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Analysis and assessment of energy efficiency in automated container terminals

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Analysis and assessment of energy efficiency in automated container terminals

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Preface

The study “Analysis and evaluation of energy efficiency in automated container terminals“ (Topic 1) rising within the scope of the MKS China mobility and fuel strategy focusing on green ports was developed by the Fraunhofer Institute for Material Flow and Logistics IML in cooperation with the ‘Deutsche Gesellschaft für Internationale Zusammenarbeit’ (GIZ) in China and the Tianjin Research Institute for Water Transport Engineering (TIWTE). In parallel the studies “Shore-to-Ship power“ (Topic 2) and “Sustainable strategies for ports“ (Topic 3) were developed.

The port of Tianjin is the main port of the Beijing region in China and is situated approximately 60 km east of the city of Tianjin on the western shore of Bohai Bay. In 2018 a handling capacity of 15.97 millions TEU (Twenty Foot Equivalent Unit) was reached. (Tianjin Port Development Holdings Limited 2019)

Within the last year the Tianjin Port (Group) Co. Ltd. finished formulating its ”Three-year Plan for Construction of an Intelligent Tianjin Port“. (TJBH 2018) That covers 29 projects in five fields focusing on the development of an information-based, worldwide leading, and modern port by modernization and transformation. In addition to economic goals also those of sustainability should be attained, so that the port of Tianjin is developing not only to an intelligent one, but also to a green one.

A green transformation is not new for the port of Tianjin. Environmental protection had been started here already in the 1970ies. In the course of this many efforts were made to improve the environmental quality of the port, e. g. by realizing the ”Green Water Project“ aiming on protecting the port waters against contamination. The realization of the “Blue Sky Project“ served to improve the air quality of the port as well as to boost environmental management.

A feature of 'intelligent' ports is the automation of equipment in the port. Tianjin port has recently become the largest terminal complex for the Navis N4 Terminal Operating System. The standardisation of data in the N4 system provides a basis for the analysis of large datasets and supports both planning and the automation of equipment in the port.

Glossary

ACT	Automated Container Terminal
AGV	Automated Guided Vehicle
ALV	Automated Lifting Vehicle
CO_2	Carbon dioxide
CT	Container Terminal
CTA	Container Terminal Altenwerder
CTT	Container Terminal Tollerort
ECT	Europe Container Terminal
GHG	Greenhouse Gas
GJ	Gigajoule
HHLA	Hamburger Hafen und Logistik AG
ICAO	International Civil Aviation Organization
IML	Fraunhofer Institute for Material Flow and Logistics
IMO	International Maritime Organization
ISO	International Organization for Standardization
kWh	Kilowatt hour
L-FTS	Lift-FTS
LNG	Liquefied Natural Gas
MKS	Mobility and Fuel Strategy
MTS	Multi-Trailer-System
NO_x	Nitrous oxide
OECD	Organisation for Economic Cooperation and Development
RMG	Rail Mounted Gantry Crane
RTG	Rubber Tyred Gantry Crane
STS	Ship-to-Shore Crane
TEU	Twenty-foot Equivalent Unit
TIPC	Taiwan International Ports Corporation
TIWTE	Tianjin Research Institute for Water Transport Engineering
TTU	Truck-Trailer-Unit

1. Introduction

The objective of this study is the analysis of the potential for automation of equipment and resulting improvement in environmental impact in Tianjin Port.

The study is structured as follows: After a description of the method (cf. chapter 1) follows a description of the general features of container terminals, their functions and equipment. Furthermore, the reasons for and aspects of automation, together with the necessary conditions in the scope of the automation implementation in the terminals are discussed. Following this, an assessment and a classification of Tianjin port's level of automation was conducted (cf. chapter 2).

Impacts of automation on the energy efficiency of container terminals are analysed. Automated processes in container terminals and the energy consumption of terminal vehicles in conventional and automated terminals are identified and specified, in consideration of the optimisation of terminal processes, infrastructure and personnel. The level of automation and the associated measures for improvement of the environmental performance of the Tianjin Five Continents International Container Terminal are assessed (cf. chapter 3).

This analysis and the data from Tianjin Port/TIWTE are used to develop recommendations for equipment and optimisation of operations described in the conclusions (cf. chapter 4). Figure 1 visualises the schematic structure of this study.

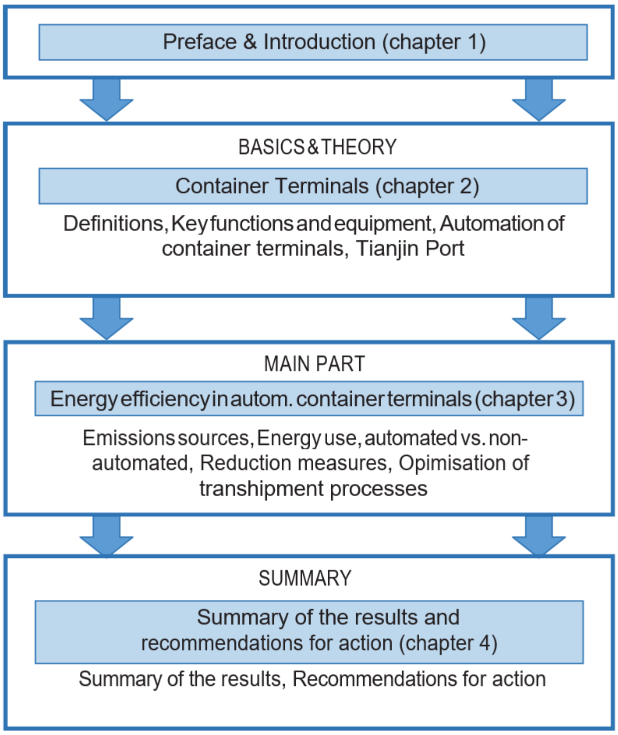


Figure 1: Schematic structure of the study

2. Container Terminals

This chapter first defines the concept of container terminals in general and provides a structure in terms of key functions (cf. chapter 2.1). Furthermore, a description of the key functions and equipment (cf. chapter 2.2) followed by an inspection of the automation of container terminals is considered (cf. chapter 2.3). Next, an introduction of Tianjin port and the Tianjin Five Continents International Container Terminal is presented (cf. chapter 2.4).

2.1 Definitions

38 million ISO containers circulating worldwide (in further course of this study declared as containers). (Welt 2018) In 2017, the global throughput of containers in ports was greater than 750 million TEU (TEU = twenty-foot equivalent unit), an increase of more than 60 % in the last 7 years. (World Bank 2019) Containers are the main form of intermodal transport of goods and container terminals therefore have an important role in global supply chains. (Gharehgozli et al. 2014)

A container terminal in a port is an intermodal system of exchange with a storage area coordinating the arrivals of goods from sea or land. The objective of operations is to ensure the availability of resources and systems for the exchange of goods between sea, land and inland waterways while optimising time efficiency, safety, environmental impact and the economics of operations. (Martín-Soberón et al. 2014)

The core business of a container terminal is the transhipment of containers. It is a hub where different modes (ships, inland waterways vessels, trains and trucks) meet. The various transport modes deliver containers to the terminal and/or collect containers for onward shipment. The classification of transhipment processes is therefore determined by the direction and mode of transport. (Speer 2017)

Three types of terminal can be identified: Transhipment-Terminals focus on the transhipment between ships, such that the hinterland is of relatively low importance. Import-Export terminals concentrate on container flows between ships and the hinterland. Transhipment between ships and between land modes is important whereas the transshipment is partially conducted onshore as well as offshore. Intermodal hubs are often hubs located in the hinterland that transfer containers between road and rail. (Speer 2017)

2.2 Key functions and equipment

A container terminal is analysed as a complex system, characterised by its functions, main activities and resources. (Kemme 2013). The general structure and the functions of a terminal will be described together with the relevant terminal equipment (cf. chapter 2.2.1 and chapter 2.2.2.)

2.2.1 Function areas and processes

Container terminals have at least three types of functional areas. The first is the wharf (quayside), followed by the lay-down area (container holding and storage). (Brinkmann 2011) This storage area is usually divided into blocks, rows, fields and levels. Special areas are provided for reefers and special containers that require electrical connections, contain dangerous goods, or are outsized containers that cannot be stacked normally. (Steenken et al. 2004) The third area is provided for hinterland operations, including parking for trucks and trailers, railway tracks, offices, storage for empty containers and maintenance. The arrangement and equipment for the functional areas and their interfaces are dependent on the desired throughput of containers, the availability of the area and the type of hinterland transport. (Brinkmann 2011) A typical layout of these functions is shown in Figure 2.

Container terminal operations in ports are divided into five processes. These are Ship-to-Shore (the arrival of the container in the ship and unloading), Shore-to-Stack (container transport from the quayside to the storage area), container storage, transport in the terminal and transhipment on to other modes like train or truck. (Geerlings et al. 2014) Figure 3 shows a section of a container terminal. The functional areas are serviced by various transhipment and handling devices. These are described in chapter 2.2.2.

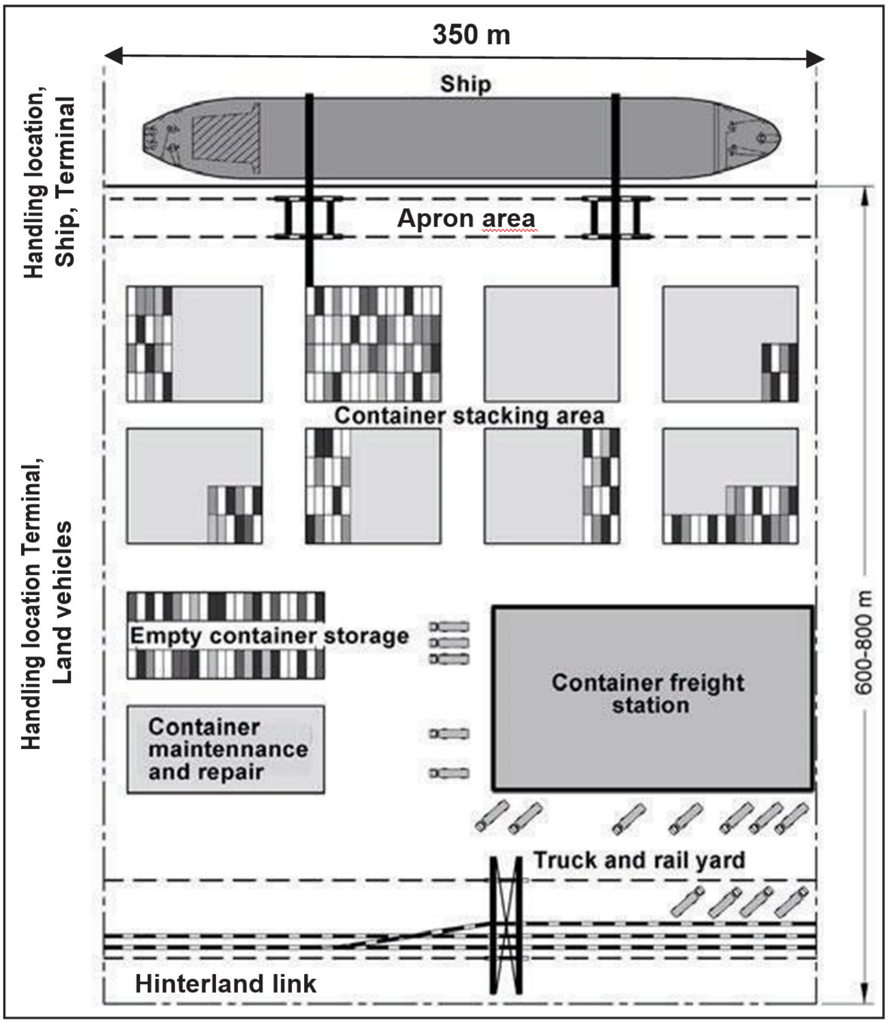


Figure 2: General layout of a container terminal (Brinkmann 2011)

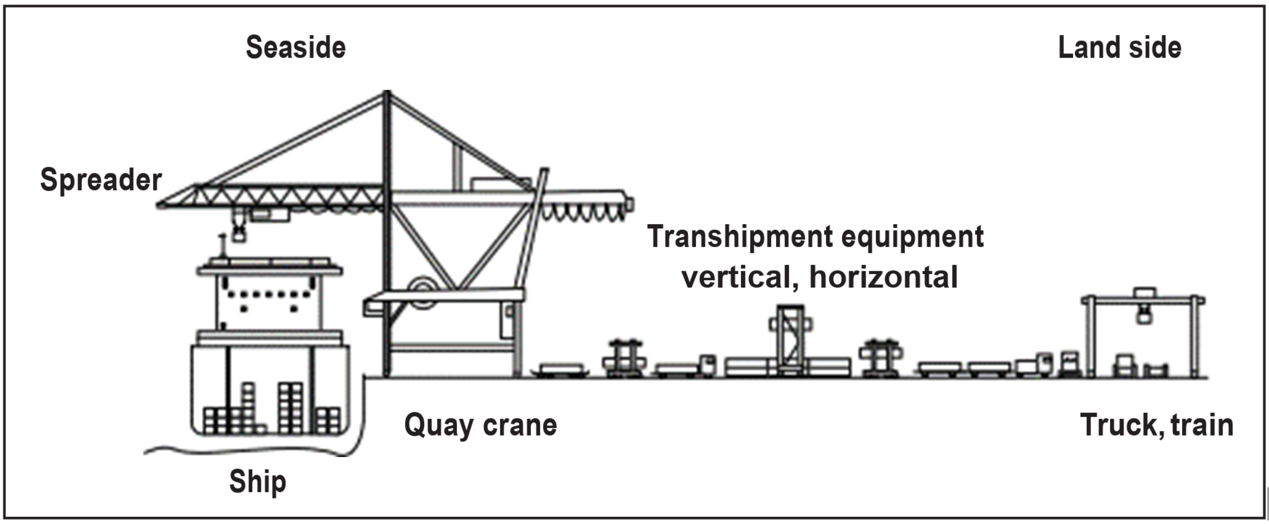


Figure 3: Section of a container terminal (Brinkmann 2011)

2.2.2 Terminal Equipment

A range of equipment is deployed for the various functions and processes. These include container stackers and transporters. These are used for loading and unloading from ships (vertical transport), transport between the wharf and storage areas (horizontal transport) and stacking (storage equipment).

Vertical transport

This equipment loads and unloads containers onto and off ships and is performed by gantry or portal cranes, port cranes and mobile cranes. (Clausen und Geiger 2013); (Brinkmann 2011, 2005)

Quayside cranes/gantry or portal cranes: These cranes (also called ship-to-shore-cranes (STS)) perform the transhipment between ship and terminal. They are used in terminals with a high turnover. These gantry cranes have a boom that reaches over the ships and the terminal quayside. They can load and unload ships in parallel and move along the length of the quay and ship, with a gantry reach to cover the whole width of the ship. Unloading is performed with a spreader, connected to the crane gantry, which grips the ISO container corner blocks and enables a rapid collection and release of the container. They have a limited facility for container stowage or storage. (Speer 2017; Brinkmann 2011, 2005) Figure 4 shows an example of container portal cranes. Rotating mobile crane: These have a considerably lower handling rate compared to gantry cranes and are used in small and medium sized terminals. Their advantages are a lower capital cost and greater flexibility compared to gantry cranes. (Brinkmann 2005) Figure 5 shows a rotating mobile harbour crane.

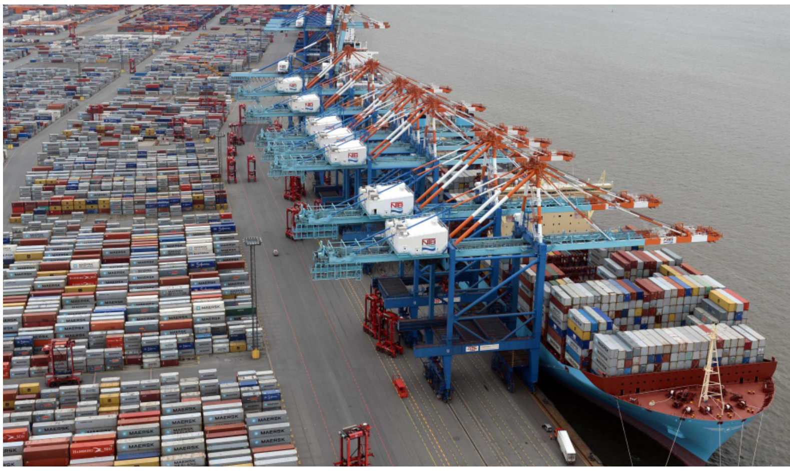


Figure 4: Container portal cranes at the North Sea Terminal in Bremerhaven (Eurogate 2017)

Figure 5: Rotating mobile crane at the inland waterways harbour in Hamburg Harburg (Metropolregion Hamburg 2019)

Horizontal transport

Transhipment and storage of goods at the terminal is performed with straddle carriers, truck- trailer and multi-trailer-systems, container stackers, reach stackers, autonomous transport systems and transtainer. (Clausen und Geiger 2013; Brinkmann 2005)

After the containers have been unloaded from the ship, they are transported to the storage area. The selected vehicle for transportation varies strongly depending on the requirements and throughput of the terminal. There are four general types of vehicles: straddle carriers, driverless transport systems, truck-trailer combinations and multi-trailer-systems. The containers are positioned in the storage area by fork-lift trucks or cranes. (Brinkmann 2005)

Container transporters can also be divided into passive and active vehicles. Active vehicles are equipped with a lifting device for the container(s) to enable independent loading and unloading. They combine transport and stowage functions. Passive vehicles can only perform the transport function and require cranes or other container handling equipment for loading and unloading. Lifting at the quayside is usually performed by the container gantry cranes, while a range of devices are used in storage areas. (Kemme 2013)

Straddle carrier: The Straddle carrier functions independently from other handling equipment and has the ability to perform all the functions for transhipment: transport, stacking, loading and unloading. They can be considered as cranes that are not restricted to a limited area in the terminal and have free access to the containers. Straddle carrier systems are therefore flexible and dynamic. They usually move independently as road vehicles with tyres and are dimensioned to carry three or four vertically stacked containers. Automated straddle carriers are also known as automated lifting vehicles (ALV), because of their lifting function. (Steenken et al. 2004) Figure 6 illustrates a straddle carrier with a diagram of a straddle carrier layout.

Figure 6: Straddle carrier with a diagram of a straddle carrier layout

Driverless container transporters/automated guided vehicles (AGVs): The original development of AGVs was not specifically for container transport. Therefore, AGVs have mature and reliable steering, drive train and navigation systems. They are passive vehicles, requiring a separate lifting device for loading and unloading. (Steenken et al. 2004) Figure 7 illustrates an AGV with a diagram of an AGV layout.

Figure 7: Diagram and picture of an AGV (Kemme 2013; Gharehgozli et al. 2014)

A further development of the AGV is a 'lift-AGV'. These are equipped with two active lifting platforms, which can lift and place containers on transfer racks at the storage area for stacking cranes. This reduces waiting times and delivers a higher transhipment rate. (Konecranes 2019) Figure 8 shows a LIFT-AGV system.

Figure 8: LIFT-AGV system (Port Strategy 2012)

Tractor units and container trailers/truck-trailer-unit (TTU): The combination of a tractor unit and container trailer is based on road container transport trucks and is the most common form of container transporters. As the container trailer is connected by the tractor unit's fifth wheel, the transfer of a container is performed by a simple, automated release of the trailer such that the tractor unit does not have any waiting time. TTUs are also passive transporters, requiring further equipment for loading and unloading. (Speer 2017) Figure 9 shows a diagram and picture of a TTU.

Figure 9: Diagram and picture of a tractor and container trailer (Speer 2017)

Multi-trailer-systems (MTS): Multi-trailer-systems are an extension of truck-trailer-units. Up to five trailers are coupled together and towed by a single tractor unit (cf. Figure 10). This reduces the number of trips required, the investment and operating costs compared to a TTU.

Figure 10: Diagram and picture of a multi-trailer-system (Kemme 2013; Hafenbetrieb Rotterdam 2016)

Storage equipment

A range of handling devices and vehicles are used in container storage areas to store and move containers. The most common are reach stackers, fork lift trucks and various types of gantry crane.

Reach stacker: Reach stackers are designed for transport and stowage of containers and can independently lift and position containers. Lifting is performed with a spreader on a telescopic arm, which enables a high stacking height and compact stowage. (Speer 2017) They have rubber tyres, which are normally diesel-powered and manually controlled. As with container fork lift trucks, they are usually employed in smaller harbours where gantry cranes and straddle carriers cannot be economically justified. (Kemme 2013) A diagram and picture are shown in Figure 11.

Figure 11: Diagram and picture of a reach stacker (Kemme 2013; Kreuzer and Konecranes 2018)

Container fork lift truck: The container fork lift truck is a large variation of a fork lift truck, used at port container terminals to transport and stack containers in a horizontal manner. They function in a similar manner to reach stackers, but with the difference that the spreader is mounted on a lifting mast to raise the containers vertically (cf. Figure 12).

Figure 12: Diagram and picture of a container fork lift truck (Kemme 2013; SVETRUCK 2019)

Gantry/portal cranes: Stowage cranes or gantry cranes are used in stowage areas in port container terminals and for the transhipment between terminal and onward transport by road or rail. They are mainly used with passive transport equipment and provide highly space-efficient stowage. They are therefore often used in terminals with restricted areas for container stowage, because they do not require access ways between the rows of stacked containers and can stack up to eight containers high. (Speer 2017; Brinkmann 2005) A diagram and picture of a container gantry crane are shown in Figure 13.

Figure 13: Diagram and picture of a container gantry crane (Kemme 2013; Gharehgozli et al. 2014)

Gantry cranes are divided into rail mounted gantry cranes (RMG) and rubber tyred gantry cranes (RTG). Both types are mainly manually operated, but have a high potential for automation. (Kemme 2013)

A system with RMGs/RTGs includes transporters or shuttle carriers, which deliver the containers to the gantry crane for stowage, or receive the containers for transport. Four or five TTUs and two RTG cranes are required per quayside container gantry crane. The stowage capacity of this type of system with stacks of four to eight containers high is 750- 800 TEU per Hectare. These systems are mainly used in large or very large terminals. (Speer 2017; Brinkmann 2005) A RTG system has greater operational flexibility than a RMG system. Figure 14 shows a Rubber Tyred Gantry Crane.

Figure 14: Rubber tyred gantry crane (RTG) and tyres of a RTG crane (turbosquid 2019)

A rail system (RMG-system) can have a greater width and reach than a RTG and therefore has a storage capacity of up to 1000 TEU per Hectare and a stacking height of four containers. Moreover, a rail system with shuttle carriers may be used instead of truck- trailer units. This system requires only two RMGs and two shuttle carriers per quayside container crane. Consequently, it reduces personnel costs and in contrast to the RTG system, functions more reliable since the number of vehicles required is lower. The rail mounted system also has a higher productivity, because they can travel at a higher speed than an RTG. (Kemme 2013; Brinkmann 2005) Figure 15 shows a rail mounted gantry crane.

Figure 15: Rail mounted gantry crane and wheels for an RMG system (Konecranes 2019b)

2.3 Automation of container terminals

Automated container terminals (ATC) have automated systems for transport and transhipment. (Speer 2017) There are already four generations of ACT. The Delta "Dedicated North Terminal" at Europe Container Terminals (ECT) from 1993 is representative of the first generation. The second generation followed with the "Container Terminal Altenwerder" in Hamburg which commenced operations in 2002. The "Holland Rotterdam Euromax Terminal" is the third generation and currently the newly opened "Xiamen Ocean Gate Container Terminal" is the fourth generation of automated container terminals. (Yang und Li 2017) In the following sections the benefits and reasons for automation as well as the conditions and elements of automation in container terminals will be described (cf. chapter 2.3.1 and 2.3.2).

2.3.1 Reasons for automation

Industrial automation uses mechanical, hydraulic, pneumatic and electrical computer controlled elements and systems for the control of equipment and processes. The personnel requirements are reduced and the processes can be better controlled than manually operated systems. Systematic and repeated operations are most suitable for automation, as they often follow specific and programmable requirements and processes. (Martín-Soberón et al. 2014)

The current and continued rapid growth of demand for freight transport through ports due to economic growth in key countries, global supply chains and increasing ship sizes presents a major challenge in handling the increasing levels of activity. The potential for extension of terminals is often limited by several factors such as space, availability of funds for investment or environmental impacts. Therefore there is a requirement for sustainable solutions, which many ports seek to address through automation. (Jiang et al. 2015)

Container terminals have several features which make them particularly suitable for automation of equipment and processes. The unit to be handled is highly standardised, the transhipment process is also standardised and there is a high throughput. Automation technologies can improve the profitability of terminals.

Automated container terminals also fulfil three strategic requirements of modern sustainable business models. These are improved operational performance and productivity, improved safety and contributing towards an improvement of environmental performance. The main reason for automation of a container terminal is an increase in performance - throughput of containers handled. ACTs use the available space more efficiently and therefore more intensively and have a higher capacity than manually operated terminals. They enable real- time decision making, use resources more effectively and minimise the sorting of containers for transport. At the same time, automation enables improved safety levels for personnel and equipment, because they reduce the risk of 'human error' and the impacts of accidents. Although automation is intended to improve productivity, automated processes also have a significant impact on reducing energy use and therefore contribute to environmental sustainability. Automation is therefore a useful option for energy management. (Martín-Soberón et al. 2014)

2.3.2 Conditions and elements for automation

The conditions for automation depend strongly on whether a new (green field) terminal is planned or an operational terminal is to be upgraded (brown field). The latter requires automation to be adapted to the pre-existing conditions and operations. (Martín-Soberón et al. 2014)

Following Rintanen et al. the following factors can be identified:

- Alignmentof the design of the terminal with the current conditions (personnel costs etc.)
- The container terminal should be brought up to the best current level of technology, in order to provide a long-term solution
- The implementation should be well planned and executed with attention to detail, in order to avoid delays and interruptions to operations
- Clear definition of the operational conditions, limitations due to the size of containers and transhipment equipment, taking working conditions into account
- Production processes should be adapted to the capacity of the container cranes
- Simulations should be used to determine the choice and number of transhipment vehicles and cranes
- Automation is more than just software implementation
    - o It implies a complete restructuring of operations and procedures in the terminal
    - o It requires change management and retraining of personnel
- The integration of IT-systems is necessary and current systems have to be adapted to the automated processes; all those involved in the process should know what the end product will be (Rintanen et al. 2016)

The elements of automation will now be described. Most container terminals are equipped with manned machines and systems. A few terminals are already semi-automated with unmanned container transporters e.g. unmanned

Straddle Carriers or unmanned RMGs in Brisbane; AGVs in several terminals in Rotterdam. (Tran 2012) Most automated port terminals have automated container handling equipment for transport from the quayside to the storage area and also within the storage area. (Kemme 2013) Unmanned Straddle Carriers are used for transport, while automation in storage area is mainly implemented through unmanned RMGs. Quayside gantry cranes are at present mainly manually operated, although there is a high potential for automation.

Yang and Li summarise differences between system technologies for current and automated container terminals. Current terminals

No.	Unit of comparison	Current Terminal	ACT
1	Terminal Layout	Storage areas mostly parallel to the berths	Storage areas mostly at right angles to the berth
2	Area	Larger	Smaller
3	Transhipment equipment	Rubber tyred crane (RTG) – diesel powered transport and quayside cranes	Rail mounted crane (RMG) electric powered transport and quayside cranes
4	Container transporters	Truck-trailer-units (TTU)	Automated vehicles
5	Quayside container gantry cranes	Quayside crane with a lifting frame and lifting ties	Quayside crane with double lifting frames and double lifting ties
6	Automation level	Manual operation	Automatic operation
7	Container flow	Relatively restricted	Relatively steady
8	Initial investment	Low	High
9	Information interaction	Relatively independent	Coordinated
10	Production capacity	Relatively low	Relatively high
11	Flexibility of rail transport	Low	High
12	Energy use	Higher	Lower
13	Environmental impact	Includes noise and local air emissions	Almost no emissions

Table 1: Differences between an automated container terminal and current container terminals after (Yang and Li 2017)

use diesel powered TTUs for container transport, gantry container cranes and RTGs. An automated terminal uses unmanned transport systems, Straddle Carriers and RMGs. This generates a higher production capacity in automated terminals, together with a lower energy demand and a significantly reduced environmental impact. (Yang and Li 2017) Further impacts are shown in Table 1.

The current trend shows that ports are willing to automate and improve the efficiency of terminals. Following the development of automated terminal equipment, current developments are focussed on whole system solutions. These developments include automated gates, yards and quayside container gantry cranes. The development of automated quayside gantry cranes has the potential for a major advance in container terminal technology. (Martín-Soberón et al. 2014)

2.4 Tianjin Port

This study analyses the potential for automation to improve the environmental performance for the example of Tianjin port. The analysis compares the international position of Tianjin port in terms of geographical, economic and environmental factors (cf. chapter 2.4.1). The Tianjin Five Continents International Container Terminal is described (cf. chapter 2.4.2).

2.4.1 Current status of Tianjin port

Tianjin Port, or Tianjin Xingang (new port) was opened in 1860 under the name Tanggu. The current name of Tianjin port Company was adopted in 1952.

Tianjin port lies at the boundary between Beijing and Tianjin, on the West bank of the Bohai Bay in the north of the Yellow Sea. It is 56 km east of Tianjin city and 160 km from Beijing. This position means that Tianjin is the main port for the Beijing region in China and it is an important international logistics hub, as well as a centre for interchange of goods in the Chinese transport network. It serves more than 20 shipping routes to over 500 ports in 180 countries. (China Rundreisen 2019)

The port has a total land and water area of 336 km2, with an area of 107 km2 and more than 36 km of quays and 140 berths. (Dehmer and Wang 2015) The nominal capacity is 458.97 million tonnes and 11.31 million TEU container throughput per year.

This gives a theoretical capacity of bulk goods and agricultural productions of

334.87 million tonnes per year. The port has five main areas: Beijing, Nanjiang, Dongjiang, Haihe and Beitang with a total of seven container terminals and bulk, general, oil, Ro-Ro and cruise terminals. (World Port Source 2012)

In 2018, the container throughput was approximately 16 million tonnes, considerably greater than the 2015 capacity, making Tianjin port the 9th largest container port globally and the largest container port in northern China. (Hafen Hamburg 2018b) Figure 16 shows an overview.

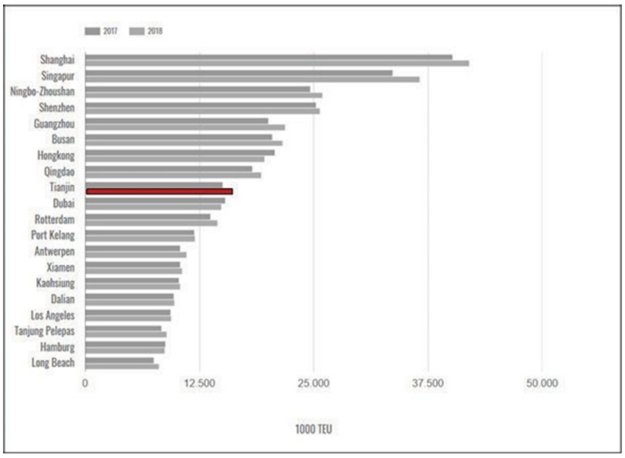


Figure 16: Top 20 container ports, ranked by container throughout 2018 (Hafen Hamburg 2018b)

The main energy carriers in Tianjin port are electricity, diesel, petrol, LNG, natural gas and heat, of which more than 90 % of energy use is electricity and diesel. The main energy users are transhipment and transport equipment including lighting and ventilation. (Tianjin Port Development Holdings Limited 2018)

The total energy use of Tianjin port in 2017 was 2,808,795 GJ. Direct resource use was 36,167 tonnes of diesel, 290 tonnes of petrol and 2085 tonnes of LNG. This was used in port equipment, ships and vehicles. The total indirect energy use through electricity and heat was 69,334 GJ. In comparison, the computer centre of the Google search engine requires 8,136,000 GJ, similar to a large city. New York, the city with the highest energy demand globally, has a demand of 280,224,000 GJ per year. (lifestrom 2018)

Direct emissions from fuel use and indirect emissions from electricity and heat use were 390,255 tonnes CO_2 in 2017. (Tianjin Port Development Holdings Limited 2018)

2.4.2 Tianjin Five Continents International Container Terminal

This section considers the Tianjin Five Continents International Container Terminal, using data provided by TIWTE. TIWTE cooperates closely with the terminal. The level of automation of the terminal and its processes is assessed. The Tianjin Five Continents International Container Terminal was the first terminal to automate RMGs.

Container handling for Tianjin Port is situated in the northern and eastern parts of the Xianjing port area. There are 23 container storage areas with a capacity of 11.25 million tonnes. The Tianjin Five Continents International Container Terminal is north of the “East Turbulent“ dike at the eastern end of the canal junction of Tianjin Port. The quay is 1202 m long and has four berths for ships up to a capacity of 200,000 tonnes. The terminal has an area of 350,000 m2 for container storage;

240,000 m2 for loaded containers and 20,000 m2 for empty containers. There are 12 quay-side gantry cranes and 31 RMGs. The Tianjin Five Continents International Container Terminal works with 16 international container lines and has 11 international routes serving 40 ports in more than 20 countries. There are also numerous feeder services in Bohai Bay. In 2016, 1.78 million TEU were handled, of which 1.52 million TEU were loaded and 526,000 TEU were empty containers.

Tianjin port is not yet at the level of the third generation of automation. Conventional, manned transhipment and container handling technology is still deployed. Although operations have been optimised and personnel working very efficiently, there is an increasing recognition that the increasing quantity of equipment requires more personnel resources. This requirement is causing bottlenecks and conflicts between the conventional operations and the trend towards larger container ships with their demands for improved efficiency of container loading and unloading processes. The demands on the terminal logistics are increasing, but the potential for development of efficient handling of larger container ships is limited. A change from manual processes to automation to current international standards would overcome the limitations in environmental performance, reduce energy requirements and deliver improved reliability of operations. Automation to achieve the next level of container terminal technology will require strengthening of associated services at the port and this would ensure the continuing international competitiveness of Tianjin port.

The implementation of the “Intelligent Port Demonstration Project“ in April 2017 was an important milestone in the overall development of Tianjin port to an intelligent port. The completion of the automation of the Tianjin Five Continents International Container Terminal is expected to deliver an increase in throughput of 200,000 TEU per annum. The refitting includes 31 current RMGs with RMG Program Logic Control (PLC) systems including the positioning, scanning, movement and identification systems. The renewal of communications systems, renovation of container repair and maintenance areas, peripheral access roads, administration and electricity supply are planned.

3. Energy efficiency in automated container terminals

Following the discussion of the key functions and equipment in a container terminal and the assessment of Tianjin port and its level of automation, this chapter assesses the sources of emissions and the energy balance of the terminal elements and equipment (cf. chapter 3.1 and 3.2). The energy efficiency, transhipment and container circulation efficiency of automated container terminals are compared with manual terminals (cf. chapter 3.3). Potential reduction measures are identified (cf. chapter 3.4).

3.1 Emissions sources in a port terminal

The OECD (Organisation for Economic Co-operation and Development) divides environmental issues into three areas: emissions from ships, port activities and hinterland activities. (Du et al. 2019) This study considers emissions inside the terminal, a part of the emissions from port activities.

The complex systems in port terminals have many potential sources of CO_2 emissions. Yang et al. has a systematic categorisation and analysis. Direct emissions come from transport and heavy equipment and two indirect sources: material and energy consumption. These emissions sources are assigned to the logistics, information and business service centres as shown in Figure 17.

A logistics service centre with transport and heavy machinery has a high level of direct CO_2

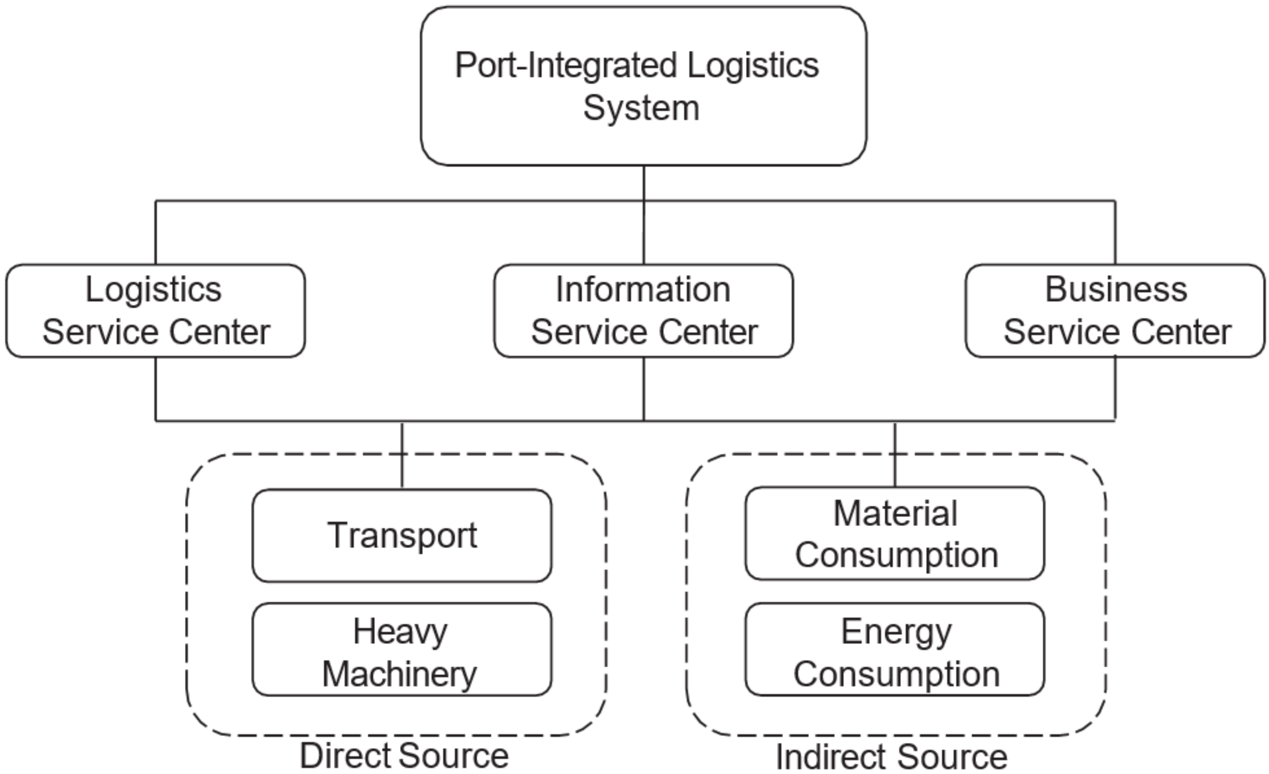


Figure 17: Emission sources in a port- integrated logistic system (Yang et al. 2017)

emissions, while the information and business service centres generate indirect emissions through material use and energy demand. (Yang et al. 2017)

CO_2 emissions from transport include all direct emissions from ships, trains, trucks and other vehicles. Direct emissions from loading and unloading processes, transhipment and stacking are included under heavy machinery. The heavy machinery uses fuel (or electricity) to conduct their operations. CO_2 emissions from material use include emissions from handling processes, in particular from rework, packing and paper use. Since these activities are usually located outside the port area, they are included in the indirect emissions of integrated port logistics. The emissions from the fourth category, electricity consumption, arise mainly from the operation of information platforms and warehousing services e.g. refrigerated warehouses, which use a large amount of electrical energy.

A more detailed examination of emission sources in a logistics service centre enables the definition of sub-categories. These include transport, storage, loading and unloading processes as well as distribution processes.

Ships and various types of vehicles are the largest emission sources for transport and dis-

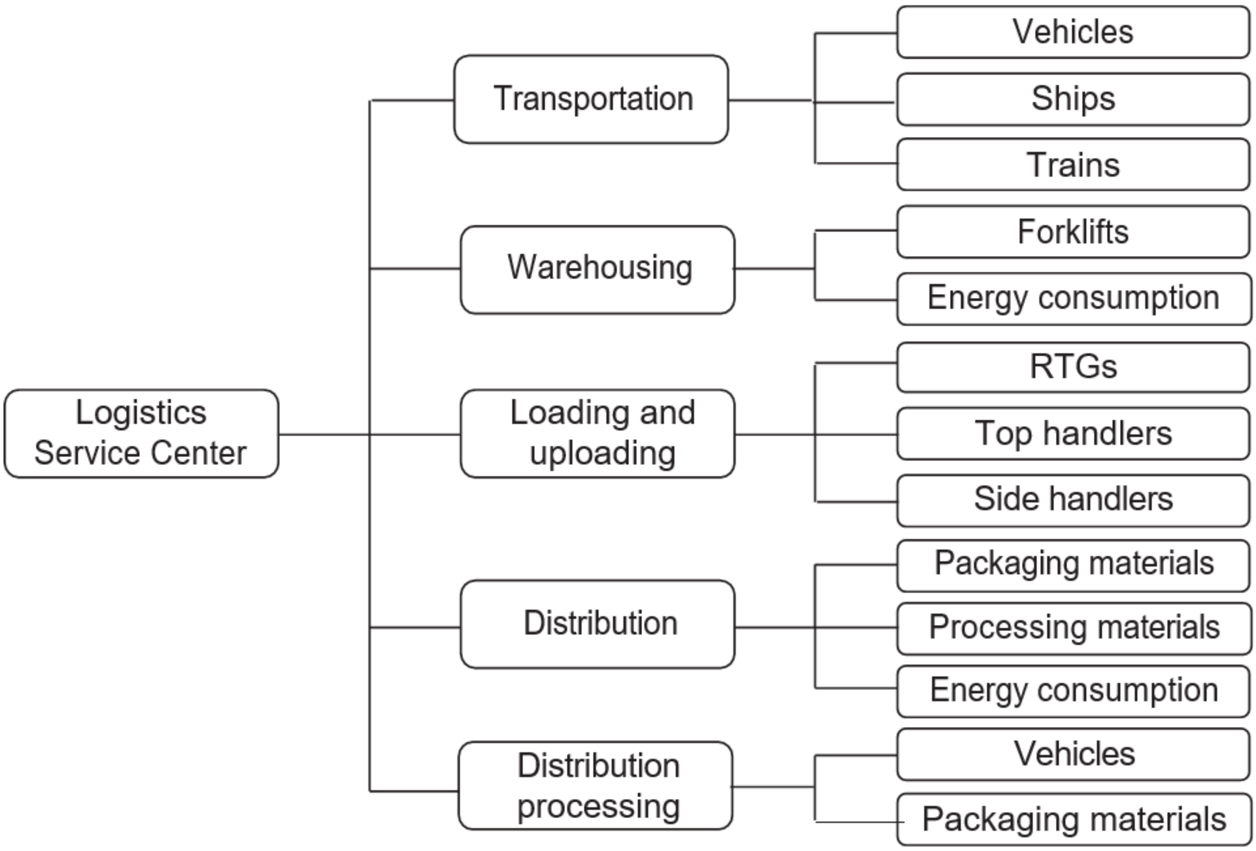


Figure 18: Emission sources in a logistics service centre (Yang et al. 2017)

tribution services. RTGs and RMGs, fork lift trucks and reach stackers are the main sources in transhipment and storage. These sources are all direct emissions and can be identified and calculated. Further sources are refrigerated warehouses, which use electrical energy as well as materials for processing and operational services which cause indirect CO_2 emissions. A detailed typology of emission sources in a logistics service centre is shown in Figure 18.

CO_2 emissions in a container terminal arise from energy consumption in transhipment equipment, warehouses and offices, heating energy demand and further energy carriers such as gas or diesel for transport and warehouse equipment. Greenhouse gas emissions (GHG) are calculated as the product of energy consumption and the emissions factor (GHG emissions = energy use * emissions factor). (Kaffka et al. 2015)

The concept of Life Cycle Assessment (LCA) has been developed to enable quantitative comparison of environmental impacts. LCAs assess the potential environmental impacts caused through the whole life cycle of a product from raw material extraction to final disposal or recycling/reuse. An important part of the assessment is the calculation of the carbon footprint, which includes a balance sheet of greenhouse gas emissions. A precise assessment requires a high level of data, with an extensive requirement for data collection and processing. For this reason, systems are often simplified for the analysis, reducing the plausibility of the results. (Kaffka et al. 2015) Therefore, this study is focussed on the investigation and assessment of CO_2 emissions. Further GHG emissions are not considered.

Geerlings et al. provide a consistent classification of functions for the allocation of emissions sources. This is based on the international Standards Greenhouse Gas (GHG) Protocol and ISO 14064. (Geerlings et al. 2014) The classification is shown in Table 2.

Functional area	Emissions source
Quay	Container gantry cranes
Warehouse	Transport equipment, stackers, lighting, refrigerated containers, packing
Transshipment	Transport equipment, transshipment equipment
Office Buildings	Building, Shower, Canteen, IT, Offices, Parking area
Other areas	Empty container storage, transport, railways, cleaning, repair/maintenance

Table 2: Allocation of emissions sources to functional areas (Geerlings et al. 2014; GHG Protocol; ISO 14064)

3.2 Energy use of terminal equipment

The analysis of the energy efficiency of automated container terminals requires data on energy use of the emissions sources discussed above. Data from Geerling et al. was used for the transhipment equipment. (Geerlings et al. 2014) The data in this study were validated to 95 % in the Rotterdam container terminals and in three further port container terminals in the Netherlands and are shown in Table 3.

Johanson has a more detailed analysis. An energy demand of 6 kWh per movement for 30 movements per hour was measured. The auxiliary energy consumption from motor cooling fans, headlights, hydraulic pumps and running lights was 2 kWh per movement. (Johanson 2010)

Saanen analysed the energy impact of automatic transporters and Straddle Carriers. CO_2 emissions per hour and the resulting costs per movement were calculated from vehicle weight, fuel or energy consumptions of diesel or battery variants. Values of 1 € per liter Diesel and 0.15 € per kWh of electricity, factors of 2.6 kg CO_2 and 0.24 kg CO_2 per kWh were used. (Saanen 2016) The results are shown in Table 4. Automated vehicles with diesel or battery electric power trains had the lowest CO_2 emissions. Straddle Carriers have a high fuel consumption and relatively high emissions by comparison.

Equipment	Fixed	Variable
Quay crane	5.3 kWh/move	
Mobile rotating crane	4 kWh/move	
Rail crane	5 kWh/move	
Automatic portal crane	5 kWh/move	
RMG Electrical	7.25 kWh/move 2.52 kWh/move	54.4 kWh/h.
RTG Hybrid	1.78 l/move 1.15 l/move	20.7 l/h. 13.33 l/h.
FTS Electrical	1.85 l/move 3.62 kWh/move	7.2 l/h. 14.2 kWh/h.
Straddle Carrier Hybrid	1.85 l/move 1.3 l/move	22.22 l/h. 15.6 l/h.
TTU Hybrid	1.33 l/move 1.1 l/move	8 l/h. 6.4 l/h.
MTS		4.3 l/km
Reachstacker	1.7 l/move	15.7 l/h.
Forklift truck	0.6 l/move	9 l/h.

Table 3: Energy use by transhipment equipment type (Geerlings et al. 2014)

Equipment	Weight	Fuel/Energy Consumption	CO_2-Emissions per Hour	Energie cost per Movement
AGV (Diesel-electric/ Battery-electric)	26 t / 26 t	7,5 l/h 17 kW/h	19.3 kg/h 4.9 kg/h	1.25 € 0.43 €
Lift-FTS (Diesel-electric/ Battery-electric)	31 t /31 t	12 l/h 27 kW/h	30.9 kg/h 6.4 kg/h	1.33 € 0.45 €
ALV (Straddle Carrier) (Diesel-electric)	52 t	17 l/h	43.6 kg/h	1.70 €

Table 4: Comparison of the energy efficiency of AGVs, lift AGVs and straddle carriers (Saanen et al. 2015)

3.3 Automated vs. non-automated container terminals

The container terminal „Xiamen Ocean Gate“, mentioned in chapter 2.3, represents the fourth generation of automated container terminals. It has three „twin vehicle“ quay cranes, 18 AGVs and 16 RMGs, which together fulfil the requirement for automation described in chapter 2.3 above. This system has a capacity of 9.5 million TEU per year, the 15th largest terminal in the world. Compared to current terminals, also described in chapter 2, a 25 % energy saving and more than 16% CO_2 emissions reduction is achieved. The transhipment efficiency is 20 % higher, bring additional economic advantages. (Yang and Li 2017)

Automation of terminal processes enables more movements per hour and therefore a higher transhipment capacity, which leads to indirect energy savings. Reduced time at the berth for ships or a reduction in the period of operation of equipment (lighting, cooling etc.) also contributes to emissions reductions. Direct energy savings are also possible, as automated processes are often more precise then manual systems. For example, a load is not lifted higher than necessary by an automated system.

Although a reduction of load saves energy, there is a loss of 20-25 % in the efficiency of mechanical and electric systems. This loss can be reduced by automation. (Johanson 2010)

Intelligent control systems or at least more efficient control systems are required to further increase energy savings. These can come from reductions in empty load movements, unnecessary movements, long waiting times, reduction in distances moved etc.

Saanen et al. conduct a comparative study between a terminal with RTGs and TTUs with automated RMGs combined with AGVs. The differences are also described in chapter 2.3 above. The result of the assessment was that an automated terminal operating at maximum throughput could achieve approximately 14 % energy savings. Allowing for the savings from increased transhipment performance and subsequent effects such as a reduction in the operating times of equipment, an overall saving of 34 % in annual electricity consumption can be achieved. (Saanen et al. 2015)

3.4 Reduction measures

Automation of terminal processes, which deliver reductions in CO_2 emissions is the first step towards an energy efficient port. A study from the Netherlands has shown that 30 % of the energy consumption in terminals is due to transhipment processes. 40 % is for refrigerated containers, 20 % comes from terminal lighting and 10 % from other requirements such as heating. (Geerlings et al. 2014) This section therefore considers further reduction measures that have the potential for reductions in energy consumption in addition to automation. Measures for optimisation of transhipment processes are considered in detail in chapter 3.4.1. Modifications to infrastructure are considered next. These are a considerable part of CO_2 emissions (cf. chapter 3.4.2). An assessment of the relevance of the results for Tianjin port and concepts for measures for emissions savings are presented (cf. chapter 3.4.3).

The analysis is based on Green Port strategies, such as port-specific environmental reporting systems, air pollution control measures, support of a change in the modal split of hinterland transport and environmentally friendly technologies in the port. (Krämer and Bargen 2018) Holocher et al. define the concept of Green Ports as a „concept for sustainable port activities“, consisting of three pillars. Green ports can be used as a necessary requirement for Green Shipping and represent ports that are equipped and managed for reduced environmental impact in their operations. (Holocher et al. 2016)

3.4.1 Optimisation of transhipment processes

Optimisation of operations includes reduction measures that have the objective of avoiding unnecessary transhipment activities and maximising the efficiency of the use of the transhipment equipment. Distances moved by transhipment equipment are particularly important, as the fuel or energy consumption is directly related to the distance moved. Therefore, the transhipment distances should be minimised, which means that the terminal layout has to be adapted to the processes in use and continuously examined and updated. Transhipments should be minimised, as every movement increases energy use. (Kaffka et al. 2015)

In this context, the port of Hamburg has initiated a multiple load project. The AGVs are loaded with two 20 foot containers, to reduce the number of AGV trips. This leads to an annual emissions saving of up to 600 tonnes CO_2. (Hafen Hamburg 2013) The AGVs at the Altenwerder container terminal (CTA) used around 5 million litres of diesel per year in recent years and represent the largest demand for fuel. For this reason, it was decided to improve the environmental efficiency of the AGVs and switch to renewable electricity. This could save up to around 15,000 tonnes CO_2 per year. (Hafen Hamburg 2018a)

With regards to the quay cranes, a reduction in energy use can be achieved through regenerative energy, feeding current back into the distribution network. If there is 20-25 % regenerative energy, the CO_2 emissions will be reduced by up to 4400 tonnes per year. (Storch et al. 2018) A further considerable savings potential arises from the possibility of operating several cranes simultaneously and using the regenerative energy to meet the overall energy demand. The energy generated at one position can be fed into the common distribution network. Studies show that with 10 cranes running simultaneously, around 30 % energy savings are possible when the energy is simultaneously generated and used. This also reduces the peak load on the distribution system, enabling the size of transformers and substations to be reduced with lighter cables for supply of the cranes. (Johanson 2010)

Energy savings can also be achieved in auxiliaries. The auxiliaries for a quay crane described consist of cooling fans, headlights, hydraulic pumps and running lights. These require 2 kW/h. This can be reduced through a series of measures. The motor cooling fans can be optimised to be switched on depending on the temperature of speed, instead of running continuously. The headlights should only be used when required in specific parts of the quay. The running lights can be switched off after a given time to reduce energy demand and emissions. (Johanson 2010)

A switch to more environmentally friendly vehicles (running with electricity or LNG) and the development of renewable energy in a port are among the most important Green Port strategies. Further possible strategies are the development of waste management and recycling, including waste water, water pollution and ballast water, reduction of noise, vibrations and dust particles from transhipment activities and measures for protection of ecosystems in the sea. The strategies for saving of energy in cranes from lowering containers or the deployment of LNG powered trucks discussed above are further examples. Smart Port Management can combine measures for reduction of emissions, energy use and costs through minimising empty voyages, use of digital technologies for optimisation of logistics processes or deployment of innovative mobility concepts. (Du et al. 2019) The feedback between energy use in the transport fleet and logistics can be identified through the measurement of electrical loads on transhipment equipment. This data can be used to develop strategies to increase container throughput while taking account of energy use. An assessment of the potential energy demand can be made through simulation of the planned future logistics processes. (Grundmeier et al. 2015)

3.4.2 Measures for infrastructure and personnel

CO_2 emissions that do not come directly from the transhipment processes arise from the operation of lighting, refrigerated containers and the use of IT equipment in offices and workshops. Lighting causes 10-20 % of the total CO_2 emissions of a container terminal and is therefore one of the largest components of energy demand. It is useful to differentiate between day and night lighting, as many terminals are run 24 hours a day and lighting at night is essential. Energy for lighting during the day is generally three levels below the night time use. (Grundmeier et al. 2015) The Hamburg Eurogate terminal has implemented the optimisation of lighting controls and a switch to LED lighting, which has achieved energy savings of 25 %. A new air conditioning unit in the computer centre saved 30 % of the annual energy demand. (Storch et al. 2018) The Taiwan International Ports Corporation (TIPC), which operates seven ports in Taiwan has reduced overall energy demand by 3 % through energy saving measures in offices. These included water, electricity, fuel and paper use. (Whelan 2019)

The port of Hamburg provides further examples of energy saving. The Hamburg Harburg Container Terminal Tollerort uses heating from waste heat from the local sewage works. This form of heat recovery saves 1000 tonnes CO_2 per year and saves energy costs. (Hafen Hamburg 2013) The Hamburg Eurogate terminal has its own wood pellet heating system, which uses a forestry waste product instead of fossil fuel for all its office buildings. Extra insulation installed during building renovation saves 50 % of the heating energy demand. (Hafen Hamburg 2013)

Personnel in a terminal are an important factor in energy saving. The “Industry 4.0“ trend to digitalisation and automation is increasing the specialisation and qualifications required for personnel. Even though it is not necessary for every worker to have special qualifications, this still leads to the recruitment of different categories of personnel for the new equipment. (Vitzthum et al. 2017) At the same time, personnel can be trained to drive and to brake in an energy-saving manner.

3.4.3 Recommendations for Tianjin port

Data on energy use by RMGs before and after automation from TIWTE was used to assess the level of the energy use of the Tianjin Five Continents International Container Terminal. The analysis assessed the advantages and disadvantages of automation and the energy saving potential of container terminal automation. Four areas were analysed:

1. Voltage, current and power requirement for various operations
2. Energy consumption by container handling operations
3. Energy consumption by cranes
4. Energy consumption by supporting equipment

Voltage, current and power

The table below shows the voltage and current of three repeated operations before and after automation. Automation did not deliver significant reductions in voltage, current or power (see Table 5 and Table 6).

Energy consumption by horizontal transportation

Data on energy use for loading and unloading have been provided. The energy use for lifting is high and when lowering the gravitational energy is used for regenerative energy production. Automation has eliminated abrupt changes of direction or velocity. The energy made available through automation is used for e.g. stabilisation of the position of the container. The control system has also been improved. However, it can be assumed that some automated systems will require more energy or generate more heat losses.

Energy consumption by vertical transportation

Automation has not made any significant difference to the energy requirements of cranes. The energy use during operation of container portal cranes was investigated. Automation

Max/Min. value	Run 1	Run 2	Run 3	Average
Max. voltage (V)	470.1	468.69	474.95	471.25
Min. voltage (V)	467.6	467.03	472.27	468.97
Max. current (A)	786.5	765.3	787.6	779.80
Min. current (A)	6	8	7	7.00

Table 5: Current and voltage from three-phase alternating current of RMGs before automation

Max./Min. value	Run 1	Run 2	Run 3	Average
Max. voltage (V)	478.1	472.12	473.53	474.58
Min. voltage (V)	468.5	467.35	470.52	468.79
Max. current (A)	783.2	776.3.3	782.3	782.75
Min. current (A)	7	8	7	7.33

Table 6: Current and voltage from three-phase alternating current of RMGs after automation

improved lifting and lowering of containers by enabling an operator in a remote control centre to control six quayside gantry cranes instead of each crane having its own operator in a cabin. Light and air conditioning systems are now only required for the central control room, instead of the cabs of cranes, which reduces the energy demand. These savings are one of the most important benefits of automation.

Energy consumption by supporting equipment

The energy consumption by the various auxiliaries is relatively small and also showing no significant changes from automation.

Table 7 shows a comparison of the energy use of individual RMGs before and after automation. The left columns show energy use for lifting and lowering the containers, followed by traversing of the trolley. These are summed to calculate the energy use per container for an RMG. Green cells show RMGs that have a reduced energy use after automation. It can be seen that only three cranes have a reduced energy use.

This data shows that automation of a crane does not necessarily lead to energy savings. This is shown by comparing the data before and after automation. Energy use was between 1.3 and 2.1 kWh before and between 1.7 and 2.25 kWh after automation. It should however be noted that the data does not enable a detailed quantitative and qualitative assessment of the potential for automation to reduce energy use. The table enables an initial, approximate assessment. Further, detailed data would be required for a complete analysis.

It is necessary to measure and compare the energy consumption under the same conditions for cranes. The weight and size of the container and the number of movements determine the energy consumption. Data for the average weight per load, lift and time of the RMGs is required to calculate and assess the potential savings per crane. Furthermore, the whole process should be assessed. The automation of the cranes, here RMGs, can lead to a higher energy requirement for the cranes, but the inclusion of variables for the whole process can show reductions in energy demand. This is because the automation of the cranes influences other elements of the process e.g. the productivity of transporter vehicles or the time to position vehicles and containers.

RMG energy consumption data on-site collecton before and after automatisation					
before	after	before	after	before	after
Lifting and Falling (kWh)		Tolley Move (kWh)		Single Container Energy Consumption Cart Move (kWh)	
1.31	1.47	0.40	0.51	1.71	1.98
1.29	1.62	0.36	0.59	1.65	2.21
1.41	1.45	0.50	0.49	1.91	1.94
1.52	1.39	0.49	0.47	2.01	1.86
1.49	1.48	0.44	0.48	1.93	1.96
1.51	1.61	0.34	0.55	1.85	2.16
1.57	1.58	0.35	0.46	1.92	2.04
1.53	1.68	0.48	0.56	2.01	2.24
1.62	1.71	0.41	0.55	2.03	2.26
1.42	1.59	0.46	0.52	1.88	2.11
1.24	1.58	0.39	0.54	1.63	2.12
1.19	1.45	0.36	0.78	1.55	2.23
1.22	1.57	0.41	0.48	1.63	2.05
1.24	1.35	0.45	0.41	1.69	1.76
1.41	1.61	0.41	0.47	1.82	2.08
1.19	1.31	0.34	0.41	1.53	1.72
4.12	1.51	1.09	0.48	5.21	1.99
1.31	1.54	0.36	0.49	1.67	2.03
1.42	1.51	0.34	0.73	1.76	2.24
1.52	1.31	0.39	0.90	1.91	2.21
1.43	3.10	0.37	1.02	1.80	4.12
1.32	1.76	0.37	0.46	1.69	2.22
1.24	0.96	0.32	0.35	1.56	1.31
1.41	1.61	0.37	0.56	1.78	2.17

Table 7: RMG energy consumption data on-site collection before and after automatisation

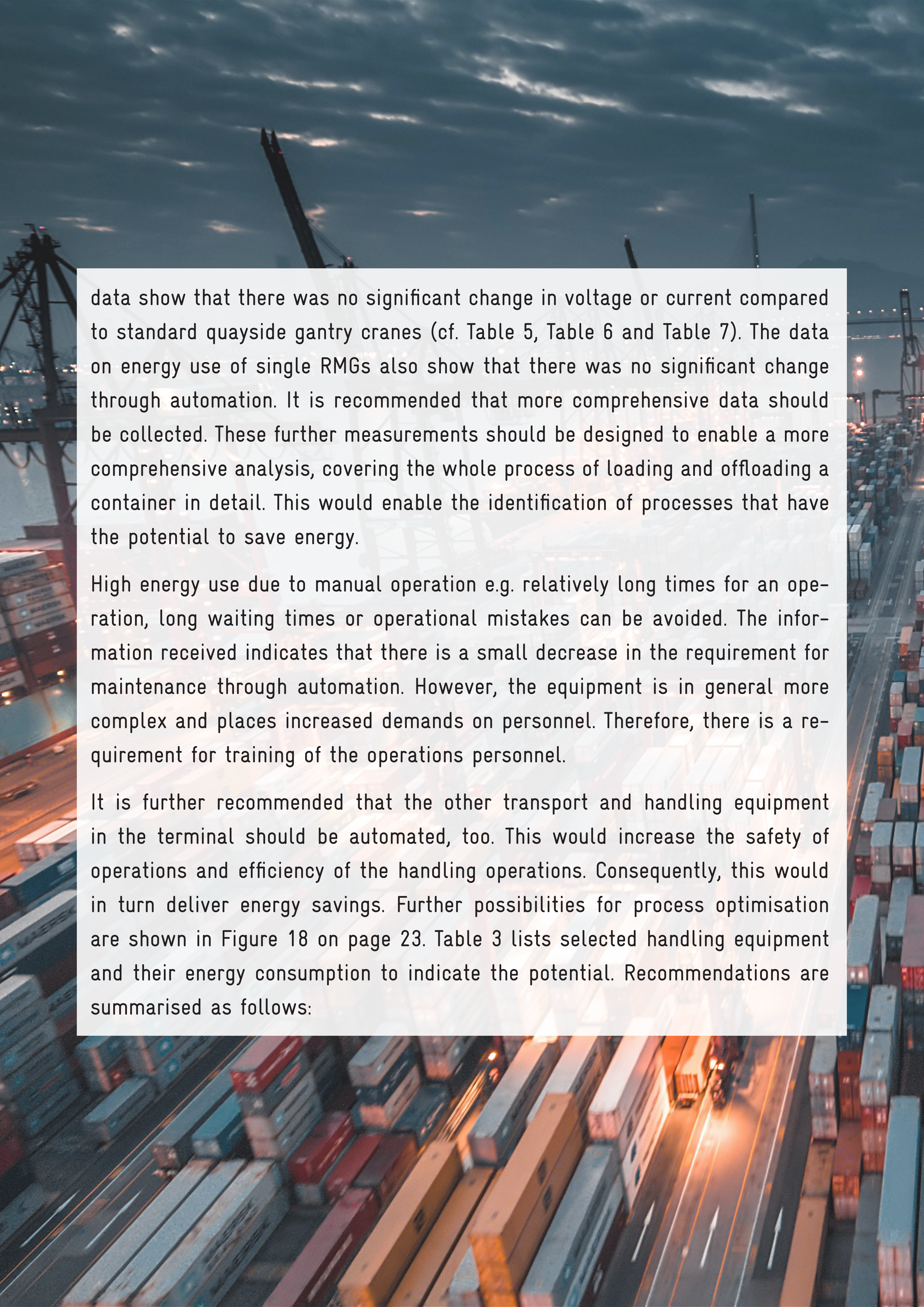
4. Conclusions and recommendations

The automation of terminal equipment leads to numerous changes in terminal operations. Complete automation requires modifications to operational procedures and in comparison to manual or partly automated terminals, they can deliver significant energy and CO_2 emissions. These can be achieved through improved operational performance with a higher throughput of containers, reduced operation times for the equipment and reduced emissions per movement. These factors can deliver savings of up to a quarter of the energy consumption by terminal operations compared to a current terminal.

The development of the port is not yet completed. Until now the logistic planning system and the Move-Job planning has been extended and optimized. There are however, further areas with the potential for improvement, some of which are outside the operations processes. Automation has mainly been applied to the RMGs, which mainly has an impact on the energy use for a single container transhipment. A broader analysis should consider the total energy demand with the inclusion of all relevant parameters (cf. chapter 3.4).

A large part of the energy demand does not necessarily come directly from transhipment operations (cf. chapter 3.4 and 1). Service and auxiliary installations and equipment including terminal lighting as well as refrigerated container electricity supply are also important. Therefore, there is an urgent requirement to implement broader organisational and terminal-specific measures to achieve significant energy demand and hence emissions reductions. Complete automation alone is not sufficient to achieve the sustainability goals that would transform Tianjin port into a Green Port. However, they are realistic further measures as part of a strategy for sustainability in Tianjin port.

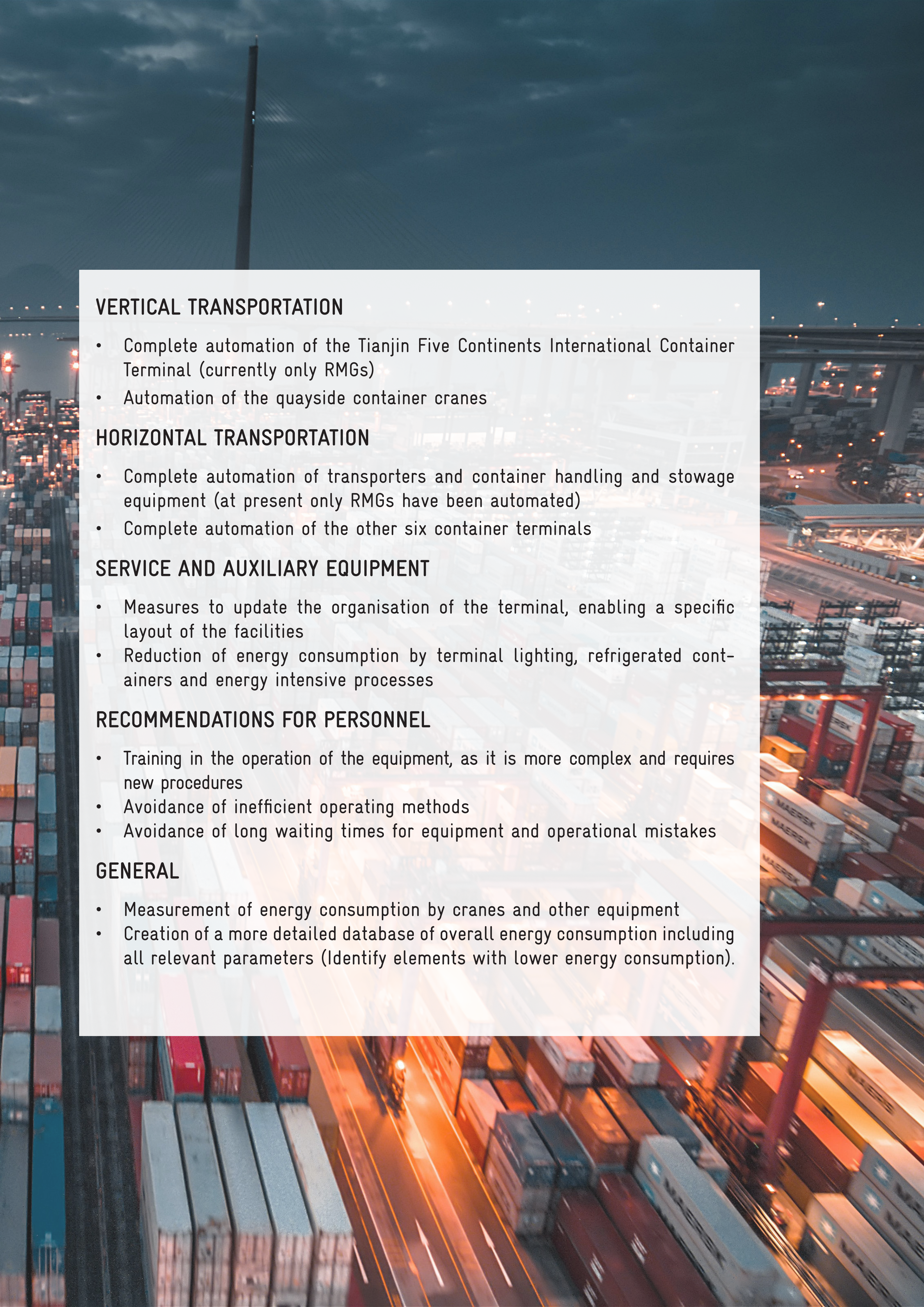
The test data received include the voltage and current of the three-phase supply and the energy use per container by RMGs before and after automation. The



data show that there was no significant change in voltage or current compared to standard quayside gantry cranes (cf. Table 5, Table 6 and Table 7). The data on energy use of single RMGs also show that there was no significant change through automation. It is recommended that more comprehensive data should be collected. These further measurements should be designed to enable a more comprehensive analysis, covering the whole process of loading and offloading a container in detail. This would enable the identification of processes that have the potential to save energy.

High energy use due to manual operation e.g. relatively long times for an operation, long waiting times or operational mistakes can be avoided. The information received indicates that there is a small decrease in the requirement for maintenance through automation. However, the equipment is in general more complex and places increased demands on personnel. Therefore, there is a requirement for training of the operations personnel.

It is further recommended that the other transport and handling equipment in the terminal should be automated, too. This would increase the safety of operations and efficiency of the handling operations. Consequently, this would in turn deliver energy savings. Further possibilities for process optimisation are shown in Figure 18 on page 23. Table 3 lists selected handling equipment and their energy consumption to indicate the potential. Recommendations are summarised as follows:



VERTICAL TRANSPORTATION

- Complete automation of the Tianjin Five Continents International Container Terminal (currently only RMGs)
- Automation of the quayside container cranes

HORIZONTAL TRANSPORTATION

- Complete automation of transporters and container handling and stowage equipment (at present only RMGs have been automated)
- Complete automation of the other six container terminals

SERVICE AND AUXILIARY EQUIPMENT

- Measures to update the organisation of the terminal, enabling a specific layout of the facilities
- Reduction of energy consumption by terminal lighting, refrigerated containers and energy intensive processes

RECOMMENDATIONS FOR PERSONNEL

- Training in the operation of the equipment, as it is more complex and requires new procedures
- Avoidance of inefficient operating methods
- Avoidance of long waiting times for equipment and operational mistakes

GENERAL

- Measurement of energy consumption by cranes and other equipment
- Creation of a more detailed database of overall energy consumption including all relevant parameters (Identify elements with lower energy consumption).

The objective of the study "Analysis and assessment of energy efficiency in automated container terminals" (Topic 1) is the assessment of the potential for automation of the equipment in Tianjin Port to improve environmental performance.

The relevant key factors, functions and processes were identified. The reasons and necessary conditions for automation were discussed and the elements of automation were identified.

The energy efficiency of an automated container terminal was described, using data on emissions sources and energy consumption by terminal equipment. Automated and non- automated container terminals were compared. Measures for energy demand reduction including optimisation of handling processes, infrastructure and personnel developments were compared with the Tianjin Five Continents International Container Terminal.

The proposed reduction measures (cf. chapter 3.4) and the assessment of the Tianjin Five Continents International Container Terminal show that the terminal is developing its level of automation. It can be regarded as the leading facility in Tianjin Port. Operation processes including the production planning system and Move-Job planning have been adapted. It is necessary to develop a representative database for an assessment of complete automation and the associated energy use of container cranes. The cooperation showed that there is a need for improvements in this area to enable a more comprehensive and detailed estimation of the potential of complete automation to deliver energy savings.

The analysis in the report "Sustainable strategies for ports" (Topic 3) shows that Chinese Ports are successfully developing their capabilities as "Intelligent ports", "Clean and renewable energies" and energy monitoring and management. They are implementing many innovative measures in these areas.

The measures recommended should be used as the basis for feasibility studies, projections of performance and the implementation of further measures, in addition to the completion of current measures.

5. References

Brinkmann, Birgit (2005): Seehäfen - Planung und Entwurf. Berlin Heidelberg: Springer.

Brinkmann, Birgit (2011): Operations Systems of Container Terminals: A Compendious Overview. In: Jürgen W. Böse (Hg.): Handbook of Terminal Planning. New York Dodrecht Heidelberg London: Springer Science+Business Media (Operations Research/Computer Science Interfaces Series 49), p. 25–39. Is available online at: https://pdfs.semanticscholar.org/e6d5/b52ebea65424384f7e05909b8e816f55e936.pdf, checked on 29.01.2019.

China Rundreisen (2019): Tianjin - Eine Hafenstadt. Is available online at: https://www.china-rundreisen.com/tianjin/.

Clausen, Uwe; Geiger, Christiane (2013): Verkehrs- und Transportlogistik. 2. Aufl. Berlin, Heidelberg: Springer.

Dehmer, Dagmar; Wang, Nina (2015): Tianjin am Abgrund. Explosionskatastrophe in China. Hg. v. Der Tagesspiegel. Is available online at: https://www.tagesspiegel.de/politik/explosionskatastrophe-in-china-tianjin-amabgrund/12195458.html.

Du, Ke; Monios, Jason; Wang, Yuhong (2019): Green Port Strategies in China. In: Rickard Bergqvist and Jason Monios (Hg.): Green Ports. Inland and Seaside Sustainable Transportation Strategies. With assistance from Joe Hayton: Elsevier Inc., p. 211–229. Geerlings, Harry; Duin, Ron van; Rossum, Tiuri van; Heij, Robert (2014): Green EFFORTS - Green and Effective Operations at Terminals and in Ports. Deliverable 4.2 A top-down methodology to calculate the CO2-footprint for terminal operations; the 6-step approach. Is available online at: https://repub.eur.nl/pub/99281/GREEN-EFFORTS-Deliverable-4.2-Geerlings-et-al.pdf, checked on 12.02.2019.

Gharehgozli, Amir Hossein; Roy, Debjit; Koster, René de (2014): Sea Container Terminals: New Technologies, OR models, and Emerging Research Areas. In: SSRN Electronic Journal, checked on 29.01.2019.

Grundmeier, Nico; Ihle, Norman; Hahn, Axel (2015): Ein Simulationsmodell zur Abbildung und Prognose der elektrischen Leistungsaufnahme in Seehafen-Containerterminals. In: Markus Rabe and Uwe Clausen (Hg.): Simulation in Production and Logistics. Stuttgart: Fraunhofer IRB Verlag, p. 555–564. Is available online at: http://www.asim-fachtagungspl.de/asim2015/papers/Proof_140_Grundmeier-V2.pdf, checked on 19.02.2019.

Hafen Hamburg (2013): Green Port Special. Is available online at: http://epub.sub.uniham-burg.de/epub/volltexte/2013/18137/pdf/port_special.pdf, checked on 18.02.2018.

Hafen Hamburg (2018a): Green Port. Port of Hamburg Magazine. Is available online at: https://www.hafen-hamburg.de/downloads/media/dokumente/HHM_POHH-Magazin_2-18-deu.pdf, checked on 18.02.2018.

Hafen Hamburg (2018b): Top Welt Containerhäfen. Hamburg. Is available online at: https://www.hafen-hamburg.de/de/statistiken/top-20-containerhaefen.

Hafenbetrieb Rotterdam (2016): Container exchange route. The smart way to connect. Make it happen. Rotterdam. Is available online at: https://www.portofrotterdam.com/sites/default/files/downloads/container-exchangeroute.pdf?token=L9FeANsV, checked on 04.02.2019.

Holocher; Meyerholt; Wengelowski (2016): Green Ports - Ein Konzept nachhaltiger Hafenaktivitäten. In: Internationales Verkehrswesen (3), p. 29–31.

Jiang, Xinjia; Peng Chew, Ek; Hay Lee, Loo (2015): Innovative Container Terminals to Improve Global Container Transport Chains. In: Chung-Yee Lee and Qiang Meng (Hg.): Handbook of Ocean Container Transport Logistics. Making Global Supply Chains Effective. New York Dodrecht Heidelberg London: Springer International Publishing Switzerland (International Series in Operations Research & Management Science, 220), p. 3–41. Is available online at: https://link.springer.com/chapter/10.1007/978-3-319-11891-8_1, checked on 29.01.2019.

Johanson, Frederik (2010): Efficient Use of Energy in Container Cranes. In: Port Technology International (48), p. 1–3. Is available online at: https://library.e.abb.com/public/c47547763b-b5d2a6852577f200706488/2010%20ABB%20Crane%20Systems%20PT48%20Fredrik%20J%20Johanson.pdf, checked on 19.02.2019.

Kaffka, Jan; Clausen, Uwe, Miodrag, Zoran; Pitsch, Holger (2015): Allokation von Emissionswerten auf Behälterebene in multimodalen Umshclagsanlagen mittels Simulation. In: Markus Rabe and Uwe Clausen (Hg.): Simulation in Production and Logistics. Stuttgart: Fraunhofer IRB Verlag, p. 365–574. Is available online at: http://www.asim-fachtagung-spl.de/asim2015/papers/Proof_137_Kaffka-V3.pdf, checked on 19.02.2019.

Kemme, Nils (2013): Design and Operation of Automated Container Storage Systems. Berlin Heidelberg: Springer Verlag. Is available online at: https://www.springer.com/de/

book/9783790828849, checked on 29.01.2019.

Konecranes (2019): LIFT AGV. Is available online at: https://www.konecranes.at/kraneund-hebezeuge/containerumschlag/automatisierte-containertransportfahrzeuge/lift-agv, checked on 04.02.2019.

Krämer, Iven; Bargen, Uwe von (2018): Nachhaltigkeitsperspektiven an der Schnittstelle globaler Supply Chains - Häfen als Treiber von Green Ports-Strategien. In: Irina Dovbischuk, Guido Siestrup and Axel Tuma (Hg.): Nachhaltige Impulse für Produktion und Logistikmanagement. Festschrift zum 60. Geburtstag von Prof. Dr. Hans-Dietrich Haasis. Wiesbaden: Springer Gabler, p. 153–166.

Kreuzer, Manne; Konecranes (2018): Elektrifizierung der Schwergewichte. Marktprognosen. Is available online at: https://www.elektroniknet.de/markttechnik/automotive/elektrifizierung-der-schwergewichte-149378.html, checked on04.02.2019.

lifestrom (2018): Welche Großstadt hat den höchsten Stromverbrauch? Is available onlineat: https://www.lifestrom.de/magazin/welche-grossstadt-hat-den-hoechstenstromverbrauch.
Martín-Soberón, Ana María; Monfort, Arturo; Sapina, Rafael; Monterde, Noemí; Calduch, David (2014): Automation in Port Container Terminals. XI Congreso de Ingeniería del

Transporte (CIT 2014). In: Procedia - Social and Behavioral Sciences 160, p. 195–204. Is available online at: https://www.sciencedirect.com/science/article/pii/S1877042814062326, checked on 29.01.2019.

Rintanen et al. (2016): Container Terminal Automation. A PEMA Information Paper, checked on 28.06.2019.

Saanen, Yvo (2016): AGV versus L-AGV versus ALV. A qualitative and quantitative comparison. In: Port Technology International (70), p. 30–35. Is available online at: https://www.researchgate.net/publication/304902856_AGV_versus_LAGV_versus_ALV_A_qualitative_and_quantitative_comparison.

Saanen, Yvo; Johnson, Daniel; DeWaal, Arjen (2015): How simulaiton modeling can support environmental initiatives at container terminals. In: Port Technology International (45). Is available online at: https://www.tba.nl/resources/press+section/publications/PT45-24_4.pdf, checked on 12.02.2019.

Speer, Ulf (2017): Optimierung von automatischen Lagerkransystemen auf Containerterminals. Wiesbaden: Springer Fachmedien Wiesbaden GmbH. Is available online at: https://www.springer.com/de/book/9783658172695, checked on 29.01.2019.

Steenken, Dirk; Voß, Stefan; Stahlbock, Robert (2004): Container terminal operation and operations research - a classification and literature review. In: OR Spectrum 26, p. 3–49. DOI: 10.1007/s00291-003-0157-z.

Storch, Hans von; Meinke, Insa; Claußen, Martin (Hg.) (2018): Hamburger Klimabericht. Wissen über Klima, Klimawandel und Auswirkungen in Hamburg und Norddeutschland: Springer Spectrum. Is available online at: https://link.springer.com/content/pdf/10.1007%2F978-3-662-55379-4.pdf, checked on 19.02.2018.SVETRUCK (2019): Stapler im Hafenbetrieb - wo jede Minute zählt. Is available online at: https://www.staplerberater.de/branchen/stapler-im-hafenbetrieb, checked on 04.02.2019. Tianjin Port Development Holdings Limited (2018): 2017 Annual Report. Is available online at: http://www.tianjinportdev.com/attachment/20180425163201000331214 42_en.pdf.

Tianjin Port Development Holdings Limited (2019): TIANJIN PORT DEVELOPMENT ANNOUNCES 2018 ANNUAL RESULTS. Tianjin Port Development Announces 2018 Interim Results 27 March 2019. Is available online at: http://www.tianjinportdev.com/html/media.php, checked on 24.06.2019.

TJBH (2018): „Intelligent Port Plan“ to promote upgrading of Tianjin Port. Is available online at: http://english.tjbh.com/system/2018/01/04/030312353.shtml#, checked on 04.02.2019.

Tran, Thanh Khanh (2012): Study of electrical usage and demand at the container terminal. Deakin University. Centre for Intelligent Systems Research. Is available online at: http://dro.deakin.edu.au/eserv/DU:30048431/tran-studyelectrical-2012A.pdf, checked on 19.02.2019.

turbosquid (2019): Gummibereifter Stapelkran - RTG. Is available online at: https://www.turbosquid.com/FullPreview/Index.cfm/ID/537282.

Vitzthum, Thorsten; Claus, Thorsten; Herrmann, Frank (2017): Einfluss von Mitarbeiterqualifikationszeiten im Rahmen nachhaltiger Produktionsplanung. In: Siegrid Wenzel and TIm Peter (Hg.): Simulation in Produktion und Logistik 2017. Kassel: Kassel university press, p. 315–324. Is available online at: https://www.asimgi.org/fileadmin/user_upload_asim/ASIM_Publikationen_OA/AM164_OA/AM164_ASIM_SPL_2017_Kassel_Proceedings_OA.pdf#page=22, checked on 19.02.2019.

Welt (Hg.) (2018): Container: Zahlen und Fakten. Axel Springer SE. Is available online at: https://www.welt.de/print/welt_kompakt/kultur/article176663554/Container-Zahlen-und-Fakten.html, zuletzt aktualisiert am 25.05.2018, checked on 30.01.2019.

Whelan, Sam (2019): Taiwan Ports group sets tough eco targets. In: Green Port (1), p. 24.

World Bank (2019): Container port traffic. (TEU: 20 foot equivalent units). Is available online at: https://data.worldbank.org/indicator/IS.SHP.GOOD.TU, checked on 30.01.2019.

World Port Source (2012): Port of Tianjin. Port Commerce. Is available online at: http://www.worldportsource.com/ports/commerce/CHN_Port_of_Tianjin_521.php.

Yang, Lei; Cai, Yiji; Zhong, Xiaozhe; Shi, Yongqiang; Zhang, Zhiyong (2017): A Carbon Emission Evaluation for an Integrated Logistics System. A Case Study of the Port of Shenzhen. In: Sustainability 9 (3), p. 1–23. Is available online at: https://pdfs.semanticscholar.org/33ab/d1eb8f675f5ef85bf1f784bbea2ba4808eae.pdf, checked on 12.02.2019.

Yang, Rui; Li, Qing (2017): Research on the system technology for automated container terminal. In: IEEE Industrial Electronics (IE) (Hg.): Proceedings of the The 29th Chinese Control and Decision Conference (2017CCDC). 2017 29th Chinese Control and Decision Conference (CCDC). Chonqing, China, 28-30 May, p. 3463–3466. Is available online at: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7979105, checked on 29.01.2019.

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