Erasmus
University
Rotterdam

MSc in Maritime Economics and Logistics

Evaluation of Relation Between Terminal Context Characteristics and Automation: A Regression Analysis

Name: Jinfeng Gu
Student ID: 515367ag

Supervisor: Dr Elvira Haezendonck

Date of the final version: 9th. September 2019

Acknowledgements

I would like to express my greatest appreciation towards my supervisor **Dr Elvira Haezendonck**. She was very patient to her student and very detailed in explanation. She offered me great help in data collection and direct me through the right way. Without her, it would be impossible to go through all the details and integrate them into a thesis.

Also, I would like to thank all my friends and family in China for all the support during my thesis writing. They gave me solid support when I was almost drowned in anxiety, and helped me out with the thesis building. I cannot imagine going through this thesis in such a short time on my own. Great appreciation to my supervisor and all my friends and family.

Abstract

Since the introduction of automation from ECT Delta in 1993, container shipping market has come through a long way. The demand for container shipping exploded after 21st century, and container vessels are becoming ever larger to accommodate the growing demand, and thereby comes the requirement for high productivity in terminal operation, which reduce the turnaround time and improve the utilization of berth. Because of the maturity of information technology, terminal automation is also advancing into new territory. What was called “full automation” has been brought to a whole new level, which covers the cargo handling process from ship all the way through the terminal gate. The improvement in productivity from adopting automation project has attracted many major ports, they either have already built or on their way to build automated terminals. Hence, this thesis aimed to find out the pattern of terminal context characteristics behind automation, to see whether automation is only applicable to larger busy ports or is it irrelevant to these characteristics. The research has found no strong statistic relation between the level of automation and terminal context characteristics, but do indicate that newer automated terminals are more likely to be fully automated, and high level of automation is likely to have positive effect on improving terminal capacity.

List of Abbreviation

(e)RTG – (electric) Rubber Tyred Gantry

(A)RMG – (Automated) Rail Mounted Gantry

AGV – Automated Guided Vehicle

TOS – Terminal Operating System

ULCV – Ultra Large Container Vessels

TEU – Twenty-Foot Equivalent

Table of Content

Abstract
List of Abbreviation

1. Introduction

The three elements of production – capital, labour and land – are the core components that determine the level of productivity. This is the universal case for both manufacturer and service provider, including container ports. Port industry used to be considered as a labour-intensive industry, especially before containerization. At that time, general cargo was packed in different packages, such as barrel and pallets, and cargoes required separate handling. The introduction of containers uniformed the maritime transportation unit as twenty-foot-equivalent (TEU). Traditionally, the containers are grabbed from ship to quay by quay crane, transported to container yard by trucks, and arrange by stacking crane. All the equipment is handled by human labour, but the workload is significantly less than pre-containerization era.

Containerization has changed the game of maritime transport of general cargo since the late 1960s. Port industry has become a capital-intensive industry (HIT, 2004), as the superstructure and cargo handling equipment needs extensive investment, and the area of port land available is related to the handling capacity of the terminal. In developed and fast-developing countries that have large shipping demand, land is also a very valuable resource that could be very costly. To improve the productivity of a conventional container port, capital is needed to train the workforce and hire more labour to extend operating hours. Another option is to expand the terminal to allow more cargo handling capacity, where capital is needed to purchase additional equipment and land, and possibly more labour to handle the increased throughput.

However, port expansion is not always possible. After years of development, major ports with large container throughput usually have limited access to port lands, as the pollution and noise of port operation may interfere with the local community. Typical mega ports like Shanghai and Rotterdam chose to expand port lands by sea reclamation, which is very time-taking and costly. The expansion of labour is subjected to the enforcement of stricter labour laws in many countries. The training and extension of working hours have become too expensive for new terminals, and laying off workforce during the economic downturn would occur extra cost.

The way out for this dilemma will be a technological upgrade, which is essentially an improvement of productivity. Containerization was the innovative packaging solution that significantly improved the efficiency of loading/discharge of cargo. The evolution of container vessel and cargo handling machine took decades, which shaped the logistics industry of today. The current trend of industry 4.0 and automation is again reshaping the logistics industry. In an enclosed environment such as warehouses or automatic line of carmakers, automation was proved to be superior in terms of productivity and cutting operational cost. For the same reason, automation could be the key to improve productivity within limited space that needs less workforce.

Automation is not new to the port industry, it has been exercised over 2 decades since the establishment of the first automated terminal in the port of Rotterdam. Automation has been proved practical and beneficial to manufacturing industry, as they reduce the workforce needed for repetitive working process, such as welding and pick and place. Ideally, it is logical to assume that automation of cargo handling at container terminal, a process that was typically operated by workforce would lead to decrease in operating cost and increase in productivity. In reality, the degree of automation has been steadily improving since 1993, which was mostly focusing on management and re-stacking of container yard and transporting containers from quay to container yard.

However, the automated operations still need supervision, since they are not fully automated, and there are quite a few exceptions that need to be handled by human workforce. According to the interview with DHL’s innovation department (Port of Rotterdam, n.d.), the fully automated loading/discharge operation is quite challenging, as the handling condition differs for each container or parcel. Moreover, the adoption of automation was slow compared to the number of emerging ports that occurred during the first decade of the 21st century. The pace of automation in container port industry is still lagging behind in automation comparing other transport and logistics sectors. In recent implementations of automated terminals, there are many mismatches between expectations and actual performance, because of a lack of experience with automated cargo handling. The slow pace of adoption and mismatch of expectation and reality highlights the challenges of high degree of automation.

While facing challenges from technical and managerial issues, port operators still recognise automation as an inevitable trend. Major ports around the world either have full or semi-automated terminal in operation or have planned building automated terminals in the following decade. Existing automated equipment also allows upgrading from conventional terminal to semi-automated terminal.

There are no identical ports in the world, and they all have different reasons for automation. Some are facing the constraint of limited port lands, which required better productivity to handle port congestion, and some new terminal projects opted automation because a one-off investment in advanced technology would reduce operating cost that benefits in the long-term. Hence, there is no universal automation solution for all ports. Even in the same port range, not all players are following the same route in competition. According to the age, size and capacity of the terminal, there are several strategies that fit in their own position. In some cases, the semi-automated port could be more productive than a fully automated one.

In this thesis, a set of port figures, such as terminal capacity, total area and age was collected from credible sources and categorised under different level of automation. They will be utilised in regression analysis in order to find out whether the degree of automation is correlated to the condition of infrastructure and the designed capacity of the terminal, and identify if there are any pattern of terminal features that would lead to different levels of automation. With this pattern, we want to conclude the common solution of automation technologies for different terminal conditions.

2. Literature Review

2.1 Different levels of automation

2.1.1 No Automation

In the context of this thesis about automation, a conventional terminal means no automation for the cargo handling process. Traditionally, a seaport was considered as labour-intensive industry because of the extensive use of labour in loading/discharge, carriage and storing process of general cargo. Before containerization, there were numerous forms of packages, such as box, sack and pallet. Different cargoes need to be handled separately, the loading/discharge operation usually took days even weeks (HIT, 2004).

The introduction of containers unified the unit of general cargo transportation, and the cargo handling process can be simplified as lifting containers from ship to quay by quay crane, transporting the containers from quay to container yard, which is carried out by lorries in conventional ports, and then stacked in the container yard waiting for pickup or transshipment, eventually containers are moved from container yard to trucks that head for the final destination. Before leaving the terminal, a series of information needs to be collected at the gate, to make sure the right inland carrier gets the right container. All these processes are carried out by human labour in conventional ports. Depending on managing level and the skill of the workforce, the berthing time varies from a few hours to a few days (Ducruet, Itoh and Merk, 2014).

2.1.2 Hardware of automation

When it comes to automation at the port, there are various degrees of automation, which represent different levels difficulties on implementation, and there is a range of cargo handling equipment that could be used in terminal operation.

To understand the specs of cargo handling equipment, we need to understand their purpose in different sectors of terminal operations. Rodrigue (2017) categorized the physical operation into 3 sectors – quay operation, horizontal transport and yard operation. Quay operation can only be carried out by quay cranes, there are several examples of quay crane automation in some latest practice, such as the Yangshan terminal phase 4 of Shanghai, which deployed remote-controlled quay crane (Swissnex China, 2018). Overall speaking, the automation level on quay crane is still minor, but it is becoming increasingly common in the newly built container terminal. Horizontal transport and yard operation could be carried out separately or combined, depending on the physical constraint of the waterfront and container yard. The traditional automated terminal design origin from ECT Delta separate horizontal transport and yard operation by deploying AGVs for horizontal transport and automated rail-mounted gantry (ARMG) cranes for yard operation, which is the design that applied by many other automated terminals (Yang, Mi and Tao, 2016; The Maritime Executive, 2015). But the combination of AGV and ARMG is not the only solution. For horizontal transport, there is lift-AGV and automatic straddle carriers that have a certain level of stacking ability. For yard operation, there are rubber-tyred gantry (RTG) cranes that have better flexibility comparing to ARMG cranes (Yang, Mi and Tao, 2016; Luo, 2014). Depending on the budget and terminal features, a different combination could be adopted. The Patrick terminal of Brisbane combined horizontal transport and yard operation by using automated straddle carriers, which has a lower investment on yard cranes, but the trade-off is low utilization of container yard because of insufficient stacking ability. While straddle carrier serves as multi-purpose cargo handling crane, the TraPac terminal of Los Angeles only use it for horizontal transport, the yard operation is still operated by ARMG cranes. (Yang, Mi and Tao, 2016)

2.1.3 Digital infrastructure

Comparing to the early age of automation, a difference from the 1990s was the emergence of the internet. Even though the internet existed in 1990s, the inter-connectivity and the amount of digital data is on a whole new level in 2010s. The wireless network is covering major cities now, and the speed and latency of wireless connection have improved a lot after 21st century, which significantly improved the efficiency of information exchange. An important pre-requisite of smart port is the emergence of 5G network, which provides high bandwidth and low latency, not only creating better internet connection for remote control of unmanned equipment, but also boost the inter-connectivity among equipment, allowing real-time tracking and update of technical status. (Saanen, 2019). Vahle (2019), another solution provider with alternative solution is also emphasizing on the reliability and low latency of their conductor bars communication and wireless connection, but the bandwidth under 5GHz is significantly lower than 5G network. Apart from the physical connection, the reliability of wireless connection is yet to be proved in the complex electromagnetic environment of a container terminal.

Software infrastructure like a terminal operating system (TOS) is able to facilitate the communication from vessel to gate, linking man and equipment together, even more so with the assist of Internet of Things (IoT) in the latest trend of port technology. The software infrastructure is beneficial not only to mega ports, but also small ports that aimed for better competitiveness (Kim, 2018) The improvement in information collection and processing technologies provides better accuracy in monitoring and anticipation. For instance, the data collected from IoT sensors and terminal throughput could be used in machine learning for anticipation and automatic decision-making purpose. The yard crane scheduler tool developed by TBA (2019) can provide support for TOS, which they claim to improve the productivity of RTG by 10%.

From a previous study on port automation (Martín-Soberón et al., 2014), it concluded that the physical movement of containers is not the only process that automation aims to solve. The automation of decision making and information exchange are also fundamental elements of port automation. They can be achieved prior to the automation of the physical movement of cargo, which also improves the performance of a conventional terminal. For example, the input of container data can be achieved by image recognition at the gate, and the transition of data could be automatically triggered, the collected digital data can be directly used for further process at data centre. The elimination of manual input and transfer of data lowers the possibility of human error, and the excessive process of transforming physical data into digital data is no longer needed (Henriksson, 2018). As the software infrastructure, they are also part of the pre-requisite to the automation of physical movement of container (Saanen, 2019).

Gate automation shall also be considered as part of the smart port infrastructure that is in line with the 5G network and IoT because of their essence of boosting data collection and exchange efficiency. The smart port infrastructure is crucial to the level of automation as it is the brain and assistant that coordinates workforce and unmanned equipment, but accessing the integration between software capabilities and hardware performance is rather difficult as they involve the detailed decision making and planning process, which is hardly accessible from public sources. Moreover, these elements are considered as the pre-requisites of a smart port, and they are applicable to conventional terminals as well, we thereby assume that automated terminals have at least certain level of smart port capabilities.

The digital infrastructure is crucial for automation as they are the “neuro system” and additional “brain” of automated terminal operation. However, some professionals regard artificial intelligence as an immature tool for precise anticipation and automated decision making, especially considering the poor uniformity and quality of data, the takeover from AI is still unrealistic (Kim, 2018). But still, as an assistant tool, the patter identification and exception prediction features of machine learning could be highly valuable to automated terminals, as these exceptions severely disrupted the productivity of automated terminals (Stork, 2019)

2.1.4 Distinguish semi-automation and full automation

2.1.4.1 Full and semi-automation

There are no rigorous criteria that define the level of automation at this moment, but it can be derived from the safety standard of a port, which requires that no human workforce shall be presented at the operation range of the unmanned equipment (Moosbrugger, 2019). In the introduction of hardware of automation, Rodrigue (2017) has separated terminal operation as quay operation, horizontal transport and yard operation. Essentially, whether a container terminal is fully or partially automated is depending on the level of automation that connects the 3 sectors together. With all 3 sectors automated and interconnected, fully automated equipment shall cover the container handling from ship to the yard and eventually the dispatch through the terminal gate. At this stage, full automation without any supervision and intervention from human is still unrealistic, as the smart port concept is still immature (Saanen, 2019), and exceptions need to be handled by crane driver, but in normal situation, there should be little to no human intervention in fully automated operation, nonetheless supervision is still needed.

Gate automation is also considered to be a key process in the evaluation of terminal automation (Martín-Soberón et al., 2014). Apart from quay and yard performance, gate time is also an element in UNCTAD’s presentation of guideline for assessing port performance, which eventually affects the terminal handling capacity (Martín-Soberón, 2012). As gate automation also reduce the need for workforce and contribute to better terminal productivity, it should be counted as an element in assessing the automation level. So together there will be 4 sectors of automation in total.

In many materials, the mention of fully automated quay crane is scarce. Instead, many sources describe the terminal as automated only mentioning that the stacking cranes and horizontal transport unit are fully automated (Port Technology, 2019). In many cases, the introduction of automated quay crane emphasizes on the remote-control capability of the quay crane (Louppova, 2018; SANY Group, 2019; Port of Rotterdam, 2015). In Martín-Soberón’s (2014) definition of full automation, she did not include quay automation as a necessary element, but she mentioned the Maasvlakte 2 that was under construction in 2014 would bring complete automation of cargo handling. The paradigm of fully automated terminals opened in recent years, such as Maasvlakte 2 of Rotterdam (Port of Rotterdam, 2015) and phase 4 of Yangshan terminal of Shanghai (Port Technology, 2017), have proved their automated quay cranes in order to perform 24 hours operation.

Considering the development of automation technology in 2 decades, we insist that full automation must be achieved in all 4 sectors, and human labour does not need to intervene when there are no exceptions occurred.

Under the rigorous definition of full automation, the range of semi-automation could be too vague because of the wide selection of unmanned equipment. Fundamentally, a semi-automated operation must include process operated by human labour from quayside until truck departures from the terminal gate. Many reports and industrial news regard unmanned equipment that is remotely controlled by human labour as a solid step towards automation as well (Alho, Pettersson and Happa-Aho, 2018). It has also been argued by Martin-Soberón et al. (2014) that remote control shall still be regarded as semi-automation, but in her study, the degree of automation is only regarded in yard operation. Since we have included several sectors of operation in evaluation, remote control shall not be distinguished in this thesis.

Because of the criteria of full automation of this thesis, the range of semi-automation is wider than many studies. Any absence of automation in the 4 sectors could be counted as semi-automated terminal. The level of semi-automation is dependent on the number of sectors automated. Because quay automation is considered as a necessary factor, some of the previous fully automated terminals will become semi-automated, but they still remain a rather high degree of automation, which will be reflected in the analysis.

2.2 Why should container terminal consider about automation?

The most fundamental driving force behind any action of business is either economic factors or political and legal factors, container terminal is no exception in this case.

The motivation of automation is to reduce the use of human labour, not only for container terminals but also any industry that requires extensive use of human labour. The manufacturing industry that does not need exclusive training and has a safe working environment (e.g. assembly of electronics) might not have the motivation to go for automation when there is a large supply of cheap labour to support the operation. The human labour in container terminals, however, needs professional training to operate the cranes and the following of regulation must be strict. The cargo handling machines or even the cargo itself could impose great threat to the health condition of personnel. The safety regulation of International Labour Office (ILO, 2010) had noted that personnel in container terminal shall be separated from vehicles and cranes as long as practical, and the terminal design must take personal safety into account. All these preventions of personal accidents can be interpreted into extra cost in construction.

From the standpoint of container terminal users, carriers have been wishing for a quayside performance of 6000 moves per day, while the terminal operators consider 3500 as the maximum realistic performance. The report from Dynamar (2015) indicated that to achieve this performance target, automated quay crane is necessary. The robotic quay crane does not suffer the neck/back stress, fatigue and inconsistent concentration over long working hours that a human would face under faster acceleration and braking of quay crane. The pressure mainly comes from the more than doubled capacity of today's ultra-large container vessels (ULCVs), while the length of ULCV remains similar around 400 metres, which means the number of quay cranes deployed for one vessel is constrained, the increased capacity comes from expanded width, draught and air draught of the vessel, meaning that each quay crane will have to travel long distance to reach a container. Because of limited quay length that restricts the number of quay cranes deployed, faster movement of quay crane is needed to reduce berthing time (Knowler, 2018; Mongelluzzo, 2019), and it could be harmful to the health condition of crane drivers, eventually brings up the necessity to introduce automation in quay operation.

Even with a better quayside performance, the pressure does not only retain on the quayside. A faster turnaround of container throughput transmits the pressure to the storage capacity of the container yard. Apart from the expansion of yard capacity and productivity, gate automation is also crucial in getting rid of the bottleneck of container throughput. Only when the container is transferred to the consignee and shipper, will the yard have enough capacity for the handling of the next vessel (Dynamar, 2015).

The pressure from demand needs to be solved by more supply of terminal capacity, and the motivation of upgrading to an automated terminal is often a lack of port land for expansion, which was the case for ECT Delta, the first automated terminal in the world. The adoption of automation at ECT Delta in the era of 1990s was to deal with the already overloaded terminal throughput (Martín-Soberón et al., 2014), and the core demand is to improve productivity with limited port land. When globalisation was at its peak in the 90s and 00s, the world has seen rapid growth in container throughput (IAPH, 2018; World Bank, 2019), and the construction of automated terminals are mostly concentrated in developed economies, since they have the access to capitals and technologies, also because of the shortage and therefore the high cost of port lands (World Bank, n.d.). There were no developing countries on the list of automated terminals since the cost of land and labour was cheap enough to offset the cost-saving from automation. The situation lasts until China joined the competition of automation after 2010. China has caught up with the resources needed for automation and is also facing the problem of the high cost of port land.

The dynamic of container shipping market has changed a lot since the financial crisis in 2008, the average yearly growth of world container throughput has dropped from around 10% before 2008 to 4% after 2008 (World Bank, 2019). At the current stage, it becomes difficult to generate profit from the growth of container throughput, and the focus of terminal operators has shifted to improving service quality by providing value-added service and vertical integration. The increase in productivity is crucial to better service quality as port congestion deteriorate. While automation might not meet the expectation of better productivity, the cost-saving effect is still crucial under the background of sluggish growth in container shipping market (King, 2019).

2.3 Pros and Cons of automation

2.3.1 Pros

The most significant benefit of container terminal automation is better productivity and cost reduction, which is commonly recognised by the port operators, and according to the type of equipment employed, it has positive environmental externalities. The expectation on fully automated terminal bringing lower operating cost and higher productivity can be reflected from McKinsey's (2018) survey on major global port operators. The result provided an expectation of 25%-55% decrease in operating cost, as well as a 13%-35% increase in productivity.

The cost reduction of automation mainly comes from reduced usage of human labour. The estimation from Sisson (2019) suggested a cost reduction of US$350,000 on labour per RTG automated when the salary level is on US$75/hour, which is much higher than the wage on the west coast of US. This is only the case for automating RTG cranes that are flexible in terminal conversion. In terms of alternative stacking cranes like electric RTG (ERTG) and ASC, the labour employed is even less for ASC, and maintenance is even cheaper for both variants as they use electrical motor rather than diesel engines, which consume less energy (Cederqvist and Holmgren, 2011).

The increase of productivity is related to faster movement of automated cranes and a higher level of digitization that allows automatic operation and remote control. Faster movement of quay crane is needed because today’s ULCV has become wider and taller, and it takes longer travel distance to grab a container. While a typical quay crane performance ranges from lower to upper 20 moves per hour, news reported that the fully automated QQCTN aimed to reach an average 40 moves per hour per quay crane (Welles and Li, 2017), and with 6 cranes deployed for a ULCV, it is able to approach to carrier’s expectation of 6000 moves per day. As the progress of digitization must be in line with automation, the visibility of quay operation is available to the whole team in the central control room, rather than relying on verbal orders via radio transmission and physical document, which is inefficient and has a higher chance of error (Henriksson, 2018). While most operations can be carried out automatically, exceptions still need to be handled by operators, but the disruption is visible to the whole team, operators and checkers only need to focus on handling the exception, and coordinate the team to carry on with the operation. In addition to the luxurious working environment of centre control room comparing to the cabin of a crane, there is no need for rotation between cranes and yards as all equipment can be access remotely, saving a lot of time from reallocation of workforce.

The positive environmental externalities of terminal automation are also valued by many industries (Dusik and Sadler, 2019), including port operators. Port of Rotterdam (Port Technology, 2019) has incorporated environmental effect as a target of automation, the APM terminal of Maasvlakte 2 is reported to be a carbon-neutral terminal (APM Terminals, 2019). IAPH (2015) has also recognised terminal automation’s positive effect on the reduction of greenhouse gas emission. This is mainly contributed by greener power of automated cargo handling equipment. Traditionally, cargo handling equipment like quay crane, RTG cranes and trucks employed for horizontal transport is powered by a diesel engine, which is heavy polluters. While not all automated equipment is electrified, as existing cranes can be transformed to be automated, newer automated cranes are either hybrid or fully electric, which is also the case for AGVs and automated straddle carriers. The electrification is not solely for environmental purpose. Electric motors have larger torque comparing to any combustion engine and need less maintenance comparing to combustion engines (Cederqvist and Holmgren, 2011).

2.3.2 Cons

It seems really promising that automation could significantly boost the productivity to a whole new level since operators and checkers only need to take care of exceptions, but the reality of fully automated operation was quite far from the expectation. While a 15%-35% decrease in operating expenditure was observed, the productivity actually falls by 7%-15%. It is difficult to persuade investors with such performance. McKinsey (2018) reckoned that a lack of experience and technical staff could be the reason for poor performance. Even though fewer operators are needed for each crane, the shortage of engineers specialised in automation is severe, and an experienced engineer takes 5 years to be properly trained. This issue was observed in the early stage of terminal automation and is still bothering the automated terminals today. Although QQCTN has set a target of 40 moves per hour per crane, the first test operation recorded 25 moves per hour, and the first port call of COSCO France recorded 26.1 moves per hour, which were quite far from the target at the beginning (Welles and Li, 2017).

Apart from the lack of experience and shortage of specialists, the other identified factors are poor data quality, siloed operation and the absence of process simplification before automation. Automation relies heavily on data input, and the quality of data is subjected to the unification of format and structure. Misalignment of data would disrupt the efficiency of the automated system (Saanen, 2019). Also, because of automated system cannot contain the error within certain step of process, different departments of cargo handling from quay to gate must work together to ensure exceptions, which is actually quite common in automated terminals, to be handled in time. Therefore, siloed operations would hinder this process, and simplifying the process before automation would mitigate the occurrence of exceptions in the first hand, automating the inefficient process is merely automating the problems (Miller, 2019). Because of the inability to contain errors within certain step of process, the semi-automated terminals that have less automated processes are less likely to be disrupted by errors, as they could be identified and got handled timely. This could be the reason for the productivity of semi-automated terminals surpassing full automation ones (Knowler, 2018).

The port of Antwerp rejected the idea of building a fully automated terminal but remained semi-automated for the greenfield project (DP World, 2019; Martín-Soberón et al., 2014). At the current stage, a well-trained crew with the assist of automated equipment appeared to be more efficient. The port of Antwerp has recorded an exceptional 40 gross crane moves per hour, which is the highest in Europe (Port of Antwerp, 2019), proving that full automation is not necessarily the only solution to achieve superb productivity level.

In the selection of automated yard cranes, there are trade-offs for different options. While automated RTG cranes need less investment as they are cheaper and the requirement for infrastructure is less restrictive, the operators needed is still more than the amount required by ASC, and the stacking ability, as well as yard space utilization, is not at the same level. The ASC option, however, is rather expensive and takes longer time to transform, depending on the original layout of terminal design, which disrupts the ongoing operation and thus is not feasible for smaller ports with limited access to capital and port lands (Cederqvist and Holmgren, 2011).

The fear of machine taking away jobs from human has existed since the early age of the industrial revolution. Since the core benefit of automation is the reduction of human resource employed, especially for developed countries with high labour cost and strong union power, the labour union is often triggered by the automation plan. The negotiation among terminal operators, labour union and government could be difficult, which postponed the plan and adds financial pressure to the automation plan (Uranga, 2019).

2.4 Current trend of automation

The port of Rotterdam was and still is the most pioneering and experienced port in terms of automation, as it has the highest automation rate among ports around the world, only APM Terminal Rotterdam remained the status of no automation, every other terminal is either semi or fully automated. As one the eldest terminal of Rotterdam, the ECT Delta terminal was reported as the first automated container terminal in 1993. It was equipped with 50 AGVs and 26 ASC to allow 24/7 operation. The driving force of Sea-Land co-developing this automated terminal with the port of Rotterdam was insufficient cargo handling capacity of existing facilities. The Pernis terminal that Sea-Land leased was only designed to handle 225,000 containers annually, while it had already faced a throughput of 400-500 thousand by 1988. The expansion was not possible due to the lack of port land, so greater productivity was required (Brennan, 1993).

It was regarded as the port of future, and indeed, ECT Delta’s automated terminal was way ahead of its time. While the innovation was appealing to North American port developers, the management and labour of American port industry were not prepared for it. The technologies (computing power, sensors and wireless network) and knowledge of operating unmanned terminal were insufficient, and duplicating an experimental automated terminal was considered taking too much time. Also, the controversy of automation threating employment existed since then and is still prevalent today.

The brownfield ECT Delta has laid the foundation of Rotterdam's position of a pioneering port in the facilitation of automation, and it is further solidified by the opening of Euromax and Maasvlakte 2. Both APM and RWG terminals at Maasvlakte 2 are considered as the paradigm of greenfield fully automated container terminal of the current era.

However, the development of automated terminals was not linear. The port industry did not follow ECT Delta's path at a fast pace. Before ECT, there was no previous example of automated port, and the industry has no experience in handling advanced equipment. Gradual implementation of automated yard operation was seen after ECT Delta, spreading from Europe to Asia and North America, but the appearance of second full automation project was nearly a decade later in CTA Hamburg. It was not until this decade that port operators started to proactively push for full automation (Barnard, 2015; Martín-Soberón et al., 2014). This could be explained from two factors. From an infrastructure perspective, the technologies needed for automated quay crane was not matured before 2010s, and it is risk-taking to be innovative on the most expensive superstructure in the terminal (Zrnić, Petković and Bošnjak, 2005). From an economic perspective, the growth of cargo throughput exploded in the first decade of 21st century, which has a fundamental implication to the container shipping industry, and the marine traffic was mostly concentrated in Europe, Asia and North America. Because of economies of scale, the capacity of container vessels has grown threefold as they used to be in the 90s. Currently, the capacity of largest container vessel had exceeded 20 thousand TEU, which is likely to enter a stagnated growth in the upcoming years (Malchow, 2017).

The port industry had a lot of discussion on adoption of advanced technology, an important background that slows the pace of automation is the depressed container freight rate as a result of sluggish growth of container shipping demand and uncertainty of international politics. Liners have been deploying ever larger ULCVs, trying to lower the operating cost per unit, which puts stress on the already congested trade routes. (Kim, 2018) It would be risky for terminal operators to invest heavily on automation when the overview of the future is not clear.

Even though fully automated container terminal is still on its way to the 40 moves per hour target, the automated operation is reaching maturity. QQCTN now typically performs 33 moves per hour per crane on average, and sets a world record of 43.23 moves per hour, promising 100% on-schedule performance for 1,100 vessels in 2018, which was very impressive (Navis, 2019). It can also be observed that the container terminal industry had seen an acceleration of automation in the recent decade.

McKinsey’s survey (2018) reported that, while the respondents are not convinced by the current status of automated terminal performance, 80% of them believed that at least half of the greenfield projects will be semi or fully automated. If the challenges are solved, automation still has great potential in near future. The statistics from Rodrigue (2017) concluded that the average land used in greenfield fully automated terminals are significantly larger than the figures of conventional terminals, hinting that major hub ports have the resources and motivation to push for high degree of automation.

2.5 Patterns of port automation

As there are more and more container terminals being automated, there might be some pattern behind terminal automation. For instance, an existing small terminal from developing economies with little throughput is very unlikely to employ expensive automated cranes since there is no urging motivation to drive up the productivity and abandon the skilful cheap labour, but this might not be the case if the design starts from scratch. Therefore, we want to find in what situation does automation suits the terminal.

2.5.1 Regional factor

From the brief list of semi and fully automated terminal (Martín-Soberón et al., 2014; Li, 2016), the majority of automated terminals are concentrated in Asia and Europe, around 21% from US and Australia. The pattern matches with the deployment of ULVC, which is also concentrated on the Asia-Europe route. Apart from one semi-automated terminal from Indonesia, all automated terminals are located in hub port of developed economies and rich countries like UAE and China, hinting that large-scale automation is dependent on access to capital and supported by sufficient cargo throughput.

2.5.2 Terminal context characteristics

2.5.2.1 Terminal capacity

To ensure the return on the high investment of automated equipment, port operators should maintain a high utilization rate of the cranes, which means there must be enough containers to feed these cranes and AGVs. The maximum capacity of a terminal is subjected to the quay length and total area of container yard (Martín-

Soberón, 2012). Quay length decided the maximum number of quay cranes deployable on the quayside, and the yard area decided the storage space of containers. They are the fundamental figures that can hardly be changed once settled.

2.5.2.1 Greenfield terminal

A greenfield project means building a container terminal from scratch. There will be no infrastructure available for utilization. All the infrastructure, equipment, labour and management system will have to build up from ground up, and the investment varies greatly depending on the geographical condition of the terminal location. For example, the whole Maasvlakte 2 expansion project was based on land reclamation (NASA, 2010). There was not even land for utilization, not to mention existing infrastructure.

While the timeframe and investment needed for a greenfield project is much longer and larger, there is no constraint from the previous infrastructure, and there is no need to consider the disruption of ongoing operation. The focus will be on the amount of investment and the actual productivity of the automated terminal. Therefore, the most progressive automated terminal designs are often greenfield projects (Hendriks, 2014). The investment needed for automated equipment and digital infrastructure is larger than the equipment cost of conventional port, but there is no need to consider the separation between human and machine, and hence allowing more cargo space for container yard, which resulted in higher land utilization, and possibly less cost on land. Moreover, what really matters about an automated terminal is the lower operating cost and high productivity in actual operation, which might shorten the time to generate profit.

2.5.2.2 Brownfield terminal

A brownfield project means an automated terminal build upon an existing infrastructure that is currently in operation, and its disruption on ongoing operations is inevitable. The focus of brownfield project is to minimize the disruption while reaching business objective on budget and performance (Martin-Soberón et al., 2014).

In terms of upgrading a brownfield terminal, the automated equipment is not subjected to the layout of the container terminal. Both perpendicular and parallel layout of container yards are compatible for an automation upgrade. The choice of automated yard cranes is mostly concerned with the business of the terminal, as

Cederqvist (2011) suggested that cantilever RMG can replace RTG in almost any terminal, and horizontal transport equipment varies from conventional trucks, AGVs to automated straddle carriers. They have different requirement for investment, operation, and different level of disruption of ongoing operation. More importantly, they represent different process design, which resulted various productivity levels and operation cost levels.

A case study of Yuanhai Terminal (Yue, Yin and Tang, 2015) has compared the characteristics of perpendicular layout and parallel layout. As a brownfield project, the existing layout of the terminal is parallel, and the cost of automation transformation project keeping the original layout is 19% cheaper than changing the layout to a perpendicular one, owing to less ARMG and AGV needed, and shorter construction period. The case study also mentioned that the operating cost of a perpendicular layout is lower than the parallel layout, because of the optimization of AGV route design.

The transformation project of Yuanhai Terminal avoided the berths that are in operation. To avoid disrupting the ongoing operations, a gradual upgrade of automated equipment would be more feasible and more profitable for the brownfield project. The white paper from Kalmar explained a gradual process of transition towards semi-automated and full automation yard automation with minimum disruption of ongoing operations, which requires careful planning before the transformation started. The difference with Yuanhai Terminal’s option of ASC is that auto-RTG takes shorter conversion time, around 12-18 months, whereas conversion to ASC might take up to 5 years and almost certainly lowers the productivity of quay operation (Alho, Pettersson and Happa-Aho, 2018; Sisson, 2019).

It would be cheaper and easier to upgrade the horizontal transport and yard operation sectors to semi-automated ones, as quay cranes are usually the most capital-intensive superstructure of the terminal, even though they are compatible for automation transformation (Rodrigue, 2017). Additionally, vastly improvement of productivity on the quayside will bring immense pressure on yard and gate operation (Dynamar, 2015). Consequently, the automation upgrade of yard operation should be prioritized, followed by horizontal transport, and eventually the quay operation.

2.5.3 Hypothesis of terminal patterns

1. A greenfield project is more likely to become fully automated, because there is

no burden of ongoing operations, and the layout of container yard is not constrained by the existing facilities, which allows more flexibility in the design stage, consequently a wider range of equipment combination is possible. This could lead to a larger amount of investment, but the optimization of terminal automation would lead to better productivity and lower operating cost in the long run. Eventually, the profitability of operation will be higher in the long run. In contrast, a brownfield project based upon an existing container terminal is more likely to become semi-automated, because the profitability will be affected by the ongoing operation of the existing terminal, and the layout of the original terminal cannot be changed, otherwise it will abort the ongoing operation. The gradual replacement of the manual cargo handling equipment would not, or to a little extent, affect the ongoing operation, which is able to generate revenue and shorten the period needed to generate profit.

2. Terminals with limited yard space and quay length are more motivated to introduce automation, since it has better utilization of land area, and the terminal with sufficient terminal throughput will need better productivity to mitigate port congestion.

3. Younger terminals are more likely to have a higher automation level since newer terminals are designed to handle larger container vessels, improved productivity is required to reduce turnaround time. Experience from previous automated terminals can be considered. Also, newer technologies like automated quay crane become accessible, which might drive up the level of automation.

3 Methodology

3.1 Research Design

3.1.1 Research approach

Induction and Deduction

Induction and Deduction are the two basic approaches to carry out a study, which have a different emphasis on the expectation. A deduction is based on a concept or theory, a prove and support it by tracing it down to details, whereas induction follows an opposite way that relies on collecting data and phenomenon, and develop a theory on this basis. A deductive approach is more appropriate in testing concept, and an inductive approach is a better option in theory building (Grey, 2009).

3.1.1.1 Selection of Research Approach

The main research method applied in this thesis is multiple case study, which requires the collection of a set of data that are similar in some way, and the selected cases shall be representative for a phenomenon (Stake, 2006). As the purpose of this thesis is to comprehend specific terminal data from major shipping markets and try to find out the patterns of terminal context characteristic behind port automation, the selected ports should be typical in the field of the automated container port. There is no existing study on this specific topic, which makes theory testing unavailable. Hence, this thesis will take an induction approach to build a theory on the pattern of port automation.

The existing studies provided the driving factors of automation, but these factors are not reflected on characteristics like size and capacity of the terminal, and these data are collected to provide a profile of current major ports, which could be considered to be a descriptive study. As we try to find out the relation between the terminal context characteristics and the degree of automation, it has the elements of an explanatory study. With two research design combined, this thesis will be a descripto-explanatory study (Saunders et al., 2009).

3.1.1.2 Validity

Validity represents the accuracy of data collection methods in measure as intended, and whether the findings describe what researchers expected to find (Saunders et al., 2016). Since automation is not applicable to all container terminals, as it needs support from investment, equipment and engineers. Using purposive sampling is to filter the smaller terminals that do not meet the requirement for automation.

Reliability refers to the accuracy of data itself, whether the same conclusion can be replicated from raw data processed by other researchers or similar observations (Saunders et al., 2016).

The sources of the data are mostly the official websites, reports or factsheets of the terminal operators. The accessibility of some terminal data is limited as they are not published on public sources, and part of them are collected from credible sources like shareholders of the terminal operator, government sources and maritime news sites. For instance, the terminals operated by HHLA in Hamburg does not provide their terminal capacity figures, nor do they report the throughput of each terminal in any of their official materials, including press release and commercial reports. Eventually, the numbers used are acquired from credible news reported the expansion of the Hamburg port, which mentioned the designed terminal capacity after 2012 (Cardebring, 2009).

Some official sources have a separate scope of the terminals, creating confusion on the operation range of the operator. Therefore, while this thesis tried to include all the terminals of the selected ports, the information is still incomplete. Only the terminals with complete information and credible source will be taken as data points. Although some terminals have provided their terminal capacity officially, the precision of the terminal capacity is questionable, as some terminal handles throughput twice as much as its terminal capacity, while reports of congestion are rarely reported.

3.1.1.3 Generalisation

The purposive sampling technique employed in this thesis is only focusing on top 20 mega container ports, while they are highly representative, the differences in port infrastructure, shipping demand, labour cost and access to capital and technology vary greatly among coastal countries. If there is any statistical conclusion to be drawn on this thesis, the generalisation is rather weak, as only part of the mentioned differences is taken into account.

3.1.1.4 Analysis technique

In order to find out the relation between the pattern of terminal context characteristics and the level of automation, a regression analysis can be employed to test the relationship between the level of automation and different elements, as the result should reveal the power of each elements if there is solid statistical relation. It depends on the overall fitment of the model as well as the P-value of each elements. Because of the characteristics of the data, both binary logistics regression and linear regression will be employed for better accuracy, owing to the limited number of samples.

As there are no existing categories that can be referred to, a category of automation was developed on the existing literature, but some modification is applied to the categories to accommodate the latest practice of terminal automation. The categories are coded as dummy variables for process in a regression analysis. Other variables are continuous numerical data.

3.2 Research strategy

3.3 Sampling technique

3.3.1 Purposive sampling

This sampling technique represents a non-probability sampling, it depends on the judgement of the researcher to select appropriate cases that fit the context. It usually comprises a small number of critical cases, rather than large amount of quantitative data. The drawback of purposive sampling is that cannot be sure whether the selected sample is typical or not. Selviaridis and Norrman (2015) applied purposive sampling in their study of performance-based contract, in order to select the most representative cases that are experienced and fits the context.

3.3.2 Selection of sampling technique

As we try to find out the pattern of container terminal in the implementation of automation, the sampling technique in selection of port is purposive sampling (Saunders et al., 2016). The reason of using non-probability sample is that terminal automation is yet to become a norm in every container terminal in the world, and when it comes to the smaller scope of automated cargo handling, the penetration rate in top 20 mega container ports is common but far from full coverage. In this case, random sampling is not appropriate in selecting samples of terminal automation.

According to brief observation of Martin-Soberon’s (2014) list of automated terminals, busy mega ports are more likely to have the investment and technology as well as the motivation to facilitate automation. The standard applied in this purposive sampling is typical case sampling because the aim of this thesis is to find out the pattern of terminal context characteristics behind automation, and the phenomenon of automation mostly occurs in major shipping markets, i.e. Europe, Asia and North America. Selection of ports is concentrated in the global top 20 ports from each major shipping markets, which ensure the samples are big enough. In our case, we referred to the major shipping routes of the 3 alliances (i.e. 2M, Ocean Alliance and THE Alliance) that represent the majority of container shipping capacity, and select the most frequently appeared ports on east-west service, trans-Pacific service and trans-Atlantic service, which ensure the ports selected are busy enough. The 3 largest European ports Hamburg, Rotterdam and Antwerp appear on almost every Asia-Europe and trans-Atlantic service. Los Angeles and Long Beach is usually the first stop on the west coast US. Among the 3 largest ports from Asia, Shanghai is the largest and most frequently called port among all routes. Qingdao, Xiamen and Busan frequently appear as the first call port of east-west and trans-Pacific service. The aforementioned ports all have certain degree of automation.

3.4 Data collection

3.4.1 Primary data and secondary data

A variety of types of data are available for research, and researcher has to decide on which type of data to use, which is dependent on the aim and objective of the study. Primary data is the fresh data collected from field, which aims to solve specific issues, while secondary data is collected from existing database (Sekaran and Bougie, 2013). Primary data is usually more up to date, as researcher needs to design questionnaires or carry out interviews. Finding an appropriate focus group could be very crucial for the depth of study (Saunders et al., 2009). However, it could take a lot of time and money to collect first-hand data. Secondary data can be extracted from a large variety of data source, like government statistics, published articles or reports of companies, etc. (Sekaran and Bougie, 2013). Considering the difficulty and variety of types of data, secondary data is more feasible, as they can be collected from multiple sources.

3.4.2 Secondary data collection

Antwerp, Rotterdam and Hamburg are the only 3 top 20 container ports among European ports, and because of their hub position, they appear on most Asia-Europe service. Moreover, the three ports are the pioneers in both full automation and semi-automation. The data is mostly collected from the official sites of each terminal operators, except for HHLA. The terminal capacity is derived from their development plan disclosed by HKTDC (2009).

The selection of Asian ports is mostly focused on the automation level, only the ports with the adoption of automation are considered, since the majority of top 20 container ports are located in Asia, and having too many samples of conventional terminals might disturb the accuracy of model that predicts the automation level. Shanghai, Xiamen, Qingdao and Busan are the major top 20 ports that frequently appear on Asia-Europe and trans-Pacific service that has emerging automated technology. It should be noted that, even though the port of Singapore is the second-largest container port in the world that is partially automated, the source of data is fragmented, and there was not enough time to acquire the data from PSA. Eventually, Singapore is excluded from the dataset. Most of the terminal data is acquired from a Chinese academic publication of automated terminal design (Yang, Mi and Tao, 2016), while the data of some of the latest automated terminals are collected from official sites of terminal operators. Some terminal data such as age and greenfield/brownfield status requires extra information from newspaper and government reports.

When it comes to North America, only Los Angeles and Long Beach fit in the range of top 20 container ports, and they are the hub ports of trans-Pacific service that has been pushing forward in the field of automation. The data is mostly collected from port authorities and terminal operators.

However, the number of automated container terminals from the sampling criteria above is too small for statistical analysis, the analysis has to involve more automated terminals to be more statistically accurate. The terminals involved are selected from the automated terminals listed by Martin-Soberón et al (2014).

There are several groups of quantitative and qualitative data we need to collect. Some are numeric data that could be processed directly, and some needs to be coded as categorical data for further processing.

The quay length is quite straight-forward because it is provided in a standard unit on the official site of that terminal. They are collected for reason that they can reflect the number of berths and quay cranes on the quayside, which can affect quayside productivity. Using total yard area would be more accurate in evaluation of storage space for container yard, but it is not always provided by every terminal, and considering that the cargo handling equipment and trucks/AGVs need space to manoeuvre, using total terminal area would still be credible. They are introduced to test the hypothesis that terminals with limited space are more likely to be automated, as they might have great impact on yard capacity, and better terminal productivity is needed to improve the turnaround of containers.

The age of terminal is introduced because younger terminals would have better infrastructure condition and access to automated technology, which is also a component from the hypothesis.

The regional factor is also taken into account since it has been mentioned in the patterns of automation that the automated terminals are mostly concentrated in Europe and Asia. It is coded as nominal number in the logistics regression analysis of SPSS and is coded as separate categories in the linear regression analysis in Excel.

The quay length, total area and terminal capacity are numeric data that can be directly used in regression analysis. The terminals data input will be categorised according to a different level of automation. The level of automation will be coded from 0 (no automation) to 4 (full automation). As mentioned from literature review, Rodrigue has segregated semi-automation in 4 sectors -- quay operation, horizontal transport (denote as HT in the table), yard operations and gate operation. According to the number of sectors that have applied automated equipment, the degree of automation is thereby decided. All 4 sectors automated means full automation.

For automated and semi-automated terminals, it needs to be identified whether they are greenfield or brownfield project since it is assumed in hypothesis that greenfield terminals are more likely to be fully automated. The value input in greenfield column is nominal binary code, 1 denotes the greenfield status of the terminal, and 0 means brownfield status. The binary code is also used in noting which part of terminal operation is automated, and the automated part is highlighted in green columns.

There are certain limits to the terminal patterns. The recently built terminals usually have no issue with the age or greenfield/brownfield status, but the older terminals may have started operation way ahead of the concession of the current operator. Considering that many new operators chose to upgrade the existing infrastructure and equipment, the starting point of terminal age shall be the date of concession to the current operator.

Additionally, separate data input of automated terminals is introduced, as the number of automated terminals from original sampling is way too small to conduct logistic regression, which aims to find out the relation between terminal context characteristics and automation level.

3.5 Tables of terminal data

Table 1: Port of Rotterdam

Rotterdam	Age	Region	Quay Length	Area	Greenfield	Quay	HT	Yard	Gate	Level	Capacity
ECT Delta	34	Europe	3600	265	0	0	1	1	1	3	6,200,000
Euromax	9	Europe	1500	84	1	0	1	1	1	3	5,000,000
APMT-R	19	Europe	1600	100	0	0	0	0	0	0	2,900,000
APMT-MV2	4	Europe	1000	86	1	1	1	1	1	4	2,700,000
RWG	4	Europe	1700	108	1	1	1	1	1	4	2,400,000

Source: (ECT, 2019) (APM Terminals, 2019) (Port of Rotterdam, 2019)

Table 2: Port of Antwerp

Antwerp	Age	Region	Quay Length	Area	Greenfield	Quay	HT	Yard	Gate	Level	Capacity
MPET	14	Europe	3700	240	1	0	0	0	0	0	9,000,000
PSA Noordzee	22	Europe	1125	79	0	1	0	0	0	1	2,200,000
PSA Europa	29	Europe	1180	72	0	0	0	0	0	0	1,800,000
Antwerp Gateway	14	Europe	1660	107	0	0	0	1	0	1	2,800,000

Source: (PSA Antwerp, 2019) (DP World, 2019)

Table 3: Port of Hamburg

Hamburg	Age	Region	Quay Length	Area	Greenfield	Quay	HT	Yard	Gate	Level	Capacity
Eurogate	20	Europe	2080	140	0	0	1	0	0	1	4,100,000
HHLA CTA	17	Europe	1400	100	1	0	1	1	0	2	3,000,000
HHLA CTT	23	Europe	1205	60	0	0	0	0	0	0	2,000,000
HHLA CTB	52	Europe	2850	140	1	0	0	1	0	1	5,200,000

Source: (Eurogate, 2019) (HHLA, 2019) (HKTDC, 2009)

Table 4: Port of Qingdao

Qingdao	Age	Region	Quay Length	Area	Greenfield	Quay	HT	Yard	Gate	Level	Capacity
QQCT	32	Asia	4073	225	1	0	1	1	0	2	6,500,000
QQCTU	10	Asia	677	210	1	0	0	0	0	0	1,500,000
QQCTN Phase I	2	Asia	2088	164	1	1	1	1	1	4	5,200,000

Source: (Yang, Mi and Tao, 2016) (QQCTN, 2018)

Table 5: Port of Shanghai

Shanghai	Age	Region	Quay Length	Area	Greenfield	Quay	HT	Yard	Gate	Level	Capacity
Yangshan Phase I&II	14	Asia	3000	139	1	0	0	0	0	0	4,300,000
Yangshan Phase III	12	Asia	2600	238	1	1	0	0	0	1	5,000,000
Yangshan Phase IV	5	Asia	2350	223	1	1	1	1	1	4	4,000,000
Mingdong Terminal	14	Asia	2118	163	1	0	0	0	0	0	5,250,000
Hudong Terminal	17	Asia	1250	155	1	0	0	0	0	0	1,800,000
Pudong Terminal	16	Asia	900	50	1	0	0	0	0	0	1,350,000
Zhendong Terminal	19	Asia	1566	108	0	0	0	1	0	1	2,500,000

Source: (Yang, Mi and Tao, 2016) (Swissnex China, 2018)

Table 6: Port of Xiamen

Xiamen	Age	Region	Quay Length	Area	Greenfield	Quay	HT	Yard	Gate	Level	Capacity
Songyu	12	Asia	1246	35	1	0	0	0	0	0	1,800,000
XHDCT (Semi-automa	8	Asia	760	29.8	1	1	0	0	0	1	1,300,000
Xiangyu	22	Asia	976	60	1	0	0	0	0	0	1,200,000
Guomao	12	Asia	550	8.5	1	0	0	0	0	0	400,000
Yuanhai	8	Asia	1500	122	0	1	1	1	1	4	2,600,000

Source: (Yang, Mi and Tao, 2016) (XSCT, 2017) (Xiangyu Group, 2003) (ITG, 2005) (Yuanhai Terminal, 2011) (Haicang Gov, 2016)

Table 7: Port of Busan

Busan	Age	Region	Quay Length	Area	Greenfield	Quay	HT	Yard	Gate	Level	Capacity
Gamman	19	Asia	1400	75	0	0	0	0	0	0	1,280,000
Singamman	17	Asia	826	30.8	0	0	0	0	0	0	650,000
HPNT	10	Asia	1150	55	1	0	0	1	1	2	2,500,000
PNC	10	Asia	2000	120	1	0	0	1	1	2	5,000,000
PNIT (PNIT official)	11	Asia	1200	84	1	0	0	1	0	1	2,500,000

Source: (Ship Technology, 2019) (Dongbu Express, 2019) (PSA, n.d.) (PNC Port, 2019) (Longshore Shipping News, 2010) (PNIT, 2019)

Table 8: Port of Los Angeles

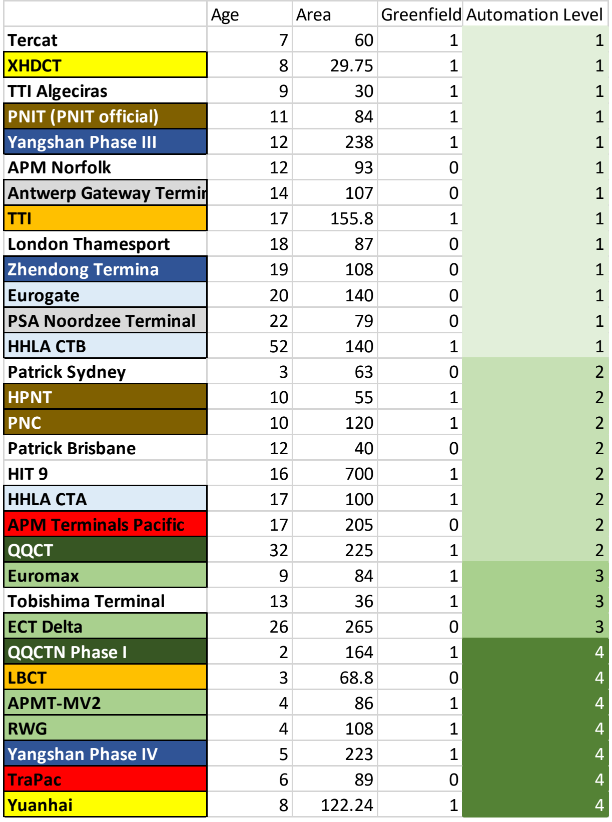
Los Angeles	Age	Region	Quay Length	Area	Greenfield	Quay	HT	Yard	Gate	Level	Capacity
APM Terminals Pacifi	17	NA	2200	205	0	1	1	0	0	2	4,400,000
Fenix Marine	22	NA	1219	118	1	0	0	0	0	0	2,400,000
TraPac	32	NA	1411	89	0	1	1	1	1	4	1,800,000
Yusen Terminals	28	NA	1767	75	1	0	0	0	0	0	1,913,000
WBCT China Shipping	14	NA	762	53.4	0	0	0	0	0	0	1,500,000

(APM Terminals, 2019) (Fenix Marine, 2019)

Table 9: Port of Long Beach

Long Beach	Age	Region	Quay Length	Area	Greenfield	Quay	HT	Yard	Gate	Level	Capacity
LBCT	3	NA	1280	68.8	0	1	1	1	1	4	3,300,000
TTI	17	NA	1524	156	1	0	0	0	1	1	3,000,000

(Port of Long Beach, 2019) (TTI, 2019) (Port of Los Angeles, 2019)



	Age	Area	Greenfield	Automation Level
Tercat	7	60	1	1
XHDCT	8	29.75	1	1
TTI Algeciras	9	30	1	1
PNIT (PNIT official)	11	84	1	1
Yangshan Phase III	12	238	1	1
APM Norfolk	12	93	0	1
Antwerp Gateway Termi	14	107	0	1
TTI	17	155.8	1	1
London Thamesport	18	87	0	1
Zhendong Termina	19	108	0	1
Eurogate	20	140	0	1
PSA Noordzee Terminal	22	79	0	1
HHLA CTB	52	140	1	1
Patrick Sydney	3	63	0	2
HPNT	10	55	1	2
PNC	10	120	1	2
Patrick Brisbane	12	40	0	2
HIT 9	16	700	1	2
HHLA CTA	17	100	1	2
APM Terminals Pacific	17	205	0	2
QQCT	32	225	1	2
Euromax	9	84	1	3
Tobishima Terminal	13	36	1	3
ECT Delta	26	265	0	3
QQCTN Phase I	2	164	1	4
LBCT	3	68.8	0	4
APMT-MV2	4	86	1	4
RWG	4	108	1	4
Yangshan Phase IV	5	223	1	4
TraPac	6	89	0	4
Yuanhai	8	122.24	1	4

Table 10: List of Automated Terminal Ranked in automation level Extra automated terminals in white column on the left.

Source:
(HPH Thamesport, 2019)
(HPH HIT, 2019)
(Patrick Terminals, 2019)
(Tobishima Terminal, 2019)
(APM, 2019)
(NPTC, 2019)
(TTI, 2019)
(Tratos, 2019)

4. Analysis and result

4.1 Introduction

To establish the relationship between terminal context characteristics and the degree of automation, a regression analysis will be employed to test the strength of the relationship between terminal context characteristics and level of automation. Since the level of automation is nominal categorical data that is not continuous, a logistic regression model is employed to test on automated terminals to find out how terminal context characteristics affect level of automation. From another angle, a linear regression analysis is employed to test the relationship between terminal context characteristics and terminal capacity, in order to find out how automation level and other terminal context characteristics affect the terminal capacity, which would be useful for explaining whether automation, and more specifically, which sector of automation, is an effective tool in improving terminal capacity.

4.2 Data analysis technique

Regression analysis is employed for the purpose of explaining how dependent variable (i.e. the automation level) reacts to the changes of independent variables (i.e. terminal characteristics). But the selection of regression methods is dependent on the characteristics of the actual data.

Since the degree of automation is a dummy variable that is not continuous, using it as the dependent variable will create a scatter plot like this (figure 1), which shows no linear relation at all, whereas the scatter plot of continuous terminal capacity as the dependent variable appears to be linear (figure 2).

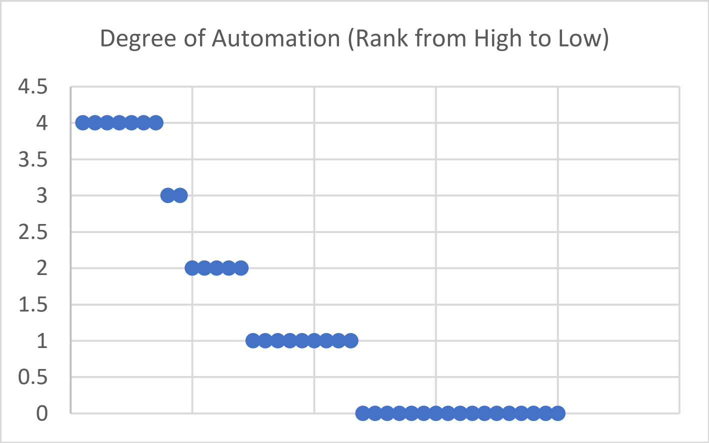
To predict the automation level, a logistics regression is more suitable for a categorical dependent variable. The predictors are age, greenfield status and total area, and the response is the automation level. To simplify the model building process, a binomial logistics regression is employed, and the automation level is coded as binomial category – full or semi-automation. Consequently, the selection of sample is limited to automated terminals, and the criteria that define full automation is that all 4 sectors of terminal operations are automated. But the first attempt with original dataset has shown no statistical significance. Therefore, a separate logistic regression was conducted with additional samples of automated terminals that are outside the top 20 container ports range.

The method requires that the predictors must be independent of each other, and having additional variables would need more samples for better accuracy, and eventually only age, greenfield status, region and total area suit for this criteria. Initially, a cutoff of 0.6 is applied to test the hypothesis that greenfield terminals are more likely to be fully automated, as around 60% of the automated terminals are greenfield terminal. However, the researcher is not very familiar with the logistics regression analysis model, a default cutoff of 0.5 is retained, and the result suggests that the model with 0.5 cutoff has a better fitment than the one with 0.6 cutoff.

The linear regression analysis is a supplement of the logistics regression analysis. Other than proving that the level of automation is correlated to terminal context characteristics, this analysis aims to find out whether terminal automation is correlated to terminal capacity, and the power of automation in this model, which might give a clue on the relation between automation and terminal capacity. This could give a hint on whether terminal automation is attractive to congested terminals.

The scatter plot of terminal capacity presented below (figure 2) was produced on the basis of raw data input. The regression analysis will be conducted 3 times, and the raw data will be filtered and manipulated to see how terminal context characteristics might affect the building of the model. The first time will include the region of the terminals with separated sectors of automation considered. The second time will exclude regional factor while still using separated sectors of automation. The third regression analysis will use combined automation level. Other elements such as age, area and greenfield status remain the same in all regression analysis.

Figure 1: Scatter plot of degree of automation



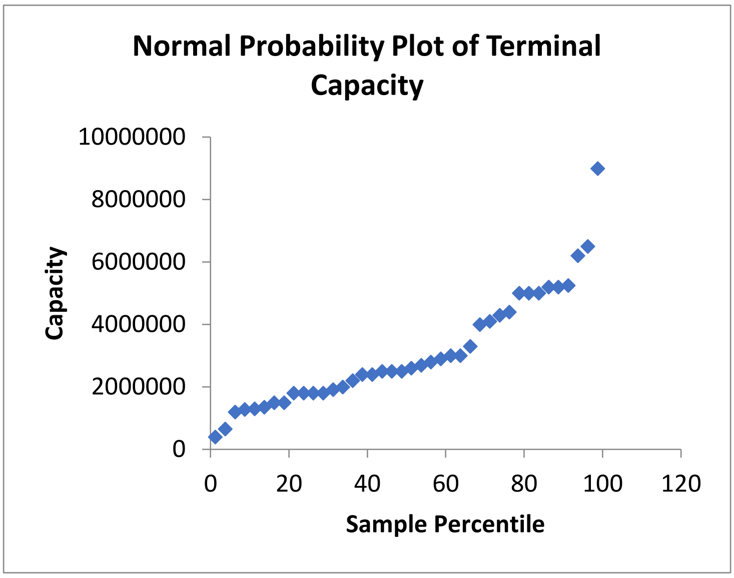


Figure 2: Scatter plot of terminal capacity

4.3 Results of regression analysis

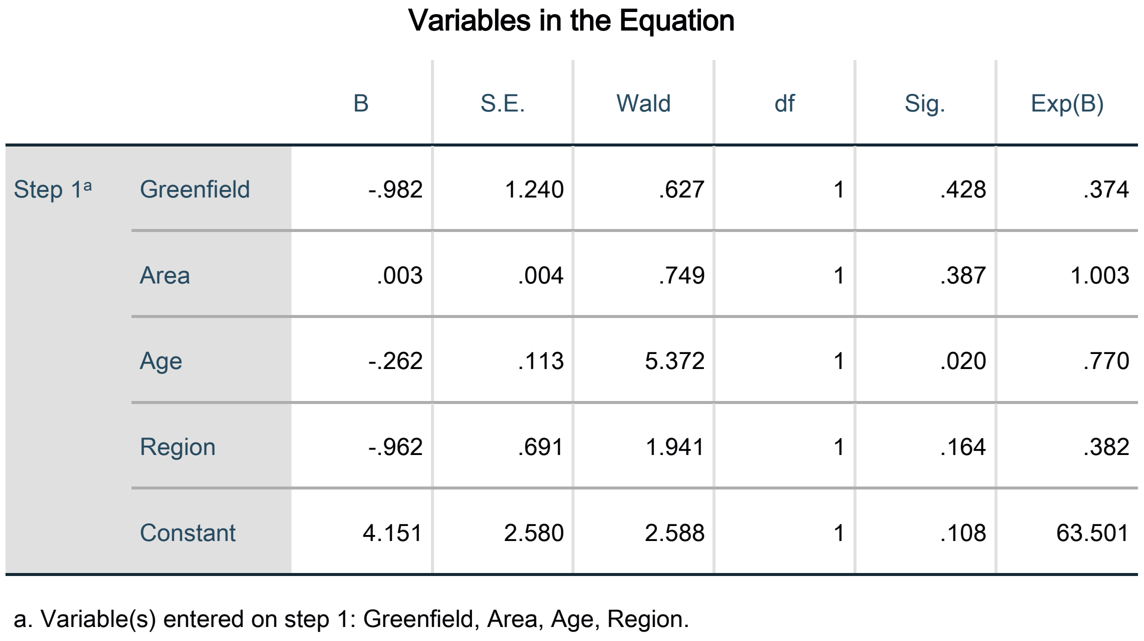
4.3.1 Result of logistic regression on automated terminals

Table 11: Result of logistic regression on automated terminals

Classification Table[a]

	Observed		Predicted		
			Automation		Percentage Correct
			Semi-Automation	Full-Automation	
Step 1	Automation	Semi-Automation	20	1	95.2
		Full-Automation	4	6	60.0
	Overall Percentage				83.9

a. The cut value is .500



Variables in the Equation

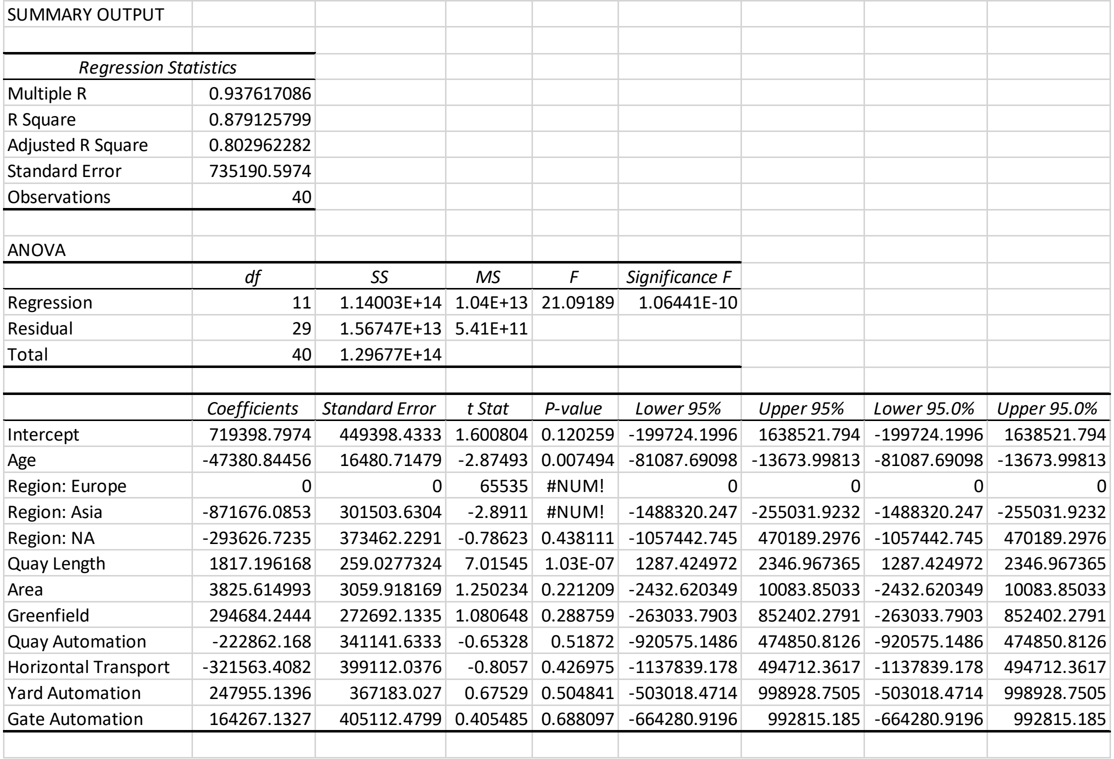
		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	Greenfield	-.982	1.240	.627	1	.428	.374
	Area	.003	.004	.749	1	.387	1.003
	Age	-.262	.113	5.372	1	.020	.770
	Region	-.962	.691	1.941	1	.164	.382
	Constant	4.151	2.580	2.588	1	.108	63.501

a. Variable(s) entered on step 1: Greenfield, Area, Age, Region.

This is the result of binary logistic regression. The model can be expressed as:

$$\text{possibility of full automation}=\frac{1}{1+e^{-(4.151-0.262*Age-0.982*Greenfield+0.003*Area-0.962*Region)}}$$

4.3.2 Result of linear regression analysis on original data



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.937617086
R Square	0.879125799
Adjusted R Square	0.802962282
Standard Error	735190.5974
Observations	40

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	11	1.14003E+14	1.04E+13	21.09189	1.06441E-10
Residual	29	1.56747E+13	5.41E+11		
Total	40	1.29677E+14			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	719398.7974	449398.4333	1.600804	0.120259	-199724.1996	1638521.794	-199724.1996	1638521.794
Age	-47380.84456	16480.71479	-2.87493	0.007494	-81087.69098	-13673.99813	-81087.69098	-13673.99813
Region: Europe	0	0	65535	#NUM!	0	0	0	0
Region: Asia	-871676.0853	301503.6304	-2.8911	#NUM!	-1488320.247	-255031.9232	-1488320.247	-255031.9232
Region: NA	-293626.7235	373462.2291	-0.78623	0.438111	-1057442.745	470189.2976	-1057442.745	470189.2976
Quay Length	1817.196168	259.0277324	7.01545	1.03E-07	1287.424972	2346.967365	1287.424972	2346.967365
Area	3825.614993	3059.918169	1.250234	0.221209	-2432.620349	10083.85033	-2432.620349	10083.85033
Greenfield	294684.2444	272692.1335	1.080648	0.288759	-263033.7903	852402.2791	-263033.7903	852402.2791
Quay Automation	-222862.168	341141.6333	-0.65328	0.51872	-920575.1486	474850.8126	-920575.1486	474850.8126
Horizontal Transport	-321563.4082	399112.0376	-0.8057	0.426975	-1137839.178	494712.3617	-1137839.178	494712.3617
Yard Automation	247955.1396	367183.027	0.67529	0.504841	-503018.4714	998928.7505	-503018.4714	998928.7505
Gate Automation	164267.1327	405112.4799	0.405485	0.688097	-664280.9196	992815.185	-664280.9196	992815.185

Table 12: Result of first linear regression

This is the first attempt of regression analysis with every element from assumed terminal context characteristic included, and used binary code in the categorization of region and level of automation. The model can be expressed as:

Terminal Capacity = 719398.7974 – 47380.84456*Age – 871676.0853*Region:Asia – 293626.7235*Region:NA + 1817.196168*Quay Length + 3825.614993*Area + 294684.2444*Greenfield – 222862.168*Quay Automation – 321563.4082*Horizontal Transport + 247955.1396*Yard Automation + 164267.1327*Gate Automation

Table 13: Result of second linear regression

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.918616
R Square	0.843856
Adjusted R Square	0.80356
Standard Error	808191.8
Observations	40

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	8	1.09429E+14	1.37E+13	20.94178	1.74854E-10
Residual	31	2.02484E+13	6.53E+11		
Total	39	1.29677E+14			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	105515.5	431010.3858	0.24481	0.808217	-773535.9815	984566.9733	-773535.9815	984566.9733
Age	-33892	16789.22804	-2.01868	0.052243	-68133.87398	349.8387048	-68133.87398	349.8387048
Quay Length	1827.381	281.5495871	6.490442	3.06E-07	1253.157021	2401.605359	1253.157021	2401.605359
Area	3299.754	3354.618458	0.983645	0.332905	-3542.035628	10141.54328	-3542.035628	10141.54328
Greenfield	105875.4	290880.0769	0.363983	0.718341	-487378.3867	699129.2693	-487378.3867	699129.2693
Quay Automation	-297136	371539.8222	-0.79974	0.429947	-1054896.065	460624.8621	-1054896.065	460624.8621
Horizontal Transport	-21762.7	422379.5645	-0.05152	0.959239	-883211.4928	839686.1096	-883211.4928	839686.1096
Yard Automation	133722.1	382672.1555	0.349443	0.72912	-646742.9236	914187.0896	-646742.9236	914187.0896
Gate Automation	285096.8	426766.1824	0.66804	0.509052	-585298.5727	1155492.162	-585298.5727	1155492.162

This is the second attempt of regression analysis without considering the regional factor of container terminals, while the categorization of the degree of automation still remains as binary code.

The model can be expressed as:

Terminal Capacity = 105515.5 – 33892*Age + 1827.381*Quay Length + 3299.754*Area + 105875.4*Greenfield – 297136*Quay Automation – 21762.7*Horizontal Transport + 133722.1*Yard Automation + 285096.8*Gate Automation

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.914737769
R Square	0.836745187
Adjusted R Square	0.812737126
Standard Error	789088.4271
Observations	40

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	1.08507E+14	2.17E+13	34.85268	1.89587E-12
Residual	34	2.11705E+13	6.23E+11		
Total	39	1.29677E+14			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	14788.54975	402527.3398	0.036739	0.970908	-803245.4263	832822.5259	-803245.4263	832822.5259
Age	-31286.55058	15839.63818	-1.97521	0.056409	-63476.56829	903.4671346	-63476.56829	903.4671346
Quay Length	1865.598588	266.1283455	7.010146	4.34E-08	1324.760719	2406.436457	1324.760719	2406.436457
Area	2653.674015	3167.806193	0.837701	0.408049	-3784.082728	9091.430758	-3784.082728	9091.430758
Greenfield	178544.5522	273967.9872	0.651699	0.518977	-378225.3854	735314.4899	-378225.3854	735314.4899
Level of Automation	50258.0476	93860.64601	0.535454	0.595821	-140489.7349	241005.8301	-140489.7349	241005.8301

Table 14: Result of third linear regression

This is the third attempt of linear regression without considering regional factors and sectors of automation, the level of automation is the number of combined sectors of automation of each terminal.

The model can be expressed as:

Terminal Capacity = 14788.54975– 31286.5505*Age + 1865.59858*Quay Length + 2653.674*Area + 178544.5522*Greenfield + 50258.0476*Level of Automation

4.4 Components of the analysis result

In the logistic analysis, the overall percentage tells the accuracy of predicting whether a terminal is fully automated or semi-automated, and the exponential B value explains the power of each element involved in the equation.

Multiple R, the square root of R square denotes the correlation coefficient between the independent and dependent variables, which ranges from 1 to -1. 1 means the response in completely positively correlated to the predicts, and -1 means a completely negatively correlated relation. 0 means the independent and dependent variables have no relation.

The adjusted R is used in denoting the percentage of the dependent variable that can be explained by the independent variables. In other words, with (1-adjusted R) we have the exceptions that cannot be explained by independent variables.

The significance F explains the statistical implication of the model. Under a typical 95% confidence interval, the value should be lower than 0.05 to reject the null hypothesis that the model is not overall significant.

The coefficient value of each element in linear regression explains the power of each element in the model.

The P-value of each variable is derived from t-test value, and it indicates the correlation between each independent variable and the dependent variable. Under a confidence interval of 95%, it has to be lower than 0.05 to assume that this independent variable is statistically significant to the dependent variable.

4.5 Result

The overall precision of the prediction in logistic regression is rather high at 83.9%.

While the significance of most elements reveals no relation to the level of automation, the highlight is that the age of the terminal has a P-value lower than 0.05, which falls in the 95% confidence interval. The exponential B indicated that for each year older, the terminal is 0.77 times more likely to be fully automated. In other words, the younger the terminal is, the more likely it will become fully automated.

All 3 linear regression models have shown a very high positive correlation between terminal context characteristics and terminal throughput, only less than 20% of terminal capacity cannot be explained by the elements of specifications. The Goodness-of-Fit of each model is very good, every model has a significance F level far lower than 0.05, which assume they are all statistically significant.

But when it comes to each independent variable, the result is quite different from the hypothesis, and the coefficient of some independent variables do not seem reasonable to the real word situation. The only independent variable that remained stable in all models is the quay length. It has rather similar power in all 3 models, as its changes in coefficient are the smallest among all 3 models, and it has a P-value far lower than 0.05 in all cases, suggesting that it is statistically significant to the terminal capacity.

While the coefficient of the terminal area remains rather stable, the P-value of area range between 0.2 and 0.4. This could be the fact that the terminal area is correlated with the length of quay. An additional regression analysis that excluded the quay length element proved this assumption correct, as it shows a P-value lower than 0.05, but a drop of 0.1 in multiple R was observed. As it still proves important to the accuracy of prediction, terminal area still remains as a part of the model.

The coefficient value of binary-coded regional categories appears to be opposing to the observation of real-life situation. In this model, the regional factor either has no effect on terminal capacity, or has negative effect on terminal capacity. The coefficient of Asian region is even smaller than North American region in negative numbers, which means the negative effect of terminal being in Asia is even more obvious than being in North America. The real-life situation is telling that among the top 20 container ports, only 2 are from North American, and only 3 from Europe, and the rest are all located in Asia. Moreover, the multiple R only reacts slightly after excluding them from the model, and the adjusted R improved slightly, meaning that the regional factors in this model are at least not significant.

The age of the terminal appears to be a negative factor to the terminal capacity. The P-value in the first analysis with regional factor is lower than 0.05, but in the later analysis climbs slightly above 0.05. While it cannot reject the null hypothesis in the second and third analysis, it was proved to be statistically significant to the terminal capacity in the first analysis.

Apart from the judgement of the region of each terminal, binary code is also used in judging whether a terminal is greenfield or brownfield project, and whether certain sector of terminal operation is automated or not. Among them, the elements of greenfield, yard operation and gate operation have positive correlation with terminal capacity, while automation of quay automation and horizontal transport have negative effect on terminal capacity. The P-value of all these elements is too big to become statistically significant.

4.6 Differences between the linear regression results

The 3 attempts of the linear regression statistics are rather similar, all models have a high degree of fitment with multiple R larger than 0.9, and adjusted R larger than 0.8. The significance F of all 3 models are far lower than 0.05.

Between the first and second attempt, apart from the extra regional elements in the first regression analysis, the sign of the predictors remains the same. The coefficient of predictors is vastly different, except for the elements of quay length and yard area.

The second and the third attempt, apart from consolidating categories of automation into a ranked level of automation, the predictors also remained the same sign. Quay length and age predictors between second and third attempts have similar coefficient, the other elements have seen obvious change.

5 Discussion of the result

A linear regression method deployed on predicting automation level is actually unfeasible, since the ranked automation level is not continuous, and the terminal capacity as a predictor is correlated to other elements of terminal context characteristics, the statistics do not give any meaningful result.

To answer the first hypothesis, a separate logistic regression analysis is deployed on greenfield/brownfield status of the terminal and the ranked automation level. The result suggested a very weak relation between the two variables, and the significance F is way too big to be statistically significant under 95% confidence interval, which rejected the hypothesis that greenfield terminal is more likely to be fully automated.

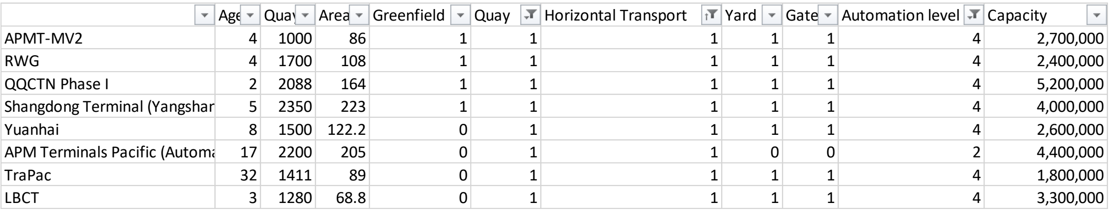
This could be the fact that among the few fully automated terminals, LBCT, TraPac and Yuanhai Terminal are all upgraded on existing infrastructure, hinting that full automation might not be constrained by the greenfield/brownfield status of the terminal. Especially when the criteria on full automation lowered (i.e. only fully automated yard operation considered), an upgrade to full automation would be easier for conventional terminals as there are multiple solutions available for different terminal design.

On the other hand, an Exponential B value of 0.77 on terminal age with a P-value smaller than 0.05 reveals the trend that newer terminals are more likely to become fully automated, which is reasonable. It is mainly caused by the rigorous definition of full automation of this thesis, i.e. all 4 sectors of terminal operations must be automated, and quay automation is necessary to fulfil the criteria of full automation, which has just started getting matured in recent years.

It has been explained in the result that quay length and the correlated total area of the terminal is the determining factors that are positively correlated to the capacity, which can be explained by statistics, and in real-life, a larger terminal space means more cargo handling and storage room.

The age factor generally shows a negative power, indicating that the younger the terminal is, the larger terminal capacity it has. Because of its P-value < 0.05 in the first analysis, this element is partially validated. As container vessels keep getting larger after the 21st century, newly built container terminal must ensure the capability of reception of ULCVs, which requires berth longer than 400m and sufficient yard capacity as a buffer zone. Older terminals that were designed to accommodate smaller container vessels would face the constraint of existing infrastructure.

The interesting part is some elements of terminal automation shows contradicting effect on terminal capacity, rather than all elements being positive to the capacity. The observation of the model is telling that quay and horizontal transport automation have negative effect on terminal capacity, which is hardly acceptable. According to the collected data (Table 15), the terminals that deployed quay and horizontal transportation have a large chance of being a fully automated terminal, which would have better productivity comparing to semi-automated and convention terminals.



	Age	Quay	Area	Greenfield	Quay	Horizontal Transport	Yard	Gate	Automation level	Capacity
APMT-MV2	4	1000	86	1	1	1	1	1	4	2,700,000
RWG	4	1700	108	1	1	1	1	1	4	2,400,000
QQCTN Phase I	2	2088	164	1	1	1	1	1	4	5,200,000
Shangdong Terminal (Yangshar	5	2350	223	1	1	1	1	1	4	4,000,000
Yuanhai	8	1500	122.2	0	1	1	1	1	4	2,600,000
APM Terminals Pacific (Automa	17	2200	205	0	1	1	0	0	2	4,400,000
TraPac	32	1411	89	0	1	1	1	1	4	1,800,000
LBCT	3	1280	68.8	0	1	1	1	1	4	3,300,000

Table 15: List of terminals with quay automation and automated horizontal transport

But when the categorical data of automation is simplified as ranked automation level, the third model indicated that the level is positively correlated to the terminal capacity, the higher the degree is, the more terminal capacity it has. The assumption is that quay automation was not common until recent years and the automated terminals without quay automation that have large capacity to offset the power of quay automation. But still, the ranked automation level did not pass the significance test, we have to reject this item as well.

Generally speaking, while the model fitment is great, all 3 linear regression models did not provide any solid statistical conclusion in explaining the relation between terminal context characteristics and level of automation. The initial idea was that if automation level proved to be highly correlated to terminal capacity, greenfield terminals and congested terminals are more likely to facilitate automation. While this is the case in real-life practice and the linear regression result produced a positive power for the automation level, the hypothesis is still rejected by the validation.

6 Conclusion

Automation of terminal operation is still relatively young comparing to the development of container shipping industry over half a century. The automated cargo handling technique is still on its way to maturity. Back in 1993, ETC Delta made the first step in terminal automation, and with yard horizontal transport automation, it was already a revolutionary step and was considered fully automated. As information technology advancing rapidly after the 21st century, the container terminal operators have seen more options and experience in facilitation of automation. With the access to latest remote-controlled quay crane and gate automation technology, we are getting closer to the territory of truly automated cargo handling.

Even though terminal automation is growing at a rapid pace, the number of automated terminals in comparison to the number of convention terminals is still very small, which is the case even in the top 20 container ports that have the motivation and capability to facilitate automation. Given the limited samples of automated terminals, it is unable to derive the patterns of terminal context characteristic behind automation by using linear regression analysis, and the result of a simple binary logistic regression analysis only revealed that newer automated terminals are more likely to be fully automated, which is partially related to the strict criteria of full automation of this thesis.

The conclusion from logistics regression is that the terminal context characteristics behind terminal automation are hardly predictable, even though the purposive sampling technique has filtered out many conventional terminals, it is still unable derive the level of automation from the age, size, greenfield/brownfield status of the terminal. If the scope of samples is extended to all container terminals, there will be even lesser chance of finding the pattern behind automation. The first and second hypothesis is rejected by the result of logistics regression.

The only meaningful finding is that automated terminals built in recent years have a higher chance of being a fully automated terminal, as the age of automated terminals is the only statistically significant component in the result of logistics regression that has a negative relation to the level of automation. This could be the result of maturity of automated quay crane. The third hypothesis is confirmed by the result of logistics regression analysis.

According to the result of linear regression analysis, we can say that the quay length and yard area is the determining factor in positive relation to the terminal capacity, but we cannot draw a conclusion from the statistics that automation is highly correlated to the terminal capacity, nor can we say that automation would be more likely under certain terminal context characteristics. But with a high fitment of the model, we may still conclude that higher automation level generally has a positive effect towards terminal capacity, which makes automation attractive to congested ports, but further study is needed on actual effect.

The greenfield and brownfield status of the terminal is largely dependent on subjective judging from the terminal history, which might be inaccurate and create disruption to the statistical analysis. Moreover, the greenfield/brownfield status might not be as impactful as expected in the hypothesis. In real-life practise, there is increasing number of fully automated projects that are built upon existing infrastructure, such as the TraPac terminal of Los Angeles. The brownfield automation project is becoming increasingly feasible since transformation of conventional quay and yard crane is coming into maturity. Equipment like eRTG cranes allows automation upgrade without halting operations. Meanwhile, not every terminal operator has the ambition or ability to follow an aggressive automation path, since smooth cooperation between automated equipment and exceptions needs to be handled by experienced engineer team. But nonetheless, the statistic has also told us that full automation is emerging in recent years, and it is likely to gain more prevalence in near future as expected by port operators.

The biggest problem with only a few elements can be explained to be statistically significant is that the sample size is too small to derive any meaningful statistical result. The number of fully automated terminal is too small to conclude the patterns behind the decision of automation. Taking more elements out of the regression analysis lowers the multiple R and adjusted R value, and quay length/area still remains as the only element with P-value < 0.05.

Apart from a small sample size, another flaw of data is not being able to reflect the level of congestion in real-life. Meanwhile, there are some severe mismatches between designed capacity and actual throughput, such as the Yantian terminal of Shenzhen, which has a designed annual capacity of 5 million TEU, while the actual throughput has exceeded 13 million (YICT, 2019). Therefore the second hypothesis was not really addressed.

Due to the time constraint on this thesis, there was not enough time to collect the latest throughput data of each terminal and compare them with the designed capacity. Moreover, the mismatch between designed capacity and throughput does not necessarily mean port congestion, and throughput lower than designed capacity does not mean absence of congestion as well. A better indicator of port congestion is needed for the accuracy of the logistics regression model in this thesis.

6.1 Suggestion for further research

This thesis is based on secondary data collected from desktop research, which cannot ensure the rigorous precision of the terminal data, especially when some data is inaccessible. There are some technical papers that estimated the cost-saving effect of automation but did not really point out the difficulties in keeping the operation smooth, and the time and cost it takes to handle exceptions.

Considering the number of samples needed to produce statistically significant result, regression analysis on all automated terminals might not be appropriate. Instead, a detailed analysis of only a few terminals that are representative of their own situation would be better. For example, detailed information on average vessel waiting time and truck waiting time would offer great help in quantifying the level of port congestion. A rigorous case study of fully automated terminal, such as APM and RWG Maasvlakte II would be favourable. A constant performance tracking on each automated sectors and their relation to port congestion would be more straightforward, and the model would be more accurate with sufficient sample size.

Despite the improvement of terminal productivity, there are some crucial factors that are not considered in this thesis, such as the availability of capital and the cost of labour, because there are some terminals with small throughput in developed countries like Japan and Australia have achieved full automation as well. Also there some unquantifiable factor like the requirement of labour law, which cannot be analysed quantitatively.

After all, whether going for automation or not is determined by multiple factors, and taking all factors into consideration might be unrealistic. Performance monitoring of fully automated container terminals is necessary, and the attitude towards port automation from port operators need to be surveyed and updated on a regular basis. The survey from McKinsey (2018) made a good example in revealing the problems, and further updates are needed to reflect the industry’s opinion on automation’s benefit on cost and performance as the technology matured.

7. References:

1. Alho, T., Pettersson, T. and Happa-Aho, M. (2018). The Path to Automation in an RTG Terminal. [online] Kalmar, p.10. Available at: https://www.kalmarglobal.com/4948ad/globalassets/equipment/rtg-cranes/kalmar-whitepaper-autortg [Accessed 9 Aug. 2019].
2. APM Terminals. (2019). Our Terminal – Los Angeles. [online] https://www.apmterminals.com/en/los-angeles/about/our-terminal [Accessed 26 Aug. 2019]
3. APM Terminals. (2019). Our Terminal - Rotterdam Maasvlakte II. [online] Available at: https://www.apmterminals.com/en/maasvlakte/about/our-terminal [Accessed 17 Aug. 2019].
4. APM Terminals. (2019). Our Terminals. [online] Available at: https://www.apmterminals.com/en/rotterdam/about/our-terminal [Accessed 26 Aug. 2019].
5. Barnard, B. (2015). *APM Terminals to open first fully automated terminal in Rotterdam*. [online] Journal of Commerce. Available at: https://www.joc.com/port-news/european-ports/port-rotterdam/apm-terminals-opens-first-fully-automated-terminal-rotterdam_20150423.html [Accessed 5 Aug. 2019].
6. Bente Elkjaer, Barbara Simpson, (2011), Pragmatism: A lived and living philosophy. What can it offer to contemporary organization theory?, in Haridimos Tsoukas, Robert Chia (ed.) Philosophy and Organization Theory (Research in the Sociology of Organizations, Volume 32) Emerald Group Publishing Limited, pp.55 – 84
7. Böse, J. (2011). *Handbook of terminal planning*. New York: Springer, p.180.
8. Cardebring, P. (2009). Container Terminal Automation – Increasing Efficiency and Cost Effectiveness. In: 16th ITS World Congress and Exhibition on Intelligent Transport Systems and Services. [online] Stockholm: ITS America. Available at: https://trid.trb.org/view/908808 [Accessed 20 Aug. 2019].
9. Cederqvist, H. (2011). Quantifying the benefits of yard automation – updated. Port Technology International, [online] 38, pp.48-51. Available at: https://ast.porttechnology.org/wp-content/media/20190528033024/PT38-10.pdf [Accessed 17 Aug. 2019].
10. Cederqvist, H. and Holmgren, C. (2011). Investment vs. operating costs: a comparison of automatic stacking cranes and RTGs. Port Technology International, [online] 47, pp.64-66. Available at: https://ast.porttechnology.org/wp-content/media/20190528022940/064-066.pdf [Accessed 17 Aug. 2019].

11. Data source:
12. Dongbu Express. (2019). Stevedoring. [online] http://www.dongbuexpress.com/eng/work/synth01.jsp?pNum=21 [Accessed 26 Aug. 2019]
13. DP World. (2019). Antwerp Gateway. [online] http://www.dpworldantwerp.com/our-businesses/antwerp-gateway [Accessed 26 Aug. 2019].
14. DP World. (2019). South Korea – Pusan. [online] https://www.dpworld.com/what-we-do/our-locations/Asia-Pacific/South-Korea/pusan [Accessed 26 Aug. 2019]
15. DP World. (2019). *Antwerp Gateway*. [online] Available at: http://www.dpworldantwerp.com/our-businesses/antwerp-gateway [Accessed 5 Aug. 2019].
16. Ducruet, C., Itoh, H. and Merk, O. (2014). Time Efficiency at World Container Ports. [online] Paris: OECD. Available at: https://www.itf-oecd.org/sites/default/files/docs/dp201408.pdf [Accessed 26 Aug. 2019].
17. Dynamar B.V. (2015). Container Throughput & Terminal Capacity in North Europe II. [online] Alkmaar, pp.14-15. Available at: https://www.dynamar.com/system/table_of_contents/140/original/Terminals%20North%20Europe%20II%20-%20Contents%20Overview%20and%20Preface.pdf? [Accessed 16 Aug. 2019].
18. ECT. (2019). Hutchison Ports ECT Delta | ECT Hutchison Ports. [online] Available at: https://www.ect.nl/en/terminals/hutchison-ports-ect-delta [Accessed 26 Aug. 2019].
19. Eurogate. (2019) Hamburg Terminal. [online] http://www1.eurogate.de/en/Terminals/Hamburg [Accessed 26 Aug. 2019]
20. Fenix Marine Service. (2019). What We’re About. [online] https://www.fenixmarineservices.com/about/ [Accessed 26 Aug. 2019]
21. Haicang Gov. (2016). Xiamen Yuanhai Container Terminal Co., Ltd. [online] http://www.haicang.gov.cn/wiki/index.php?doc-view-145 [Accessed 26 Aug. 2019]
22. Hendriks, E. (2014). Automation for brownfield terminals. Port Technology International, [online] 61, pp.52-54. Available at: https://ast.porttechnology.org/wp-content/media/20190528111310/Hendricks_Kalmar.pdf [Accessed 17 Aug. 2019].
23. Henriksson, B. (2018). Next Level Remote Operations: The Remote Crane Operator and Beyond. Port Technology International, [online] 80, pp.46-48. Available at: https://ast.porttechnology.org/wp-

content/media/20190528005817/ABB_e81.pdf [Accessed 17 Aug. 2019].

24. HHLA. (2019) CTA-Technical-data. [online]https://hhla.de/en/container/cta/technical-data.html [Accessed 26 Aug. 2019]
25. HHLA. (2019). HHLA Chronicle. [online] https://hhla.de/en/history/chronicle.html [Accessed 26 Aug. 2019]
26. HHLA. (2019). History of the HHLA Container Terminal Burchardkai in Key Words. [online] https://hhla.de/de/container/burchardkai-ctb/geschichte-ctb.html [Accessed 26 Aug. 2019]
27. HIT. (2004). 35 Years Anniversary. [online] Available at: https://www.hit.com.hk/Services/ViewDoc?dbid=ehWTRsHfF3255301 [Accessed 24 Aug. 2019].
28. HKTDC. (2009). New capacities for the Port of Hamburg. [online] http://info.hktdc.com/shippers/vol29_1/vol29_1_ports04.htm [Accessed 26 Aug. 2019]
29. HPH HIT. (2019). Total Logistics Management Services. [online] https://www.hit.com.hk/en/Our-Services/Service-Delivery/Key-Facts.html [Accessed 26 Aug. 2019]
30. HPH Thamesport. (2019). Port Services – Terminal Facilities. [online] http://www.londonthamesport.co.uk/services/frmterminalfacilities.aspx [Accessed 26 Aug. 2019]
31. IAPH. (2018). World Seaborne Trade UNCTAD. [online] Available at: http://www.iaphworldports.org/iaph/wp-content/uploads/World-Seaborne-Trade_-UNCTAD-2018.pdf [Accessed 7 Aug. 2019].
32. International Association of Ports and Harbours (2015). IAPH’s Initiatives to reduce Emissions from Ports. Multi-year Expert Meeting. [online] Geneva: UNCTAD, p.16. Available at: https://unctad.org/meetings/en/Presentation/Susumu%20NARUSE.pdf [Accessed 17 Aug. 2019].
33. International Labour Office (2005). ILO code of practice: Safety and health in ports. Geneva, pp.94-98.
34. ITG Holdings. (2005). Progress of Terminal Building Project 2005-12-28. [online] http://www.itg.com.cn/chs/investordetail-1364.aspx [Accessed 26 Aug. 2019]
35. Kim, J. (2018). Smart is the New Small. Automation Trends 2018. [online] Port Technology, pp.2-3. Available at: https://ast.porttechnology.org/wp-content/media/20190528004904/CYBERLOGITEC-WITH_AD.pdf [Accessed 15 Aug. 2019].
36. King, M. (2019). Early indicators point to sluggish peak container shipping

season - Lloyd's Loading List. [online] Lloydsloadinglist.com. Available at: https://www.lloydsloadinglist.com/freight-directory/news/Early-indicators-point-to-sluggish-peak-container-shipping-season/74461.htm#.XWPlbegzZPY [Accessed 26 Aug. 2019].

37. Knowler, G. (2018). European shippers: Terminal automation gains lost on inland moves. [online] Journal of Commerce. Available at: https://www.joc.com/port-news/european-ports/port-antwerp/european-shippers-say-terminal-automation-gains-lost-inland-moves_20180504.html [Accessed 26 Aug. 2019].
38. Knowler, G. (2018). *Costs found to outweigh port automation benefits*. [online] Joc.com. Available at: https://www.joc.com/technology/costs-found-outweigh-port-automation-benefits_20181213.html [Accessed 3 Aug. 2019].
39. Kostas Selviaridis, Andreas Norrman, (2015) "Performance-based contracting for advanced logistics services: Challenges in its adoption, design and management", International Journal of Physical Distribution & Logistics Management, Vol. 45 Issue: 6, pp.592-617, https://doi-org.plymouth.idm.oclc.org/10.1108/IJPDLM-11-2014-0267
40. Kostas Selviaridis, Andreas Norrman, (2015) "Performance-based contracting for advanced logistics services: Challenges in its adoption, design and management", International Journal of Physical Distribution & Logistics Management, Vol. 45 Issue: 6, pp.592-617, https://doi-org.plymouth.idm.oclc.org/10.1108/IJPDLM-11-2014-0267
41. Longshore Shipping News. (2010). [online] PSA's Busan terminal receives first customer [Accessed 26 Aug. 2019]
42. Louppova, J. (2018). Automated quay cranes on trial in Singapore. [online] Port.today. Available at: https://port.today/automated-quay-cranes-trial-singapore/ [Accessed 16 Aug. 2019].
43. Malchow, U. (2017), "Growth in containership sizes to be stopped?", Maritime Business Review, Vol. 2 No. 3, pp. 199-210. https://doi.org/10.1108/MABR-01-2017-0001
44. Martín-Soberón, A. (2012). The Capacity in Container Port Terminals. Ad Hoc Expert Meeting on Assessing Port Performance. [online] Geneva: UNCTAD. Available at: https://unctad.org/meetings/en/Presentation/dtl_ttl_2012d10_Soberon.pdf [Accessed 26 Aug. 2019].
45. Martín-Soberón, A., Monfort, A., Sapiña, R., Monterde, N. and Calduch, D. (2014). Automation in Port Container Terminals. *Procedia - Social and Behavioral Sciences*, 160, pp.195-204.
46. Miller, M. (2019). Modernizing Port Operations for the Digital Age. Port

Technology: Smart Ports, [online] 86, p.22. Available at: https://ast.porttechnology.org/wp-content/media/20190712231154/OSISOFT.pdf [Accessed 17 Aug. 2019].

47. Mongelluzzo, B. (2019). *More North American port automation expected*. [online] Journal of Commerce. Available at: https://www.joc.com/port-news/port-productivity/more-north-american-port-automation-coming-moody%E2%80%99s_20190704.html [Accessed 5 Aug. 2019].
48. NASA. (2010). Land Reclamation at Rotterdam. [online] Available at: https://earthobservatory.nasa.gov/images/47122/land-reclamation-at-rotterdam [Accessed 19 Aug. 2019].
49. Navis (2019). Navis Case Study - QQCTN. [online] Oakland, pp.1-2. Available at: https://www.navis.com/contentassets/eb3d32cc87fd4df68062ff5780f4f834/qqctn-case-study_pdf.pdf [Accessed 18 Aug. 2019].
50. NPTC. (2019). Tobishima Pier South Side Container Terminal. [online] http://www.nptc.co.jp/en/container/index.html [Accessed 26 Aug. 2019]
51. Patrick Terminals. (2019). Operations. [online] http://www.patrick.com.au/operations [Accessed 26 Aug. 2019]
52. PNC Port. (2019). Terminal Status. [online] https://www.pncport.com/kor/index.php?pCode=facilities [Accessed 26 Aug. 2019]
53. PNIT. (2019). Facilities. [online] https://www.pnitl.com/homepage/eng/webpage/ter_faci.jsp [Accessed 26 Aug. 2019]
54. Port of Antwerp. (2019). *Containers*. [online] Available at: https://www.portofantwerp.com/nl/node/920 [Accessed 3 Aug. 2019].
55. Port of Long Beach. (2019). Total Terminals International. [online] http://www.polb.com/economics/cargotenant/containerized/piert.asp [Accessed 26 Aug. 2019]
56. Port of Los Angeles. (2019). TraPac Container Terminal. [online] https://www.portoflosangeles.org/business/terminals/container/trapac [Accessed 26 Aug. 2019]
57. Port of Los Angeles. (2019). WBCT China Shipping. [online] https://www.portoflosangeles.org/business/terminals/container/wbct-china-shipping [Accessed 26 Aug. 2019]
58. Port of Los Angeles. (2019). Yusen Terminal. [online] https://www.portoflosangeles.org/business/terminals/container/yusen-terminals [Accessed 26 Aug. 2019]
59. Port of Rotterdam. (2015). Big carriers want full quay crane automation.

[online] Available at: https://www.portofrotterdam.com/en/news-and-press-releases/big-carriers-want-full-quay-crane-automation [Accessed 16 Aug. 2019].

60. Port of Rotterdam. (2015). Three new container cranes arrive at ECT. [online] Available at: https://www.portofrotterdam.com/en/news-and-press-releases/three-new-container-cranes-arrive-at-ect [Accessed 16 Aug. 2019].
61. Port of Rotterdam. (n.d.). The robot is coming. [online] Available at: https://www.portofrotterdam.com/en/doing-business/logistics/cargo/containers/50-years-of-containers/the-robot-is-coming [Accessed 8 Aug. 2019].
62. Port of Rotterdam. Not Dated. [online] Available at: https://www.portofrotterdam.com/sites/default/files/bulk/files/Containerkaart.pdf [Accessed 26 Aug. 2019].
63. Port Technology. (2017). Watch China’s Biggest Automated Terminal in Action. [online] Available at: https://www.porttechnology.org/news/watch_chinas_biggest_automated_terminal_in_action/ [Accessed 16 Aug. 2019].
64. Port Technology. (2018). Super Quay Cranes Kick Off Maasvlakte II Expansion. [online] Available at: https://www.porttechnology.org/news/super_quay_cranes_kick_off_maasvlakte_ii_expansion/ [Accessed 16 Aug. 2019].
65. Port Technology. (2019). Rotterdam Kick-Starts Zero Carbon Plan. [online] Available at: https://www.porttechnology.org/news/rotterdam_kick_starts_zero_carbon_plan/ [Accessed 26 Aug. 2019].
66. Port Technology. (2019). WATCH: China’s Three Biggest Automated Ports. [online] Available at: https://www.porttechnology.org/news/watch_chinas_three_biggest_automated_ports/ [Accessed 15 Aug. 2019].
67. Port Technology. (2019). WATCH: New APM Terminal Receives Final Crane Batch - Port Technology International. [online] Available at: https://www.porttechnology.org/news/watch-new-apm-terminal-receives-final-crane-batch/ [Accessed 16 Aug. 2019].
68. PSA Antwerp. (2019). Terminals. [online] Available at: https://www.psa-antwerp.be/en/terminals [Accessed 26 Aug. 2019].
69. PSA. (2019). Terminals of PSA Singapore. [online] Available at: https://www.singaporepsa.com/our-business/terminals [Accessed 20 Aug. 2019].
70. PSA. Not Dated. South Korea Busan Terminal. [online]

https://www.globalpsa.com/wp-content/uploads/BUSAN-TERMINALS.pdf [Accessed 26 Aug. 2019]

71. QQCTN. (2019). Era of Fully Automated Intelligent Ports. [online] http://www.en.qqctn.com.cn/qqctn/about/index.jhtml [Accessed 26 Aug. 2019]
72. Ren, X. (2019). *Guangzhou to build world's first automated parallel container quay*. [online] China Daily. Available at: http://www.chinadaily.com.cn/a/201907/24/WS5d37b3f7a310d83056400ada.html [Accessed 5 Aug. 2019].
73. Saanen, Y. (2019). 10 Pre-requisites for Smart Terminals. Port Technology: Smart Port, [online] 86, pp.7-10. Available at: https://ast.porttechnology.org/wp-content/media/20190712231121/TBA86.pdf [Accessed 15 Aug. 2019].
74. SANY Group. (2019). SANY Automated Quay Crane Dispatched for Hong Kong | 三一自动化岸桥发货香港大码头-三一集团. [online] Available at: https://www.sanygroup.com/xwzx/6952.html [Accessed 16 Aug. 2019].
75. Saunders M., Lewis P., and Tornhill. A. (2009) Research methods for business Students. 5th edition. Essex: Pearson Education Limited.
76. Saunders M., Lewis, P. and Thornhill, A. (2016). Research methods for business students. 7th ed. Harlow: Pearson, pp.184-187, 302, 569, 590-591.
77. Sekaran, U., and Bougie, R. (2013) Research methods for business: a skill-building approach. (6th edn) New York: Wiley
78. Ship Technology. (2019). Port of Busan. [online] https://www.ship-technology.com/projects/portofbusan/ [Accessed 26 Aug. 2019]
79. Sisson, M. (2019). Automation Options for RTG Terminals. Port Technology: Terminal Automation Design. [online] pp.6-7. Available at: https://ast.porttechnology.org/wp-content/media/20190528004726/AECOM-E2.pdf [Accessed 15 Aug. 2019].
80. Stake, R.E. (2006), Multiple Case Study Analysis, New York & London: The Guildford Press.
81. Stork, F. (2019). The Art of Applying Artificial Intelligence and Machine Learning to Container Terminal Operations: Focusing on Automating Decision-Making. [ebook] Port Technology: Supply Chain Collabouration 85th ed.. Available at: https://ast.porttechnology.org/wp-content/media/20190712231216/NAVIS_ed85paper.pdf [Accessed 15 Aug. 2019].
82. Swissnex China. (2018). Swissnex China visits the World’s Largest Unmanned Container Terminal with S&TDC. [online] http://www.blog.swissnexchina.org/innovation/2018/10/25/swissnex-china-

visits-the-worlds-largest-unmanned-container-terminal-with-samptdc [Accessed 26 Aug. 2019]

83. Swissnex China. (2018). swissnex China visits the World's Largest Unmanned Container Terminal with S&TDC — swissnex China news. [online] Available at: http://www.blog.swissnexchina.org/innovation/2018/10/25/swissnex-china-visits-the-worlds-largest-unmanned-container-terminal-with-samptdc [Accessed 21 Aug. 2019].
84. TBA. (2019). Friday Focus: Yard Crane Scheduler Powered by TBA. [online] Available at: https://www.porttechnology.org/news/friday_focus_yard_crane_scheduler_powered_by_tba/ [Accessed 17 Aug. 2019].
85. Terminal Investment Limited. (2012) TTI Long Beach Terminal, Pier T - Port of Long Beach. [online] https://www.tilgroup.com/terminal/port-long-beach-0 [Accessed 26 Aug. 2019]
86. Terry Brennan. (1993). FUTURE UNFOLDS IN ROTTERDAM AS SEA-LAND OPENS FIRST UNMANNED AUTOMATED TERMINAL. *Traffic World*. Retrieved from https://advance-lexis-com.eur.idm.oclc.org/api/document?collection=news&id=urn:contentItem:3SJD-V3N0-001X-82YG-00000-00&context=1516831.
87. Total Terminals International. (2019) Main Page. [online] http://www.ttilgb.com/main/index.do [Accessed 26 Aug. 2019]
88. Tratos. (2019). Tercat Port. [online] https://tratosgroup.com/case-study/tercat-port-spain/ [Accessed 26 Aug. 2019]
89. TTI Algeciras. (2019). Facility. [online] http://www.ttialgeciras.com/en/facility/ [Accessed 26 Aug. 2019]
90. Uranga, R. (2019). Deal Reached Over Automation at the Port of LA | Los Angeles Business Journal. [online] Los Angeles Business Journal. Available at: https://labusinessjournal.com/news/2019/jul/18/deal-reached-over-automation-port/ [Accessed 26 Aug. 2019].
91. Vahle (2019). Vahle SMGX: Reliable Wireless Data Communication. [ebook] Port Technology. Available at: https://ast.porttechnology.org/wp-content/media/20190712231305/VAHLE_300419.pdf [Accessed 15 Aug. 2019].
92. Welles, M. and Li, Y. (2017). Qingdao Terminal: Fully Automated to Welcome Megaships. Port Technology: Automation and Optimisation, [online] 75, pp.48-49. Available at: https://ast.porttechnology.org/wp-content/media/20190528051010/Qingdao_Terminal_QQCTN_Automated_to_Welcome_Megaships_Navis.pdf [Accessed 17 Aug. 2019].
93. World Bank (n.d.). Module 3: Alternative Port Management Structures and

Ownership Models. World Bank Port Reform Tool Kit. [online] World Bank, p.6. Available at: http://siteresources.worldbank.org/INTPRAL/Resources/338897-1117197012403/mod3.pdf [Accessed 26 Aug. 2019].

94. World Bank. (2019). *Container port traffic (TEU: 20 foot equivalent units) | Data*. [online] Available at: https://data.worldbank.org/indicator/IS.SHP.GOOD.TU [Accessed 7 Aug. 2019].
95. Xiangyu Group. (2003). Xiangyu Terminal reach 5 million TEU throughput. [online] http://www.xiangyu-group.com/chs/newsdetail-174.aspx [Accessed 26 Aug. 2019]
96. XSCT. (2017). Development of Songyu Container Terminal. [online] https://www.xsct.com.cn/xsct/development.aspx [Accessed 26 Aug. 2019]
97. Yang, X., Mi, W. and Tao, Q. (2016). Design and Simulation of Automated Container Terminal | 自动化集装箱码头设计与仿真. Shanghai: Shanghai Scientific and Technical Publishers.
98. Yantian International Container Terminals. (2019). About YICT - Annual Throughput. [online] Available at: https://www.yict.com.cn/about-throughput/annual-throughput.html?locale=en_US [Accessed 24 Aug. 2019].
99. Yap, W. (2009). Container shipping services and their impact on container port competitiveness. Brussels: UPA University Press Antwerp.
100. Yuanhai Terminal. (2011). Equipment arrives at port. [online] http://xmyh.coscocs.com/art/2011/7/28/art_14217_103440.html [Accessed 26 Aug. 2019]
101. Zrnić, N., Petković, Z. and Bošnjak, S. (2005). *Automation of Ship-To-Shore Container Cranes: A Review of Stateof-the-Art*. Faculty of Mechanical Engineering. University of Belgrade.