OCR – optical character recognition

PCT - port container terminal

PEMA - Port Equipment Manufacturers Association

PPS - purchasing power standards

PPT - Pasir Panjang Terminal

QQCTN- Qingdao Qianwan Container Terminal

RFID - radio-frequency identification

RMGC - rail-mounted gantry crane

Ro-Ro - roll-on roll-off

RTG - rubber-tired gantry crane

SC - stacking crane

ShC - shuttle carrier

TCT - transhipment container terminals

TEU(s) - twenty-foot equivalent unit(s)

TOS - terminal operating systems

TPS - target positioning system

TTI - Total Terminals International

ULCV - ultra large container vessels

USD - United States Dollar

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Introduction

In this chapter the research outlook of the presented paper is explained. In the following subsections the research is defined, the main questions of the thesis are given along with the thesis contribution. Finally, the structure and outline of the presented thesis are presented.

Problem definition

Ports can be considered as the moving engines of different economies. Ever since the past, ports have been strategic meeting points for merchandise and workers. Nowadays, different types of ports exist based on different categorisations. However, the main focus of this work is concentrated on ports specialised in containerised transhipment cargo and their performance. Today, port performance is determined by different factors including the ship's turnaround time, throughput volume, added value of a port, ship waiting time, investment level in a port, and many others (de Langen et al., 2007). In addition, as argued by Rodrigue et al. (2016) automation as well is playing an important role in the performance of ports and transhipment ports. Thus, the work presented to you is conducted in order to complement the scarce studies on port performance and the impact of automation within transhipment ports.

Research question

To be able to conduct this research, several questions will be answered throughout the next chapters. The main question of this thesis is presented as follows:

A. *What is the impact of automation on the performance of transhipment ports?*

In order to answer this question a quantitative analysis based on multiple regression will be presented. In addition, a qualitative analysis discussing automation in different ports will be conducted. With answering the question, an outlook on the possible importance of automation will be given.

In addition, to be able to provide an extensive overview the following question will be answered:

B. *Which determinants impact port performance?*

The question will be answered as well through the use of quantitative and qualitative analysis. Multiple regression will show what determinants impact positively or negatively port

performance. While qualitative analysis will take a look at port productivity and its impact on port performance. By answering this question it will be possible to provide an overview of different determinants which along with the use of automation effect port performance. The use of quantitative and qualitative analysis will help answering this question.
Furthermore, another sub-question will be examined.

C. Does the use of automation on terminals reduce greenhouse emissions?

The main method in answering this question will be provided by the quantitative analysis where multiple regression analysis will be implemented. Answering this question will give an overview on the sustainability of ports and terminals.

Thus, answering the above questions should provide a complete overview on the topic of this work.

Thesis contribution

The objective of this thesis is to explain, quantify and highlight the importance of different determinants of port performance with the focus on automation and the influence it has on the performance of port container terminals in transhipment ports. Nowadays, only 3% of ports worldwide are automated to a certain degree and among these 3% are also transhipment ports. Since transhipment ports are widely used to berth large container vessels due to the increasing trade volumes, automation can be one of the key elements in gaining the competitive edge in today's transhipment market.
Because the current literature does not focus explicitly on automation in transhipment container terminals, this paper will contribute to anyone who is considering the adoption of automation within ports focused on transhipment cargo or is interested in innovations and automation.

Structure and outline

The structure of this paper is as follows. In the second section the literature review is presented. The main focus of the literature review is on transhipment ports, port performance indicators and determinants, and an extensive outlook on automation in port container terminals. With it, the scene for the analysis is set. In Chapter 3, the methodology of this thesis is presented. The variables and methods selection are explained as part of the quantitative analysis which focuses on answering the question A, B and C. The description and discussion on the selected ports as case studies is shown in the qualitative analysis. In addition, the review on port productivity helps in answering question B. Chapter 4 is focused on the results of both analyses and the implications the results show, while the final chapter provides the conclusion and discussion of this work. In addition, in Chapter 5 recommendations for further research are offered.

Literature review

In the following chapter the literature review is presented in order to qualitatively explain the topic of this paper. One of the main subjects covered are automation in PCTs (port container terminals), the performance of PCTs and the impact of automation in transhipment ports.

Ports and port container terminals

In the following subsection, a theoretical view of ports is given including the definition of ports, different classifications of ports and a view on container and transhipment ports.

Port definition and classification

Ports can be considered as meeting points for cargo but also for passengers. As defined by Alderton (2008) "seaports are areas where there are facilities for berthing or anchoring ships and where there is the transfer of goods from ship to shore or ship to ship" (p. 8). With this definition Alderton focused mostly on cargo ports. On the other hand, Talley (2009) defined ports as "a place at which the transfer of cargo and passengers to and from waterways and shores occurs" (p.1). By this definition, passengers are also included as possible users of ports and the location of the port is geographically more accurate. An interpretation which best encompasses the two definitions previously mentioned is given by the European Commission. The European Commission (2014) stated:

> A port or seaport means an area of land and water made up of such works and equipment as to permit principally, the reception of ships, their loading and unloading, the storage of goods, the receipt and delivery of these goods, and the embarkation and disembarkation of passengers. (p. 11)

It can be recognised that ports serve not only for the exchange of goods but they also provide additional services in the same area. From the given interpretations it can be understood that ports have an important role when it comes to connection. They are used as an interjection between the shore and the waterway, but also they are used as an interjection between different means of transportation such as rail or road. Another imperative function which is the port's crucial role in trade, whether it is cargo or passengers coming in a country, leaving the country, or staying within the port for future transportation or operations.

In addition, de Langen et al. (2007) indicated different roles of ports:

- port as a cargo transfer point
- port as a logistics interaction point
- port as a manufacturing point.

All three roles indicate that ports are not only meeting points but they are nodes or clusters of different activities. As explained by Nijdam & van der Horst (2018) one of the main competitive advantages for a port as a transport node is the geographical location. Based on the geographical location, a port can attract more cargo, for example if the hinterland connectivity is well developed. But also it can be used as a location for other industries such as manufacturing, logistics, petro-chemical and other. These industries can take advantage of the location and availability of the port. In addition, Sorgenfrei (2013) stated that ports can consist of different specialisations and thus they can be: fishing ports, factory ports, sports/leisure ports, military ports. But also it can be a Ro-Ro port for cargo, a liquid bulk port, a general cargo port, or a container port. It can be summarised that ports differ by function, by type of cargo, and by geographical location.

1. Categorisation by function. The main categorisation by function includes transhipment ports, transit ports, hub ports and gateway ports.
2. Categorisation by specialisation. The categorisation by specialisation intends the division of ports based on their main function or specialisation. The two main categories include container ports, and multipurpose ports.
3. Categorization by geographical location. Ports can be categorised based on their location. They can be regional ports, inland ports, river ports, dry ports, autonomous ports, and many others.

Since the focus of this paper is on container ports specialised in transhipment cargo, the most interesting classification is by specialization and by function. The reason behind it is because both categories include transhipment ports and container ports. Thus, in the next section, a deeper insight is provided for the two cases.

Container and transhipment ports

Container and transhipment ports can be two separate ports but they can also be one port performing both functions. A typical example of such a port would be the port of Kaohsiung which is focused on containerised cargo - container port- and transhipment cargo - transhipment port. In this section, a short overview of both container ports and transhipment ports is presented in order to fully understand the role of each type.

Container port

A container port is intended as a port where sea containers and other containerized goods represent at least 50% of cargo which is handled (Sorgenfrei, 2013). Containerisation plays a very important role in intermodal transport since without a container the use of different types of transport for one shipment would be difficult to obtain. It would require more labour hours, less efficiency, less productivity, and a disintegrated supply chain. Back in 1956, 60 containers were shipped on deck from Newark to Houston which marked the beginning of a new transportation service (Levine, 2019). Since then, containerized shipping has facilitated the carriage of freight to any part of the world. Today 90% of global trade is supported by sea due to lower costs of transportation and the reliability of it (business.un.org, n.d.). The need of container ports is quite important since the seaborne trade accounts for such a great percentage of world trade.

There are different types of containers based not only on their dimensions, but also on the settings and usage. The main categorisation is focused on the dimension, which for ocean freight goods is mostly either 20-foot (1 TEU) or 40-foot (2 TEUs) (iContainers, n.d.). There is also an interesting distinction among different types of containers including dry and refrigerated containers. Dry containers do not have a pre-set temperature, while refrigerated containers do have a set temperature and are used for the transportation of either chilled or frozen goods. Additionally, shipments of containers can be either full container loads (FCL) or less-than-container load (LCL). In the case of FCL shipments the moves are from a container yard to another container yard, whereas for LCL shipments the moves can also include a container freight station (CFS). A CFS represents an area where the cargo is sorted and consolidated into a container or out of it. If the LCL shipment is also a consolidated shipment it means that different LCL shipments are stocked into one forming a full container load.

For simplicity reasons, this paper will not consider different types of containers or types of shipments within port container terminals; but it will consider the volume measured in twenty-foot equivalent units (TEUs).

Transhipment port

There are two types main of transhipment: intramodal and intermodal. Intermodal transhipment or intermodal transportation is the transportation and transfer of cargo on different modes of transport whether by sea, land or air (McCalla et al., 2005). For the purpose of this paper, intramodal transhipment is considered to be between the same types of transportation - among container ships at seaports. Thus, transhipment port implies that cargo is imported to a named port on a particular vessel and exported from the named port on another vessel. This cargo is not allowed to leave the port in any other way.

The geographic location is one of the advantages of transhipment ports; it is usually at the intersection of shipping routes and at a point where bottlenecks such as a strait of a canal occur (Rodrigue, 2015). Based on the geographical position transhipment can be categorised as follows (Genco & Pitto, 2000; Rodrigue et al., 2016).[1]

- Hub-and spoke: this type of transhipment port is connecting deep-sea vessels, also known as mother vessels, and feeder vessels which are usually smaller than the former.
- Intersection or interlining transhipment: as the name implies this type of transhipment ports focus on linking multiple long distance shipping routes.
- Relay transhipment: ports active in this type of transhipment present a junction between different shipping routes on the equal maritime range.

Transhipment activity can be measured by a port’s transhipment incidence, "which is the share of the total port throughput that is “ship to ship” compared with the total throughput that includes hinterland traffic as well” (Rodrigue, 2015). A port is considered a transhipment hub when having high transhipment incidence. In ports with less than 25% of transhipment incidence, transhipment occurs rarely. On the other hand, ports with high transhipment incidence (75% and

[1] A visual representation is shown in *Appendix A*.

higher) transhipment is a key activity and ports with 90% incidence are considered pure transhipment hubs (Rodrigue et al., 2016).

Gioia Tauro, Freeport, Algeciras, Tangers Med, and Port Said, are just some examples of pure transhipment hubs, having the transhipment incidence higher than 90% (for complete list see *Appendix B*).

Even though container ports and transhipment ports can be considered as two separate functioning ports, in reality it is often a case that one port is focused both on containerized cargo and on transhipment cargo. Hence, in this thesis ports which are focused on containerized and transhipment cargo will be examined with the goal to see the different effects impacting port performance. Accordingly, in the next section an overview on port performance is presented.

Port performance

This section will present some important characteristics of port performance. An overview on the possible measures of port performance is provided, followed by the various effects which impact port performance.

How to measure port performance?

One of the most used measures of port performance is port throughput. Port throughput indicates the volume of inbound and outbound cargo and it can be indicated in TEUs (Ng et al., 2019). However, port throughput does not provide all the information. UNCTAD (1976) indicated the general guidelines for port performance measurement. Both financial and operational indicators were presented. The former, among others, included: ship revenue related to the berth group, cargo revenue from handling services, labour and capital equipment costs; while the latter consisted of service time, tonnage per ship, tons per ship hour in port, and other.

However, these indicators do not include any indicators regarding port-related employment or the value added. Thus, de Langen et al. (2007) looked into other possible port performance indicators focusing on three port products: cargo transfer product, port logistics product, and port manufacturing product. Hereby, the authors introduced new performance indicators including for example the investment level in a port, the warehouse area (in m^2), the emissions of greenhouse gasses, and others.

The three port products or port functions identified by Geerlings et al. (2018) focused also on the performance indicator used for economic activities of a port - the value added. Value added includes the sum of the wages of employees, profits and depreciation. In addition, the number of firms, the percentage of gross domestic product (GDP) achieved in the port area, and the level of employment in the port and surroundings could be used as a measure of port performance.

However, even though there are different measures of port performance, throughput is still preferred. This might be because it shows directly the amount of cargo and makes it for an easier comparison on larger scales. Therefore, for the purpose of this paper, port performance will be measured by port throughput in TEUs per year.

Determinants of port performance

Different characteristics affect port performance thus making it almost impossible to have two completely equal ports with the same throughput. Some determinants such as hinterland accessibility, natural determinants of ports like winds, tides, draft, but also the number of firms located in the port area, number of ship calls, port charges, terminal efficiency, crane efficiency, and many others, play an important role when it comes to port performance (Tongzon, 1994; Geerlings et al., 2018). For the purpose of this paper, five main determinants are discussed: location, economic factors, employment, port productivity, and automation. The latter is reviewed in a separate chapter.

Location. A strategic location of a port plays an important role in port performance. Song & Yeo (2004) argued that one of the main factors which impacts port competitiveness is the geopolitical location of the port. In addition, Barros & Peypoch (2007) claimed that location might lead to operations levels below port capacity. Thus, indicating that location plays quite an important role for port's performance. Similar findings have been proved by Caldeirinha et al. (2009) showing that the operational performance of a port is influenced by the location, but also by size, infrastructure, specialization and maritime services.

Finally, Tongzon (2009) identified location as one of the important determinants of port selection for freight forwarders which can be linked with an increased throughput in selected ports. Therefore, location will be considered further on in this paper.

Economic factors. The most commonly used economic factors in analysing port performance are the economic growth indicators. Some of the factors include GDP levels, import levels and export levels expressed in TEUs, and different capital investment (Meersman & Van de Voorde, 2008; Sun & Chen, 2009). Chou et al. (2008) explored the volumes of Taiwan's import containers based on the economic growth in Taiwan. In the study, different macroeconomic variables were included such as the volume of export containers, import containers, the gross national product, the gross domestic product and other. The study found evidence that these factors appear to be substantial for forecasting port performance.

On this note, Vanoutrive (2010) examined in his paper the impact of economic indicators on port throughput in the case of Antwerp. In the analysis it was concluded that port throughput does indeed depend on the GDP. Interestingly it reveals that also neighbouring countries and their GDP influences port throughput. This could be explained by the interconnection of economies bordering with Belgium and the fact that part of the demand of these economies is reflected through the throughput of a Belgium port. Since transport can be considered as derived demand, transport growth is detected when economic growth is present.

Additionally, the study conducted on container throughput in Korea and China ports added evidence on the importance of the development of the hinterland and its economy (Liu & Park, 2011). Also, de Langen et al. (2012) presented a scenario analysis on the ports of Hamburg - Le Havre range with the focus on the factors impacting port throughput. In their analysis, four different scenarios were presented, each of them reporting an increase in throughput and identifying economic development as one of the critical drivers.

Based on the above literature, economic factors will be taken into account for the purpose of this research.

Employment. Ports are considered as important players in the economy. Nowadays, ports are not only focused on trade itself but also on other activities such as manufacturing, logistics, transportation and other.

Bottasso et al. (2013) conducted a research on 116 ports in Europe and found evidence indicating a positive effect of throughput on the levels of employment. As indicated by Geerlings et al. (2018) the study analysing the effects of port throughput and regional employment concluded that ports are important for regional employment.

On the other hand, employment might be used as a predictor of port performance. As suggested by de Langen et al. (2007) employment in the port regions can be used as an indicator of port performance. The relationship between employment and port performance can be explained by a possible boost in productivity which could lead to an increase in terms of employment and port throughput. Thus, employment will be examined further on in this research.

Productivity. Both port and terminal productivity impact port performance. As argued by de Langen & Helminen (2015), ship productivity, ship turn-around time, berth occupancy, crane productivity, labour productivity and truck turn-around time, have an impact on port performance. Thus, those indicators can be used as productivity indicators. Ship productivity indicates the rate of containers handled during a ship's call and the total time employed to assist the vessel. Ship turn-around time shows the productivity by vessel; it can be represented as the total time the vessel spends at a port. Lower turn-around time indicates higher productivity. Berth productivity implies the total time of a vessel at a berth in relation to the total number of berths in a port. On that note, crane productivity can be measured by the total number of moves of a crane or container per hour. Additionally, labour productivity can be expressed as the number of TEUs by the annual labour per employee. Finally, truck turn-around time is another indicator of productivity considered by de Langen & Helminen (2015), and is measured by the total time employed by a truck to get in the port pick-up the cargo and leave.

In addition, van Marle (2015) argued that port productivity can be measured solely on a berth level. Thus, the indicators representing port productivity include the capital expenditure per berth, the amount of cranes employed per berth, the average crane moves per hour and berth utilisation. In addition, berth productivity can be determined by the total number of containers

moved per vessel per hour (XVELA, n.d.). As explained by JOC Group (2013), terminals which can employ more cranes per vessel have a possibility of having higher berth productivity.
On another note, productivity can be derived by vessel size. Mooney (2017) argued that the larger the vessel the lower the productivity levels are. Based on crane performance, vessels larger than 14 000 TEUs lead to lower productivity levels. The optimal productivity is achieved on vessels within 7 000 and 10 000 TEUs capacity. Thus, it might be deduced that terminals which are able to berth larger vessels might suffer from lower crane productivity, consequently indicating lower port performance.

It must be noted that the aforementioned determinants are not the only elements impacting port performance. In some scenarios other determinants provide different impacts on port operations. However, further analysis on it goes beyond the scope of this paper. The above presented determinants of port performance including location, economic factors, employment, and productivity are the main focus for this paper, thus they will be used in further analysis. In addition, automation - the last determinant- is studied extensively in the next section.

Automation

The maritime industry has been more prone to its already proven processes than to experimentation and change. However, the development of technology started to influence the maritime sector when in 1993 the first use of unmanned equipment was implemented on the ECT Delta terminal in Rotterdam (PEMA, 2016). Since then, the use of automation in the maritime industry and, more precisely, within the port container terminals has been slowly growing as a result of many advantages following automation. The benefits include, among others, lower operational costs, lower risks of container damage, lower emissions and higher safety levels. Terminals in Medway Ports in the United Kingdom, Port of Hong Kong, Port of Hamburg, Port of Los Angeles and many other port facilities started with automation adoption due to its many advantages. Nowadays, the world’s most automated terminal is located in Yangshan port, Shanghai. With an initial investment of 2.15 billion USD and the ability to handle 6.3 million TEUs, the terminal expands over 2.23 million square meters, including 7 berths in total, 80 automated guided vehicles, 88 automated stacking cranes, 16 container-handling gantry cranes with 16 operators working from a remote location (Doe, 2017; Ying, 2018; Hapag-Lloyd, 2019). Even though, in the past few years an increase in adoption of automation has become present, it is still not fully adopted. 97% of port container terminals are not yet automated (UNCTAD, 2018) and based on Figure 2.1, only 2% are semi-automated, thus resulting in only 1% of fully-automated terminals (Drewry Maritime Research, 2018; Port Technology, 2018a).

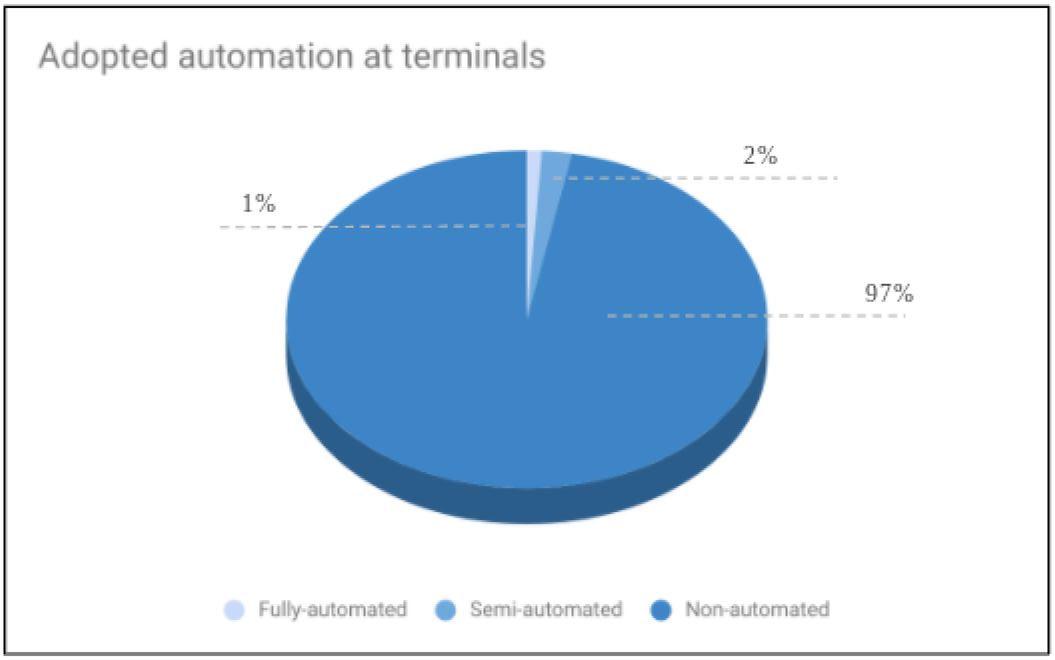

Figure 2.1. Proportion of automated container terminals (worldwide by number of terminals).
Adapted source: Port Technology (2018a).

Transhipment ports are as well included within the above stated percentage of automated container terminals. Since the transhipment market is increasing (see Figure 2.2), terminals focused on transhipment cargo need to optimize their yard operations due to land scarcity and increasing labour costs which are presenting bottlenecks for terminals (Zhou et al., 2016). One of the best methods in approaching these challenges might lie in the adoption of automation within terminals.

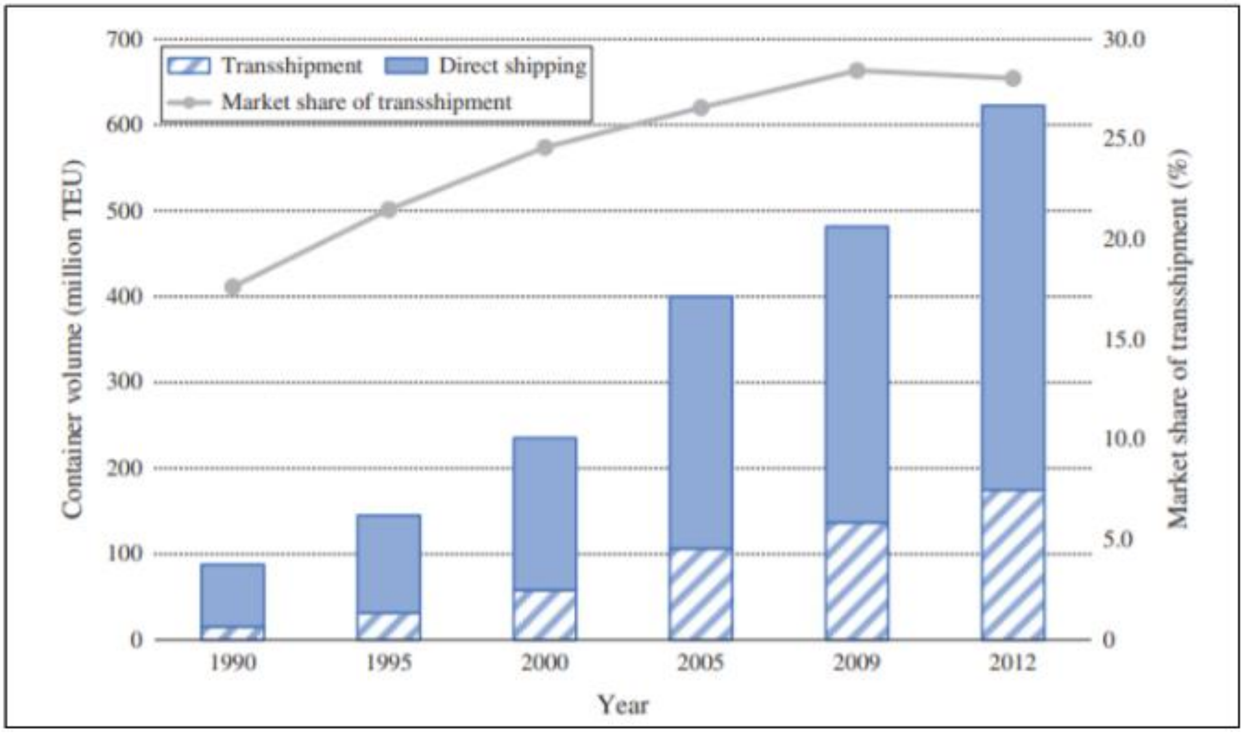

Figure 2.2. Global container trade and market share of transhipment.

Source: Zhou et al., (2016)

The reason behind the acceptance of automation within port container terminals is argued by Martín-Soberón et al. (2014). Based on the authors, there are different characteristics which allow automation:

1. the standardised mean of transport - containers;
2. the standardised freight handling method;
3. the high level of interchanges taking place;
4. the strong technological effect on the cost-effectiveness of terminals.

In addition, Rodrigue et al. (2016) stated that automation in takes place when:

1. a terminal is facing difficulties in expanding, for example due to lack of land;
2. a terminal has a role of a major transhipment hub;
3. a new terminal is developed with the latest automation technology.

Based on it, the first two arguments can be considered more within already operating terminals - as brownfield investments - while the third argument can be considered only for newly built terminals – known as greenfield investment. Although automation in the first two cases might lead to an increase in throughput, it is important that the implementation of automation does not lead to lower levels of operational performance and efficiency (Martín-Soberón et al., 2014).

Even though the greater part of automated container terminals serve gateway ports (Zhou et al., 2016), transhipment terminals could benefit from the automation as well. Within transhipment terminals, among other improvements, the yard needs to be better utilized due to a large number of container interchanges and potential reshuffling due to a lack of space or possibility of expansion. In addition, the productivity of handling large vessels might be influenced by automation. Automation could be a solution which would lead to better performance of transhipment ports. Following, the next sub-chapter is focused on automation within transhipment terminals and the reason behind the implementation of it.

Automated transhipment container terminals

Rodrigue et al. (2016) discussed that one of the arguments for automation is when a terminal has a role of a major transhipment hub. Transhipment hubs are characterised by high transhipment incidence "which is the share of the total port throughput that is "ship to ship" compared with the total throughput that includes hinterland traffic as well" (Rodrigue, 2015).

Automation in transhipment ports and in transhipment container terminals (TCTs) has the same characteristics of automation in PCTs. It can take place vertically or horizontally based on the needs of the terminal. Transhipment ports should have the ability of accepting larger vessels, since they are situated at geographically important locations (Rodrigue, 2015).

Based on Ducruet & Notteboom (2012), the observation on world container traffic and world port throughput shows that a container is loaded or unloaded 3.5 times between the initial port of departure and the last port of arrival. Thus, it suggests the importance of transhipment operations and the impact of vessel enlargements when it comes to the growth of container volumes (Kavirathna et al., 2018).

Due to the increase in trade volumes, there is a need for larger container vessels which in turn puts more pressure on ports (McLellan, 2006). It is up to ports and container terminals to be able to handle larger vessels in order to be more competitive.

As a result of economies of scale, larger vessels can benefit from lower costs per unit hence why

the constant increase in vessel size (Cullinane & Khanna, 2000). Vessel size is measured by the capacity which a vessel can carry. The most interesting for this analysis are: E "Emma" Class with 12 500 TEUs, "Triple E" Class with 18 000 TEUs, and more than 18 000 TEUs which characterise mega-ships or ultra large container vessels (ULCV) (Rodrigue, 2020).
At the moment the largest vessel is MSC Gülsün with the carrying capacity of 23,756 TEU (The Maritime Executive, 2019). Other examples of ultra large container vessels include OOCL Hong Kong with the capacity of 21,413 TEUs, COSCO Shipping Universe with 21,237 TEU, CMA CGM Antoine De Saint Exupery with 20,594 TEUs, and many others (MI News Network, 2019).

The impact of ULCV has been examined in the study by Meng et al. (2017) and it concluded that this type of vessel will have a major impact on the terminals in the future. In the study the authors argued that the increased throughput, due to ship size, can be accommodated only by the physical expansion of the terminals by building longer continuous berths. However, automated container terminals which opened after 2015 have a length of berth more than 1000 m (Park & Suh, 2019). In addition, as explained in the study from Park & Suh (2019) quay cranes in the automated container terminal Jebel Ali, Port of Dubai, have the outreach of 80 m which is very useful when handling ULCV. Thus, investing in automation and the accompanying equipment for a container terminal will lead to successful handling of ULCV and to an increase in the performance of terminal operations.

In Table 2.1 only part of the current automated and semi-automated transhipment container terminals around the world are presented. The selection is partially predetermined by the list of Port Technology (2018a). Additionally, it includes some of the different equipment used within the terminals and which might be used in other transhipment terminals, based on the needs of the terminals. Table 2.1 is for representation purposes only and it is not aimed to portrait all existing transhipment ports with implemented automation.

Table 2.1. Transhipment terminals and automation implementation examples.

Container terminal/port	Location	Level of automation	Innovations
PSA Singapore terminal - Tanjong Pagar - Keppel - Brani - Pasir Panjang (PPT)	Singapore	Fully-automated	At PPT 4, 5 and 6: 61 stacking cranes including 3 automated quay cranes (AQCs); 8 fully hybrid automated guided vehicles (AGVs); 22 fully battery operated automated guided vehicles; zero-emission, fully-automated electric crane system; terminal operating system (TOS).
-Five Continents International Container Terminal (FICT)	Tianjin	Semi-automated	31 automated rail mounted stacking cranes (ARMGs) operated by the N4 TOS
APM Terminals MedPort Tangier	Tanger Med	Semi-automated	ARMGs; Shuttle carriers; Automated gate lanes
Total Terminals International (TTI) Algeciras	Algeciras	Semi-automated	Automated Stacking Cranes (ASCs); Shuttle carriers; Differential Global Positioning System (DGPS)
Manzanillo International Terminals	Manzanillo	Semi-automated	24 RTG cranes Including 6 ASCs; Tidework’s TOS; Chassis anti-lift system
Xiamen Ocean Gate Container Terminal	Xiamen	Fully-automated	ARMGs; AGVs; TOS; 5G wireless network; Pollution free and zero-emission green terminal; Laser scanning and positioning; Laser collision avoidance; Lithium batteries

Evergreen Marine Terminal	Kaohsiung	Semi-automated	Cantilever automated rail mounted gantry cranes; CATOS[2]

Source: Data for Singapore retrieved from PSA Singapore (n.d.), MACGREGOR 2018, Louppova (2018), and The Maritime Executive (2018); for Tianjin from Navis (2019); for Tanger Med from APM Terminals (n.d. a); for Algeciras from TTI (n.d.); for Barcelona from Hutchison Ports BEST (n.d. a); for Manzanillo from MIT (n.d.) and RefrigeratedTransporter (2015); for Xiamen from MACGREGOR (2018), YiCai (2019), Cosco Shipping (2017) and Miaomiao (2019); for Kaohsiung from PEMA (2016).

Although not all transhipment ports have been included in Table 2.1, the number of automated or semi-automated TCTs is not large since only 3% of all worldwide PCTs have a certain degree of automation implemented (Drewry Maritime Research, 2018, Port Technology, 2018a).

However, among others, transhipment ports such as Port Said East and Port of Valencia are as well considering terminal automation. For example, ‘Egypt Vision 2030’ is an enormous plan made to improve the economy of Egypt (Schwerdtfeger, 2019). Part of these plans includes the automation of the terminals since more than 95% of cargo is transhipment cargo. In addition, in Europe, Port of Valencia is considering building a new, semi-automated terminal which will be focused on transhipment volumes, with the plan of becoming a competitive transhipment hub in Europe (Port Technology, 2018b).

It is noticeable that automation is becoming a new trend in the maritime industry with ports and countries becoming more interested in this type of investment. Nonetheless, the concept of automation is far-reaching and the decision makers need to be aware of different levels of automation and equipment which would best fit the terminal. Thus, in the subsequent section, particular levels of automation are described. In addition, an overview on the various equipment implemented in port container terminals, is given.

[2] Computer Automated Terminal Operation System

Levels of automation and equipment in automated container terminals

The process at container terminals (see Figure 2.3) consists of different steps. Once a vessel arrives at the port the containers for import need to be unloaded and the ones for export need to be loaded. This process is executed by quay cranes. After the import container has been unloaded it is transported to the stack with different types of vehicles such as straddle carriers (SCs), shuttle carriers (ShCs), automated guided vehicles (AGVs) based on the level of automation. A vehicle or crane transports a container to an adequate location in the stack. From the stack the container can be transported to other intermodal transportation modes for example trains, trucks, barges or other deep sea ships (Vis & de Koster, 2003).

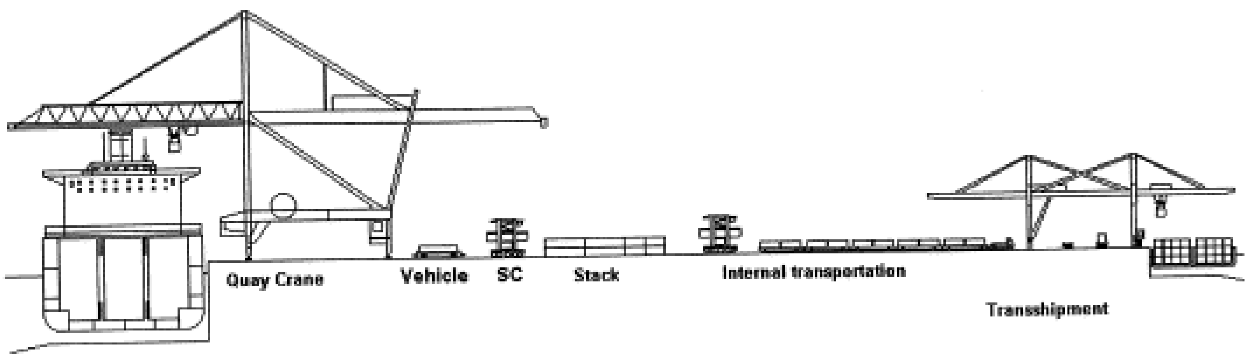

Figure 2.3. Process at the container terminal.

Source: Vis & de Koster, (2003).

Since containers are used as a standard unit of transportation, the process is quite standardised and there are standard procedures in the freight handling movement. Because of it, it is possible to introduce automation in several parts of the operations on terminals. Therefore, automation can take place horizontally and/or vertically within the terminal.

Horizontal transport consists of the landside transport and waterside transport (PEMA, 2016). According to the Port Equipment Manufacturers Association (2016) landside transport consists of repositioning the containers from the truck gate at the terminal up to the automated stacking cranes and vice versa. In this case, equipment such as Automated Rail Mounted Gantry Cranes (ARMG) and side-loading Cantilever Automated Rail Mounted Stacking Cranes (CARMG) are used. Based on the article from Bryfors (n.d.) CARMG have the ability of handling wider blocks and thus increasing the storage capacity up to 20% more compared to yards using other types of equipment, such as rubber-tired gantry cranes (RTGs). RTGs are limited in size and in lifting capacities when compared with rail-mounted gantry cranes (RMGs), but they have the ability of moving freely within the yard (Libbey, 2019). The main difference between the ARMG and CARMG lies in the yard separation. External trucks drive up to the landside part of the ARMG stacks. On the contrary, with side-loading, external trucks drive under the cantilevers of the CARMG and there is no possibility of separating them from the waterside/container yard (PEMA, 2016).

On the other hand the waterside transport consists of the repositioning of the containers from the quay cranes to ASCs and conversely. The equipment used on the waterside consists of different types such as Inter Terminal Vehicles (ITVs), automated guided vehicles or automated straddle-type vehicles which are able to lift and reposition containers from the ground. In addition the use of straddle carriers and shuttle carriers is common on the waterside. The main difference between the two is that shuttle carriers do not stack containers but only move them from the quay cranes and automated stacking cranes.

In Figure 2.4 the process at the container terminal is presented in detail with the representation of the possible types of automation and the use of automated equipment.

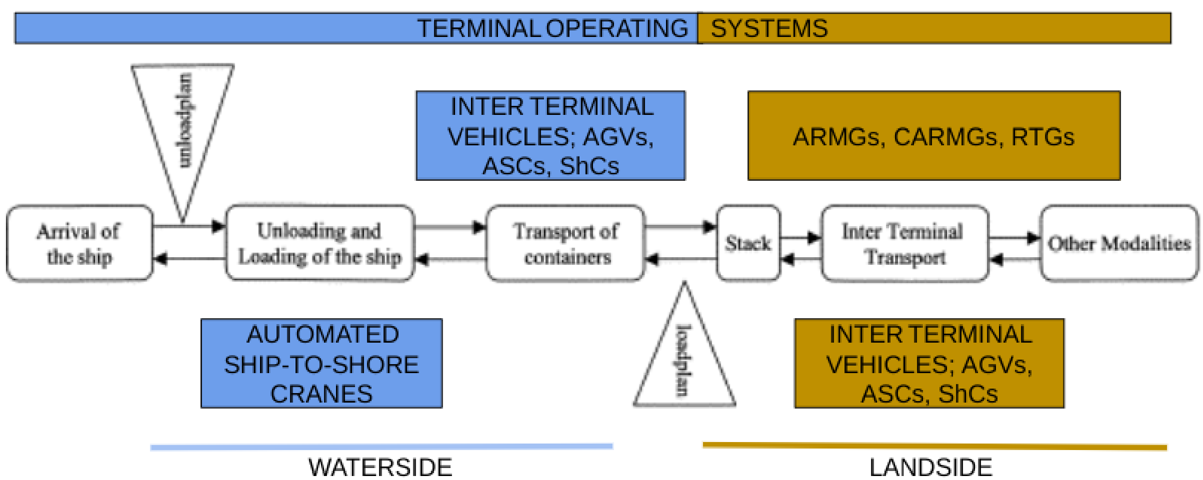

Figure 2.4. Process at the container terminal and the implementation of automation.

Adapted source: Vis & de Koster (2003), PEMA (2016), Martín-Soberónet al. (2014).

Figure 2.4 is split in two parts, the waterside and landside. The terminal operating systems (TOS) can extend all over the terminal, coordinating the movements of all the automated equipment, avoiding collisions, routings, et cetera (Saanen, 2004). Every TOS is particular and there is no standardized software since each terminal has different characteristics and goals.

Consequently, different automated equipment is being used within different port container terminals and automation can be adopted at different rates which are described in the coming part.

Automation adoption

Based on the level of automation, port container terminals can be non-automated, semi-automated or fully-automated. When terminals are non-automated all movements and operations are done manually, by workers at the terminal and no automated equipment is used. On the other hand, in a fully-automated terminal all the equipment is unmanned and fully automated. Acciaro & Serra (2014) argued that in a fully automated terminal, automated guided vehicles or automated lifting vehicles (ALVs) are used for the horizontal transport and automated stacking cranes are used for piling containers in the yard. In addition, Martín-Soberón et al. (2014) presented full automation in PCTs as the automation of yard movements and dock-yard exchanges, while crane-ship operations are still controlled manually. Contrary, semi-automated terminals focus only on the automation of stacking operations or the vertical transportation on the terminal (Acciaro & Serra, 2014).

Chu et al. (2018) stipulated that automation within port container terminals can be present in different forms, some particularly interesting include:

1. the automation of equipment and robotisation such as automated guided vehicles, automatic stacking cranes and other;
2. the automation of equipment-controlling systems including sensors, special software, and camera technologies.

Moreover, SHM Shipcare (2018) provided another classification of automation: automation at gates, ship-to-shore cranes, and stacks and inventory.

Automation at gates is seen necessary in order to speed up the entry or exit at port gates. Because of an increase in trade volumes the incoming and outgoing number of containers has accordingly increased leading to potential higher waiting times at gates. Thus, automating the entry and exit with, for example, special radio-frequency identification (RFID) cards and sensors to identify them can speed up the process in order to avoid waiting costs or other possible costs.

Ship-to shore cranes have evolved with the help of technology in the past years. The automated stacking cranes are operated through computer software which is based on the data of the terminal such as the width or the length, the position of containers, and other information.

Finally, robotisation plays an important role for stacks and inventory.

No matter the level or form of automation, the adoption of automation within port container terminals is a time and capital intensive decision. Thus, an overview of advantages and disadvantages is discussed in the following chapter in order to represent possible reasons for acceptance or rejection of automation.

Advantages and challenges in automated container terminals

Automation can lead to an improvement in terminal productivity and capacity, a decrease in operational costs, an increase in safety of workers, and a decrease in the ecological footprint (Martín-Soberón et al., 2014; iContainers, 2018).

In the survey by Navis 53% of respondents found terminal automation as a way of increasing operational productivity (Port Strategy, 2018). In fact, 75% of PCT operators consider automation as a competitive edge in the next 3 to 5 years. In addition, Zhu et al. (2010) argued that new implemented technologies such as RMGCs can lead to an increase in the operations efficiency up to 50%. The reason behind the increase in operational productivity and efficiency can be explained by better quay utilization and yard density (Martín-Soberón et al., 2014). With the automated equipment and the TOS, planning, allocation and decision making is completed by algorithms (Saanen, 2014) which provide the best possible solutions, thus the resulting increase in quay utilization and yard density.

In case of transhipment terminals, land utilization is one of the important factors when considering automation (Zhou, 2016). Hence, container terminals which handle greater volumes of transhipment cargo have to secure high productivity levels in order to provide an acceptable service standard. A decrease in the turnaround time of a vessel can be provided by better yard utilization and allocation of stored containers with the help of technology. In order to do so, different studies have looked into possible solutions (see Henesey, et al., 2007; Jiang et al., 2012; Zhou et al., 2016) which would lead to higher overall terminal productivity.

However, one of the main bottlenecks of automation is the cost of it. In fact, the TOS is not an off-the-shelf product. The software needs to be designed specifically based on the terminal's characteristics. The implementation costs of automation in PCTs range from USD 500 million to USD 1 billion and in order for the investment to pay off, terminals should be handling approximately 1 million TEUs per year (Michigan State University, 2019). In addition, the time of implementation is another negative factor. It takes between 3000 and 5000 tests before finalizing the whole process (Chu et al., 2018) which can take up to several months and years.

But, on a long term scale, operational costs (such as labour costs and costs per handling unit) and maintenance costs decrease (Alho et al., 2015) both in transhipment and non-transhipment focused terminals. As advised by Keskinen et al. (2017) maintenance costs can result in savings of up to EUR 9 million over a 10-year service. In addition, Qingdao New Qianwan container terminal in the Port of Qingdao, has seen the return on investment quite fast. Only 10 months after the project was implemented, there was an increase from 26.1 containers handled per crane to 33.1, which shows a result higher than the global average (iContainers, 2018). As reported by Zhanh Liangang, the General Manager of QQCTN, labour costs have been reduced by 70% because of the implemented automation along with the increase of 30% due to the possibility of working overnight.

Nonetheless, the reduction in labour costs comes at a certain price. From a social perspective, automation leads to a decrease in employment since workers are replaced by robots. A study by Gekara & Nguyen (2018) stated that since 2014, before Patrick's Sydney terminal has been automated, the number of employees amounted to 436. While after the implementation of automation, the total number of workers was 213. This decrease of 51% causes a threat to society.

On the other hand, new technologies also provide new jobs and transform current jobs. There is a greater requirement of digital skills since technology is taking over the terminal, thus a change in workforce skills is present. For example, a crane operator is not physically on the crane but in a remote office, in a safer location, controlling the movements of the crane with particular programs.

The safety of workers has increased with the introduction of automation on terminals. Since there is no need to be physically on the terminal and operate with different machineries, injuries on the terminal are theoretically impossible. For example, stacking cranes have a very low performance because of recurrent workers' injuries and traffic collisions (Yang, 2017). With automated equipment collisions are minimized because every movement is directed, all vehicles are controlled, and the overall moves of the equipment are synchronized (Kim et al., 2004). The same reasoning applies to transhipment terminals where the safety of workers is increased with the introduction of automation, especially because transhipment containers are generating more handling activities (Zhou et al., 2016).

Additionally, different studies have highlighted the importance of automated and semi-automated use of equipment with respect to the environment. Clarke (2006) argued that the use of such equipment can lower greenhouse emissions, prevent and mitigate damages of containers, and reduce noise pollution. Yang (2017) argued that the use of different equipment, such as automatic rail transtainer, and electric tire transtainer, can increase working efficiency, energy savings, and contribute to CO2 reductions. Thus, it can be concluded that automation of terminals and equipment at terminals have a positive impact on the environment and the environmental footprint.

The increased adoption of automation within port container terminals hints an overall positive outlook on automation and its acceptance on a global scale. So far most research has been focused on different equipment in automated port container terminals and on the best utilization of the equipment within the terminals (see Rebollo et al., 2001; Yang, 2004; Henesey et al., 2007; Gharehgozli et al., 2017). However, the focus of this study is on the implemented automation particularly in transhipment ports, and its influence on the overall performance. Since the impact of automation in transhipment ports has not been studied on a larger scale, it is interesting to investigate if and how the adoption of automation is affecting ports and terminals focused on transhipment cargo. The main driver towards the selection of transhipment ports is the large number of container movements within the yard. This might be the perfect setting for automated processes in order to reduce the number of unnecessary movements.

A more intensive look into the different effects on port performance is provided in the following sections in order to qualitatively and quantitatively answer the raised questions in this paper.

Methodology

In the following sub-chapters, quantitative and qualitative analysis is described in order to examine the impact of automation and other variables on the performance of container ports. Based on the results it will be possible to answer the following questions.

1. What is the impact of automation on the performance of transhipment ports?
2. Which determinants impact port performance?
3. Does the use of automation on terminals reduce greenhouse emissions?

The quantitative analysis is performed with the use of multiple linear regressions. As indicated by Schmidheiny (2019), multiple linear regression models are based on ordinary least squares (OLS). This method allows estimating the relationship among a dependent variable and several independent variables. In addition, it helps quantify the impacts of different determinants on the dependent variable. With it the first two questions of this work will be answered. In addition, the use of this method will facilitate the analysis on greenhouse emission and the impact automation has on it, which answers question three of the paper.

The part of qualitative analysis will present the case studies which set the scene for the comparison of automation in four different ports in the Mediterranean region. In addition, port productivity will be examined in order to investigate the effect of it on port performance. Thus, this analysis will focus mostly on the first and second question of this paper.

Since two analyses are used in the research, methodology consists of two parts. The quantitative analysis is presented in Chapter 3, Sub-chapter 1; while the qualitative analysis is presented in Chapter 3, Sub-chapter 2. The use of both quantitative and qualitative methods will provide a wider perspective on the topics of this work.

Quantitative analysis

To be able to perform the quantitative analysis, different hypotheses are drawn from the literature review and will be tested through the next sections.

Hypothesis selection

H_1: The implementation of automation has a positive influence on port performance.

H_2: The implementation of automations has a positive influence on terminal productivity.

H_3: The implementation of automation has a negative influence on operational and maintenance costs.

H_4: The implementation of automation has a positive influence on the safety of workers.

H_5: The implementation of automation has a negative influence on greenhouse emissions.

H_6: The economy has a positive influence on port performance.

H_7: Employment has a positive influence on port performance.

H_8: Location has a positive influence on port performance

Data and variable selection

Data from four different ports is tested in this research during the period of 10 years. The necessary data was retrieved from Eurostat, port authority pages, and official statements from port authority. The selection of ports was based on the geographical position, implemented automation and transhipment specialization. Since the Mediterranean region has an increased number of transhipment focused ports in Europe (Notteboom et al., 2019), ports from Spain and Italy were selected. The most important ports are Algeciras, Valencia, Barcelona, and Gioia Tauro and their respective characteristics of selection are presented in Table 3.1.

Table 3.1. Selected ports in the Mediterranean region.

Port	Region	Country	Implemented automation	Transhipment cargo
Algeciras	Andalusia	Spain	Yes	Yes
Valencia	Valencia	Spain	No	Yes
Barcelona	Catalonia	Spain	Yes	Yes
Gioia Tauro	Calabria	Italy	No	Yes

Source: Created by the author.

In order to test the above presented hypotheses several variables will be used in the multiple regression analysis. Since the focus of this work is on container terminals the determinant of container throughput will be used to present port performance. The unit of measure for port performance will be represented through the throughput volume of containers expressed in twenty-foot equivalent units (TEUs) per year.

Automation of container terminals will be measured by a dummy variable where automated terminals are equal to one (1) and non-automated terminals are equal to zero (0).

Since most of the data depends on the transparency of terminal operators, some data is not available for this research. Terminal productivity can be measured by the number of crane movements per hour, however due to high inter-terminal competition data is partially available for the public. Thus, although the impact of automation on terminal productivity is assumed to be influential, it cannot be tested in this setting. However, in the qualitative research it will be examined.

Operational costs might be measured by the salaries of workers at the terminal per year; however this information is not attainable. Maintenance costs might be measured by the incurred maintenance costs per year, yet this information as well is not available. Safety of workers could be measured either by the number of sick leaves incurred due to an accident at the terminal or by the number of terminal accidents in which workers were involved. Nonetheless, those data are not shared by the terminals. The economy will be measured by the national GDP in purchasing power standards (PPS) per inhabitant and by the regional GDP in PPS per inhabitant. In addition, employment will be represented both on a national and regional level in 1000 persons per year. Finally, location will not be implemented in the model since it is quite challenging to quantify in and it goes beyond the scope of this paper. On the other hand, greenhouse emissions can be measured with the level of carbon dioxide emissions and nitrous oxide emissions in tons per year; however this data does not represent the emissions by the terminals. Thus, the use of carbon dioxide and nitrous oxide emissions on a regional level will be used as a proxy further in the analysis. The use of a proxy will enable a partial representation of port emissions in the context of this research.

Method of analysis

In order to research the impact of automation on port performance, and the different factors impacting port performance and greenhouse emissions, four different ports are analysed during a period of ten years. Thus, the analysis is a cross-sectional time series analysis known also as panel data analysis. The dataset contains in total 40 observations since 4 ports are observed during 10 years (2008-2017). It can be observed that the data set is strongly balanced.

In order to analyse the effects of different independent variables on the dependent variable, multiple linear regression analysis is selected as a method. Since both port productivity and greenhouse emissions will be analysed and considered as dependent variables, three regression functions are needed. The functions are presented below (Jobson, 1991).

(1) $THROUGHPUT_{it} = \beta_1 + \beta_2 * N\_GDP_{it} + \beta_3 * R\_GDP_{it} + \beta_4 * N\_EMPLOYMENT_{it} + \beta_5 * R\_EMPLOYMENT_{it} + \beta_6 * AUTOMATION_{it} + e_{it}$ *(Eq. 1)*

(2) $NOx\_EMISSIONS_{it} = \beta_1 + \beta_2 * THROUGHPUT_{it} + \beta_3 * AUTOMATION_{it} + e_{it}$ *(Eq. 2)*

(3) $CO2\_EMISSIONS_{it} = \beta_1 + \beta_2 * THROUGHPUT_{it} + \beta_3 * AUTOMATION_{it} + e_{it}$ *(Eq. 3)*

Following:

THROUGHPUT = container throughput per year in TEU

N_GDP = the national GDP in PPS per inhabitant

R_GDP = the regional GDP in PPS per inhabitant

N_EMPLOYMENT = the national employment levels per year in 1000 persons

R_EMPLOYMENT = the regional employment levels per year in 1000 persons

AUTOMATION = a dummy variable, where the variable _AUTOMATION1 represents no implemented automation and _AUTOMATION2 represents implemented automation within terminals

NOx_EMISSIONS = nitrous oxide emissions, resulted by transportation and storage, in tons per year, used as a proxy variable

CO2_EMISSIONS = carbon dioxide emissions, resulted by transportation and storage, in tons per year, used as a proxy variable.

The subscript i represents the observed individual - in this case a port, while the subscript t represents a particular point in time - in this case year. Additionally β_1 indicates the intercept, β_2

until β_6 shows the slope coefficients of the independent variables. Finally, e_{it} indicates the error term.

Equation 1 relates to port productivity as a dependent variable, while Equation 2 and Equation 3 represent greenhouse emissions expressed as nitrous oxide and carbon dioxide emissions.

The analysis will focus on the estimates and significance of different parameters. If variables appear to be insignificant and if there is a conclusive reason for them to be omitted, elimination will follow and a new model without those variables will be predicted. Once the model is completed, an analysis of the predicted parameters will be reviewed. In addition, the R^2 will be discussed since it represents the variance of the outcome variable examined by the model. However, because of some data unavailability, the estimates and the R^2 could be affected if more variables would have been included. Thus, the model must be carefully explained.

To be able to understand the possible results and impacts of the quantitative analysis, the qualitative analysis consisting of four analysed ports is considered in the next chapter. Thus, it will be used to complement the quantitative analysis.

Qualitative analysis

In this section, a qualitative analysis on the selected ports will be presented. The information obtained from the following paragraphs will complement the quantitative analysis and will mostly aid in answering the research question "which determinants impact port performance?".

Method of analysis

The first part of the analysis aims to represent port and terminal productivity and its impact on port performance based on partially available data. In total, three indicators will be used to represent productivity.

The second part focuses on case studies of the four selected ports where the port's structure and main characteristics, the level of implemented automation at terminals, and port productivity are described. With this analysis four case studies will be presented. With the use of this qualitative analysis the research will show another perspective, which the quantitative analysis cannot fully examine.

Port productivity Based on Mooney (2017) and Arvis et al. (2018), the first indicator for productivity on the terminal level is berth productivity based on the ability of handling large vessels, and is presented in *Appendix C*. Thus, with an increase in vessel size, berth productivity increases since it is possible to employ multiple cranes during the handling process (JOC Group, 2013).

The second indicator is the crane movements per hour based on the vessel capacity; it is used only in cases when information on the movements is publicly available (Tongzon, 1994; Mooney, 2017; Geerlings et al., 2018). When vessels have high capacities the movements per crane are lower when compared with vessels of smaller capacities (see *Appendix D*). This indicator as well represents the productivity level of a terminal. The third indicator is the *combination* indicator of the two aforementioned determinants of productivity and it represents the overall port productivity level (*Appendix E*).

It is assumed; when port productivity is high port performance might experience significant positive effects. On the other hand, when port productivity is low it might have a significant negative effect on port performance. However, when port productivity is on an average level, the effect on port performance can be considered as unbiased (*see Appendix F*).

Case study. The next paragraphs will focus on the Port of Algeciras, the Port of Valencia, the Port of Barcelona and the Port of Gioia Tauro. Each of them will be considered separately, showing the port's structure, level of automation, and productivity levels.

Port of Algeciras. Port of Algeciras is located in the region of Andalusia at the south of Spain. It is the largest port in Spain and one of the major ports in Europe and worldwide. Its position on the Strait of Gibraltar gives the port a great competitive advantage in the transhipment sector (Rodrigue, 2015). In 2013 it surpassed the port of Valencia (Yellow & Finch, n.d.) and today it is considered the 33rd busiest port in the world (Lloyd's List, 2019a).
The port is considered to handle relay transhipment (Hughes, 2019), also known as deep-vessel to deep-vessel transhipment or mother-to-mother vessel transhipment. Thus, the terminals are able to handle ships with large TEU capacity. With the possibility of handling large capacities, berth productivity also rises. As argued by Arvis et al. (2018) productivity increases with throughput levels, ship size and call-size since more cranes are able to handle larger vessels, thus leading to better efficiency of operations. In 2015, the Port of Algeciras was rewarded by The Journal of Commerce Review with the award for being the 3rd most productive container port in Europe (ESPO, 2016). The main reason for the success in productivity is explained by handling megaships or ULCV. In addition, as informed by Mr. Landuce, in the article by Hughes (2019), another factor impacting growth and productivity is the connectivity of the Port. Additionally, three megaships can be handled at the same time due to the capacity of the Port of Algeciras (Fernandez, 2019). Thus, terminals are successfully handling vessels such as MSC Gülsün and MSC Mina which have the capacity of more than 23 756 TEUs. The two terminals handling containerised cargo in Algeciras are Total Terminals International (TTI) and APM Terminals Algeciras and are portrayed in the next paragraphs.

TTI Algeciras. TTI is one of the first terminals which introduced semi-automation in 2010, making it the first Spanish and Mediterranean port which invested in this type of innovation (Hughes, 2019). Nowadays, TTI has implemented different types of automation.

The terminal is equipped with shuttle carriers which are used to carry containers on the waterside up to the stack. The use of ShC allows the automatic traceability through real-time locating services including Differential Global Positioning System (DGPS) technology (TTI Algeciras, n.d.; Kim, 2016). DGPS is used for surface positioning (Bai & Bai, 2019) and it allows a decrease in the margin for error to less than 1 metre since it is utilizing the established locations of reference stations in the yard (Kim, 2016). The use of DGPS informs the terminal's operating system of the correct position of a container which facilitates the operations at terminals. Automatic stacking cranes are also one of the innovations at TTI. The use of ASC allows autonomous stacking guided by the terminal operating system. In addition, ASC are supplemented with Crane Information Management System (CIMS), Load Control System (LCS) and Target Positioning System (TPS) (TTI Algeciras, n.d.). All of it allows TTI to have fully automated yard operations. Finally, the use of ship-to-shore cranes allow operations on the waterside to be semi-automated since the cranes are complemented by automated and advanced checking container systems - Optical Character Recognition (OCR) and damage inspection.

All of the aforementioned innovations lead to the possibility of operating mega-ships at TTI terminal. In 2015, two mega-vessels were handled at the same time at TTI Algeciras, Triple E Marit Maersk and CMA CGM Marco Polo. Both vessels have the capacity of more than 16 000 TEUs (Ship Technology, n.d.; Marine Traffic, n.d. a). In addition, in 2018 at TTI Algeciras, 2 500 containers were handled from CMA CGM Antoine de Saint-Exupery, with 20 600 TEUs capacity (Utor, 2018). Since berth productivity might improve with ship size it can be deduced that TTI Algeciras is highly productive because handling mega-ships is possible. In addition, it is proven to be possible to even handle two mega-ships at the same time, meaning multiple cranes are used at the same time on one vessel leading to higher productivity levels.

APM Terminals Algeciras. APM Terminals Algeciras is considered as one of the largest terminals in the Western Mediterranean.

However, this terminal does not have complete automation implemented on the quay or yard side, but it still has the equipment necessary to handle ULCV. The equipment at the terminals consists roughly of 19 ship-to-shore cranes, 56 rubber-tyred gantry cranes (RTGs), complemented by different innovations (APM Terminals, n.d. b). Active Load Control technology is used by RTGs in order to provide an accurate position for pick-and-place and to eliminate container sway (Konecranes, 2013). In addition, RTGs are also equipped with DGPS autosteering, stuck collision prevention system and TRUCONNECT® (APM Terminals, n.d. b). DGPS autosteeting provides better accuracy and minimizes excess deviation (Konecranes, 2009). a stuck collision prevention system is used in order to prevent any crashes among containers in the stack below the RTG. The avoidance is possible due to the use of laser scanners (Orbita, 2020). With TRUCONNECT® system it is possible to collect and analyse the data from the RTGs for the prediction of maintenance and prevention of possible equipment failures (Konecranes, 2020).

Even though APM Terminals Algeciras is not relying on automation, it still achieves great results in terms of productivity. The first mega-ship The Triple-E Class Maersk McKinney Moller, with a total capacity of 18 270 TEUs, was handled at APM Algeciras back in 2012 (APBA, 2019; Marine Traffic, 2020). Since the terminal has the capacity of handling ULCV it was able to handle MSC Gülsün in 2019 with a capacity of over 23 000 TEUs (Fernandez, 2019). Thus, as TTI Algeciras, APM Terminals Algeciras can be considered as highly productive when the handling of mega-ships is considered.

To conclude, at the present moment, the Port of Algeciras and its terminals can be considered as having high productivity levels based on the *combination* indicator (*see Appendix G*) thus the effect on port performance might be considered significant and positive.

Port of Valencia. The port of Valencia is positioned in the Community of Valencia in the south east of Spain. It is the second largest port in Spain, at times overtaking the port of Algeciras in certain prospects (Larsson, 2019). The port area itself creates 50% of Spain's GDP and employs 50% of Spain's working population (POC, 2019). Although the terminals do not have any automation implemented, their performance is quite high. In 2018, cargo volumes in the Port of Valencia were at a high 76 million tonnes, while the Port of Algeciras was at 107 million tonnes (Statista, 2019). As stated by Mr. Palaci, in the article by Hughes (2019), the Port of Valencia has seen increased growth mostly due to the shipping companies which are starting to focus their activities in Valencia. Thus, major shipping companies, including Maersk Line, Mediterranean Shipping Company (MSC), and Cosco, have a presence at the terminals in Valencia. It can be deducted that in the case of Valencia, berth productivity can also be seen through the possibility of handling ULCV. Three container terminals are present in the port of Valencia. Cosco Shipping Ports (CSP) Iberian Valencia Terminal, APM Terminals Valencia, and MSC Terminal Valencia are providing the necessary operations for container handling. In 2014, the port of Valencia handled Eleonora Maersk, part of Maersk E-class with the capacity of 15 500 TEUs (Veintepies, 2014). In 2018, MSC Eloane with 19 472 TEUs was handled at the Port of Valencia thus increasing productivity levels (PortSEurope, 2018). However, many larger vessels might be calling Valencia thus leading to an increase in berth productivity and port productivity levels. That is because the Port Authority plans on investing 30 million euros in order to increase the draft in the docks of APM terminals Valencia, CSP Valencia and MSC Valencia (Larsson, 2019).

CSP Iberian Valencia Terminal. Following the acquisition of the terminal in June 2017, Noatum Ports SLU was denominated as CSP Iberian Valencia in April 2019 (Spanish Ports, 2019).

The terminal extends over a total of 145 hectares and has 2310 meters of berthing line with a draft of 15.5 meters. In addition, 20 ship-to-shore cranes, 55 RTGs, 105 yard tractors are present at the terminal. The innovations present at the terminal are the terminal gates with OCR and the automatic location & tracking system which is integrated with the crane management system. In addition the operation system of the terminal is a computer automated terminal operation system which enables real time web services and is integrated in the communication system of Valencia Port Community (Valencia Port, n.d. a). In 2014, the terminal handled a 15 500 TEUs capacity vessel - Eleonora Maersk. In addition, in 2018 the terminal handled MSC Eloane with a capacity of 19 472 TEUs. Based on the possibility of using multiple cranes when handling large container vessels, with more than 15 000 TEUs, the terminal experienced an increase in berth productivity. Additionally, an increase in productivity might be possible in the future since the Port Authority plans on investing into the terminal in order to be able to handle ships with more than 22 000 TEUs (Larsson, 2019).

APM Terminals Valencia. The terminal where APM Terminals operates was established in 1999 with the merger of three stevedoring companies at the time.

As of 2016, APM Terminals has started dominating the area (APM Terminals, n.d. c). The terminal's area has 45 hectares and a very good rail connectivity, making it easier for the transportation of cargo into Spain and Europe. However, no automated equipment has been implemented yet. Twelve cranes are featured on the shore, enabling the handling of 1.6 million TEUs per year. In addition 30 RTGs, 26 forklifts and a dozen tractors are present in the yard (Valencia Port, n.d. b). One innovation present at the terminal is the automated global positioning system (GPS) which facilitates the location of the equipment (APM Terminals, n.d. c). Nowadays the terminal can handle vessels up to 18 000 TEUs (TBY, 2020) which might lead to high berth productivity levels. However, the investment in equipment and facility upgrading could potentially lead to higher productivity levels.

MSC Terminal Valencia. MSC Terminal Valencia extends over 33.7 hectares with 8 ship-to-shore cranes with the previous capacity of handling 18 000 TEUs. In addition, 25 transtainers, 53 terminal tractors, 7 reachstakers and 4 empty container handlers are participating in everyday operations.

Although no automation is implemented at the terminal, an increase in the capacity is possible due to an investment in re-designing the operating cranes. Nowadays, the cranes at MSC Terminal Valencia are able to handle ULCV and the total capacity of 20 000 TEUs. This has been achieved with the project executed by Kalmar where the booms have been prolonged on all cranes, while the height of six cranes have been extended (Kalmar, 2019), thus providing extra handling capacity to the terminal and the possibility of having average-high productivity.

However, since the terminal has not experienced any handling of large vessels it can be assumed that the berth productivity levels are on an average scale.

To summarise, at the present moment the port of Valencia and its terminals can be considered as having high productivity levels based on the *combination* indicator (*see Appendix H*), thus port performance might experience a significant positive effect.

Port of Barcelona. Located in Catalonia, the Port of Barcelona plays an important role within Spain's GDP. 18% of the total GDP is produced by the Port (Larsson, 2019). In 2019, based on the Lloyd's List, the port was ranked 48th mainly because of the 3 million TEUs throughputs achieved in 2018 (Lloyd's List, 2019b; Port de Barcelona, 2019). Barcelona is the third largest port in Spain, following the Port of Valencia. In 2018, the total cargo volume handled was 67 million tonnes (Statista, 2020), making it approximately 10 million less than Valencia.

Since not many particularly large vessels have been present in the Port of Barcelona, it is possible to examine port productivity through the lense of average moves per crane per hour based on some publicly available data. In 2014, the Port of Barcelona was rated among the head three European ports for productivity based on the number of moves per hour. In 2012, the Port had an average of 41 moves per hour, while in 2014 on average 78 moves per hour were registered (Offshore Energy, 2014). Thus, an increase in productivity is present. The reason behind it might be the focus on handling medium sized vessels up to 14 000 TEUs which have been proven to provide the optimal terminal productivity levels (Mooney, 2017). Hence, it can be assumed that berth productivity based on the handling of larger container vessels is approximately at the average in the case of the Port of Barcelona.

Nowadays, two terminals are operational: APM Terminals are operating on the APM Terminal Barcelona, and the second being the Hutchison Ports Barcelona Europe South Terminal (BEST).

APM Terminals Barcelona. The terminal expands over 81 hectare with a quay of 1515 meters on which 14 cranes are situated. The total handling capacity amounts to 2.3 million TEUs with the possibility of handling vessels of 16 000 TEUs capacity (APM Terminals, n.d. d). At the terminal, among other equipment, at least 29 straddle carriers are present, which along with the Super post-Panamax cranes have enabled one of the best productivity levels on the Mediterranean. The only automation processes implemented on the terminal are the automated gate procedure which uses the OCR technology in order to increase the efficiency at the gates (APM Terminals, n.d. e). In 2019, because of the new equipment, the terminal made a record of 135.46 crane moves per hour on the vessel Millau Bridge with a total capacity of 13 900 TEUs (Safety4Sea, 2019; Marine Traffic, n.d. c). When compared with the global average of 26.5 moves per hour on vessels up to 14 000 TEUs (Mooney, 2017), the increase of approximately 411% is mainly because of the investment in equipment at the terminal. Thus, it can be assumed that the terminal has high productivity levels when handling vessels up to 14 000 TEUs; however when handling larger vessels the productivity levels might be on an average degree.

Barcelona Europe South Terminal. BEST is the second container handling terminal in the Port of Barcelona.

It is the first semi-automated terminal by the Hutchison Group found on the area of 79 hectares with 27 automated blocks and with the capacity of 2.36 million TEU. The terminal has different innovations implemented. In total there are 11 Super post-Panamax cranes, 54 automated stacking cranes, 32 shuttle carriers and 2 RMGs operating at the terminal. In order to synchronize the automated equipment, the next Generation Terminal Management System (nGEN) operating system has been adopted (Hutchison Ports BEST, 2019). nGEN is a tool used to increase capacity, service and profitability by operating remote equipment and semi-automated terminals (Hutchison Ports Best, n.d. b). In addition to the already present equipment, new investments are planned for the terminal with the goal of increasing the total capacity and operating equipment on the terminal. In 2016, the terminal achieved one of its record on MSC Beatrice, with capacity of 13 798 TEUs, when 221.3 moves per hour were made (Hutchison Ports BEST, 2016; Vessel Tracking, n.d.). It also maintained an average of 40 moves per hour in terms of productivity (Wee, 2018). As in the case of APM Terminals Barcelona BEST productivity levels are high when handling vessels up to 14 000 TEUs. However, productivity might be on an average scale if larger vessels would be handled.

It can be concluded that based on the *combination* indicator shows productivity on a high average level (*see Appendix I*), meaning that port performance might experience an unbiased positive effect.

Port of Gioia Tauro. The Port of Gioia Tauro is located in the South of Italy in the region of Calabria. Its position close to the Strait of Gibraltar and on the strategic location between the East and the West trades, make a great location for a transhipment hub. However, on the Lloyd's List Gioia Tauro takes 79th place (Lloyd's List, 2019c). There are several reasons why the once biggest transhipment hub in Europe is on the lower level on the list. One of the possible explanations is the loss of Maersk in 2017 and the arising labour issues. Additionally, the throughput decrease can be explained by the increases in neighbouring Italian ports including Cagliari, Ravenna, and La Spezia but also by the increased competitiveness of other Mediterranean ports such as Tangier Med, Valencia, Algeciras, Port Said and others (Musso et al., 2013). When considering the possibility of handling large vessels as an indicator of berth productivity it can be assumed that the Port of Gioia Tauro has a high level of productivity. On the other hand, in terms of productivity by crane moves per hour, approximately 25 moves per hour are registered thus, leaving the Port at an average productivity level based on the global data (C&T Logistics, n.d.; Mooney, 2017). Based on the aforementioned it can be assumed that the *combination* indicator of the port shows productivity on a high average scale (*see Appendix J*). Thus, the productivity of the port has an unbiased-positive effect on port performance. However, a brighter future might be ahead for Gioia Tauro. In 2019, an 8% increase in throughput was detected, when compared with 2018. This might be strongly influenced by Mediterranean Shipping Company - MSC- which in July 2019 became the new terminal operator of MedCenter Container Terminal (PortSEurope, 2020).

Only one container terminal is operating at Gioia Tauro - MedCenter Container Terminal.

MedCenter Container Terminal. The total area of the terminal spreads over 160 hectares with the capacity of handling 4.2 million TEU per year (TIL, n.d.). The terminal is equipped with 3 post-Panamax cranes and 19 Super post-Panamax cranes, making it possible to handle ultra large container vessels. Additionally, it has a mobile crane, approximately 170 straddle carriers and different yard equipment (Autorita' Portuale del Porto di Gioia Tauro, n.d.; ITJ, 2019). No equipment at the terminal has any automation implemented; however this might change if the new terminal operator decides on implementing such innovations.

Berth productivity in terms of the ability of handling large vessels can be considered as high. In 2015, the terminal handled MSC London, at the time the largest container vessel carrying a maximum of 15 908 TEUs (Corriere della Calabria, 2015; Marine Traffic, n.d. d) . In 2016, the terminal handled MSC Ingy, at the time the largest container vessel by MSC, with the capacity of 19 462 TEUs (ANSA, 2016; Marine Traffic, n.d. e). Finally, in 2019 the terminal handled MSC Miriam, at the time the largest container vessel in the world, with 19 224 TEUs (Calabrò, 2019). Thus, it can be assumed that berth productivity based on the handling of large vessels is high. On the other hand, the last productivity data on productivity measured by moves per hour indicates an average of 25. Thus, it shows that the productivity levels are on an average level consistent with the global standard. Hence, based on the two indicators it is possible to assume that the terminal's productivity level is on an average-high level.

From the above presented information it is visible how different ports and terminals implement different equipment and innovations in their daily operations. In addition, the effect of productivity on port performance has been taken into consideration based on three indicators.

1. *Terminal productivity based on berth productivity;*
2. *Terminal productivity based on crane movements per hour per vessel capacity;*
3. *Productivity based on combination indicator by vessel capacity and crane movements per hour.*

However, it must be taken into account that the *combination* indicator is not completely accurate since some data on the second indicator aforementioned is missing. Additionally, the data retrieved does not represent the 10 year period from 2008 to 2017 but the latest data available.

Thus, the results of the qualitative analysis need to be explained with caution. In the following section the interpretation of the results will be provided.

Results

In this chapter the results of the quantitative and qualitative analysis will be presented and analysed. The focus will be on the main questions, based on the impacts on port performance, the role of automation, and the impacts on greenhouse emissions.

Model selection

In order to conduct the quantitative analysis, three different functions are linked to the models presented in the analysis. The first function referring to Model 1 and presenting port performance is shown below.

$$THROUGHPUT_{it} = \beta_1 + \beta_2 * N\_GDP_{it} + \beta_3 * R\_GDP_{it} + \beta_4 * N\_EMPLOYMENT_{it} + \beta_5 * R\_EMPLOYMENT_{it} + \beta_6 * AUTOMATION_{it} + e_{it} \qquad (Eq.\ 1)$$

The estimates of Model 1 can be seen in *Appendix K.* However, since the analysis shows a very insignificant effect of regional employment on port throughput (p=0.575) omitting it from the equation has been the following step. The insignificant effect of regional employment can be explained by the selection of the type of ports in this analysis. Since the main focus is on transhipment ports it can be concluded that due to the particular operations focused more within the terminals than around the port area regional employment does not impact port throughput and is insignificant in this analysis. Thus, the Model 2 for analysis of port productivity has a new function with omitted regional employment:

$$THROUGHPUT_{it} = \beta_1 + \beta_2 * N\_GDP_{it} + \beta_3 * R\_GDP_{it} + \beta_4 * N\_EMPLOYMENT_{it} + \beta_5 * AUTOMATION_{it} + e_{it} \qquad (Eq.\ 4)$$

The estimates of Model 2 can be seen in *Appendix L.* Additionally, when comparing the R^2 in the first model 75.16% of the results are explained by the included variables, while in the second model when regional employment is omitted, 74.93% of the results are given with the included variables. Thus, since the difference is less than 0.5 percentage points, the second model is selected for the analysis.

On the other hand, the models on greenhouse emissions including nitrous oxide emissions and carbon dioxide emissions are as presented in the below equations. Model 3 is represented by the below Equation 2 (see *Appendix M* for estimates), while Model 4 is explained by the Equation 3 (see *Appendix N* for estimates).

$$NOx\_EMISSIONS_{it} = \beta_1 + \beta_2 * THROUGHPUT_{it} + \beta_3 * AUTOMATION_{it} + e_{it} \quad (Eq.\ 2)$$

$$CO2\_EMISSIONS_{it} = \beta_1 + \beta_2 * THROUGHPUT_{it} + \beta_3 * AUTOMATION_{it} + e_{it} \quad (Eq.\ 3)$$

Where the R^2 for the nitrous oxide model represents 38.29% of the results, while the carbon dioxide model shows only 20.02% meaning more variables could be included for further interpretation. Even though the R^2 appears small, the results will be discussed further on.

Impacts on port performance

The Model 2 following equation 4 will be interpreted in order to see different impacts on port performance.

$$THROUGHPUT_{it} = \beta_1 + \beta_2 * N\_GDP_{it} + \beta_3 * R\_GDP_{it} + \beta_4 * N\_EMPLOYMENT_{it} + \beta_5 * AUTOMATION_{it} + e_{it} \quad (Eq.\ 4)$$

The parameter, estimates and p-values are presented in Table 4.1. Based on the results it appears that the following variables N_GDP, R_GDP, N_EMPLOYMENT, _AUTOMATION1, and _AUTOMATION2 have a statistically significant effect on the dependent variable THROUGHPUT. In addition, the R^2 is 0.7493 indicating the 74.93% of variance in the dependent variable THROUGHPUT is explained by the independent variables.

Table 4.1. Model 2 linear regression results for the relation between port performance and multiple independent variables.

Variable	Estimate	P-value
N_GDP	478.9304 (85.13809)	0.000***
R_GDP	-166.0166 (19.66686)	0.000***
N_EMPLOYMENT	-744.8943 (82.13701)	0.000***
_AUTOMATION1	0[a]	-
_AUTOMATION2	-920422.4 (221122.5)	0.000***
Constant	9219414 (1715491)	0.000***
Observations	40	-
R^2	0.7493	-

Note. Standard errors are in parenthesis

[a] set to 0 to avoid dummy variable trap

* p < 0.05, ** p < 0.01, *** p < 0.001

Source: Created by the author.

Hypothesis testing

The next paragraphs present the obtained results from quantitative analysis. In addition, a possible explanation of the results will be connected with the qualitative analysis.

H_1: The implementation of automation has a positive influence on port performance.

The presence of automation at the terminals has a statistically significant negative effect on port performance.

When automation is adopted throughput decreases by 920.422 TEU per year. Thus, indicating that port performance decreases as well. Accordingly, the hypothesis H_1 is rejected.

Based on the literature this result is quite astonishing since most terminals do not report negative throughput when automation is implemented. However, it needs to be emphasised that mostly transhipment focused terminals were considered in the analysis. The negative effect of automation on port performance might be due to more handling activities (Zhou et al., 2016) taking part in the terminals. Following, Martín-Soberón et al. (2014) indicated that when automation is implemented there is less flexibility in operational planning and it is more challenging to react on unexpected events. Since a lot of yard and stack movements are necessary in transhipment terminals, flexibility in operational planning and the ability to react on unexpected events should be crucial for terminal operators. Hence, that is why automation might lead to lower throughput levels.

On the other hand, the reason for a predicted negative throughput might solely lie in the selection of ports for the analysis. In Figure 4.1 the throughput of the automated and non-automated ports is presented. When the overall throughput of automated ports is compared with the non-automated ports it is visible that non-automated ports have a higher performance throughout the years.

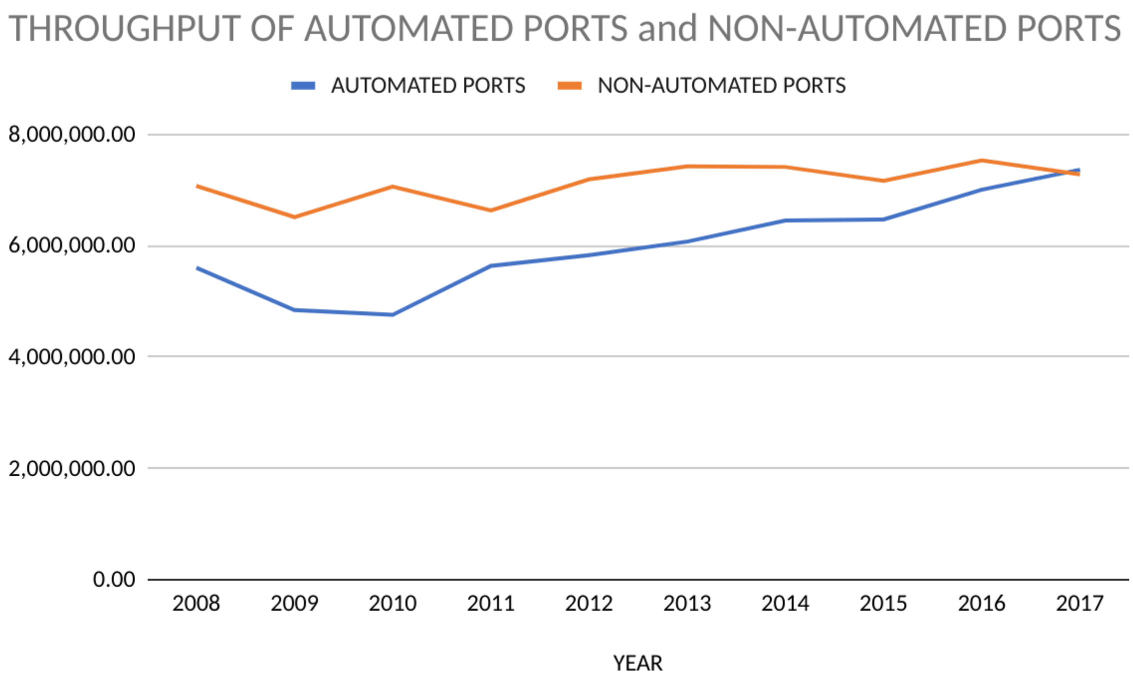

Figure 4.1. Throughput of selected automated ports and non-automated ports.

Source: Made by author based on data from the Port authority of respective ports.

In addition, if the throughput growth is analysed, it is visible that the trend in both automated and non-automated ports is negative (Figure 4.2). Thus, the port selection for this analysis might be the cause of the negative output.

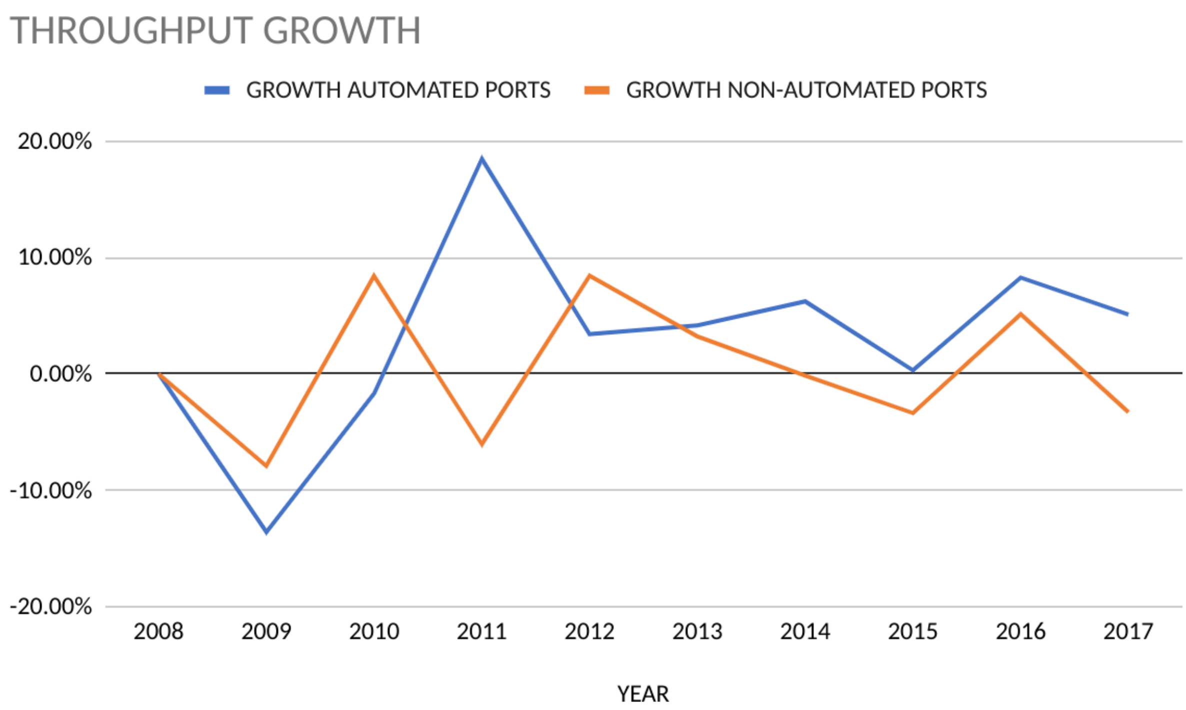

Figure 4.2. Throughput growth of selected automated ports and non-automated ports.
Source: Made by author based on data from the Port authority of respective ports.

Based on the qualitative analysis, the *combination* indicator shows that automated and non-automated ports are equal in terms of productivity (see *Appendix O*). Thus, they should have the same impact on port performance. However, this indicator should be taken with doubt since in the case of Algeciras and Valencia terminal productivity, based on crane movements per hour per vessel capacity, is not known due to unavailable data.

On the other hand, the selected non-automated ports of Valencia and Gioia Tauro, have higher productivity on a terminal level than the ports of Algeciras and Barcelona when the indicator of berth productivity, based on container vessel capacity, is considered. Meaning, with higher productivity levels of non-automated ports the effect on port performance is more positive than in the case of automated ports.

Thus, this comparable data suggests that based on the choice of ports in this analysis, non-automated ports have higher performance than automated ones. Hence, all of the aforementioned might validate the predicted negative throughput of 920.422 TEU in automated ports.

H_6: The economy has a positive influence on port performance.

Both national GDP and regional GDP appear to have a statistically significant effect on port throughput. However, national GDP has a positive effect meaning when it increases by one million PPS port throughput increases by approximately 479 TEU. On the other hand, regional GDP has a negative effect on port throughput. When regional GDP per capita increases by one thousand PPS, throughput decreases by 166 TEU.

Both effects can be explained by the choice of ports. Since the analysed data refers to transhipment ports and throughput levels are mostly derived from transhipment cargo, the economy does not have a very large impact on throughput. That is because the import and export levels are not derived only by the economy itself but also by transhipment cargo.

Another explanation can be found in the work from Vanoutrive (2010) and the research on the port of Antwerp. In the study, the importance of Belgium's neighbouring economies and the impact of other countries' economic accounts present an effect on port performance. Thus indicating that, not only Spain's or Italy's GDP should be considered. The national accounts from bordering countries can also present a part of supply and demand (in this case imports and exports) which can influence the performance of analysed ports.

Thus, the hypothesis H_6 is neither accepted nor rejected.

H_7: Employment has a positive influence on port performance.

During economic growth employment levels are higher. Thus, port performance should increase since more goods would be imported and exported due to the higher purchasing power and higher industrial activities. However, surprisingly this is not the case in this analysis. National employment levels have a statistically significant negative effect on port performance. When national employment levels increase by one thousand persons, port throughput decreases by approximately 745 TEUs. Thus, it is leading to a rejection of the hypothesis H_7.

Based on Figure 4.3 it is visible that national employment levels of the two countries have quite a similar trend throughout the years. The main difference is that the level of employment is lower in Spain than in Italy.

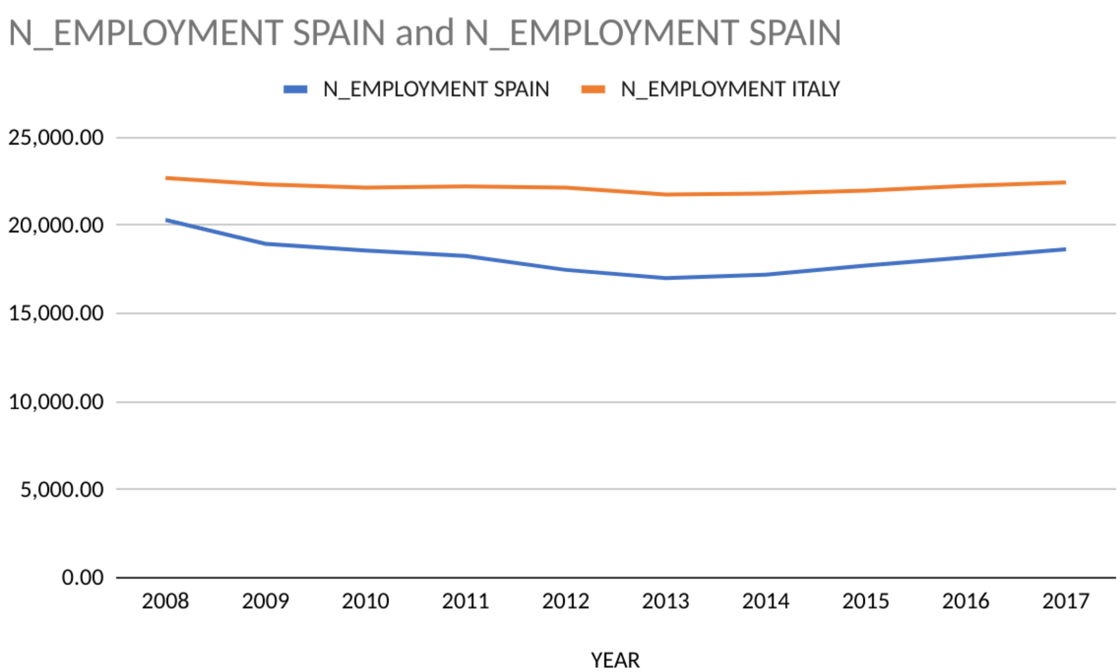

Figure 4.3. National employment levels of nations from selected ports.

Source: Eurostat (2020).

However, in Figure 4.4 the performance of ports is presented where the choice of ports might once again play a role in this analysis.

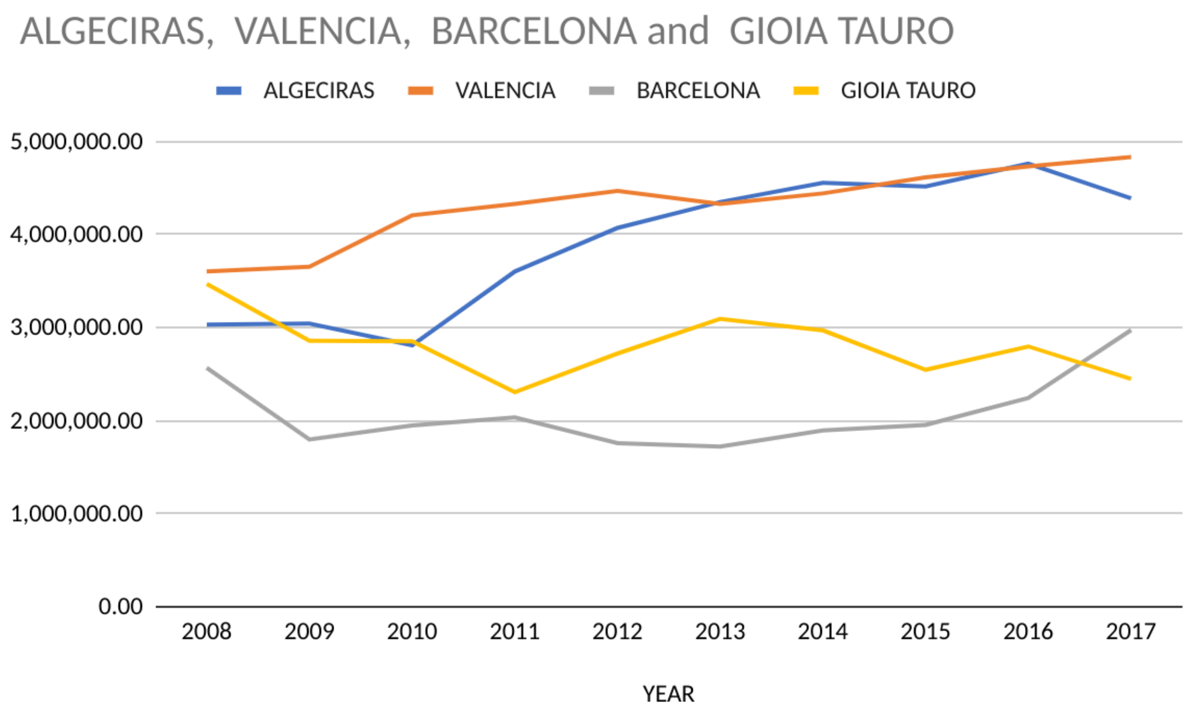

Figure 4.4. Port performance of selected ports.

Source: Made by author based on data from the Port authority of respective ports.

It appears that the port of Barcelona and the Port of Valencia are both following the trend of national employment. But the ports of Gioia Tauro and Algeciras are not. The reason behind it might be the transhipment incidence level. Gioia Tauro and Algeciras have the transhipment incidence higher than 90% (see *Appendix B*) while Valencia and Barcelona have the incidence higher than 50% (Notteboom et al., 2020). Meaning that the impact of employment is higher in ports with lower transhipment incidence. That is because transhipment ports are not focused on imports and exports which could be derived by employment levels, but rather by other determinants, such as location, terminal operators, and port structure.

Thus, the employment levels might not influence port performance on a high scale when the majority of port activity is focused on transhipment. However, the negative effect on port performance could be because of the omitted variable bias. Since employment levels might be correlated with other variables such as import or export levels which are not included in this analysis, the results might suffer. Meaning, this outcome should be adopted with caution.

A better result of the impact on port performance could be presented by the employment levels on a port scale. Since these levels of employment might be more related to port performance a better analysis could arise thus showing more precise results.

Impact on greenhouse emissions

The models on greenhouse emissions include nitrous oxide emissions and carbon dioxide emissions are as presented in the below equations. Model 3 is represented by the below Equation 2, while Model 4 is explained by the Equation 3.

$$NOx\_EMISSIONS_{it} = \beta_1 + \beta_2 * THROUGHPUT_{it} + \beta_3 * AUTOMATION_{it} + e_{it} \qquad (Eq. 2)$$

$$CO2\_EMISSIONS_{it} = \beta_1 + \beta_2 * THROUGHPUT_{it} + \beta_3 * AUTOMATION_{it} + e_{it} \qquad (Eq. 3)$$

The Model 3 parameter estimates and p-values are described in Table 4.2 indicating that THROUGHPUT and _AUTOMATION2 have a statistically significant effect on the dependent variable NOx_EMISSIONS. In addition, the R^2 is 0.3829 indicating the 38.29% of variance in the dependent variable THROUGHPUT is explained by the independent variables.

Table 4.2. Model 3 linear regression results for the relation between port performance and multiple independent variables.

Variable	Estimate	P-value
THROUGHPUT	.0000838 (.0000266)	0.003**
_AUTOMATION1	0[a]	.
_AUTOMATION2	204.876 (55.82491)	0.001**
Constant	1005.858 (93.73731)	0.000***
Observations	40	-
R^2	0.3829	-

Note. Standard errors are in parenthesis

[a] set to 0 to avoid dummy variable trap

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Source: Created by the author.

While the parameter estimates, and p-values are described in Table 4.3 showing THROUGHPUT has a statistically insignificant effect (p=0.086), and _AUTOMATION2 has a statistically significant effect (p=0.016) on the dependent variable CO2_EMISSIONS. Furthermore, the R^2 is 0.2002 indicating that only 20.02% of variance in the dependent variable is explained by the independent variables.

Table 4.3. Model 4 linear regression results for the relation between port performance and multiple independent variables.

Variable	**Estimate**	**P-value**
THROUGHPUT	5.447536 (3.0924)	0.086
_AUTOMATION1	0[a]	.
_AUTOMATION2	1.63e+07 (6485918)	0.016*
Constant	1.25e+07 (1.09e+07)	0.258
Observations	40	-
R^2	0.2002	-

Note. Standard errors are in parenthesis

[a] set to 0 to avoid dummy variable trap

* p < 0.05, ** p < 0.01, *** p < 0.001

Source: Created by the author.

H_5: The implementation of automation has a negative influence on greenhouse emissions. The implementation of automation has a significant and positive effect on greenhouse emissions. Indicating that, terminals with implemented automation see an increase in greenhouse emissions. Thus, nitrous oxide emissions increase by approximately 204 tons per year. On the other hand, carbon dioxide emissions increase by approximately 16.3 million tons per year. Therefore, the hypothesis H_5 is rejected. These results are quite surprising since Yang (2017) argues that the adoption of automated equipment would lead to a reduction in CO2 emissions.

However, the results can be explained by the equipment used at the terminals. Since the ports selected are semi-automated or non-automated, parts or even all of the equipment is not eco-friendly, thus leading to higher emissions. In addition, it needs to be emphasised that the data analysed refers partially to ports. That is because the variable for emissions is represented as a proxy and it represents the total emissions for transportation and storage in the region where the port is located. A more accurate estimate would be provided by using the exact emissions of the terminals, provided by the terminal operators.

Conclusion & discussion

In the final part of this work a conclusion and discussion are provided. Firstly the research question and hypotheses will be reviewed, followed by the limitations of this study, concluding with the recommendations for further research.

Research question and hypotheses

The main focus of this thesis is on the performance of transhipment ports and the influence of adopted automation on the port's performance. The main question of this work was: *What is the impact of automation in transhipment ports?* In addition, two sub-questions have been researched: "*Which determinants impact port performance?*" and "*Does the use of automation on terminals reduce greenhouse emissions?*".

The first part of the conducted work focused on the literature review which focused on the different types of ports and on the main category of the ports observed - transhipment ports. In addition, an overview on port performance has been explained. Based on the literature, different factors determine port performance including: hinterland accessibility, value added, location, natural characteristics, and other. However the quantitative analysis focused on: economic factors such as national and regional GDP, employment levels on a national and regional level, and automation.

In addition, the qualitative analysis focused on case studies of selected ports and port productivity. Based on the qualitative analysis, three different indicators for port productivity in the ports of Algeciras, Valencia, Gioia Tauro and Barcelona were presented:

1. terminal productivity based on berth productivity,
2. terminal productivity based on crane movements per hour per vessel capacity,
3. productivity based on combination indicator by berth productivity and crane movements per hour.

The *combination* indicator showed that non-automated ports appear to have higher productivity levels than automated ports, thus leading to higher performance levels.

Following, the quantitative analysis concentrated on testing multiple hypotheses with the use of multiple linear regression. In order to test the effects of different determinants on port performance and the role of automation two analyses have been made. The first analysis focused on port performance measured by container throughput. Hypothesis H_1*: The implementation of automation has a positive influence on port performance.* - has been rejected. Hypothesis H_6*: The economy has a positive influence on port performance.* - has been adopted. Hypothesis H_7*: Employment has a positive influence on port performance.* - has neither been rejected nor accepted. The port performance model showed that national GDP has a positive significant influence on port performance, regional GDP, national employment and automation have a negative significant influence on port performance, while regional employment appeared to have an insignificant impact. The second analysis focused on greenhouse emissions where the hypothesis H_5*: The implementation of automation has a negative influence on greenhouse emissions.* - has been rejected. Throughput and automation on terminals have been the main variables in the analysis of greenhouse emissions.

To answer the research questions, the impact of automation within transhipment ports does not provide any significant positive effect on port performance or greenhouse emissions. On the other hand, based on the analysed ports, it shows significant negative impacts on port performance and on greenhouse emissions. The main cause behind this result is the choice of transhipment ports. It appears that this type of port does not support automation. Meaning, implementing automation within transhipment ports, based on this research, does not provide benefits in terms of port performance or greenhouse emissions. Thus, terminals and ports around the world could consider automation as an unnecessary expense, rather than a competitive advantage. On the other hand, the research shows different determinants which positively impact port performance including port productivity. Although productivity was not quantified and included in the regression model, the qualitative analysis shows its positive influence on port performance. Thus, rather than focusing on automation, port authorities and terminal owners should focus on the right equipment implemented at terminals. This equipment should offer the possibility of handling large container vessels, which are contributing to economies of scale and tend to be more common in the sector nowadays. With the right equipment and handling processes berth productivity might increase and an increase in port performance would be visible, thus leading to a competitive advantage of ports and terminals.

However, this research suffered from certain limitations which might have led to the above discussed results. Along these lines, the next sub-chapter presents the possible drawbacks of this paper.

Research limitations

The main limitation in this research is the availability of data. Since port terminal operators are not quite transparent data used for the analysis might not completely represent the situation at the terminals. In addition, due to the lack of data it is difficult to test other determinants impacting port performance, such as the number of moves per hour, which might be influenced by the use of automation. Thus, the variables used in the model for port performance explain 74.93% of the variance in throughput. However, if more variables were used the variance might have been even higher; hence explaining the model and analysis in a more sharpened way but it would also lead to a possible over-fitting of the model.

The same reasoning applies for the greenhouse emission model. Due to the lack of data availability, it was not possible to use the exact data of greenhouse emissions arising from the terminals, but rather from the region where the ports are located. In addition, the descriptive power of the model might have been higher if more variables were included. Whereas the current result of 38.29% explaining the variance of the greenhouse emissions seems low.

In addition, only four ports were used in the analysi. A larger sample might lead to more plausible results, providing that the necessary data is available.

In conclusion, the obtained results must be interpreted with caution since they might not provide the overall perspective of the impact of automation in transhipment ports.

Further research recommendations

There are several research recommendations on this topic, some of which are described in the following section.

In this paper, only four transhipment ports were used for the analysis. Although this might be acceptable for the purpose of this research, a larger sample of transhipment ports would provide more accurate results. Thus, one of the main recommendations is the use of a larger sample. In addition, the use of a different methodology might be convenient. Further research might consider including more variables in order to have a better explanation of the variance in the dependent variable. In addition, fixed and random effect models could be considered in the next analysis.

The same applies to the qualitative analysis. A political, economic, social and technological (PEST) analysis could provide a deeper insight in the analysed ports. However, most importantly it is crucial to use accurate data, preferably provided by terminal operators since it would advance any further research on this topic.

To conclude, there are multiple possibilities in conducting a research on this topic. Any further analysis would contribute greatly to this subject since the current number of studies are rather limited.

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Appendix

Appendix A

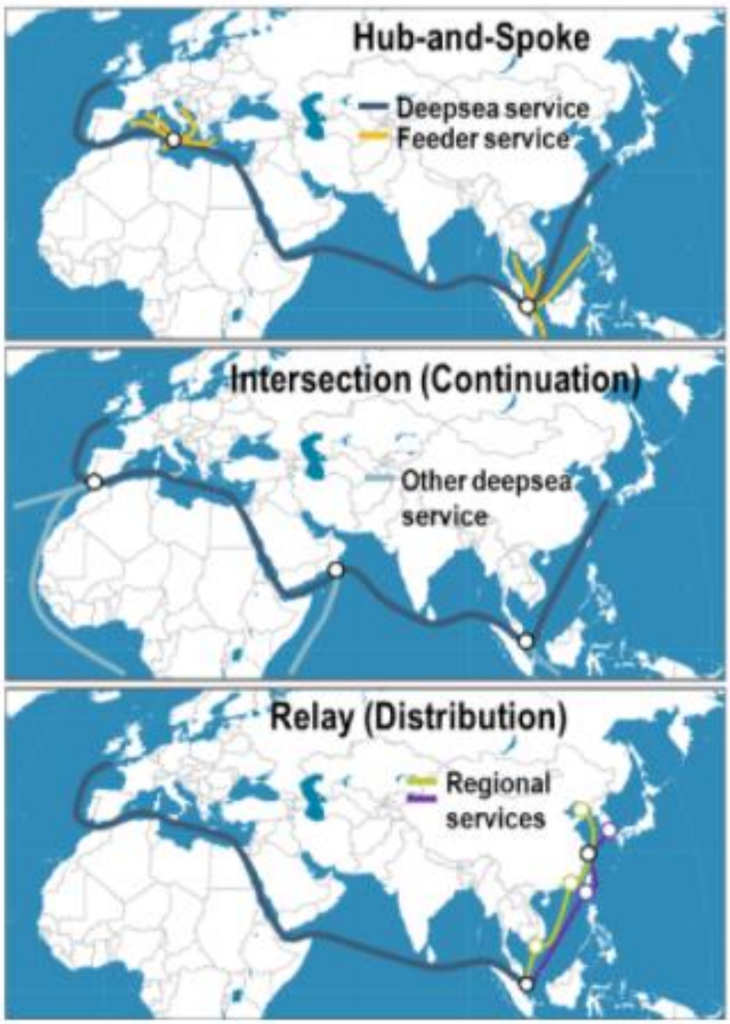

Figure A.1. The insertion and location of transhipment hubs.

Source: Rodrigue et al. (2016)

Appendix B

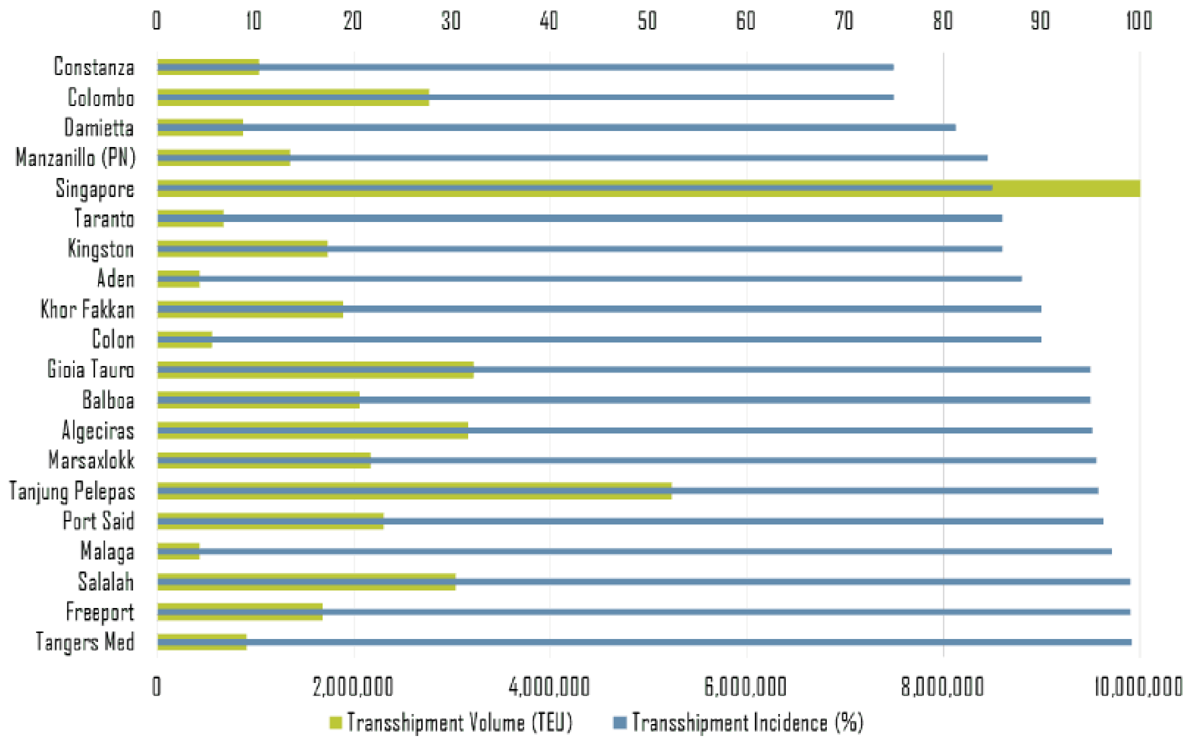

Figure B.1 Ports with the highest transhipment incidence.

Source: Rodrigue et al. (2016)

Appendix C

Table C.1. Berth productivity based on container vessel capacity.

Container vessel capacity	Berth productivity
14 000 TEUs or less	low
14 001 TEUs - 18 000 TEUs	average
18 001 TEUs or more	high

Adapted source: Mooney (2017); Arvis et al. (2018)

Appendix D

Table D.1. Terminal productivity based on crane movements per hour per vessel capacity.

Crane movements per hour per vessel capacity	Productivity levels based on crane movements per hour per vessel capacity
more than 25 crane moves per hour on 14 000 TEUs or less	high
average of 25 moves per hour on vessels of 14 001 TEUs - 18 000 TEUs	average
less than 25 moves per hour on vessels of 18 001 TEUs or more	low

Adapted source: Mooney (2017)

Appendix E

Table E.1. Productivity based on combination indicator by berth productivity and crane movements per hour.

Productivity levels based on berth productivity	Productivity levels based on crane movements per hour per vessel capacity	Combination indicator on a port level
low	low	low
low	high	average
low	average	low average
high	low	average
high	high	high
high	average	high average
average	low	low average
average	high	high average
average	average	average

Source: Made by author

Appendix F

Table F.1. Effect of combination indicator on port performance.

Combination indicator	Effect on port performance
low	negative
low average	unbiased- negative
average	unbiased
high average	unbiased-positive
high	positive

Source: Made by author

Appendix G

Table G.1. Port of Algeciras productivity level.

Terminal productivity indicator	**TTI Terminal Algeciras productivity level**	**APM Terminals Algeciras productivity level**	**Port of Algeciras productivity level**
Terminal productivity based on berth productivity.	high	high	high
Terminal productivity based on crane movements per hour per vessel capacity.	N-A[a]	N-A[a]	N-A[a]
Productivity based on combination indicator of berth productivity and crane movements per hour.	-	-	high

Note. [a] not applicable, no available information

Source: Made by author

Appendix H

Table H.1. Port of Valencia productivity level.

Terminal productivity indicator	**CSP Iberian Valencia Terminal productivity level**	**APM Terminals Valencia productivity level**	**MSC Terminal Valencia productivity level**	**Port of Valencia productivity level**
Terminal productivity based on berth productivity.	high	high	average	high
Terminal productivity based on crane movements per hour per vessel capacity.	N-A[a]	N-A[a]	N-A[a]	N-A[a]
Productivity based on combination indicator of berth productivity and crane movements per hour.	-	-	-	high

Note. [a] not applicable, no available information

Source: Made by author

Appendix I

Table I.1. Port of Barcelona productivity level.

Terminal productivity indicator	APM Terminals Barcelona productivity level	BEST productivity level	Port of Barcelona productivity level
Terminal productivity based on berth productivity.	average	average	average
Terminal productivity based on crane movements per hour per vessel capacity.	high	high	high
Productivity based on combination indicator of berth productivity and crane movements per hour.	high average	high average	high average

Source: Made by author

Appendix J

Table J.1. Port of Gioia Tauro productivity level.

Terminal productivity indicator	MedCenter Container Terminal productivity level	Port of Gioia Tauro productivity level
Terminal productivity based on berth productivity.	high	high
Terminal productivity based on crane movements per hour per vessel capacity.	average	average
Productivity based on combination indicator of berth productivity and crane movements per hour.	high average	high average

Source: Made by author

Appendix K

Table K.1. Model 1 linear regression results for the relation between port performance and multiple independent variables. [3]

Variable	Estimate	t	p > |t|	95% confidence level	
				Lower bound	Upper bound
N_GDP	489.3563 (87.92139)	5.57	0.000***	310.6785	668.0341
R_GDP	-175.2356 (25.67071)	-6.83	0.000***	-227.4042	-123.0671
N_EMPLOYMENT	-731.2483 (86.36844)	-8.47	0.000***	-906.7701	-555.7265
R_EMPLOYMENT	95.47724 (168.4456)	0.57	0.575	-246.8454	437.7999
_AUTOMATION2	-973513 (242147.2)	-4.02	0.000***	-1465615	-481410.8
_AUTOMATION1	0[a]	-	-	-	-
Constant	8708905 (1952512)	4.46	0.000***	4740925	12700000
Observations	40	-	-	-	-
R^2	0.7516	-	-	-	-

Note. Standard errors are in parenthesis

[a] set to 0 to avoid dummy variable trap

* p < 0.05, ** p < 0.01, *** p < 0.001

Source: Created by the author

[3] Dependent variable container throughput in TEU per year.

Appendix L

Table L.1. Model 2 linear regression results for the relation between port performance and multiple independent variables.[4]

Variable	Estimate	t	p > |t|	95% confidence level	
				Lower bound	Upper bound
N_GDP	478.9304 (85.13809)	5.63	0.000***	306.0909	651.77
R_GDP	-166.0166 (19.66686)	-8.44	0.000***	-205.9425	-126.0908
N_EMPLOYMENT	-744.8943 (82.13701)	-9.07	0.000***	-911.6413	-578.1473
_AUTOMATION2	-920422.4 (221122.5)	-4.16	0.000***	-1369325	-471519.8
_AUTOMATION1	0[a]	-	-	-	-
Constant	9219414 (1715491)	5.37	0.000***	5736782	12700000
Observations	40	-	-	-	
R^2	0.7493	-	-	-	

Note. Standard errors are in parenthesis

[a] set to 0 to avoid dummy variable trap

* p < 0.05, ** p < 0.01, *** p < 0.001

Source: Created by the author.

[4] Dependent variable container throughput in TEU per year.

Appendix M

Table M.1. Model 3 linear regression results for the relation between nitrous oxide and multiple independent variables.[5]

Variable	**Estimate**	**t**	**p > |t|**	**95% confidence level**	
				Lower bound	**Upper bound**
THROUGHPUT	.0000838 (.0000266)	3.15	0.003*	.0000298	.0001377
_AUTOMATION2	204.876 (55.82491)	3.67	0.001**	91.76402	317.9881
_AUTOMATION1	0[a]	-	-	-	-
Constant	1005.858 (93.73731)	10.73	0.000***	815.9283	1195.788
Observations	40	-	-	-	
R^2	0.3829	-	-	-	

Note. Standard errors are in parenthesis

[a] set to 0 to avoid dummy variable trap

* p < 0.05, ** p < 0.01, *** p < 0.001

Source: Created by the author.

5 Dependent variable nitrous oxide in tons per year.

Appendix N

Table N.1. Model 4 linear regression results for the relation between carbon dioxide emissions and multiple independent variables.[6]

Variable	Estimate	t	p > |t|	95% confidence level	
				Lower bound	Upper bound
THROUGHPUT	5.447536 (3.092495)	1.76	0.086	-.8184544	11.71353
_AUTOMATION2	16300000 (6485918)	2.51	0.016*	3164946	29400000
_AUTOMATION1	0[a]	-	-	-	-
Constant	12500000 (10900000)	1.15	0.258	-9547378	34600000
Observations	40	-	-	-	
R^2	0.2002	-	-	-	

Note. Standard errors are in parenthesis

[a] set to 0 to avoid dummy variable trap

* p < 0.05, ** p < 0.01, *** p < 0.001

Source: Created by the author.

[6] Dependent variable carbon dioxide in tons per year.

Appendix O

Table O.1. Productivity level by port.

Productivity Indicator	Port of Algeciras	Port of Valencia	Port of Barcelona	Port of Gioia Tauro
Productivity based on combination indicator of berth productivity and crane movements per hour.	high	high	high average	high average

Source: Made by author