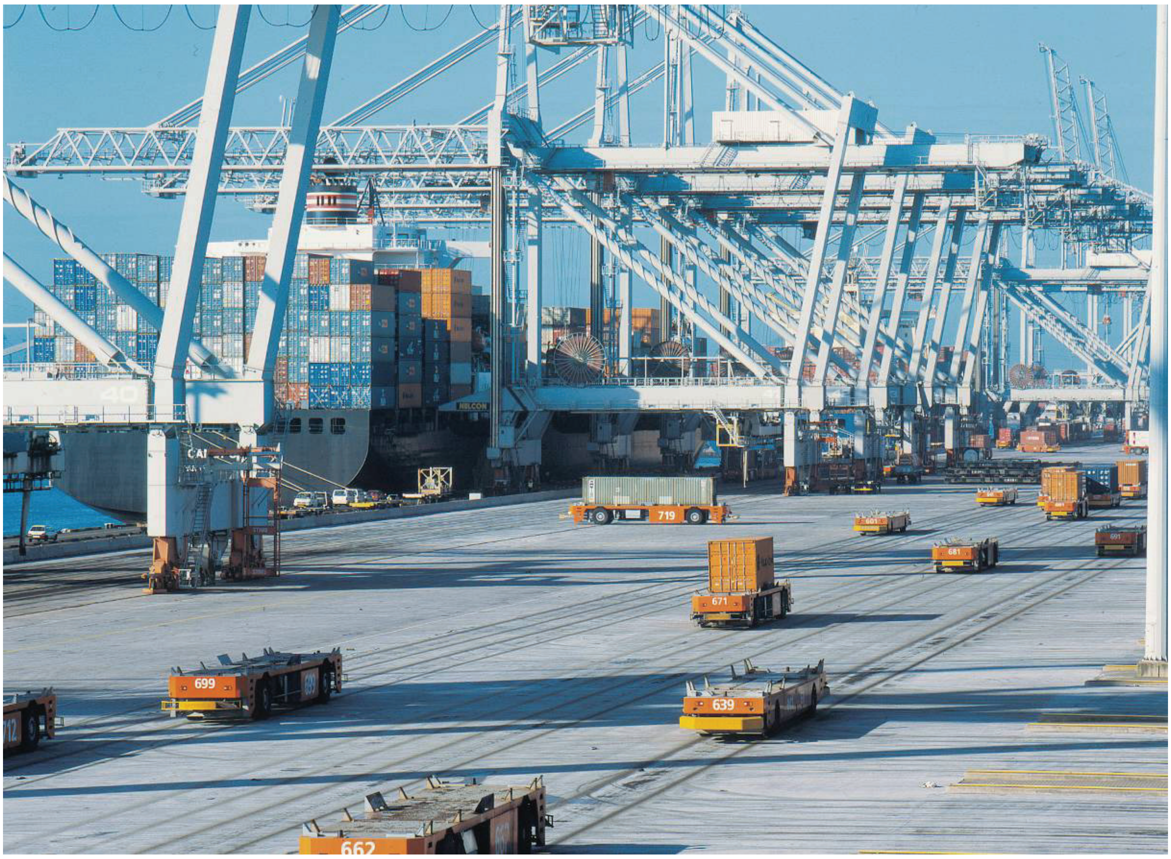

Container Terminal Automation

Feasibility of terminal automation for mid-sized terminals

W.C.A. Rademaker

30 March 2007

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PREFACE

The preface or foreword: written at the very last moment, to be put on the very first page of a book or a report. In this case, that is the final report to conclude my graduation project. It all started in October 2005 at a graduation reception. There, helped by lager or two, and his enthusiasm, my former friend from university, Niek van der Sluijs, convinced met that this project was one opportunity I shouldn't miss.

Full of energy, after my traineeship with Van Oord in Dubai, work began in Peterborough on the 15th May. Now, ten months and a handful of days later, after working through the night and the following day, to finish everything in time, it's finally my turn to write a foreword. Some of the very last words I'll be writing as a student.

The past ten months, I've been granted the opportunity to work at the offices of Royal Haskoning in Peterborough, to complete my graduation project. The subject of my study, container terminal automation, was unknown terrain for me. In Peterbrough I was provided with a perfect environment to study anything I got my hands on regarding the subject. Final goal of the project was to get acquainted with terminal operations and to demonstrate to the industry that the technology, for automated container handling, is ready to make the step to terminals smaller terminals.

Knowing close to nothing about container terminals, it's not been easy finding my way around the subject. In the first month of the project, I was able to jumpstart my knowledge of container terminals by attending the Terminal Operators Congress in Hamburg. Further more I'm proud to say that I've been able to pick the brains of the three foremost people in automated container handling. First there is Professor Rijsenbrij, who was technical director of ECT in Rotterdam throughout the development of the first automated container terminal in the world. At TOC in Hamburg I was able to meet dr. Richter of HHLA, who was one the leading people involved in the development of the worlds most modern container terminal, the Altenwerder terminal in Hamburg. Finally, in October I was able to meet Mr. Robin MacLeod, former director of the Thamesport terminal, the UK's first and, so far, only automated container terminal.

It may be debated whether this report will convince the sceptic terminal operators that the time has come for them to make the step to automated container handling. What I am convinced of is that I have been able to give an overview of some of the most impost important considerations in the design process of automated container terminals.

The preface is often used for thanking people, so will I. Of course there are many people I owe my gratitude for their contribution to this thesis in one way or another.

First I would like to thank Jonathan Tyler and Niek van der Sluijs of Haskoning for inviting me to come to England and do this project at their offices. Being among some of the foremost consultants has been very stimulating for me. Most of all, it allowed me easy access to the treasure of expertise that is bundles in the consultants of Haskoning.

Of course I'm very grateful for the support and feedback I've received from the members of my graduation committee. The pile of papers on the subject that Professor Rijsenbrij gave me, as well as the help of Mr. Groenveld and Professor Ligteringen, all these things have greatly helped me to write this report.

Finally, I would like to thank Joppe, Stefan, Milan, Dough, Marcus, Keith, Darren, Rob, Dennis, Neil, Garry, Leah, Mike, Kevin, Tamsen, Benjamin, Guillaume and all other

colleagues of Royal Haskoning in Peterborough, for making my time in Peterborough a great one when I was not working on my graduation.

Now it’s time to start reading!

Wieger Rademaker
The Hague, 26 March 2007

SUMMARY

Containers have become the standard for unitised cargo transport. In the past two decades, the emergence of the global economy has caused a boom in the volume of containers transported by sea.

Maritime container transport can be divided into a global network of major shipping routes and numerous regional, short-sea services. In ports, container terminals link the different shipping lines and provide the intermodal connection between the maritime and continental transportation networks.

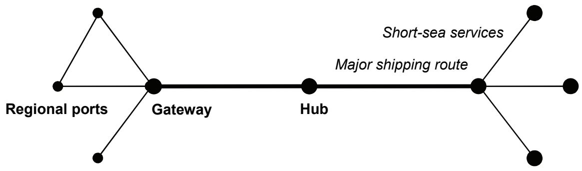

Figure 1.1 Schematisation of the maritime network

On the major shipping routes, very large container ships operate the intercontinental services. Container terminals in gateway and hub ports, along these routes, annually handle throughputs of over 500,000 TEU. The majority of these terminals is owned and operated by so called global terminal operators (GTO) that own and operate many terminals worldwide.

Regional and short-sea services between regional and minor ports in the periphery of the network are operated by smaller vessels. For the majority of terminals in these ports, annual throughput is much less. Local, single terminal operators (STO) generally operate these container terminals. Public sector involvement is often large.

Shipping lines are pressuring both larger and smaller terminals, to increase the level of services offered and, at the same time, reduce handling costs. Labour expenses take up a large part of those handling costs. For large terminals automated container handling has proven itself as a reliable and effective way to reduce operational costs.

Especially in Europe, small and medium sized terminals face heavy competition. The number of ports that compete for the same hinterland is increasing. To stay ahead of the competition, terminals are forced to offer a very high level of services. Meanwhile, flexible routes of regional services makes business development forecasts uncertain. Investment risks are therefore high in this capital intensive industry. As a result conservativeness is considered a virtue among small and medium sized terminal operators, and scepticism towards innovative technology is widespread.

The goal of this study is to inventory “off-the-shelf” automated container handling equipment and study the feasibility of automated container handling in small and medium sized terminals.

Container terminal analysis
A container terminal consists of 3 elements: a quay for serving ships, a yard for storing containers and a gate and transfer area for serving road vehicles and/or trains. The framework of a terminal designed is formed design requirements. These are based on external and site specific (boundary) conditions on one side. On the other side they are derived the demand for port services and service level requirement established by market analysis.

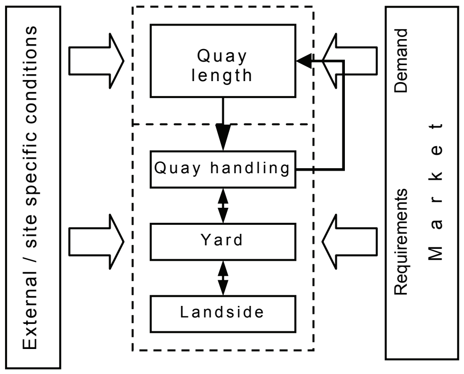

Figure 1.2 Overview of the influencing aspect on the functional design

Terminal performance can be evaluated on the basis of performance indicators. Key performance indicators are used to index the use of equipment and terminal infrastructure.

At container terminals, the term automation applies to information systems, automated vehicle processing at the terminal gate, and equipment automation. The unmanned operation of terminal equipment complicates a number of aspects of day to day terminal processes.

For automated container handling the following equipment is available:

Table 1.1 Overview automated equipment

	Function	Development status	Advantages	Disadvantages
Automated Guided Vehicle (AGV)	Internal transport quay ←→ yard	Fully operational; In operation since 1993	• Proven technology • Reliability	• Required equipment numbers
Automated Shuttle carrier (SHC)	Internal transport	Prototype (production ready); Technically equal to Autostrad	• Decoupling of quay and yard operations	• Operating costs of equipment (maintenance requirements)
Automated straddle carrier (Autostrad)	Internal transport, stacking and landside transfers	Fully operational; In operation since 2006	• Operational flexibility • Decoupling of quay and yard operations	• Operating costs • Large area requirements
Automated RMG / Automated Stacking Crane (ASC)	Yard handling; waterside transfers, housekeeping, landside vehicle transfers	Fully operational; In different variations operated since 1993	• High productivity • Proven technology	• Low flexibility • Crane rail required
Overhead Bridge Crane (OBC)	Yard handling	Prototype (production ready); Remote controlled operation since 1996, automated prototype fully tested	• High yard density • Well adaptable for unfavourable soil conditions$	• High construction costs of overhead bridge • Low accessibility of stored containers

Case study
Within the Risavika Havn port development project in Norway, an area has been reserved for a modern container terminal. A preliminary design is made of an automated container terminal based on the following design parameters

- Annual throughput : 200,000 TEU
- Transhipment ratio : 20%
- Mixing (Dry : IMO : RF : MT) : 60 : 10 : 5 : 25

- Storage demand avg : 3,871 TEU
  peak : 5,033 TEU
- Vessel size LOA max : 195 m
  avg : 140 m
- Calling rate : 12 – 14 $^{calls}/_{wk}$
- Max. average waiting time : 15% of service time

The quay length is set to 250 m, based on the design vessel and the queuing theory ($E_2/E_2/n$ system). To meet the waiting time requirement, a minimal quay handling capacity of 49,8$^{mvs}/_{hr}$ is required. Five concepts for automated container handling are compared. The different concepts are compared by a multi criteria analysis. The proven concept of AGVs and RMGs is selected. In the MCA, this concept scores marginally better than the Autostrad concept which has only just come onto the market.

A layout is made of the terminal for two alternative arrangements of the container stacks. The queuing theory is applied on a model of the container handling process to get an indication of the terminal's handling system. Equipment cycle times and equipment numbers are calculated. The resulting estimate of 3 STS cranes, 15 AGVs and 6 RMGs is verified in a simulation study. Within Royal Haskoning the terminal simulation package Posport CT has been developed. Due to assumptions in the modelling for the purpose of the study, the results produced by Posport CT can be questioned. The package is very useful for an indication of equipment quantities and productivities. Based on the results of the simulation study, the handling system is reduced to 2 STS cranes, 12 AGVs and 6 RMGs.

A detailed layout of the terminal is given appendix V. On a concept level, the civil works of the terminal are discussed. The following costs estimate is made.

- Fixed terminal structures and installations
  - Quay wall : € 11,281,250.00
  - Terminal infrastructure : € 6,517,000.00
  - Terminal buildings : € 2,833,000.00
  - Terminal facilities : € 7,800,000.00
- Terminal equipment:
  - Quay cranes(+ spreaders) : € 14,200,000.00
  - Yard cranes (+ spreaders) : € 16,120,000.00
  - AGVs : € 4,800,000.00
  - Other equipment : € 1,195,000.00

Including preliminary cost (15%) and contingency (15%) the total cost of the terminals structures and installations are estimated at 37,732,578.13 Euro. The total cost of terminal equipment, including contingency (20%), is estimated at 39,042,000.00 Euro.

The commercial feasibility of the project is evaluated using the discounted cash flow model. The Net Present Value (NPV) and Internal Rate of Return (IRR) are calculated for three investment scenarios. Each scenario is compared with a basic cost estimate of a conventional terminal design.

Table 1.2 Overview of results of DCF-model

Investment structure	NPV		IRR	
	Automated	Conventional	Auto	Conv.
• Land leased from PA in ready for building state • No foreign capital	-5,457,314.28	-21,678,434.03	7%	3%
• Quay wall included in lease • No foreign capital	2,253,254,07	-15,505,979.35	8%	3%
• Land leased from PA in ready for building state • 50% foreign capital (6% interest)	3,769,430.12	-15,504,769.26	9%	1%

Conclusions and recommendations

The NPV calculations show that the additional investment costs of automation are recovered in 6 to 8 years. From the discounted cash flow calculations it can be concluded that the project, in its proposed form, would not be feasible as a commercial investment. Public sector involvement is required in the form of, either (partial) ownership of the terminal infrastructure and / or equipment, or through financial support in the form of low cost financing or financial guarantees. Considering the influence of ports on regional economies it is not unthinkable a regional or national government will provide this support.

Due to the long life of the project, the investment risk is high. Confirmation of the forecast throughput development and terminal income is therefore recommended. The Autostrad concept was not selected for the case study on the grounds of area requirements, reliability and maintenance costs. To confirm the grounds on which the Autostrad was not selected, further study of this concept is recommended.

CONTENTS

GLOSSARY

Terms and abbreviations

AGV	Automated Guided Vehicle; internal movement vehicle that can operate without human control.
Aisle	The space between stacks of containers allowing access for mobile equipment.
Apron	Area of the terminal between the quay and the container stacking area.
Apron (construction)	Portion of the terminal area carried on piles beyond the solid fill, also called quay apron.
Bay	Row of containers placed end-to-end.
Beam	The width of a vessel at its broadest point.
Berth	Slot on the quay for mooring and service of a single vessel.
Block stack	Grouping of containers without leaving easy access to all containers, often used for storage of empty containers.
Bollard	Post, fixed to the quay for securing mooring lines.
Box	Term used for container.
Call size	Volume of containers (TEU) that is to be loaded onto or unloaded from a vessel calling at a terminal.
Carrier	Transport vehicle for cargo.
Cash flow	Sum of all expenses and income over a certain period.
CBA	Cost Benefit Analysis; Evaluation method for the costs and benefits of an investment.
Cell-guide	Steel bars and rails in the cargo holds of a ship used to steer containers during loading and discharging.
CFS	Container Freight Station; Warehouse facility where containers are packed and unpacked.
(Terminal) Chassis	Special trailer or undercarriage for transporting containers around a terminal.
Container	Metal box structure of standard design, used for carrying general cargo in unitised form.
Container yard	Container stacking area of the terminal.
Containerisable cargo	Cargo which can physically, conveniently and comically fit into a container.
Containerisation	System of intermodal freight transport cargo transport using standard ISO containers that can be loaded and sealed onto container ships, railroad cars, planes, and trucks.
Discharge	Removal of unloading of a container from a vessel.
Downtime	Period during which a certain equipment item, or terminal component can not be used for its primary function.
Draft	Vertical distance from the waterline to the lowest part of a vessel, not be confused with depth.
Dry container	Non-refrigerated general cargo container.
Dwell time	The time in days that containers remain in the container yard.
EDI	Electronic data interchange.
FCL	Full container load; Refers to a fully loaded container.

Fender	Shock absorbing appliance made of rubber, foam or other materials attached to the quay to prevent damage to the hull of a vessel, especially during mooring and un-mooring operations.
FEU	Forty-foot equivalent unit. A term used in indicating container vessel or terminal capacity.
FLT	Forklift truck
Front-end loader	A large forklift truck used for lifting and stacking containers.
Gate	The entrance point of road trucks entering and leaving the terminal.
GC	General cargo, dry container
GDP	Gross Domestic Product
Greenfield site	An area of foreshore and land to be developed in an unimproved condition, except for the infrastructure to the site boundary.
Ground slot	The area required for the footprint of a container.
GTO	Global Terminal Operator
Hatch cover	Watertight means of closing the openings in the deck of a vessel (hatchway) through which cargo is loaded into, or discharged from the hold.
Haulier	Road carrier of cargo.
High cube	Term indicating any container exceeding 8ft 6in in height.
IMO	International Maritime Organisation, abbreviation to refer to containers containing dangerous goods. (The IMO publishes the International Maritime Dangerous Goods Code)
Internal movement vehicle	Mobile terminal used for moving containers within the terminal, between the stack and quay area.
IRR	Internal Rate of Return.
Lashing	Securing of cargo (containers) stored on the deck of a vessel by the use of, wires, ropes, chains and straps.
LCL	Less-than-container load; Cargo not sufficient to fill a container
Lift	Term for actual container handling operation of quay crane.
Lift on/lift off	Cargo loaded or unloaded by either ship or shore cranes.
LOA	Length Over All, full length of the vessel.
Load	To move containers from the terminal onto the vessel
Loading sequence	The order in which containers are to be loaded to or discharge form the vessel.
MCA	Multi Criteria Analysis, decision tool for objectively weighing options on a number of criteria.
MHC	Mobile Harbour Crane
Mooring	Securing a ship to a fixed place by means of lines and cables.
Mooring gang	Group of workmen acting together, responsible for support to mooring operations, twistlock handling and in some cases lashing of containers on a vessel.
Moves	Actual containers handled as opposed to TEU handled.
MT	Abbreviation for empty containers.
MTS	Multi-trailer system, internal movement equipment of multiple chassis pulled by a single tractor.
NPV	Net Present Value
OBC	Overhead bridge crane

OCR	Optical Character Recognition, technology for digitally reading and processing documents.
Origin destination cargo	Cargo originating in or destined for the natural hinterland of the port, as opposed to transhipment cargo
Panamax	The maximum size of vessel able to pass through the Panama Canal.
Parcel size	see: Call size
Port Authority	The recognised statutory body responsible to the government for overall governance of the port (abbr. PA)
(Super-) Post-Panamax	Refers to a vessel too large to transit the Panama Canal.
Privatisation	The alteration of the legal and management structure of a government trading body to permit private equity of ownership. This is different to corporatisation under which ownership control remains with the government.
PTT	Port tractor trailer
Quay	The area parallel to the shoreline, accommodating ships on only one side.
QC	Quay crane, specialised crane located on the quay for the purpose of loading and unloading (containerised) cargo.
RS	Reach stacker, equipment similar to a large forklift truck, but able to lift containers from above
Reefer	Refers to refrigeration equipment or refrigerated containers, but may also be used in reference to cargo.
Reefer container	Refrigerated container, requires an external power source.
Reefer plug	Slot for storage of reefer containers, equipment with a power outlet.
RF	Reefer container
RMG	Rail mounted gantry
Roll on/roll off	Cargo that is, or can be, fitted to wheel to be driven on of from board.
RTG	Rubber tired gantry
SC	Straddle carrier
SHC	Shuttle carrier
Shipper	The party offering the foods for transportation, i.e. the generator of cargo
Slot	Place to store a single container, no to be confused with ground slot.
Spreader	A framework device enabling the lifting of containers by their corner castings
SSG / STS	Ship-to-Shore Gantry crane
Stack	The stack of containers in the yard
Stevedore	Individual of firm employed for the purpose of loading and unloading a vessel
STO	Single Terminal Operator
(Auto-) Strad	Straddle carrier
Stripping	A term often used to denote the process of removing cargo form a container
STS	Ship To Shore gantry cane

Stuffing	A term often used to denote the process of loading cargo into a container
Suezmax	Generation of vessel, who's size is limited by the width of the Suez Canal.
Tariff	List of rates, charges, regulations, and requirements of a port
TGS	TEU ground slot, area required for the footprint of a twenty-foot ISO container, including surrounding safety margins.
TEU	Twenty-foot equivalent unit
Throughput	Sum of all handled cargo handled by the terminal, normally measured at the quay.
Tier	A row of containers arranged one above or behind the other
TOS	Terminal Operating System
Tractor	A traction unit, similar to a road truck cab, but specially designed for port use
Trailer	see: Chassis
Transhipment cargo	Cargo landed at the terminal and shipped out again on another vessel without leaving the port area
Transit cargo	Cargo loaded at a port, but destined for another country via overland routes
Twistlock	Device that is inserted into the corner castings of a container and is turned or twisted, interlocking locking the container for the purpose of securing or lifting.
VBS	Vehicle booking system
Vessel	General term for any watercraft or ship.
Yard	See: Container yard

Symbols

A	Area	m^2
a	Accessibility of stored containers	
B	Breadth	m
C	Number of containers	TEU
C_i	Cash flow	TEU
D	Depth	m
f	TEU-factor	$^{TEU}/_{container}$
h	Height	m
I	Investment costs	€
L	Length	m
N	Number	-
n	Number access mores	(-)
P	Productivity	$^{TEU}/_{hr}$ or $^{moves}/_{hr}$
p	Peak factor	(-)
r	Discount rate	80%
S	Stack visits	TEU
T	Period	s
t	Time	s

u	Utilisation	$^{Km}/_{hr}$
V	Volume	m^3
v	Speed	$^{m}/_{s}$
v_a / v_s	Variability coefficient	(s)
W	Waiting time	(-)
μ	Transhipment ratio	(-)
μ	Average (probability distribution)	
σ	Standard deviation (prob. dist.)	

1 INTRODUCTION

Container transport by sea has been growing explosively in the past two decades. The annually transported volumes of containers have been growing at astonishing rates. As the transported volumes of containers grow, so will the demand for intermodal handling at the interface between the maritime and continental transport networks: the container terminal.

The continuing growth has lead to increasing pressure on container ports and terminals to increase their capacities, while at the same time reducing the costs of their services.

Labour costs account for a very large portion of the operational costs of container terminals. Terminal operators and equipment manufactures have been working together to reduce the dependency on labour. They developed new technologies to move more containers with less hands. Automation has been one of these innovations. The introduction of unmanned vehicles and container cranes has allowed a handful of terminal operators to drastically reduce the number of labourers in their operation. After twenty years of continuing development, automated container handling has matured. Automation has become an opportunity that can not be overlooked the majority of the, mainly large, container terminal operators. An increasing number of terminals has either made to step to automation or is in the progress of automating (part of) their operation.

Ventures of the industries pioneers have been cautiously observed. Smaller terminal operators have gotten the idea that they too may be able to profit from automation. This has resulted in an awareness of the need to investigate automation. These operators , do not have the time, nor the resources to look into this issue themselves. More importantly the perception of the costs involved with the development of new terminal concepts and the long lifespan of these terminals feed a strong conservatism and scepticism toward automation. No serious studies have been carried out as a result so far.

1.1 Goal of the study

This research project will investigate the feasibility of terminal automation for container terminals with a handling capacity of up to 500,000 TEU.

Firstly, an understanding of operations on a container terminal will be identified followed by the specific aspects and challenges that are typical for small en medium sized terminals. The specific aspects and challenges will form the starting point for the inventory analysis. The inventory analysis discusses the existing possibilities on implementing automated container handling on small terminals. Furthermore, an analysis of the costs and benefits of the required investment will determine the feasibility of automation as a commercial investment. Irrespective of the outcome of that analysis, this study will provide an insight in the existing options for terminal automation and the aspects and hurdles that are involved.

At the end of this study the following questions will have been answered:

- How can automated container handling be implemented on small terminals with “off-the-shelf” technology?
- I have Is automation of container handling operations in small terminals feasible as a commercial investment and by what factors is this feasibility affected?

1.2 Approach

To provide an answer to the two main questions just formulated, this study will be divided into two; a research part and a case study.

The first part of this study, the research, will one by one discuss the industry in general and the aspects of small and medium sized terminals. It will also analyse the terminal operating process and draw up an inventory of existing container handling technology and possible concepts of automated container handling.

The case study will follow up on the research. The most favourable concept of the presented concepts will be applied on a preliminary design of a real development project. Namely the development plans for a container terminal that is part of the Risavika Havn in Southern Norway. The feasibility of automation as an investment opportunity will be evaluated. An analysis of the required investment will finally be developed, based on the preceding feasibility of automation. Operating costs and the generated income from handling charges will be identifiable.

The figure on the opposite page illustrates how the different chapters of this report are split into the research and the case study.

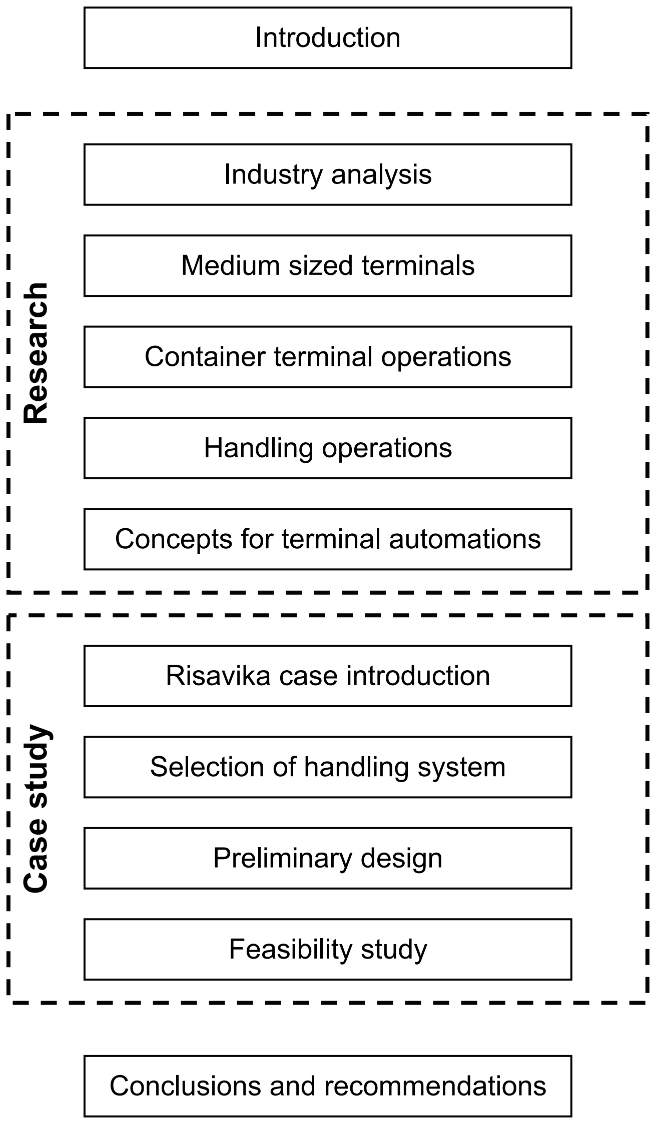

Figure 1.1 Overview of report outline

2 INDUSTRY ANALYSIS

2.1 Development of containerisation

The first containers were transported along the East coast of the United States in the 1950's. Since then containerised transport has seen continuous growth and has developed into a reliable standard for unitised transport of goods. At present day containerised cargo transport outgrown general cargo shipping to such extend that in many ports the image of the classic dockworker has become one of the past.

As the different world markets are expanding into one growing global market, containerisation has played an important role in the geographical separation of production and market. As a result the volumes and distances of transported goods have increased at astonishing rates over the past few decades. In the past decade the opening up of the Chinese market has played a key role in this development. It has become a huge new market for luxury goods from the West but most of all a good location for bottom price production.
For these reasons over the past two decades total transported volumes of containers has seen an annual growth of 10%.

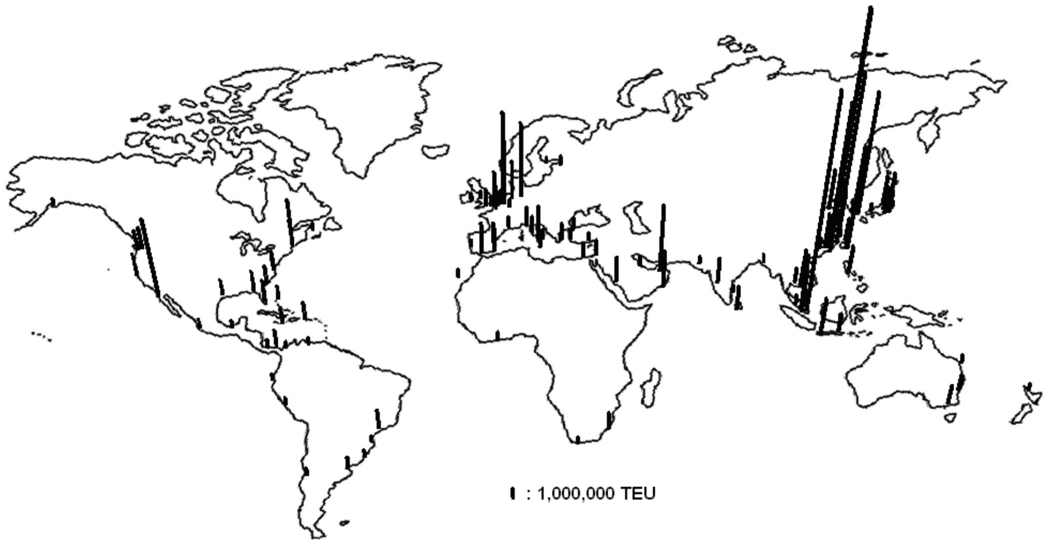

Figure 2.1 Overview of ports with a throughput in 2005 of over 500,000 TEU

To deal with the increased demand for transport capacity and to improve efficiency and reduce costs by introducing economies of scale, shipping lines are operating increasingly large vessels on their main routes. A number of vessels with capacities of up to 11,000TEU are already sailing the seas and ships have been ordered that exceeding the current size limit for the Suez channel of 13,000TEU.

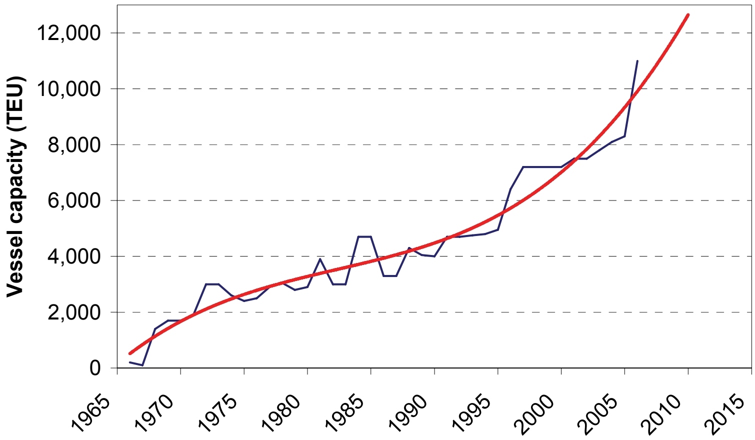

Figure 2.2 Development of maximum vessel size by year of build

The growing flow of cargo and the increasing ship sizes are stretching the limits of the handling capacity of the mayor ports. The result of this is congestion and the increased waiting times lead to severe loss of productivity.

The past decades Europe and North America have seen a continuous rise in labour costs. While shipping costs have been reduced by up to 50%[1] port handling costs however have hardly reduced and are now taking up as much as 15 to 20% of the overall shipping costs. As a result the shipping lines are exerting strong pressure on terminals to increase handling capacity and productivity and at the same time reduce the costs.

Terminal operators have been investigating the options to reduce their operating costs by automating container handling for their large terminals. However investments in the port industry are made for periods from 15 to 25 years, and terminal operators are facing a dilemma. On one hand terminal and berth designs must account for developments beyond the horizon in order to cater for a period of 25 years of growth. On the other hand the large time scales causes conservativeness when it comes to truly innovative issues such as automation.

Regardless of this scepticism a number of terminals in large ports have made the step towards automation and an increasing number is planning to do so.

2.2 Developments in terminal automation

In 1988's ECT in the Port of Rotterdam was the first terminal to decide to make the step to automating of its handling operations. Like for many competitors, business had been growing steadily and services and efficiency were permanently improved through mechanisation and automation. Despite this however revenues had remained modest and labour costs accounted for 60% of the container handling costs. Automation of the handling operations seemed to be the only solution to reduce (labour) costs and increase revenues.

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[1] Cost of shipping 20ft container from China to Hamburg: 1992: 4000 US$, 2001: 2200US$ (JR: currently 1,300 US$ with APC)

The Delta/Sealand Terminal was designed and constructed to operate fully automated from the very start of operations in 1993 as it did. To do so the entire system and every piece of handling equipment had to be developed from scratch. This included the development of everything from the terminal operating system up to the unmanned container handling equipment automated RMGs and AGVs in the yard. The project was a daring piece of pioneering watched closely by the competition.

Around the same time at the Isle of Grain, Thamesport was planned to be an automated container terminal. To reduce risks and ensure an early start of operations the terminal was designed and built to start operations with manned RMGs and terminal tractor trailers that were to be automated in a later phase. After an early, manned, start of operations in 1990, development on the RMGs continued and these were indeed automated within two years after generating the first revenues. A development project for AGVs ran out of funding and was abandoned. Up to date AGVs have not been introduced. There is however no restriction to do so in the future.
The Pasir Panjang Terminal in Singapore was built using automated Overhead Bridge Cranes (OBC). The OBC system was picked as it allows for much greater stacking heights and it can be made much less susceptible to settlements of the reclaimed land. Like in Thamesport the transport between storage yard and quay is still by manned tractors.

In 2002 in Hamburg the fully automated Altenwerder Terminal of HHLA became operational. This terminal makes use of triple RMGs using two identical RMGs for each side of the stack and a single larger one that can pass the smaller ones and service the entire length of the stack to increase productivity.

In January the Fisherman’s Island terminal of Patrick Corp 2006 in Brisbane commenced operations. On the terminal Automated Straddle Carriers perform all handling operations between the quay and the loading of trucks. In its final phase, the terminal is designed to handle an annual throughput of 800,000 TEU.

Automated container handling has today become a proven concept for large container terminals. While only a handful of automated terminals are currently in operation, the industries trust in the concept is being demonstrated by port authorities and terminal operators all over the world. New automated terminals are being planned and conversions are scheduled for existing ones. In the table below an overview is given of the terminals in the world that have been automated and some of the ports that are currently planning automated container handling.

2.3 Maritime networks and port classification

The maritime transportation network of shipping routes connecting ports and terminals can be modelled as a network of hubs (ports) and spokes (shipping routes). The network is build up of numerous regional networks of regional and minor ports that are that are connected by short sea shipping routes. These networks feed the intercontinental network of large port classified as hubs and gateways that are connected by the main shipping routes.

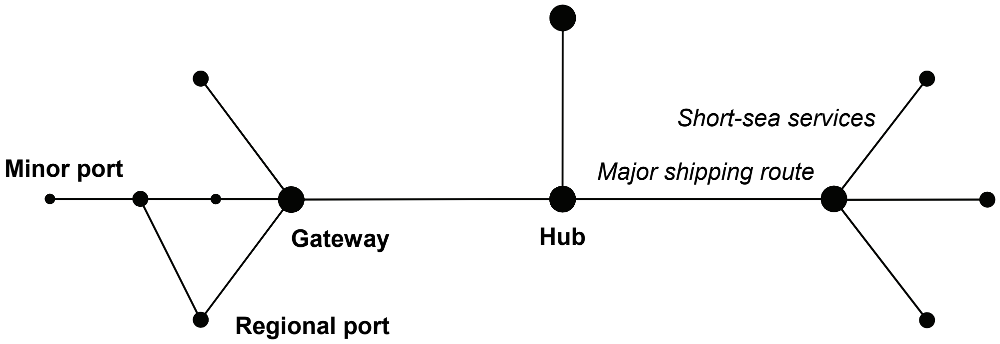


Figure 2.3 Port classification in maritime networks

In global container shipping this network becomes visible by large container liners operating the main east-west routes stopping only at large deep sea ports. Smaller vessels feed this network and connect the nodes with the regional network. Figure 2.4 below gives an overview of the highest ranking port in the world with regards to throughput. From the picture it becomes clear that the main container hubs and gateways are located in North America, Western Europe and East and Southeast Asia.

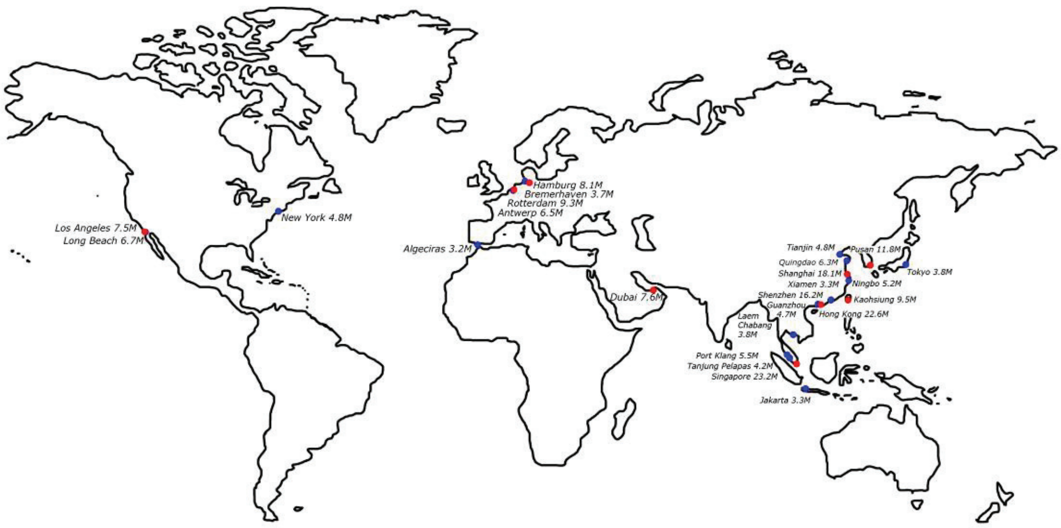


Figure 2.4 Largest 25 container ports by throughput over 2005

Ports are classified in the network as hubs, gateways, regional and minor ports according handled volumes over the quay, their role in maritime and hinterland networks, their focus on transhipment or import/export and the service characteristics. Along the main shipping routes hubs function on connecting the different shipping routes and focus on transhipment of containers. Gateways, also classified as load centres are also connected to the major shipping routes but serve a vast continental hinterland and focus on connecting the maritime network with inland networks of roads, rail and inland waterways. Regional and minor ports have a similar function in the regional network and mainly characterised by the difference in the size op operations.

Below their characteristics will be discussed point by point:

Gateway
- Origin / destination on main shipping route: focus on import and export
- Large hinterland is served
- Focus on import/export requires high quality of intermodal connections
- Called upon by largest carriers (up to 11,000 TEU)
- Annual throughput well over 1,000,000 TEU
- Hong Kong, Rotterdam, Felixstowe, Antwerp

Hub
- Located at or near intersection of major shipping routes
- Connecting main shipping routes
- Focus on deep sea transhipment: intermodal connections of limited importance
- called upon by largest carriers vessels (up to 10,000 TEU)
- Annual throughput well over 1,000,000 TEU
- Singapore, Dubai, Colombo, Algeciras

Regional port
- Peripheral in maritime network
- Serve a substantial industrial / metropolitan hinterland
- Little transhipment
- Largest vessels up to 4,000 TEU
- Annual throughput over 250,000 TEU
- Thamesport, Zeebrugge, Chittagong, Liverpool

Minor port
- Insignificant position in maritime network
- Local traffic base
- No transhipment
- Vessel size up to 1,000 TEU
- Annual throughput below 250,000 TEU
- Copenhagen, Malmö, Cork

Where gateways and hubs take up the first 100 places of the annual container port traffic ranking, regional and minor ports take up the next 260 places. This makes them a part of the market that should not be overlooked.

2.4 Terminal classification and ownership structures

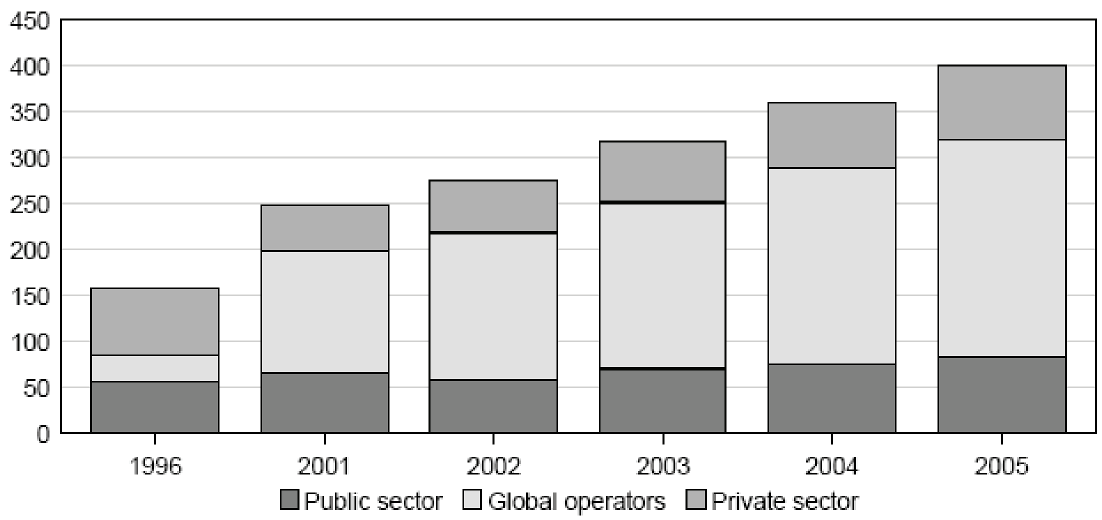
Up to this point in the report only ports have been discussed. The actual container handling operations take place on the different terminals within these ports. Three different types of container terminals can be identified. Deep-sea container terminals are located in either Gateway ports of hub ports, while feeder terminals and mixed Ro/Ro and Lo/Lo terminals are found in the short-sea and inland networks of regional and minor ports.

In this industry many different types of terminal owners and operators exist. Historically the involvement of the public sector in the ports industry is rather large, as governments tend to view ports as strategic infrastructure assets which should remain under governmental control. Over the past decade however the trend has been for governments to release public control over port operations to the private sector. As a result an increasing number of terminals is owned and operated by a so called global terminal operator (GTO), operating multiple container terminals worldwide, while others are owned single terminal operators (STO) operating one or only a few terminals in one region.

Table 2.1 Typical ownership and operating structures for container ports

Mode of Ownership	Land Area	Terminal Infrastructure	Terminal Superstructure (Cranes / Yard Equipment)	Quayside Operations	Landside Operations	Example
100% state owned & operated	State owned	Owned and constructed by port authority	State owned	Port authority	Port authority	Callao, Peru
"Suitcase" stevedores	State owned	Owned and constructed by port authority	State owned	Private stevedores (on common-user berths)	Port authority	Norfolk International Terminal, Hampton Roads, USA
Leased terminal	State owned	Owned and constructed by port authority	Privately owned or rented from port authority	Terminal operator	Terminal operator	Oakland Container Terminal, USA
Concession agreement	State owned	Owned and constructed by port authority	Privately owned	Terminal operator	Terminal operator	Port 2000, Le Havre, France
BOT concession	State owned	Construction privately funded	Privately owned	Terminal operator	Terminal operator	Laem Chabang International Terminal, Thailand
100% privately owned	Privately owned	Privately owned	Privately owned	Terminal operator	Terminal operator	Teesport, UK

Source: Drewry Shipping Consultants Ltd



Source: Drewry Shipping Consultants Ltd

Figure 2.5 Development public/private control of container terminals

Today many of the large terminals in the major container hubs and load centres are operated by a so called global terminal operator (GTO). GTOs own and operate an often large number of terminals around the world in strategic parts of the global shipping network. Striking is the share of the terminal operating market that is held by the top 5 of GTOs. In the following table an overview the most important GTOs is provided, showing the number of ports in which they operate terminals and the total volume of containers that were handled over the quay in 2005.

Table 2.2 Overview largest global terminal operators in quay throughput (2005)

Terminal operator	Origin	Ports	Throughput (mln TEU)	Share
Hutchinson Port Holding	Hong Kong PA	41	51.8	13%
PSA	Singapore PA	20	41.2	10%
APM Terminals	Maersk line	40	40.3	10%
P&O Ports	P&O line	27	23.8	6%
DP World (acquired P&O)	Dubai PA	26	12.9	3%
Total			170	43%

3 MEDIUM SIZED TERMINALS

The Containerisation International global ranking of container ports contains a total of 360 ports worldwide handling containerised cargo. The 100 largest terminal in terms of throughput handled total volumes of 737,000 TEU (Cape Town, SA) up to 23.2 million TEU (Singapore) in 2005. The next 190 ports in this ranking all handle an annual throughput of over 100,000 TEU. These ports can be considered as medium sized terminals and will be considered for this study.

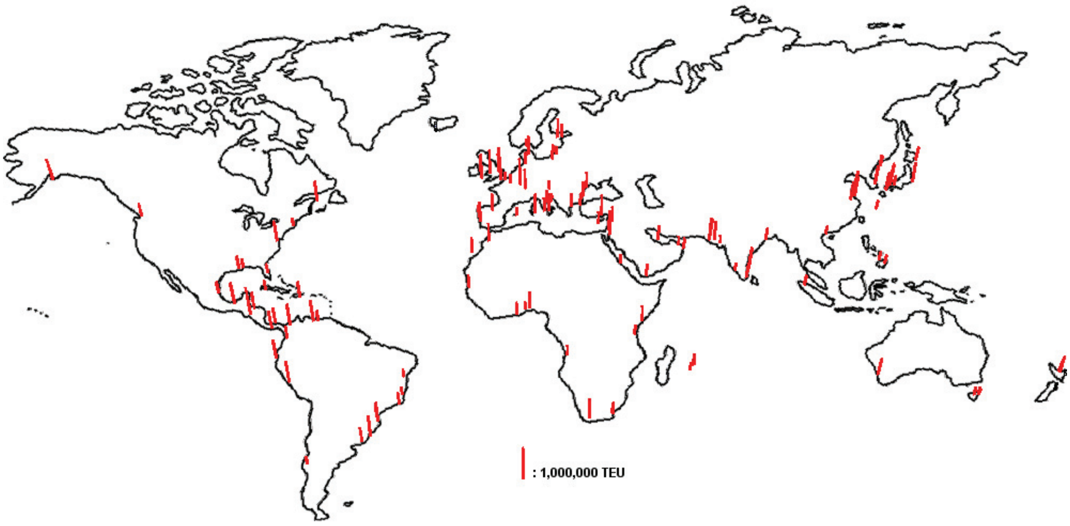


Figure 3.1 Terminals 100,000 - 600,000 TEU

Unlike the global hub ports that are concentrated along the main routes from East and Southeast Asia to Europe and North America, these smaller ports are spread out over the world.

3.1 Analysis of medium sized terminal operation

3.1.1 Regional analysis

Latin America and Africa

In the large developing continents of South America and Africa general cargo is still the main for of cargo transportation and container shipping has only a little share of the market. Located away form the main transport artery the Far East, Southeast Asia, Europe and North America container ports are few and function as regional import and export centres along the shipping routes to and from markets in North America, Europe, Asia and Australia. Terminals in these ports are in most cases under government control, operated by the local Port Authority. Even ports that are not far apart often face little competition from each other as the local infrastructure is very limited. This combined with the plenty availability of cheap labour provides little incentive for technological development to improve efficiency.

Table 3.1 Container ports Latin America and Africa[1]

	Central Am and Caribbean	South America	Africa
Regional throughput (TEU)	11,939,095	9,441,061	9,028,131
Hub ports (throughput TEU)	San Juan PR (1,667,868) Pt Manzanillo PA (1,473,159) Freeport BH (1,148,800) Manzanilla MX (830,777)	Santos BR (1,882,639) Buenos Aires AR (1,138,503) San Antonio CH (639,762)	Durban SA (1,716,700) Las Palmas CI (705,618) Abidjan Cd'I (670,000)
Ports <600,000 TEU/yr	9	14	14

The Panama Canal, connecting the Pacific and the Atlantic ocean, has given container handling in Central America a more important role with good connections to both Asia, Europe and both North American coasts. There is much competition between the different transhipment ports competing for PostPanamax vessels that cannot pass the Panama Channel. Labour is relatively inexpensive.

North America, Europe and Oceania
In North America, Europe and Oceania containerisation has become the main mode of cargo transportation. Small and medium sized ports in Europe and North America are close to the main transport artery. Regional short sea networks connect the local markets and feeder services to the many hubs connect these ports with the global network. The high quality of the infrastructure in Northwest Europe stimulates competition among neighbouring ports and with hubs.

Table 3.2 Container ports North America, Europe and Australia & New Zealand

	North America	Europe	Australia and New Zealand
Regional throughput (TEU)	38,315,872	69,338,385	6,245,819
Hub ports (throughput TEU)	Los Angeles (7,321,440) Long Beach (5,779,852) New York / NJ (4,478,480)	Rotterdam NL (8,281,000) Hamburg DE (7,003,473) Antwerp BE (6,063,746)	Melbourne AUS (1,910,351) Sydney AUS (1,376,365) Brisbane AUS (706,242)
Ports <600,000 TEU/yr	41	41	6

An important cost factor for container terminals in North American and Australian ports is the strong unionisation of the workforce. For some ports in the United States powerful unions have boosted labour expenses to well over 60% of the total port handling costs. In Northwest Europe labour legislation rather than unionisation has a similar effect on the cost of labour in the port.

In the strife to remain in competition smaller terminals have many incentives to improve cost efficiency of their operations limited only by social economical motives such as unemployment relief.

[1] Source: Containerisation Int. Yearbook 2006

Middle East and South Asia
The rich markets of the Middle East and the very large market of India located right next to main shipping route between East Asia and Europe have stimulated containerisation in these regions to a sizeable market. As in Europe and North America, smaller ports have a peripheral function in the network. Here however low cost labour is again plenty available and erratic quality of infrastructure limits competition.

Table 3.3 Container ports Middle East and South Asia

	Middle East	South Asia
Regional throughput (TEU)	16,248,868	7,469,043
Hub ports (throughput TEU)	Dubai UAE (6,428,883) Jeddah SA (2,425,930) Salalah O (2,228,546)	Jawaharlal Nehru (2,370,000) Colombo SL (2,220,573) Karachi PK (607,000)
Ports <600,000 TEU/yr	4	7

China and Far East
Pacific Tigers: Export, export, export
Huge growth in China, labour plentiful and cheap
Most ports in range are new and way up

3.1.2 Port functions

In the periphery of the maritime network small terminals strongly rely on the shipping lines that connect them to regional container hubs. The main function of the port is the import of and export of containers and the modal split[1] of these ports shows very little transhipment.

In regions with good transport networks small container terminals have to compete with continental transport from larger operations in the region. Where this is not the matter these terminals play an important role in the economical development of the region connecting it with the rest of the world in terms of cargo shipping. In the developed world where container transport is the main mode for cargo transport the presence of a container terminal is an important precondition for economical development.

To attract shipping lines however, the terminal must be able to offer a high level op services for a most competitive price. Regarding quay capacity and berth availability, these demand high levels of service before considering to take up a new stop in the schedule.

On the land side, shippers often tend to use terminals as a relatively cheap storage facility with on-demand availability. Containers dwell of up to 10 days is no exception in many small ports. This increases the required storage capacity.

[1] The modal split expresses how the imported and exported volumes of containers through a terminal are divided between road-, rail, inland navigation and sea-to-sea transhipment.

3.1.3 Terminal management

With a small captive hinterland and an increasing labour costs, offering the relative high level of services at competitive prices can be a big challenge. For this reason small and medium sized terminals are often not interesting investment opportunities global terminal operators (GTO) are in most cases operated by the local port authority or a private single-terminal operator (STO). Their negotiating powers are limited when dealing with shipping lines. The flexibility of their sailing routes makes the long term market developments uncertain when competition if strong.

For its important economically function in a region government involvement is often high. Although subsidies can help to reduce costs for the terminal operator, government control can be constricting by imposing regulation on labour involvement.

3.1.4 Market development

In this part of the network not only the volumes of transported containers are increasing, but also the number of destinations. While existing ports are experiencing a continuous growth of handled volumes, new ports and services are entering the network.
Ports in this category often serve only a small captive hinterland of one city or region. In regions where travelling distances are relatively small the contestable hinterland is relatively large. To compete with neighbouring ports in the region there often is a strong dependency on the quality of their connections to this contestable hinterland.

In regions with good inland waterways such as the Northwest of Europe looming congestion in inland rail and road transport has increased the market share of inland shipping services. The size and number of inland container terminals is therefore increasing as well. For example in 2004 the port of Duisburg in Germany handled as much as 712,000 TEU.

3.1.5 Innovation versus conservativeness

Operators of medium sized terminals are stuck with a dilemma. On one hand shipping lines are imposing increasing demands on terminal productivity and availability. On the other hand, within this segment of the container terminal industry there is a growing need to reduce operating costs to improve competitiveness. The terminal could meet client demands on services through investments in modern equipment and addition capacity. This would however requires additional expenditures instead of reducing them.

A possible solution to reduce operating costs is increased flexibility of labour to limit expenses to those times containers are actually handled. Strong unionisation in Anglo-Saxon countries and unfavourable labour legislation elsewhere prevents this flexibility. Terminal automation seems to be an obvious solution to highly reduce the dependency of labour and increase flexibility.

Awareness of this need to invest in new technology is spreading among terminal operators. Investments in the port industry require a large amount of capital and have a life time of 10 to 15 years. The industry in general and especially the segment of medium size terminals is therefore very conservative in their investments. This conservativeness is amplified by the scale of the operations, but also by scepticism. The general consensus among these operators is that automation is groundbreaking, expensive and technically too complex to take the early pain themselves (MacLeod, 2005).

Secondly the scale of the operations limits the size and level of training of maintenance and repair crews. To keep this part of the workforces small and skills levels limited, operators of these terminals prefer cheap and robust equipment over innovative solutions. As up to date no terminal in this segment in operating automated handling equipment it is necessary to investigate the feasibility of this option.

3.2 Terminal automation

Numerous definitions are in use to describe automation. One of which is the ability of a machine to perform complex and non-repetitive tasks without human intervention (MacLeod, 2005). In the context of container terminal automation this definition seems to refer to a state beyond the present reach. It, however, does emphasise the primary goal of automation, i.e. eliminating the dependency on human labour to operate equipment en control terminal processes.

A number of container terminals have already automated parts of the container handling process and an increasing number of large terminals are planning to make the step towards a degree of automation.

Meanwhile development of automated container handling equipment continues to provide the industry with a widening set of options. Following the technical developments of the past decade automated container handling is starting to become a mature and reliable technology with equipment being offered by a growing number of manufacturers. The choice in off-the-shelve available solutions continues to grow and the costs of automation decrease.

Although scepticism towards automation is still wide spread among operators of small and medium sized terminal operators, awareness has arisen among this segment of the terminal operating industry that automation is the modus operandi of the future.
Unlike their larger counterparts smaller terminal operators hardly do any research and development themselves. As a result of this so far no serious progress has been made in this segment of the industry.

Due to the lack of research into automated container handling on small and medium sized terminals it remains unclear how this could be achieved using existing technology and what would be the impacts of this.

4 CONTAINER TERMINAL OPERATIONS

In this chapter the operations at the container terminal are looked at. What are its functions, which operations are carried out and how? The way the performance of a terminal is assessed is discussed from the points of view of both the users and the operator. Finally the various levels, forms and consequences of terminal automation is discussed.
For the first parts of this chapter substantial references have been made to chapter 2 of "An approach for Designing Robotised Marine container terminals" by Saanen (2004).

4.1 Function and operations of container terminals

4.1.1 Functions

A container terminal links the maritime and the continental transportation networks by providing intermodal connections. In that role the main functions of the terminal are transhipment of containers from one transportation mode to another and temporary storage of containers for the period in between, but also to function as a node in the separate networks. The process in which these functions are fulfilled is schematised as follows:

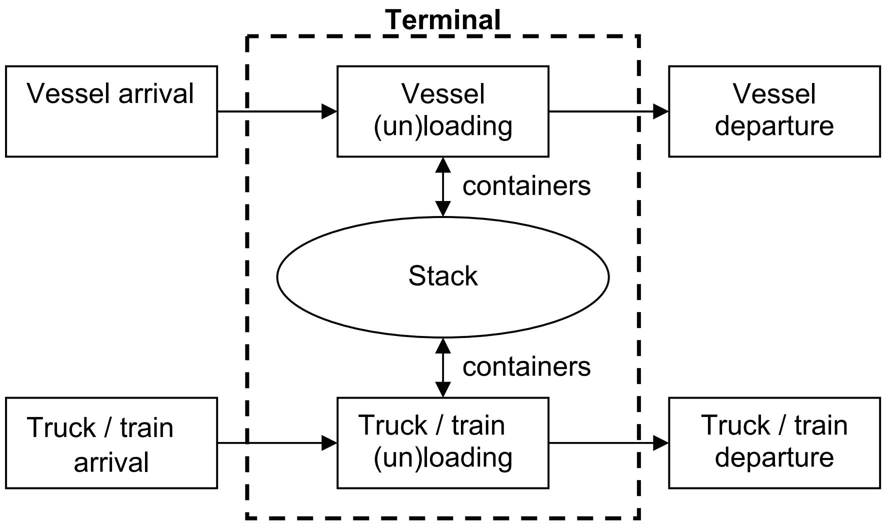


Figure 4.1 Schematic representation of the general terminal process (Saanen, 2004)

Secondary functions of container terminals are the storage of empty containers and consolidation of cargo. The consolidation takes place in the Container Freight Station (CFS) where so called Less than Container Loads (LCL) with different destination or origin, are loaded into (at origin) or unloaded from (at destination) containers.

4.1.2 Operations

Studying the main terminal process more in detail three main processes can be identified. Below the according operations are listed in their respective order for imported conventional containers, as well as a general introduction of the equipment that is used for it.

Quay process

- Berthing of vessels
- Container operations
  - Unlashing of containers on deck
  - Handling of containers between ship and quay
  - Removal of twist locks that interlock containers on deck
  - Transfer to internal transportation mode
- Quay handling equipment
  Loading and unloading of containerships at the quay is done by rail mounted ship to shore gantry cranes (SSG) and mobile harbour cranes (MHC). The mobile harbour crane is the more flexible crane, but the maximum size of vessel it can serve is limited. Secondly it cannot reach very high transfer rates between quay and ship as the whole crane has to turn around its base. The ship to shore gantry crane has limited flexibility to move around the terminal, but because of its rigid design, higher hoisting, and quicker trolley travel in a straight line to the quay, its productivity is better than the mobile harbour crane.

Terminal processes

- Internal transport between quay and storage yard
  - Transport to storage yard
  - Unloading of internal transportation mode
  - Equipment for horizontal transport:
    On internal transport between quay and yard is handled by modified forklift trucks, reach stackers and port tractor trailer combinations. Larger terminals operate tractor trailers, multi trailer systems or automated guided vehicles that are loaded at the quay and unloaded in the yard and vice versa. Reach stackers, straddle carriers and shuttle carriers can pick up a container themselves and do not need to be loaded or unloaded and can also perform stacking operations discussed next.
- Handling operations in storage yard
  - Handling of containers to the stack
  - Storage of containers and internal shifting in the stack (housekeeping)
  - Transfer to landside internal transportation mode
    - Transport to rail / inland barge terminal
    - Transport to gate transfer port for transhipment to road transport
  - Direct transhipment to road transport
  - Equipment for yard handling:
    In the yard containers are stacked using rubber tired gantry cranes, rail mounted gantry cranes or overhead bridge cranes. Rubber tired gantries the most flexible yard crane but cannot travel as quickly as rail mounted cranes or overhead bridge cranes. Both these cranes travel on a rail of which the latter is placed on a rudder high over the terminal surface.

Landside operations

- Transport to the transhipment point for the continental transportation mode (inland barge, rail, truck, short-sea, feeder)
- Transhipment to continental transportation mode

The process is schematised in the following scheme.

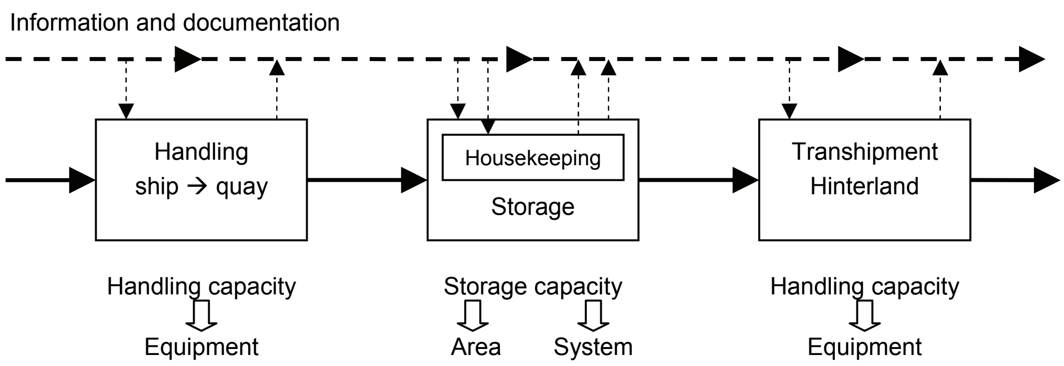


Figure 4.2 Flow of cargo through the terminal

Secondary operations such as handling of off-standard containers (reefers, dangerous goods, flatbeds, over-sized) and at the CFS are not included in this overview. Although services and facilities for these operations are indispensable in the terminal design, they generally account for a limited share of the total process.

4.1.3 Throughput, transhipment and modal split

The throughput of a container terminal is measured at the waterside of the terminal and is expressed in the annual volume of containers that either enter or leave the terminal by sea going vessel. This quay wall throughput is divided into import-export and transhipment. Import-export containers arrive at the waterside of the terminal and leave from the landside and vice versa. Transhipped containers indicate those containers that arrive at the waterside and depart from the terminal from the waterside.

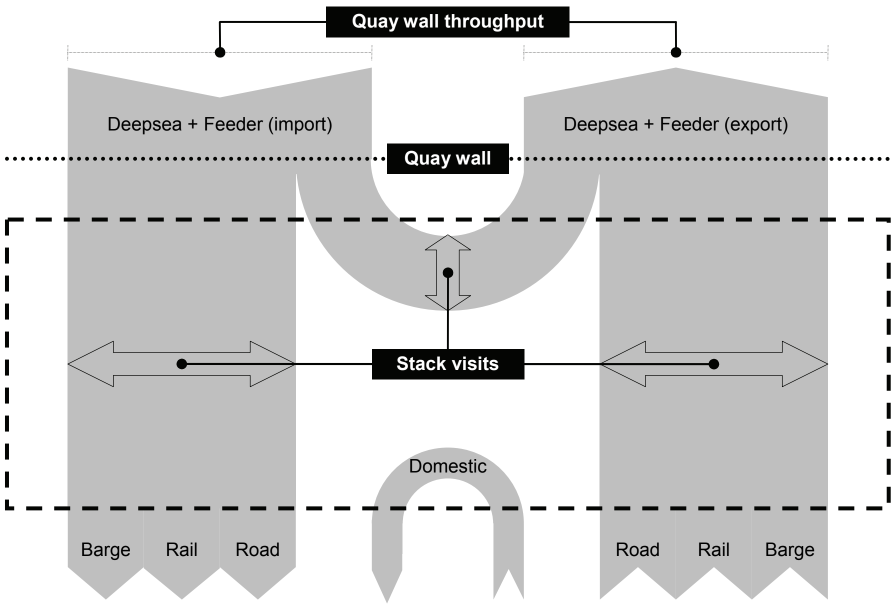


Figure 4.3 Container flow through terminal (Saanen 2004)

How the total flow of containers through the terminal is divided over the different modalities (e.g. seagoing vessels, inland barge, road, rail) is expressed by the modal split:

$$sea : barge : rail : road = \left(V_{quay}\left(deepsea\right) + V_{quay}\left(feeder\right)\right) : V_{barge} : V_{rail} : V_{road} \quad (4.1)$$

The ratio of transhipped containers to import-export containers is expressed in the transhipment ratio and is an indicator of the terminals network function. A high value indicates the hub function of the terminal; where as a low ratio indicates the gateway function of the terminal.

Transhipment ratio:

$$\mu = \frac{V_{quay}\left(transhipment\right)}{V_{quay}\left(export\right) + V_{quay}\left(export\right)} \quad (4.2)$$

Some larger terminals and most smaller terminals do not have a separate inland barge facility and inland barges are served at the deep sea quay. In such cases these volumes should be counted as quay wall throughput.

The required storage capacity of the terminal is determined by the terminal throughput, the terminal dwell time and the transhipment ratio. The dwell time is the average number of days containers are stored on the terminal between arrival and departure from the terminal.

Handled volumes are measured at the quay, transhipped containers are thus counted twice as handled volume, while taking up only one slot in the storage area. For equal throughput and dwell time a terminal with 100% transhipment would therefore require half the storage capacity as a terminal with no transhipment. For this reason hub terminals with high percentages of transhipment require less storage area in relation to their quay handling capacity.

4.2 Functional terminal design

Terminal design can be split up into waterside area and yard area. The waterside includes the quay and the quay handling systems, while the yard contains the container storage area, internal handling systems and landside interface.

As the interface between ship and land, the quay is the most critical area of the terminal expensive to alter once built. The maximum vessel size a terminal expects to receive is the primary requirement for minimum quay length and draught. The actual quay length is determined to enable an anticipated number of vessels to berth with acceptable levels of waiting and service time. This is determined using the capacity of the handling systems and data obtained through local market research and such as:

- Expected annual throughput
- Average / maximum vessel size
- Vessel arrival pattern
- Call size; number of container exchanged per call

- service requirements
- quay handling capacity (type and number of cranes per berth)

The service requirement follow from service demands from shipping lines expected to call a terminal. The extend to which these demands are met differs from case to case depending local factors such as competition. The client demands are focussed on the following issues:

- Berth availability; waiting time
- Berth productivity; service time
- Reliability; certainty of minimal level of service
- Flexibility; ability to deal with unexpected events (i.e. breakdown, last minute changes or special requests)
- Reasonable tariff compared to service quality

In the preliminary design phase of the terminal the queuing theory can be used to make initial estimation of required quay length and quay handling capacity. In later phases of the design process simulation models can help to determine more accurately the occupancy and utilisation and to achieve an acceptable compromise between handling capacity and (cost-) efficiency.

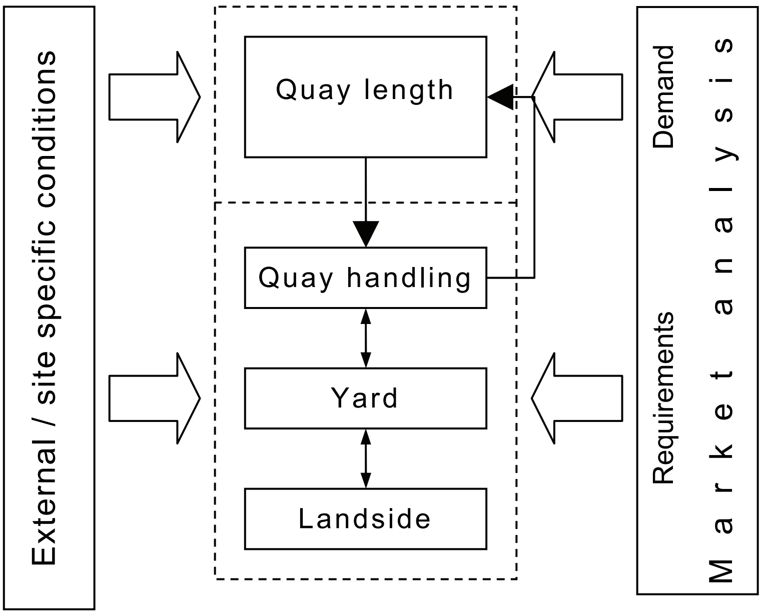


Figure 4.4 Functional design process

The image above displays the schematised design process for the terminal. Each step in the design includes a backwards iteration for optimisation. The choice for the layout of the terminal and the handling system is also influenced by external and site specific conditions such as among others the price and size of available land area, soil conditions, public sector support, cost of labour, competition and hinterland connections.

4.3 Handling systems design

The systems handling capacity must be equal to the required service capacity and is determined per part of the system as the product the number of equipment units and their productivity during hours of operation.

$$C = N \cdot P \cdot f \cdot T_{equipment}\left(running\right) \tag{4.3}$$

C	: Total volume of handled containers	(TEU)
N	: Number of handling equipment	(-)
P	: Equipment productivity	(moves/hr)
f	: TEU factor	(TEU/move)
$T_{equipment}$	: Total running hours per equipment unit per year	(hrs/yr)

The container handling process between ship and storage yard or gate and storage yard and vice versa is a chain of operations with the handling capacity of its weakest link. Therefore, in the system design, subsystems between the quay and landside operations are designed to at least have the same maximum capacity. This way congestion and overload at the interface with clients is prevented.

Equipment productivity
As mentioned above handling capacity depends on equipment productivity. For terminal equipment productivity is determined from the number of container moves one piece of equipment can handle over a certain period. This number depends on the number of containers that are moved per cycle and the time it takes to complete one operation cycle. The terminal equipment productivity is influenced by a large number of factors such as, travel distances, equipment travelling speed, surface conditions, operator skills, waiting times for other equipment to interchange with etcetera.

$$P = \frac{n}{t_{cycle}} \quad \begin{array}{l} : \text{ Containers per cycle} \\ : \text{ Average cycle time} \end{array} \tag{4.4}$$

Saanen (2004) distinguishes the following four different productivities depending on the method of calculating the cycle time:

- Technical productivity
  Technical productivity is the maximum theoretically achievable productivity by a piece of equipment determined solely by equipment specifications and travel distances. Disturbances, interventions and delays are not taken into account.
- Operational productivity
  Operational productivity is the maximum productivity of a piece of equipment in operational cycle. Operators' skills and external influences are taken into account such as surface conditions
- Net productivity
  The operational cycle of one piece of equipment is a link in the container handling process and during one operational cycle several interactions with other equipment may occur. The most important interaction is the interchange of containers between, for example, a quay crane and an AGV, but also equipment

of the same type interacts as when that same AGV gives way to another AGV. The net productivity is calculated total number of productive moves divided by the production time.

- Gross productivity
  The gross productivity of terminal equipment is measured from start to end of vessel handling operations taking all disturbances into account. These disruptions include operator related delays such as crew changes and meal breaks, equipment related disruptions due to refuelling and breakdowns, and operational disruptions such as handling hatch covers and bay changes.

Gross productivity < Net productivity < Operational productivity < Technical productivity

In terminal design net productivity and gross productivity are the most important variables. For terminal layout and systems design net productivity is a key selection criterion in the initial phases. The gross productivity of terminal equipment is used in the final phases of the design to determine the required additional equipment units to achieve the required annual terminal capacity.

Occupancy and utilisation
As mentioned earlier, shipping lines aim to spend minimum time in ports and demand minimum waiting times before berthing and vessel service time. The total time a vessel spends in the port is broken up as follows

$$\begin{aligned} T(port) &= T(waiting) + T(service) \\ T(service) &= T(berthing) + T(operational) \end{aligned} \tag{4.5}$$

The occupancy ratio of a quay is used to express the average portion of the total quay length that is occupied by a vessel measured over a certain period. With the occupancy ratio, thus the average length of available quay can be determined.

$$Occupancy = \frac{\sum_{i=1}^{n} L_i(vessel) \cdot T_i(service)}{L(quay) \cdot \sum T} \tag{4.6}$$

There is a direct, hyperbolic, relationship between the occupancy ratio of a quay and the average waiting time of vessels before service. This relation is illustrated in the graph below.

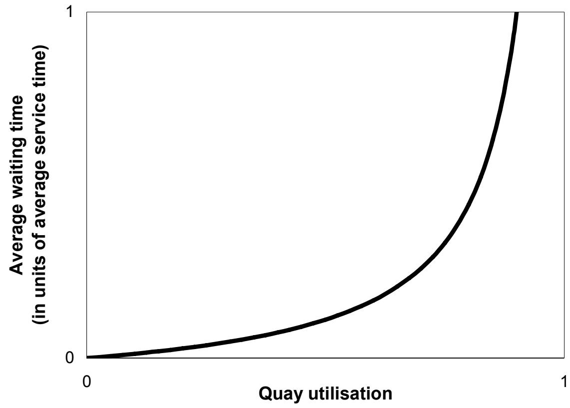


Figure 4.5 Development of average waiting time for increasing quay occupancy

During terminal operating hours not always a vessel is actually berthed at the quay, but also during vessel operations not always all cranes at the quay can be put into service and a number of cranes remain idle. For terminal operations a certain period can be broken up as described below.

$$\begin{aligned} \sum T &= T(operational) + T(idle) \\ &= 365 \times 24 - T(Terminal\_closed) \\ T(operational) &= T(service) - T(berthing) \\ &= T(running) + (delays) \\ T(idle) &= T(equipment\_idle) + T(maintenance) \end{aligned} \quad (4.7)$$

For the handling system, equipment utilisation is used to express the ratio of the time equipment is idle.

$$Utilisation = \frac{T(operational)}{\sum T} \quad (4.8)$$

From the terminal operators point of view the optimum lies at a maximum occupancy of the available quay length and full utilisation of terminal equipment. To achieve the required service capacity within certain limits for waiting times terminal operators often aim keep utilisation between 50 and 60 percent accounting unexpected events and breakdowns.

4.3.1 Quay handling system

Quay handling capacity (C_q)

$$C_q = N_c \cdot P_c \cdot f \cdot T_c(running) \quad (4.9)$$

N_c	: Number of quay cranes	(-)
P_c	: Nett productivity per crane	(moves/hr)
T_c	: Running hours per crane per year	(hrs/yr)

The application of the formula for calculation of handling capacity for quay equipment as above is used for an initial indication of the type and number of quay cranes on the terminal using the required annual handling capacity of the terminal.
Vessel service time depends on berth productivity, crane productivity multiplied by the number of cranes that can work on one vessel.

Quay equipment productivity
The cycle time of quay cranes can be broken down in the following operations.

Table 4.1 Production cycle quay crane

Operation	Possible delay
connect to container	lashing
	hatch cover handling
	sway
hoisting and transfer to quay	waiting for other crane
twistlock handling	sway
	no handlers (unloading)
	no twistlocks (loading
handover	sway
	waiting for transportation system
empty travel next container	waiting for other crane
	crane repositioning (bay changes)

Crane productivity can be improved in the following ways:

- reduce cycle time
- reduce cycle length
- reduce operations in cycle
- increase number of moved containers per cycle (dual cycling, twin-lifting, tandem-lifting)

In the next chapter on terminal equipment will be gone deeper into the how these improvements may be achieved.

4.3.2 Horizontal transport

Horizontal transport capacity (C_h)

$$C_h = N_h \cdot P_h \cdot f \cdot T_h\left(running\right) \qquad ,with \quad C_h \geq C_q \qquad (4.10)$$

N_h	: Number of horizontal transport units	(-)
P_c	: Unit productivity	(moves/hr)
T_h	: Operational hours per unit per year	(hrs/yrs)

To ensure quay operations are continuous and waiting times for quay cranes are minimal, horizontal transport capacity equal the maximum quay handling capacity. The level of extra capacity required depends on the transfer method between crane and transport unit. Transport equipment that has to be loaded and unloaded by the quay cranes, requires the cranes cycles to be in line with their cycle. Additional transport units then make sure the link between yard and quay is never broken and reduce the waiting of the cranes in their cycle time (see Table 4.1) and thereby increases the productivity. but long queues in front of a crane may cause congestion on the apron area.

Units that pick up and ground a container themselves (e.g. straddle carriers) can pre-stack containers in the crane's back reach during loading operations. The crane and straddle carrier cycles are less interdependent, which reduces the waiting time factor in the crane cycle

Productivity
The cycle time of horizontal transport can be broken down in the following operations.

Table 4.2 Production cycle horizontal transport

Operation	Possible delay
container handover with quay crane	queuing in front of crane waiting for crane
travel to stack (full / empty)	traffic interactions with other equipment (congestion, priority rules)
Container handover with yard equipment	queuing in front of yard crane waiting for yard crane
travel to quay (empty / full)	traffic interactions with other equipment

Equipment productivity can be improved in the following ways:
- reduce cycle time (travel speed)
- reduce cycle length (travel distance)
- increase number of moved containers per cycle (equipment dimensions)
- decrease queuing

4.3.3 Storage yard

Storage capacity (C_s)

$$C_{storage} = \frac{S \cdot \bar{t}_d \cdot p}{365} = N_{TGS} \cdot \hat{h} \qquad (4.11)$$
$$S = C_q \left(1 - 0.5\mu\right)$$

S	: stack visits	(TEU/yr)
t_d	: average dwell time	(days)
p	: peak factor	(-)
N_{TGS}	: no. of TEU ground slots	(-)
$\hat{h}$	: maximum operational stacking height	(-)
μ	: transhipment ratio	(-)

The required storage capacity is calculated from the average number of containers stored on the terminal multiplied by the storage peak factor. The peak factor accounts for periodical fluctuations in terminal throughput. Dividing the result of this calculation by the maximum stacking height gives the required number of TEU ground slots.

Yard density

$$density = \frac{N_{TGS} \cdot \hat{h}}{A_{yard}} \qquad (4.12)$$

A_{yard} : Total yard area (m^2)

Area requirements can be reduced by increasing yard density. This can be achieved in various ways. The obvious solution for increasing yard density is to increase the stacking height, but by reducing the workspace between stacks more ground slots become available. Increased density however has a negative influence on the accessibility of containers in the stack.

Accessibility of containers stored in the yard is very important in for determining the average cycle time for retrieving a container from the yard. The accessibility of stored containers depends on the time it takes to reach a required container and the average number of containers that are placed on top of it at the moment it is ordered from the yard.

$$\bar{n}_{access} = \frac{\bar{h} - 1}{2}$$
$$accessibility = \frac{\bar{h}}{1 + ... + \bar{h}} \qquad (4.13)$$

n_{access} : average number of access moves to retrieve container
h : average stacking height

For increasing average stacking height accessibility rapidly reduces as is displayed in the graph below.

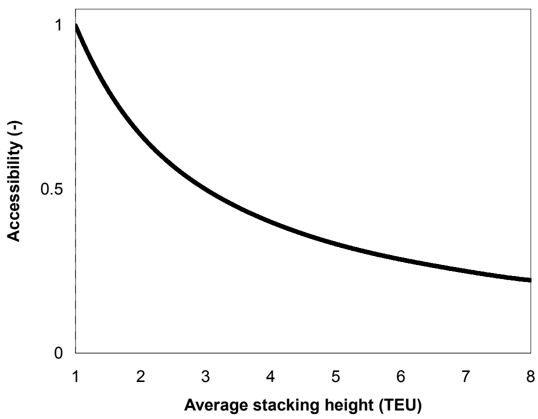


Figure 4.6 Relation accessibility and stacking height

Yard handling capacity (C_y)
Handling capacity of yard equipment can be divided into transfers operations and housekeeping operations. Transfer operations indicate all landside of waterside exchanges of containers to store containers in the yard or retrieving containers from it.

Housekeeping operations indicates re-shuffling of containers to optimise transfer capacity.

$$C_{yard} = C_{yard}^{transfer} + C_{yard}^{re-shuffling} \tag{4.14}$$

$$T_y\left(running\right) = T_y\left(running\_transfers\right) + T_y\left(running\_housekeeping\right) \tag{4.15}$$

Transfer capacity (C^T)

$$\begin{aligned} C_y^T &= N_y \cdot P_y^T \cdot f \cdot T_y\left(running\_transfers\right) \\ &= S\left(2 + \overline{n}_{access}\right) \end{aligned} \tag{4.16}$$

N_y	: No. of yard cranes	(-)
P^T	: Yard crane productivity when transferring	(moves/hr)
T_y	: Operational hours per yard crane per year	(hrs/yr)
S	: No. of stack visits	(-)

In the yard waterside transfer capacity indicated the capacity to store and retrieve container that are loaded onto or unloaded from vessels. Continuity of vessel operations is again the main focus for the waterside handling capacity. Landside transfer capacity handled the storing retrieval of containers that arrive at or leave from the terminal by continental transport mode. During peak periods the yard cranes need to have ample capacity to serve both sides at acceptable levels.

Housekeeping capacity (C^r)

$$C_y^r = N_y \cdot P_y \cdot T_y\left(running\_housekeeping\right) \tag{4.17}$$

P^r	: Yard crane productivity when re-shuffling	(moves/hr)

By housekeeping operations and stacking strategies, yard crane productivity can be improved and thereby improve the capacity of the equipment, resulting in less equipment being required. During periods that quay or landside operations are idle (i.e. no vessel operations or no trains or trucks are being loaded), containers are rearranged in the stacks. Placing containers soon to be transferred on top of the stacks reduces the required access moves, and relocating them as close to the transfer point as possible reduces travel distances of the yard cranes.

Advanced stacking strategies are often used as a way to improve capacity of existing systems with minimal investments. Within this study these will not be further considered.

Yard handling productivity

More than any other terminal handling systems, the productivity of yard handling equipment depends of the system's design. Yard density, stack orientation parallel or perpendicular to the quay, stack width and length, and whether or not cranes can pass each other in the stacks are all items that influence productivity.

Within a certain system productivity depends on whether what in what function the crane is operating. For yard cranes three different operating cycles can be distinguished, with their own set of possible delays to limit productivity. These are storing of containers in the yard, retrieval of containers from the yard and housekeeping.

The productivity of the yard equipment during storage and retrieval is strongly dependent on the time spend on housekeeping. This time can be considerable in relation to other operation. By increasing the running hours on housekeeping, the housekeeping factor is increased and thereby accessibility. This increased the crane productivity during transfer moves, thus requiring less running hours for transfer moves.

Table 4.3 Crane cycle for container storage

Operation	Possible delay
Pick up container from horizontal transport	Waiting for transport unit
Travel to empty container slot	Waiting for other crane
Place container in stack	Sway
Empty travel to transfer point	

Table 4.4 Crane cycle for container retrieval

Operation	Possible delay
Travel to assigned ground slot	Waiting for other crane
Pick-up container	Access handling
	Sway
Travel to transfer point	
Handover to horizontal transport / truck	Waiting for transport unit / truck
	Transfer point full (no space for container)

Table 4.5 Crane cycle during housekeeping

Operation	Possible delay
Travel to assigned ground slot	Waiting for other crane
Pick up container	Access handling
	Sway
Travel to new-assigned ground slot	Waiting for other crane
Place container in stack	Sway

The productivity of various types of yard handling equipment depends very much on the design of the storage yard.

Crane productivity during transfer operations can be improved in the following ways:

- reduce cycle time (travel speed)
- reduce cycle length (travel distance, housekeeping)
- reduce access moves (stack planning, housekeeping
- increase number of moved containers per cycle (twin-lifting)

4.4 Terminal performance

4.4.1 Performance indicators

For objective assessment of terminal existing terminal operations or proposed terminal designs quantifiable indicators are used. Depending on the purpose of the assessment, a large number of different indicators can be used for assessment of crane productivity, quay handling capacity, terminal profitability, equipment use or environmental impact.

Terminal performance refers to realised production of an existing operation. Through simulation modelling indicative figures can be generated to assess different design proposals. Goal of these assessments are of course to achieve maximum throughput for an optimal use of resources. The most important performance indicators are referred to as key performance indicators or KPI.

Performance indicators:

- Quay occupancy and equipment utilisation (%)
  High values for quay occupancy and equipment utilisation indicate optimal use of the quay length and quay cranes. On the other hand low values for occupancy are a measure of berth availability.
- Annual throughput per meter of quay
  Related directly with quay occupancy, the annual throughput per meter of quay wall indicates its value. Determined by maximum vessel size and the arrival pattern on which terminal operators have limited influencing powers, the value of this indicator depends on handling facilities and the willingness of shipping lines to co-operate by optimising sailing schedules. For this reason the value of this indicator can vary between 150 and 2000 TEU/m/yr.
- Annual throughput per equipment unit (moves / year)
  The annually handled number of containers per quay crane can be used to assess the number and value of quay cranes and yard equipment in the system. A high throughput per unit indicates a high value of that equipment, but can also indicate the need for additional units. As an example a rule of thumb for ship to shore gantry cranes indicates 70,000 (low μ) to 100,000 (high μ) moves per crane per year as a the threshold to acquire additional cranes.
- Berth productivity (moves / berthed hour)
  As the product of the average number of cranes that can work on a ship and their gross productivity, berth productivity is an indicator for the average waterside service time.
- Yard density (TEU / ha)
  Measured in TEU per hectare of yard under operational conditions, taking the max filling rate into account, yard density is an indicator for efficient use of land. As an indication terminals operating straddle carriers this index lays around 700 TEU/ha, for terminals operating overhead bridge cranes this can run op to 1,500 TEU/ha.

4.4.2 Financial indicators

Terminal income
The price charged to shipping lines for port services is expressed as the price per moved container. The combination of berth productivity and the price per move indicates the attractiveness of a terminal for shipping lines. The price a terminal can charge per move depends on the trade of between the cost per move and the berth productivity balanced against the demand for terminal services.
Often the charges differ between clients on the basis of services provided and yearly throughput.

Price per storage day
Terminals are often used by shippers as a relatively cheap and easy accessible storage

location. The average time a container is stored in the storage yard, the dwell time, usually lies around 4 days. Depending of the scarcity of land and regional competition, terminal operators can keep influence average dwell time with the charged costs for storage.

Terminal operating costs
Like any enterprise the main goal of a container terminal is to earn money. Whether this actually happens depends on the difference between the benefits and the costs.
In terminal operations the operating costs determine the profitability in the long term. The investment costs are determining for the payback time. By reducing this period to a maximum of 10 to 15 years terminal operators reduce the risks involved. This timescale is often well below the technical lifespan of the terminal equipment.

Investment costs
As stated above, the investment costs determine the payback period of the terminal, i.e. the period over which all investments are earned back. The main components of the investment costs are the terminal facilities (quay, paving, buildings) and the equipment.

Operating costs
The profitability of a terminal determines on the operating costs. The price a terminal can charge for their service arises in most cases from the market forces. The costs however are a controllable factor. Its main components are capital costs (interest), land costs (often leased from port authority), maintenance and labour costs.

The labour costs often take up a very large portion of the total operational costs. The actual costs are very much dependant on local factors differing from region to region such as local wage level, unionisation, historical factors but also labour productivity. Indicators for labour efficiency are the handled volume of containers per headcount (TEU/headcount) and the resulting labour cost per handled container (labour cost/TEU).

4.5 Automation

To increase efficiency and reduce labour dependency, terminal operators have been working for years on automating parts of the container handling process.
In terminal operations three levels can be identified where automation can be applied. The first level is exchange of information. At this level automation means the electronic management and exchange of information between shipper, carrier, hauler and the terminal operator. At second level the processes at the terminal are controlled and planned. At this level all information is processed and used for the planning and management of operations. Automation at this level indicates the use of information systems to take planning decisions and control terminal operations. The actual handling of containers is the final level for automation. At this level automation indicates partial or complete robotised operation of equipment.

4.5.1 Information systems

The management and exchange of information between the actors on the terminal is the most vital factor of smooth, efficient operations. To plan operations well in advance of arrival, terminal operators depend on carriers to supply it with detailed information. This information involves stowage plans of vessels indicating the containers to be off-loaded, freight letters stating contents, destination and even expected time of collection. Abandoning conventional communication methods like telephone and facsimile this information now digitally exchanged through EDI networks.. At the terminal this information is processed and managed by comprehensive terminal management packages that take over planning and operational tasks and improve customs processes. Depending on the operators wishes these packages can be configured to support every operation from the gate process to stowage planning.

4.5.2 Gate automation

At terminals peaks in the service demand at land side often leads to congestion and long waiting times. Instead of increasing peak capacity, terminal operators some possibilities to spread the land side service calls though gate planning. A relatively new but effective tool for this is a vehicle booking system (VBS). This system allows haulers to book a timeslot at the terminal to collect or drop-off a certain container. This way the terminal operator can spread and plan landside operations and provided the hauler arrives at the gate well within his slot, waiting times and service times can be reduced.

The administrative process and the customs procedures at the gate can be speeded by automation. Digital imaging technologies in the form Optical Character Recognition (OCR, container codes, chassis codes, licence plates), image-based inspection, paperless customs and intelligent gate kiosks can be, and have been, developed into automated gate systems that can combine sophisticated process automation with increased security.

4.5.3 Equipment automation / robotised equipment

Automated container handling is the final step in the automating process of the terminal. Although a lot of electronic systems are available to make the drivers job a lot easier, only when the driver is taken away and the equipment operates autonomously, one can speak of full automated equipment. The equipment operates on instructions of the terminal operating system and by transponders embedded in the terminal surface or state of the art positioning system AGVs, Shuttles, Autostrads and yard cranes safely navigate the terminal relying on radar and object sensors to look around. Automated cranes and straddle carriers rely on optical object recognition and load positioning systems to accurately pick up and drop containers.

Besides fully automated operations a variety of partially automated operating equipment exists. Remote controlled yard cranes, both rubber tired and rail mounted, are operated in Asia. These systems allow one operator to control multiple cranes maintaining human control over safety and complicated parts of the handling cycle, e.g. connect the spreader to the container and positioning.

4.6 Restrictions of operating automated equipment

Most automated equipment is very similar to its manned equipment performing exactly the same operation. However there are some specific operational complications related to operating automated equipment. Safety regulations complicate certain parts of the

handling process, while the lack of ability to improvise and safety margins in the operating system can enlarge the impact of small irregularities.
To ensure smooth operations from day one, this increased impact of seemingly minor issues creates a necessity to take into account each possible situation assess its impact on operations, rather than being dealing with it occurs. Therefore in the planning phase of automated terminals issues are often considered that seem trivial for conventional terminals.

4.6.1 Mixing of manned and unmanned equipment

The biggest limitation on automated terminal operations is the strict separation of fully automated equipment form the rest of the terminal operations, imposed by health and safety regulations. This means no person or manned equipment can operate in the same area as automated equipment. As result automated yard equipment operates in fenced of areas where no man can be allowed to go.
In the transfer areas between different equipment this complicates the terminals processes and maintenance and repair works become a much greater challenge. Often this can be solved by the use of air locks, remote controlled operation or cranes that can reach into the yard.

As developments continue to improve safety systems the discussion can be raised whether or not this limitation is necessary. However no breakthrough is expected on this point in the near future.

4.6.2 Maintenance and repairs

The safety requirement of strict separation also complicates the maintenance and repair works. For small repairs on for example an AGV strict safety measures have to be taken. The Altenwerder terminal in Hamburg for example has the option to make the area where mechanics are working inaccessible for AGVs. In other cases the recovery of broken down equipment can prove to be quite complicated. For works on stacking cranes the design of the terminal has to provide service areas on either side of the stack. In such areas work can be done while operations continue.

A different problem of unmanned operation is that computers, unlike equipment operators, do not provide much feedback on the functioning of equipment. Little noises and vibrations that may be the prelude to a breakdown or the behaviour of the equipment preceding the break down are not often recorded by the equipment. Instead it just stops working, making troubleshooting a lot more difficult.

5 HANDLING OPERATIONS

5.1 Introduction

In the previous chapter the container handling process on a terminal has been split up into three steps. These steps are quay handling services to vessels, yard handling divided into horizontal transport, and containers storage and landside services to continental transport modes.

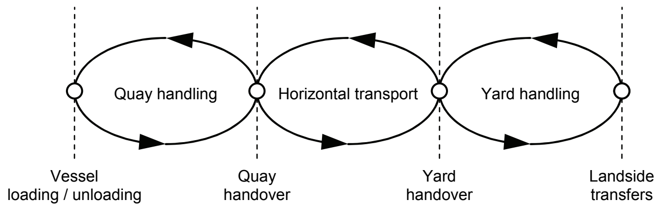


Figure 5.1 System cycles quay and yard handling

For each of these steps equipment is available to complete the sequence of operations within that step and to establish the link to the next step of the process. In the following paragraph an inventory will be made of the equipment available for these operations, their specific properties and their influence on the systems design.

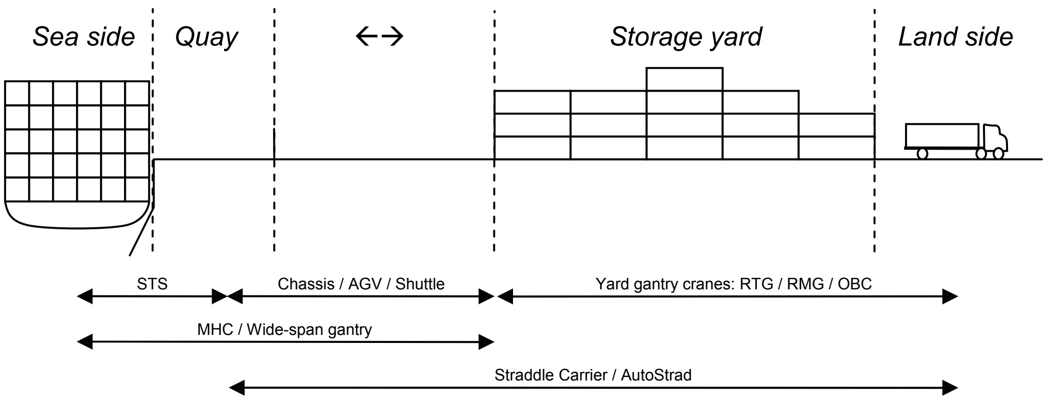


Figure 5.2 Workarea terminal equipment

In the light of this research the most important aspect of this inventory is the aspect of automation. To what extend can the equipment be automated and how suitable is it for operation in conjunction with automated equipment.

5.2 Quay cranes

Quay cranes are the most expensive equipment at the terminal. Investment costs for cranes can be in excess of ten million Euros for a single crane. At the quay regardless what type of equipment is used the following handling operations are carried out by the quay cranes:

- pick up from deck
- transfer to quay
- remove twist locks
- place at transfer point / load horizontal transport

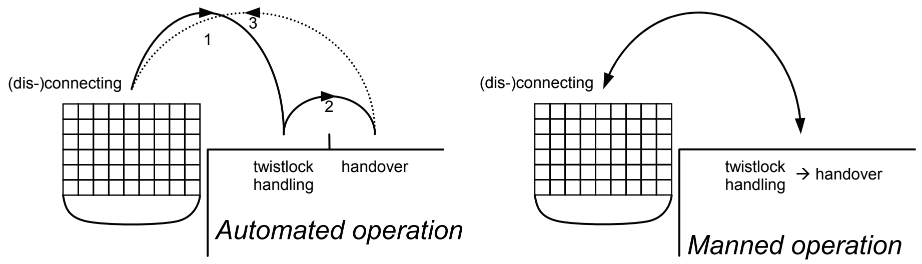


Figure 5.3 Quay operations

Any type of quay crane is suitable for action in conjunction with automated equipment. As shown in the figure above yard automation ads an handling operation to the quay handling cycle, namely the transfer to and from the automated yard. Although several prototype spreaders have been developed for automatic twistlock handling up to date it placing and removal of twistlock remains manual labour that has to strictly separated from automated yard equipment.

As discussed in the previous chapter, quay capacity is the main performance indicator for the terminal. The number of cranes required for the system to achieve the required capacity depends therefore on crane productivity, the annually handled volume per crane (100,000 TEU per STS crane) and the density of quay cranes (1 STS crane per 100 meter),

5.2.1 Spreaders

The interface between crane and container is the spreader. It connects to the slots for twistlocks on the four upper corners a container. The spreader can automatically adjust its size to connect to either a 20ft container, or a 40, and even 45, foot container. Several different manufacturers produce various types of spreaders.

Figure 5.4 Twin-Lift spreader (Bromma)

The productivity of container quay cranes can be improved by increasing the number of containers that are handled per cycle. The twin lift spreader is designed to either handle a single 40ft unit or two 20ft units, increasing the average production per move to 2 TEU.

A more recent development is the tandem spreader that can be used to handle two 40ft containers side by side, increasing production per cycle even further to 4 TEU. This however complicated the container handover to chassis or AGVs, as the have to be lined up perfectly in the cranes back reach.

5.2.2 Ship-to-shore gantry crane

Rail mounted ship-to-shore gantry cranes (STS) come in varying sizes and can be built large enough to operate on largest types on container carriers. Its rigid structure is designed specifically for container handling, transporting boxes to the quay in a straight line. STS cranes can therefore work relatively closely side by side without obstructing operations. In practice canes will work every other cargo hold to ensure a smooth flow of internal transport equipment in the apron area.

Due to the vast amount of steel that is needed to build a STS crane it is expensive equipment. Prices range from 5 million Euro for a Panamax crane that can handle ships up to thirteen boxes wide, up to 10 million Euro for a dual trolley, Super-PostPanamax sized crane. These increasing crane sizes pose increased loads on the quay and have to be taken into account in the quay design.

Figure 5.5 STS gantry crane (Jebel Ali, Dubai)

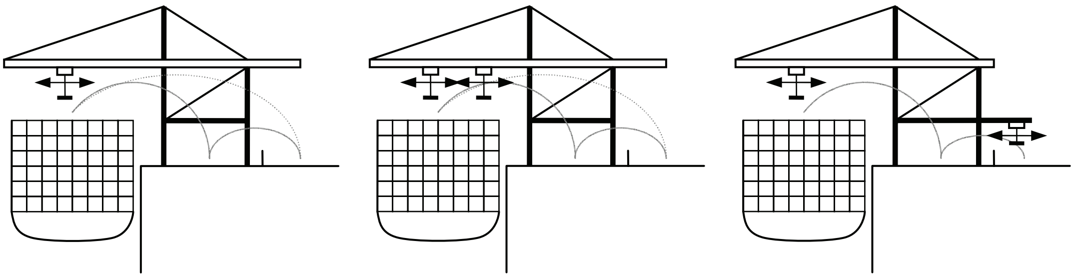


Figure 5.6 STS Crane operations (fltr): conventional, twin trolley and dual trolley crane

To increase crane productivity the container can be equipped with a second trolley. The trolleys travel automatically, while the operator is responsible for picking up and grounding containers. Another development is the dual hoist system that splits crane operations in two short cycles, one between vessel and quay, and one for loading horizontal transport equipment.

Containers are transferred to the quay in a straight line at speeds of 45 m/min (Panamax) up to 240 m/min (Super-PostPanamax). As cranes grow higher to accommodate larger vessels sway becomes an increasing problem complicating accurate positioning of spreader and container. Cranes are therefore equipped with anti sway systems, but a new development is the height adjustable boom that adapts to the vessel berthed at the quay.

Table 5.1 Equipment benchmarks STS

Outreach	40 – 65 m (up to 23 TEU on deck)
Rail span	15 – 35 m
Back reach	25 m
Lifted load (under spreader)	40 – 100 MT
Crane weight	800 – 1,600 MT
Trolley travel	120 - 240 $^{m}/_{min}$
Hoisting speed (laden / empty)	75 - 90 / 150 - 180 $^{m}/_{min}$
Crane travel	45 - 60 $^{m}/_{min}$
Crane productivity	25 - 30 $^{moves}/_{hr}$
Handling capacity per crane per year	70,000 - 120,000 $^{TEU}/_{yr}$
Investment cost	€ 4,500,000 – 7,000,000
Maintenance and repairs costs (annually, % of investment costs)	2.8 – 4 %

Advantages
- High productivity
- Limited space between cranes

Disadvantages
- Investment costs
- Limited flexibility
- Surface loads

5.2.3 Mobile harbour crane

The mobile harbour crane (MHC) is a wheeled or rail mounted conventional crane designed for loading and unloading any type of cargo. Equipped with a spreader for containers it is a flexible and relatively cheap alternative for the STS that can go anywhere on the terminal to perform handling operations on vessels up to seventeen boxes wide. General prices for mobile harbour cranes range between two and three million Euros per crane.

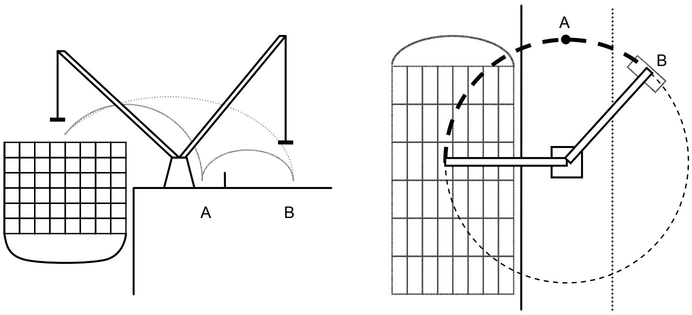


Figure 5.7 Crane operations mobile harbour crane

Figure 5.8 Mobile harbour crane (Gottwald)

Productivity of the MHC is not as high as that of the STS, the turning motion of the crane increases the travelled distance between vessel and quay and prevents cranes from working close to each other. The turning motion and the height between the tip of the boom and the spreader cause increased problems with sway and thus accuracy. The most modern cranes are equipped with “fly-by-wire” anti-sway systems but productivity remains much lower that that of gantry cranes.

Because of its large back reach MHCs can place containers immediately within the reach of yard handling equipment, this would reduce the need for a horizontal transport system and resulting delays.

Table 5.2 Equipment benchmarks MHC

Outreach (maximum)	48 m (up to 17 TEU on deck)
Lifted load (under spreader)	
at 10 m	41 MT
at 48 m	17 MT
Crane weight	200 – 350 MT
Turning speed	0 - 1.6 rpm
Hoisting speed (laden / empty)	50 / 100 $^{m}/_{min}$
Crane travel	0 – 90 $^{m}/_{min}$
Crane productivity	15 $^{moves}/_{hr}$
Handling capacity per crane per year	50,000 – 75,000 TEU/yr
Investment cost	€ 2,600,000 – 3,500,000
Maintenance and repair costs (annually, & of investment costs)	3 – 4 %

Advantages

- Flexibility
- Investment costs
- Possibility to skip horizontal transport

Disadvantages

- Productivity
- Workspace

5.2.4 Wide-span gantry crane

The wide span gantry crane is a widened ship-to-shore gantry crane. The first container stack of the terminal is placed between the legs of the crane combining ship to shore container handling with stacking operations. This way the need for horizontal transport between quay and yard is eliminated and a very compact terminal design is achieved.

For operations on inland and short sea feeder barges the concept has been successfully applied on terminals in Ireland and along the Rhine where ship sizes are limited.
Due to its size the crane is expensive to acquire placing high loads on the quay structure.

Figure 5.9 Wide-span gantry crane on inland terminal Ludwichshafen (Gottwald)

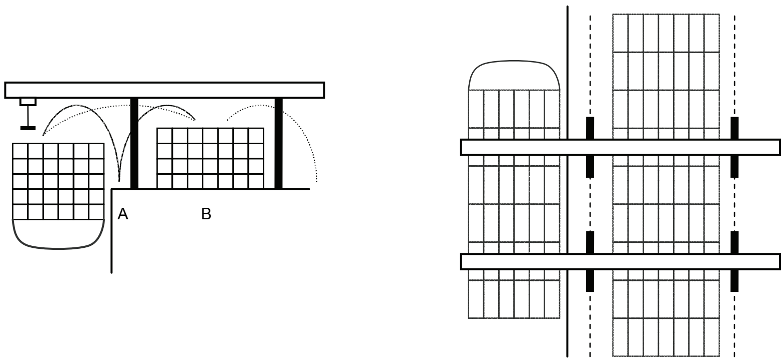


Figure 5.10 Crane operations wide span gantry crane

The relatively short cycle with hardly any interaction with other equipment allows the crane to reach high values for productivity during vessel unloading. For loading operations containers have to be well pre-stacked to limit crane travel to the absolute minimum. Last minute changes and breakdowns therefore have a severe impact on berth productivity.

The terminal can be expanded in inland direction with a additional container stacks parallel to the existing stacks. Containers are then transferred between stacks via the overlapping outreaches of quay and yards cranes. This concept is less suitable for terminals that are expected to be expanded in later phases.

Table 5.3 Equipment benchmarks wide span gantry crane

Outreach (maximum)	40 m (up to 16 TEU on deck)
Rail span	35 – 70 m
Back reach	25 m
Lifted load	40 MT
Trolley travel	150 – 180 $^{m}/_{min}$
Hoisting speed	50 - 75 / 100 – 150 $^{m}/_{min}$
Crane travel	45 - 120 $^{m}/_{min}$
Crane productivity	20 - 25 $^{moves}/_{hr}$
Handling capacity per crane per year	50,000 - 100,000 $^{TEU}/_{yr}$
Investment cost	€ 3,500,000 – 4,000,000
Maintenance and repairs costs (annually, % of investment costs)	4 %

Advantages
- Compact design
- Less equipment needed

Disadvantages
- Little flexibility
- No well suited for expansion

5.3 Integrated yard handling

As discussed in the previous chapters yard operations can be divided into three areas. At the waterside containers are transported between yard and quay and vice versa, while in the yard containers are stored, re-shuffled and retrieved. At the landside containers are handed over to road transport or transported to a rail terminal.

In this paragraph equipment is discussed that can be used for each of these operations. In the following paragraphs equipment is discussed developed specifically for ether container transport between quay and yard or for stacking and landside operations only.

5.3.1 Reach stacker / Fork lift truck

Reach stackers (RS) and fork lift trucks (FLT) can be used for any container handling operation in the yard. The relatively low price and flexibility make them very popular among smaller and multi purpose terminals. In larger terminals they are often used in the start-up situation and later remain in use for handling of empty containers. Containers can be stacked relatively high with this equipment but need quite much workspace. Using reach stackers a storage density of up to 500 TEU per hectare can be achieved.

Figure 5.11 Reach stacker (Kalmar)

Advantages
- Flexibility in operations
- Low investment costs

Disadvantages
- Labour cost; not suitable for automation
- Throughput capacity

5.3.2 Straddle carrier

The straddle carrier (SC) is the most popular piece of equipment for yard handling for its ability to combine horizontal transport with stacking of containers. It transports containers directly form the quay to the storage yard, where containers can be stacked up to a maximum of four. Because the SC can pick up and ground a container without interaction with other equipment it decouples the different terminal processes.

Figure 5.12 Straddle carriers port of Kingston, Jamaica (Kalmar)

In the yard stacks are divided into blocks of rows ad lines separated by the wheel-spaces perpendicular to the quay. Typically rows are between 14 and 18 TEU long, balancing the risk of damage, accessibility and use of area. The blocks are separated by an access isle of about 20 m wide.

Straddle carriers are quite expensive equipment with average prices of around 800,000 Euros. In general per quay crane at five straddle carriers are required at the minimum each requiring highly skilled and trained operators (Dynamar 2005). **ADD indirect straddle carrier operation.**

Table 5.4 Equipment benchmarks straddle carrier

Lifting capacity	40 – 50 MT
Travel speed	5 $^{m}/_{s}$
Lifting height (1-over-)	3 – 4
Weight	60 MT
Equipment units per quay crane	5.5
Investment cost	€ 800,000
Maintenance and repairs costs (annually, % of investment costs)	7 – 8 %

Automation
Since January 2006 automated straddle carriers (AutoStrad) are for the first time operated in a real terminal. DGPS systems and millimetre wave radar in each crane ensure save and accurate navigation of each straddle carriers on the terminal without having to rely on transponders in the terminal surface. This “free range” operation allows the AutoStrad to be deployed any terminal with a surface suitable for straddle carriers.

As for any automated equipment productivity of AutoStrad is less than of its manned counterpart because of large required safety margins manned operators are known to sometimes ignore.

Advantages
- Flexibility
- Homogeneity of equipment

Disadvantages
- Costs: Investment and labour
- High maintenance costs

5.4 Horizontal transport

5.4.1 Port tractor trailer

The manned port tractor and trailer (PTT) combination is the most conventional mode for horizontal transportation of containers. Containers are loaded on a trailer which is transported to the storage yard. Common practice is to stack containers in the yard, but on terminals without space constraints the trailers are used as a stacking place.
To increase capacity and labour efficiency multi-trailer systems of one tractor and a train of up to six trailers may be used.

Terminal trailers are designed not to leave the terminal and therefore can be built rather inexpensively. Labour requirements are high and if containers are stored on the chassis land usage is very high.

Figure 5.13 Tractor trailer combination (Terberg Benschop)

Table 5.5 Equipment benchmarks port tractor trailer combination

Travel speed		$10\ ^{m}/_{s}$
Weight tractor (MTS)		10 MT (15)
Weight (chassis)		5 MT
Equipment units per quay crane (MTS)		5 (3)
Investment cost (MTS)	tractor	€ 105,000 (150,000 – 175,000)
	chassis	€ 25,000 (40,000)
Operating cost		8 %

Because the trailer needs to be loaded, buffer capacity can be obtained by operating additional PTT units. Usually 5 PTT units are used per quay crane (Drewry, 1998).

Advantages

- Low investment cost for both equipment and surface
- Low maintenance cost, high reliability record

Disadvantages

- High labour cost
- High maintenance costs

5.4.2 Automated Guided Vehicle

The driverless automated guided vehicles (AGV) was developed by Gottwald and used first at the Delta terminal (ECT) in the port of Rotterdam and is, since 2002, also in use at CTA terminal (HHLA) in Hamburg. The driverless AGV navigates the yard area following electronic transponders embedded in the surface area and object sensors.

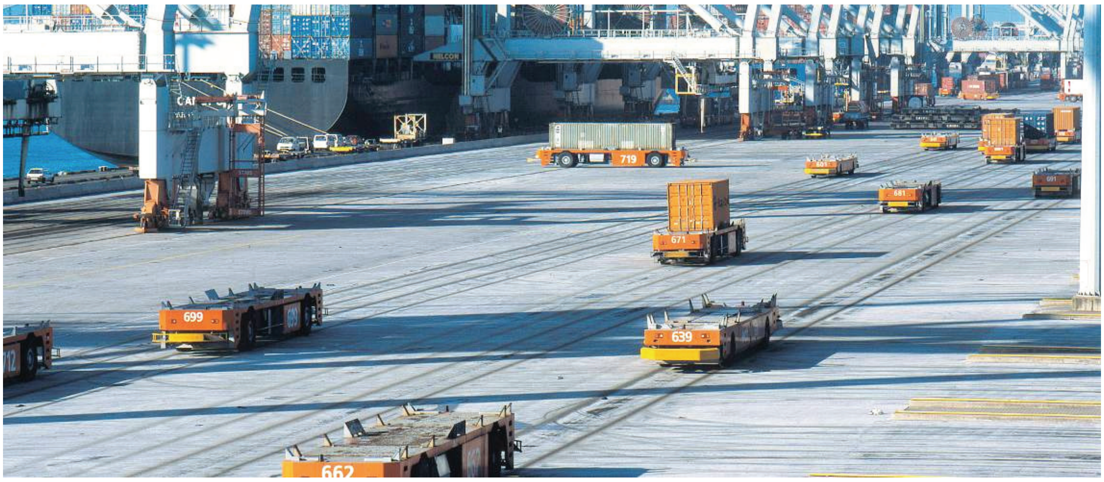


Figure 5.14 Driverless AGVs at Rotterdam's Delta Terminal (ECT)

For safety reasons AGV units do not travel at same speeds as the manned PTT, but collisions are non-exiting and accuracy in positioning is very good. This is an advantage for terminals considering quay cranes equipped with tandem spreaders.
An AGV is much heavier than a regular PTT and , unlike man, the AGV always drives on exactly the same line causing ruts in the surface to develop much quicker.

Figure 5.15 Ruts in pavement CTA terminal Hamburg

Table 5.6 Equipment benchmarks AGV

Load types	2 x 20 / 1 x 40 / 1 x 45 ft
Load capacity (single unit / max.)	40 / 60 MT
Dead weight	25 t
Travelling speed (max./ cornering/ crab)	6 $^{m}/_{s}$
Equipment units per quay crane	5
Investment costs	€ 400,000
Maintenance and repairs costs (annually, % of investment costs)	4 – 5 %

The AGV has a very good reliability record. While in Rotterdam 218 AGVs serve 28 cranes (7.8 : 1) at CTA in Hamburg this ratio was reduced to much better 2.7 units per quay crane.

At the moment several manufacturers have developed or are developing AGVs. Some of these use GPS systems for guidance, this would be an advantage over the more expensive wiring in the terminal surface.

Advantages

- Very low labour costs

Disadvantages

- Although unit costs are reducing still high investment costs

5.4.3 Mini straddle carrier

The mini straddle or shuttle carrier is a low straddle carrier used exclusively for horizontal transport on the terminal. In can lift containers no higher that one over one, but due to its reduced height it is much easier to operate and more manoeuvrable that a straddle carrier. Like the straddle carrier, the main advantage of shuttle carriers for horizontal transport is the decoupling of quay and yard crane cycles, eliminating waiting times during handovers between equipment.

Figure 5.16 Shuttle carrier (Kalmar)

As the shuttle carrier is not as tall as the conventional straddle carrier, it is easier to operate requiring less skilled and training from its operators.

Table 5.7 Equipment benchmarks shuttle carrier

Lifting capacity Travel speed Lifting height (1-over-…) Unit weight	40 MT 6 $^{m}/_{s}$ 1 43 MT
Equipment units per quay crane	4 – 5
Investment cost Maintenance and repairs costs (annually, % of investment costs)	€ 600,000 7 – 8 %

Automation
Like the straddle carrier, an automated shuttle carrier is available. Although more expensive than an AGV unit, less units are needed per quay crane as a buffer can be created at the quay and productivity of both quay cranes and stacking cranes is improved as waiting times are eliminated.

In the scope of this study below the automated shuttle is only considered.

Advantages
- Very low labour costs for automated shuttle
- Much improved efficiency over AGV

Disadvantages
- High requirement on terminal surface
- High maintenance costs

5.4.4 Developments in proto-type phase

Non-mobile systems for horizontal transport of containers between quay and storage yard are still in the proto-type phase. Dutch manufacturer Promo-Teus has developed a system of heavy duty conveyor belt modules in a grid configuration. Chinese ZPMC is working on a system overhead grid cranes and mobile platforms on rails.

Figure 5.17 Apron overhead grid cranes (ZPMC)

5.5 Yard gantry cranes

5.5.1 Introduction

Gantry cranes specifically developed for container handling have been developed to achieve increased yard density and productivity. The large cranes are designed to very productive in performing only stacking and transfer operations in the storage yard.

5.5.2 Rubber Tyred Gantry

Rubber Tired Gantry Cranes (RTG Cranes) are very popular among medium to large terminals and owe their popularity to their flexibility. As a RTG rides on wheels it can easily ride from one stack to another to provide handling capacity there where it is most needed. The relatively high wheel loads require good subsoil and pavement conditions.

Figure 5.18 Rubber tyred gantry crane (Kalmar)

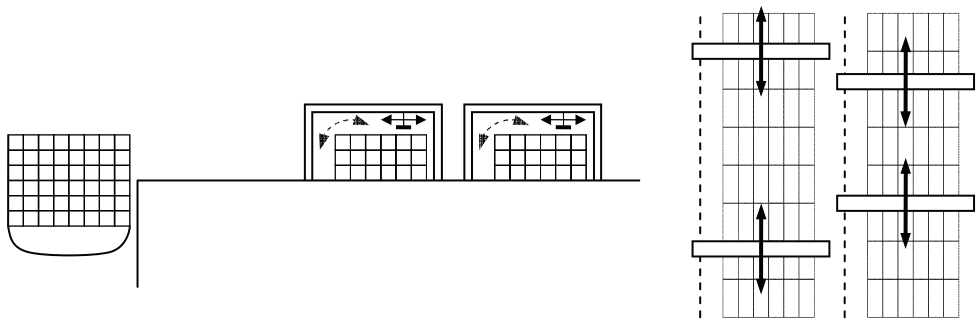


Figure 5.19 Crane operations and typical stack orientations RTG

The RTG crane does not travel very vast (max ~140 m/min), that travelling speeds calls for side loading along the entire length of the stack at the cost of storage space under the crane. Containers are stacked up to eight boxes wide plus a traffic lane and 6 container high. The common yard layout for RTG operated terminals is parallel to the quay in order to keep minimal travel distances for quay to yard transport. In this layout landside and quayside operations are not clearly separated making it less suitable for automation.

Table 5.8 Equipment benchmarks RTG

Crane span	20 – 30 m (5 – 8 + 1 lanes)
Lifting height (1-over-…)	up to 21 m (6 TEU)
Hoisting speed (laden / empty)	26 / 52 $^{m}/_{min}$
Trolley speed	70 $^{m}/_{min}$
Gantry travel	135 $^{m}/_{min}$
Gross productivity	20 $^{moves}/_{hr}$
Equipment unit per quay crane	5
Investment cost	€ 1,200,000
Maintenance and repairs costs (annually, % of investment costs)	3 – 4 %

Remote controlled RTGs are operating on terminals in Japan and South-Korea.

Advantages

- Flexible to allocate handling capacity where it is needed
- No rails needed

Disadvantages

- Mixing of waterside and landside services

5.5.3 Rail mounted gantry

The Rail Mounted Gantry Crane (RMG Crane) is highly popular among the largest terminals. On a rails the crane can travels at twice the speeds of a RTG crane allowing container transfers at end of the stack, end-loading. This way optimal use of container stacking space under the crane is achieved. Rail mounted gantry cranes can stack wider and higher that rubber tired gantry cranes, requiring less equipment units for the entire terminal.

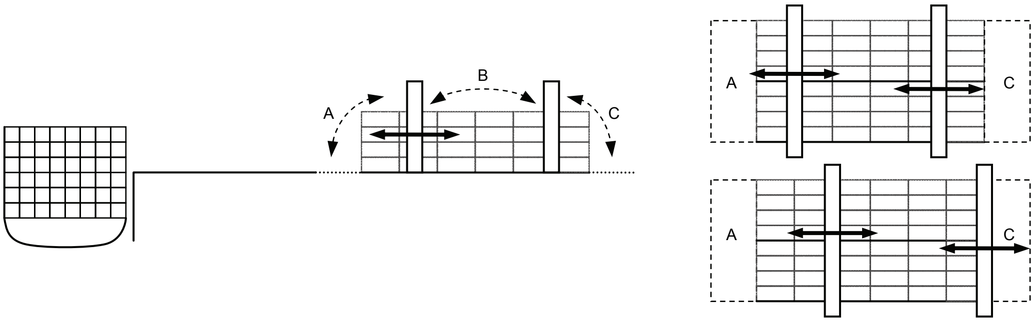


Figure 5.20 Crane operations and typical stack orientation RMG

Stacks are generally laid out perpendicular to the quay creating a clear separation between quayside and landside operations.

Figure 5.21 Automated RMG performing landside transfers at CTA, Hamburg

Table 5.9 Equipment benchmarks RMG

Crane span	20 – 50 m
Lifting height (1-over-…)	up to 19 m (4 – 6 TEU)
Hoisting speed (laden / empty)	30 / 60 $^{m}/_{min}$
Trolley speed	150 $^{m}/_{min}$
Gantry travel	240 $^{m}/_{min}$
Crane productivity	20 – 25 $^{moves}/_{hr}$
Equipment units per quay crane	2 - 3
Investment cost	€ 2,500,000
Maintenance and repairs costs (annually, % of investment costs)	3 %

Automation
The RMG is very well suited for unmanned operation and many terminal opting for rail mounted cranes do this with the plan to automate operation at some stage. The automated RMG is often referred to as automated stacking crane (ASC). All three automated terminals in European operate automated RMGs. In both Rotterdam and Hamburg these are coupled to automated transport by AGV.

Advantages
- High productivity
- Most suitable solution for automation

Disadvantages
- Rails needed
- Flexibility

5.5.4 Overhead Bridge Crane

The overhead bridge crane (OBC) is similar to the RMG. The rails of the crane are placed on elevated beams on concrete columns, allowing for large stacking heights. As the concrete support structure can be founded on piles it is also very suitable for locations with poor subsoil conditions.

As only small part of the construction is mobile, the cranes can travel at even higher speeds than a RMG while power units can be smaller. It is just as suitable for automation or remote controlled operation. The Port of Singapore is currently the largest port operating a terminal with automated OBCs.

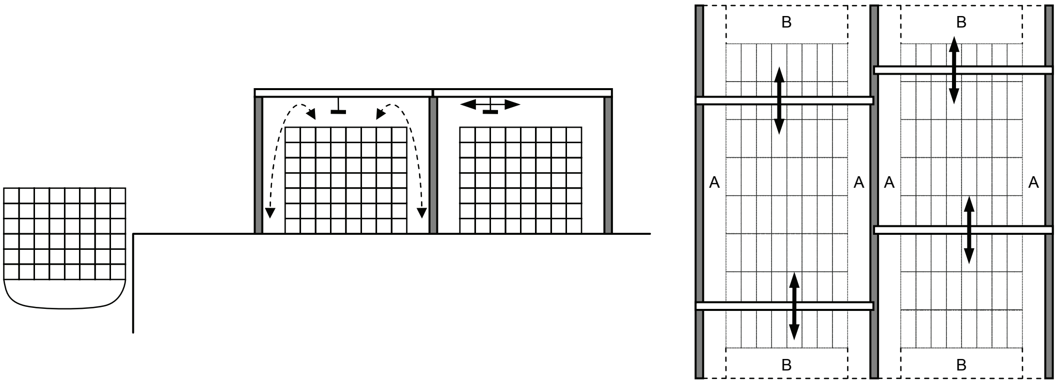


Figure 5.22 Crane operations and possible stack arrangements OBC

As shown in the figure above, yard overhead bridge cranes can be laid out parallel to the quay line with transfers along the entire length of the stack. Stack orientation perpendicular to the quay with transfers at both ends of the stack is however also a possibility. To allow multiple cranes per stack the first option however is favourable.

Advantages

- Very high and dense stacking
- Pilled columns suitable for unfavourable soil conditions

Disadvantages

- High investment cost for support structure
- Very high density requires much re-handling

Figure 5.23 Discontinued test plant of an automated OBC, Hessenatie Antwerp (Gottwald)

6 CONCEPTS FOR TERMINAL AUTOMATION

6.1 One size does not fit all

For terminal development of any size no “unisex” base solution is available. Functional requirements on terminal design are very case sensitive and depend on expected throughput, vessel call pattern, vessel size and service requirements. This is especially true for container terminal handling annual volumes ranging between 100,000 and 500,000 TEU. For example, terminals with annual throughputs in the top end of the range may regularly handle PostPanamax vessels. These terminals can hardly be compared with those at the lower end handling merely short sea feeders with average call sizes below 500 TEU.

Layout of existing facilities, the size and shape of the available area and other external factors have such an influence on the systems design that no single optimal system exists.

From the inventory of container handling equipment a number of concepts can be developed for terminal automation, each with their own specific properties. In this chapter these will be discussed after an overview of approaches to terminal development, the motivations for automation and methods of implementation.

6.2 Terminal development

Three different types of terminal development can be identified. These are Greenfield developments, extensions of exiting operations, or systems changeovers of existing operations.

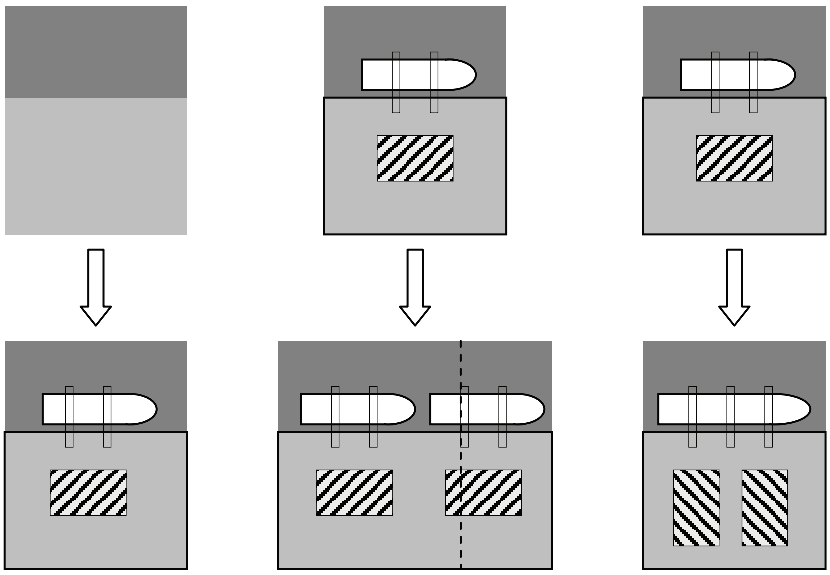


Figure 6.1Development forms (fltr): Greenfield development, extension and system changeover

The term Greenfield refers to the construction of a completely new operation on a previously unused site. From scratch a new terminal is designed and build on an newly developed location. Extension and systems changeovers of existing terminals occur when the existing operations can not, or no longer, meet the market demand. To meet this demand for container handling the current terminal can be enlarged, or a new and more efficient handling system can be implemented to replace the old. Often these two are combined by implementing a new system in the expansion area and gradually replace the system in the old part of terminal.

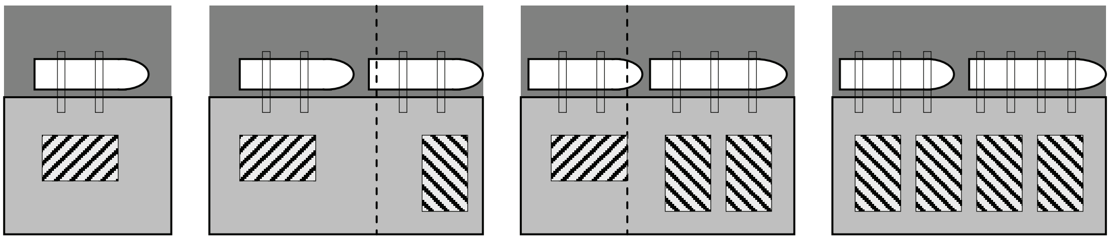


Figure 6.2 Phased combination of terminal extension and systems changeover

Terminal extensions, systems changeovers, and phased combinations provide mayor operational challenges. When competition is strong, loss of handling capacity during the project will be unacceptable. For extension projects this risk can be controlled, but for systems changeovers interferences of project works with current operations can only be minimised.

6.3 Terminal automation: design and implementation

As mentioned in chapter four the decision to go for automated container handling is made to reduce the operating costs of the terminal by cutting labour requirements. This decision is based on expectations on the development of service demand, labour costs and competition. An important part of this decision is the level automation that is aimed at for the handling system and the implementation of it.

Evolution versus revolution
For any investment a determining factor of its success is the length of the time necessary for it to start generating income. For Greenfield terminal developments the aim would be start handling the first containers as soon as possible after the first expenses have been made. However, while the choice of terminal equipment that can operate driverless is increasing, up to date no terminal operating system is available on the market that can directly interact with this equipment. This means that each automation project requires the development of new operating system involving extensive testing, simulation and the inevitable start-up problems.

For implementing terminal automation two approaches can be identified. These are the revolutionary implementation of automation and the evolutional implementation. The revolutionary approach aims to deliver a fully operational automated terminal. The aim of the evolutional implementation is to start operations as soon as possible. This is achieved by operating equipment manually while the necessary control and operating systems are being developed and tested. In the early years of automated container handling this approach followed by for the development of Thamesport in the UK generating an incoming cash flow before the technological developments were completed. As mentioned in the second chapter the Delta Terminal in Rotterdam is an example of the revolutionary approach.

Design phases
The design of the terminal is an iterative process in which the size and shape of the available area for the terminal influences set the boundaries terminal layout and systems design. Multiple iterations may be required involving several alternative functional designs, to generate a set of alternative layouts and handling systems.

6.4 Automation concepts

By combining container handling equipment available on the market today a number automated handling systems can be made. For each type of quay crane a conceptual system has been made.

6.4.1 Wide span gantry

The wide span gantry is popular solution for inland terminals and short sea feeder terminals that are very restricted in the available space and are not called upon by PostPanamax vessels.

In Northwest Europe the annual transported volume of containers on inland waterways is growing rapidly. Especially on the rivers Rhine and Danube a number inland terminals are handling large volumes of containers.

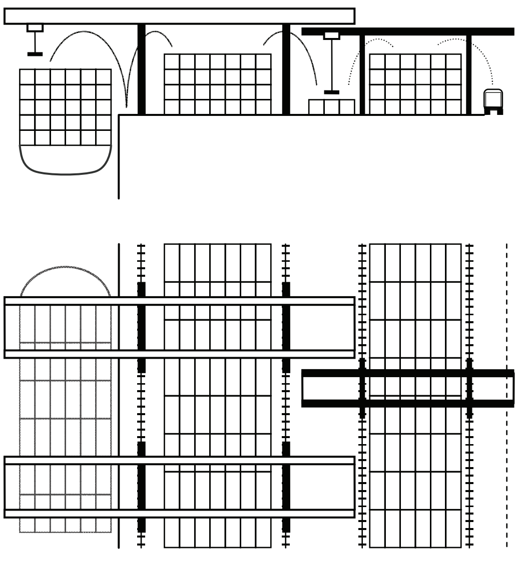


Figure 6.3 Wide span gantry crane and automated RMG

Concept
Automation of terminals operating wide span gantry cranes is achieved by automating the RMGs operating the import stacks behind the quay. Automated RMG have a good reliability record and have proven themselves as an innovation that works. Due to its size, the crane will not be able to achieve high speeds for gantry travel, making loading of road vehicles over the entire length of the stack the most feasible solution.

Terminals operating wide span gantry cranes require only a few yard gantry cranes. Expansion of the yard area away from the quay requires additional stacks parallel to the quay. The quay gantry crane may be partially automated itself, but actual vessel operations require control of a crane driver.

It remains uncertain if a reduction of operating costs can be achieved.

Advantages

- Compact terminal lay out
- Suitable for regular call pattern

Disadvantages

- Quay crane not suitable for PostPanamax vessels
- Large part of system remains un-automated
- Productivity very sensitive to last minute changes
- Less suitable for expansion

6.4.2 Ship-to-shore gantry cranes

AGV + RMG

The concept of automated container handling of driverless chassis providing the link between quay and yard has proven itself in the large automated terminals of Rotterdam and Hamburg. For smaller terminals the lower threshold will have to be identified above which the costs of additional facilities for the system and investments will weigh up to the savings through labour reduction.

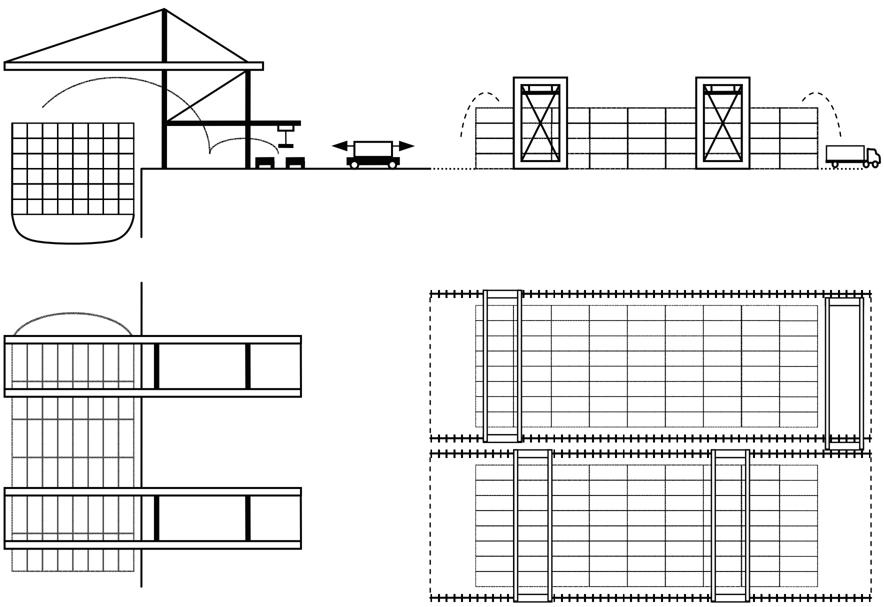


Figure 6.4 STS, AGV and automated RMG

Advantages

- Proven concept for large terminals

- Unlimited expansion parallel to quay
- System suitable for evolutional automation

Disadvantages
- Flexibility on small terminals
- Costs benefit for small terminals unknown

Automated straddle carriers
Combining the flexibility of a straddle carrier operation with those of automation seems to be a very promising concept. Specific advantages of the automated straddle carrier already available are its free ranging capacity on any hand surface and the possibility of increasing capacity in small steps. Straddle carriers are however expensive equipment of which a relative high number of units is required for small operations, with the added disadvantage that the currently available systems can not stack higher than two units.

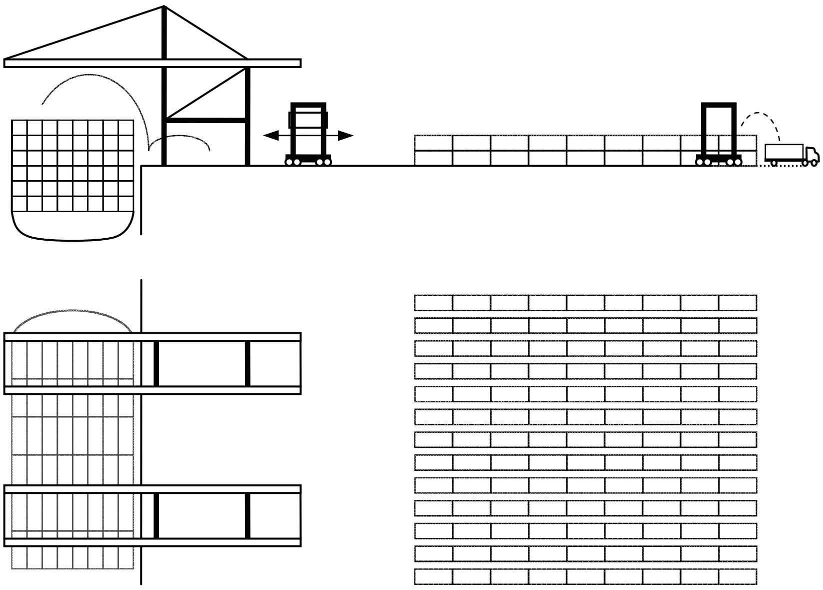


Figure 6.5 Autostrads

Advantages
- Flexibility of yard
- No structural requirements on pavement
- Suitable for expansion

Disadvantage
- Low yard density
- Cost and numbers of equipment

Shuttle + RMG
The automated mini straddle or shuttle is interchangeable with the AGV. Relying on the same technique as the automated straddle carrier it has the same free ranging ability. By breaking the link between yard and quay crane, less equipment would be needed to achieve comparable handling capacity. Shuttles able to lift 1-over-1 can be used to achieve additional stacking capacity on temporary stacks.

Advantages
- No connection between yard and quay cranes
- High efficiency in equipment use
- Reduced need for stacking capacity

Disadvantages
- Cost of equipment
- Flexibility of yard equipment
- Costs benefit for small terminals unknown

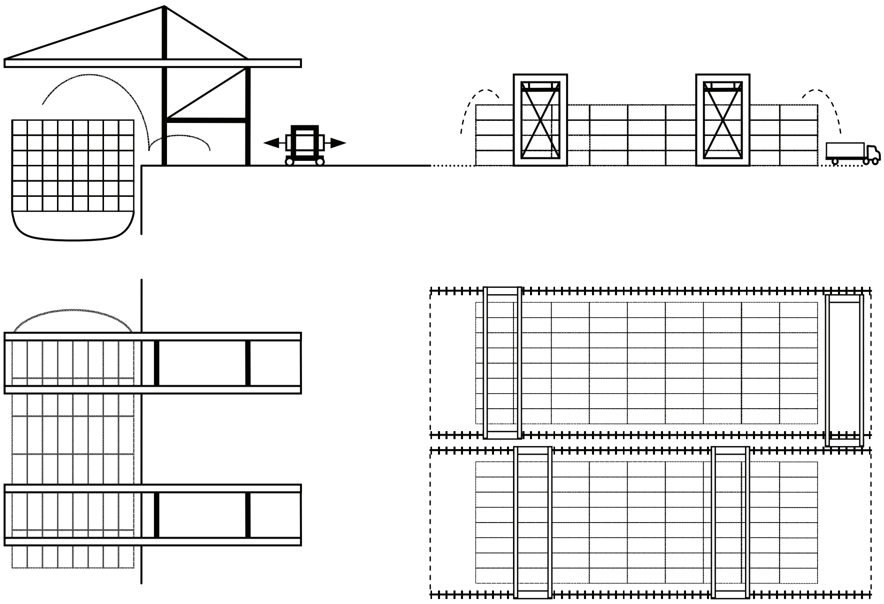


Figure 6.6 STS, mini Autostrads and automated RMGs

6.4.3 Mobile harbour crane

Quay handling equipment accounts for large portion of the investment costs of container terminals. Modern mobile harbour cranes packed with latest the latest operating systems can achieve productivity levels that can rival quay gantry cranes.
The reach of the crane allows it place and collect container directly in the stacking area. The combination of mobile harbour cranes with a compact automated overhead crane system reduces area requirements. A second advantage of the overhead system is the much smaller mobile plant of the system. It therefore requires a less powerful power unit. These savings are made at the cost of the overhead support structure.

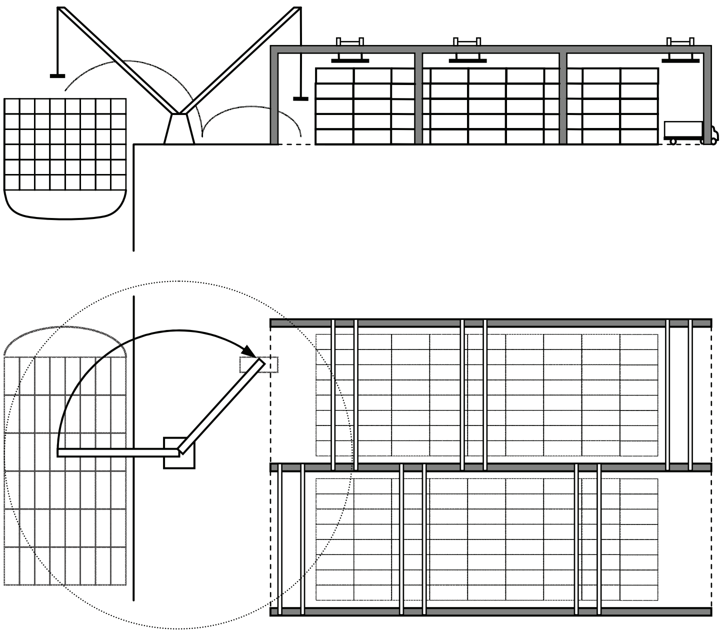


Figure 6.7 Mobile harbour crane and automated OBC

Advantages
- Flexibility of quay equipment
- Cost of quay equipment
- Compact terminal layout
- Suitable for high density stacking

Disadvantages
- Productivity of quay cranes
- Productivity sensitive to last minute changes
- Costly support structure for overhead cranes

7 RISAVIKA CASE INTRODUCTION

7.1 Introduction

In the next chapters a case study is carried out for the design of a medium sized automated container terminal. For this purpose the case of the Risavika Havn port development near Stavanger is studied.

Stavanger is currently the central hub of the Norwegian oil and gas industry. The development plans for Risavika Havn include the construction of a container terminal. The new harbour aspires to play a central role in container shipping along the Norwegian coast and become a regional hub in the Northern North Sea.

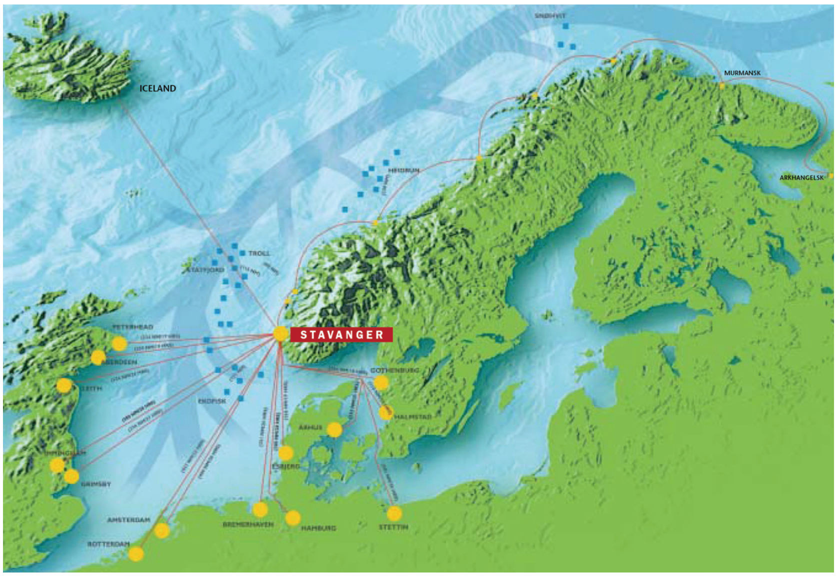


Figure 7.1 Stavanger in North Sea network

The Risavika Havn container terminal has been selected for this case study as it is an excellent example of a small container terminal as mentioned in chapter 3 of this report. Aspiring to become a hub connecting the Norwegian coastal network with the regional network on the North Sea, it is aiming to handle an annual volume of 100,000 to 200,000 TEU over its quay. Furthermore it is located in the periphery of the global maritime network and will be connected to the main deep sea shipping routes through feeder services to the main North Sea ports of Hamburg, Bremerhaven, Rotterdam, Antwerp and Felixtowe.
Another similarity with the general properties of small terminals is the public sector involvement. This development project is initiated by the local Port Authority. It is looking for cooperation with private operators. A BOT operating structure, as mentioned in Table 2.1 in chapter 2 of this report, will be assumed.

7.2 Scope of study

The aim of this study is to plan and design an automated container terminal for Risavika Havn. The economic feasibility will be studied by determination of the required investment cost for building the terminal and the costs for operating the terminal.

Automated container handling would enable Risavika Havn to distinguish itself as a state-of-the-art facility offering a high level of services. By using possible cost savings from labour reduction it may be able to offer a high level of services at highly competitive charges, allowing it to obtain a fair share of the local market for container handling services.

Figure 7.2 Artist impression of terminal area

Task list:

- Analysis of economical and local conditions case study
- Determine boundary conditions and functional requirements.
- Development of alternative terminal concepts
- Selection of terminal concept
- Preliminary design of quay, terminal area and handling systems
- Cost analysis of investment costs and operating costs.

7.3 Case analysis

7.3.1 Risavika Havn Project

At present Risavika is the main base for the petroleum industry in Norway. Next to that it is a port for goods being imported to Norway and for fresh fish exported to the markets in Europe. Currently al necessary port services are provided by the existing facilities at NorSea base and Sola harbour, but there is no more room for growth.

To create space for sustainable growth and development, an area of 65 hectares has been made available for port facilities and related industry. Part of the development plans are the construction of a total of 1650 meters of quay including a bulk terminal and a modern container terminal. The goals of the development project are the expansion of Risavika Havn and make the Stavanger region into a logistical hub on the Norwegian coast and in the North European transportation network.

For the development of the container terminal a site has been reserved in the Southeast corner of the project area available for lease to a terminal operator. The maximum available area of development measures 350 meter along the waterline and 500 meter inland, including space for future expansion.

Figure 7.3 Aerial picture of present site and development plans with location of terminal

7.3.2 Economic conditions

The greater Stavanger area has a population of 300,000 people, with Stavanger and Sandness as the mayor urban areas with respectively 112,000 and 58,000 inhabitants. The high GDP is mainly induced by the Petroleum industry.

The Norwegian economy in general has shown a steady growth over the past years. Over 2005 the GDP[1] of 238 Bn EUR (51,658 EUR per capita) was divided as follows:

- Agriculture 1.5 %
- Industry 37.5 %
- Services 61.1%

Scandinavian countries are well known for their high wages and strict labour legislations. Norway is no exemption to that. As a new player along the Norwegian coast the container terminal at Risavika Havn will need to set itself apart from the pack. Automated container handling can be used to just that.

7.3.3 Hinterland connections

Hinterland connections to other Norwegian regions are mainly provided by coastal liner services. Due to the shape of the Norwegian coast and its mountainous inlands land based hinterland connections such as road and rail are limited. A motorway connection to Bergen exists, but it involves two ferry crossings. Continuous motorway and rail connections to Kristiansand and Oslo are found 15 kilometres east of the project site.

[1] Source: DG Trade statistics Norway, Eurostat September 2006

Figure 7.4 Overview of region with intermodal connections

7.3.4 Competitors analysis

To get an indication of the scale of competing operation, the table below gives an overview of the competing container handling ports in Southern Norway.

Table 7.1 Existing Norwegian ports handling containerised cargo

	Throughput (*2004, TEU over quay*)	Facilities	Container berth	
			Length (m)	Draft (m)
Bergen	110,681	Ro/Ro & Lo/Lo	310	9.5
Frederikstad	41,000	Ro/Ro	-	-
Kristiansand	41,500	Ro/Ro & Lo/Lo	310	11
Oslo	177,019	Ro/Ro & Lo/Lo	310	11

The majority of containerised cargo is transported to, and along, the Norwegian coast by coastal liners and short sea feeders offering weekly services. The majority of vessels operating these services are classified in the ranger below 200 and 1,000 TEU. A large number of these vessels are equipped to transport containers and general cargo both Ro/Ro as well as Lo/Lo.

[Map indicating competing ports in Southern Norway]

7.3.5 Hydraulic conditions

Hydraulic conditions for the terminal site at Risavika are favourable. Due to the nearby amphidromic point of Egersund just south of Risavika, the vertical tide is very low. Due to the Gulf stream flowing along the Norwegian coast, in winter freezing of the harbour basin is no issue.

The sheltered location of the site of the container terminal does not raise any concerns on wave intrusion.

7.4 Design criteria

Terminal throughput

Total annual throughput : 200,000 TEU

- Vessel calling rate : 10 – 15 vessels per week
- Transhipment ratio : 20%
- Modal split : (transhipment : road : rail) = (20 : 80 : 0)
- Mixing (TEU : FEU) : 1 : 1 (f = 1.4)
- Average dwell time : 8 days

For the mixture of containers and the average dwell per type of container the table gives an overview of the assumed values.

Table 7.2 Assumed break-up of expected throughput

	Share (%)	Dwell (days)
Import / Export	60	6
Reefer	10	2
Dangerous goods	5	6
Empty	25	15

Using formula for storage capacity from chapter 4, the average required storage capacity can be calculated as displayed in the table below.

Table 7.3 Breakdown of required average storage capacity

	share	dwell	volume	Stack calls	storage
General	60%	6	120,000	108,000	1,775
Reefer	10%	2	20,000	18,000	99
Dangerous	5%	6	10,000	9,000	148
Empty	25%	15	50,000	45,000	1,849
Total	100%	-	200,000	180,000	3,871

Ship dimensions

The assumed load capacity of the largest ship size calling at the terminal is assumed in the range of 2,000 to 2,500 TEU. In appendix I the corresponding dimensions are determined, comparing the dimensions of a selection of vessels with load capacities between 1,500 and 2,500 TEU.

Maximum vessel : 2,000 TEU

- LOA : 194.7 m
- Beam : 29.2 m

- Draft : 10.9 m

Average vessel : 740 TEU
- LOA : 140 m
- Beam : 21.7 m
- Draft : 7.7 m

Client service requirements
The following service requirements on the terminal are provided by client demands in the level of services. These are assumed based on market indicators for container terminals.

- Available cranes per berth : 2
- Average waiting time : 15% of service time (max.)
- Waterside operations : 24 hr/day, year round
- Landside operations : 12 hr/day, 6 days per week

Assumptions
- Adequate connections to the existing continental infrastructure be available and of sufficient capacity.
- Reclaimed site will be fully prepared and suitable for construction with sufficient depth along the quay.
- The quay wall is not provided by the port authority.
- Terminal design and security systems will comply with ISPS code.

8 SELECTION OF HANDLING SYSTEM

8.1 Introduction

In this chapter the concept for container handling system for the terminal is selected. This is done within boundaries set in the previous chapter.

First the concept quay must be set. The quay length of the terminal is determined on the one hand by the size of the vessel that call at the terminal, and on the other hand by service requirements and an optimal level of utilisation.

Next capacity requirements on the other terminal systems are set as well as the storage capacity. A selection of alternative concepts is elaborated into an indicative terminal layout and equipment numbers are estimated.
Each concept is evaluated by the same set of criteria on the basis of which a multi criteria analysis is performed and the most favourable terminal concept is selected.

8.2 Quay concept

The quay wall is not only the terminals most important asset, at an indicated cost over 25,000 Euro per meter it is also its most expensive asset. The terminal operator will therefore aim to limit the length of quay it needs while still being able to service the largest vessel it expects to serve. An excellent tool for the industry to determine the required length of the quay is the queuing theory.

The queuing theory was developed to determine waiting times for customers arriving at a service point, based on the rate of arrival, service rate and the type of distribution of both. Without going into detail about the theory, the theory provides a number of tables for different combinations of distributions to giving average relative waiting times based on the number of service points and their utilisation.

For the case terminal the combination $E_2/E_2/n$ is used, meaning both service rate and arrival rate are assumed to be Erlang-2 distributed with n-number of berths. The table for this distribution as well as other tables used later in this study are given in **appendix III**.

Quay length
The minimum length of the quay is determined by the design vessel with an overall length of 220 m. Accounting for 30 meters of space for mooring this gives a minimum quay length of 250 meters. To determine weather this is sufficient, the quay is divided in a number of berths. This division in berths is merely theoretical as in reality terminal operators only work with available quay length and available quay handling equipment. Based on the average vessels size of 140 meters each berth has a length of 165 m to allow space for mooring.

The table for the $E_2/E_2/n$ system is used to determine under what level of utilisation the maximum average waiting time of 15% of the service time is not exceeded. The minimum quay length of 250 meter is divided into 1.5 berths. This number of berths combines the situations in which two smaller ships can be served at the same time and the situations in which one ship does not leave any room on the quay for other vessels to be berthed. By interpolating between the series 1 and 2 berths a value can be found for this virtual number of 1.5 berths.

Table 8.1 Waiting times for the $E_2/E_2/n$ queuing system

utilisation (u)	number of servers (n) 1	2	3
0.2	0.0604	…	…
0.3	**0.1310**	…	…
0.4	**0.2355**	0.0576	…
0.5	0.3904	**0.1181**	0.0512
0.6	…	**0.2222**	**0.1103**
0.7	…	0.4125	**0.2275**
0.8	…	…	0.4600

By linear interpolation the results from the table gives the following utilisations for a waiting time of 0.15.

Table 8.2 Interpolated utilisation

number of berths (n)	Waiting time %	Maximum utilisation %
1	15	31
2	15	53
1.5	*15*	*41*

Quay handling capacity
To determine the required quay handing capacity and berth productivity, the maximum utilisation as determined above is used to determine the annual the total annual hours of vessel operations.

$$u_{berth} = \frac{T(service)}{T(available)} \qquad \Leftrightarrow T(service) = u_{berth} \cdot T(available)$$

As discussed in chapter 4, the service time includes berthing operations and other operational inefficiencies. To account for these, a factor of 0.8 is taken for the actual operational time on vessels. The total operational time per berth per year is now calculated as follows.

$$T(operational) = 0.8 \cdot u_{berth} \cdot T(available) \tag{8.1}$$

$$n=1 \quad : \qquad T(operational) = 0.8\cdot 0.31\cdot 8760 = 2172\ {}^{hr}\!/_{yr}$$

$$n=1.5: \qquad T(operational) = 0.8\cdot 0.41\cdot 8760 = 2873\ {}^{hr}\!/_{yr}$$

$$n=2 \quad : \qquad T(operational) = 0.8\cdot 0.53\cdot 8760 = 3714\ {}^{hr}\!/_{yr}$$

Now the required berth productivity can be calculated as follows:

$$P_{berth} = \frac{200,000\ {}^{TEU}\!/_{yr}}{f\cdot n\cdot T(operational)} \tag{8.2}$$

$$n=1: \qquad P_{berth} = \frac{200,000}{1.4\cdot 1\cdot 2172} = 65.8\ {}^{mvs}\!/_{hr}$$

$$n=1.5: \qquad P_{berth} = \frac{200,000}{1.4\cdot 1.5\cdot 2873} = 33.2\ {}^{mvs}\!/_{hr}$$

$$n=2 \quad : \qquad P_{berth} = \frac{200,000}{1.4\cdot 2\cdot 3717} = 19.2\ {}^{mvs}\!/_{hr}$$

From the calculation above it can be concluded that a quay length of 250 meters will be sufficient provided that a total handling capacity of 1.5 · 33.2 = 49.8 ${}^{mvs}/_{hr}$ is achieved over the entire length of the quay, with a minimum of 3 cranes.
A longer quay 340 meter may also be considered, requiring a lower handing capacity of only 2 · 19.2 = 38.4 ${}^{mvs}/_{hr}$ from a minimum of 4 cranes.

Given additional costs of equipment and length of quay the first option can be regarded as the most feasible of the two.

8.3 System requirements and evaluation

With the waterside capacity requirements determined in the previous chapter the remaining service requirements to be determined are the storage capacity and the landside handling capacity. On the basis of these three parameters terminal concepts can that be developed to match that match those demands.

In this paragraph first the remaining service requirements are determined. The level to which these requirements are met by each concept is an important evaluation criterion. There are however many more evaluation criteria by which developed concepts are assessed. The are discussed at the end of this paragraph.

8.3.1 Service requirements

Storage capacity
The storage total capacity is calculated using the formulas discussed in chapter 4.

$$C_{storage} = \frac{\sum_{i=1}^{n} \left(S_i \cdot \bar{t}_i\right) \cdot p}{365} = N_{TGS} \cdot \hat{h} \quad \text{, with : } S = C_q \left(1 - 0.5\mu\right)$$

With a peaking factor p=1.3 (Drewry, 1998) and the figures for table 7.3 this gives:

$$C_{storage} = \frac{\left(108{,}000 \cdot 6 + 20{,}000 \cdot 2 + 10{,}000 \cdot 6 + 50{,}000 \cdot 15\right) \cdot 1.3}{365} = 5{,}033 TEU$$

Saanen (2004) indicates that the peaking factor of 1.3, which is used throughout the industry, may in fact be as high as 1.5. Using this value a required storage capacity of 5807 TEU is found. The required maximum storage capacity of the terminal and the number of TEU ground slots depends on the type of yard equipment, stacking height and strategy and the maximum operational filling rate of the storage system.

Table 8.3 Storage demand per type of container

	share	**dwell** (days)	**volume** (TEU)	**Stack calls**	**Average** (TEU)	**Peak** (p = 1.3)
General	60%	6	120,000	108,000	1,775	2,308
Reefer	10%	2	20,000	18,000	99	128
Dangerous	5%	6	10,000	9,000	148	192
Empty	25%	15	50,000	45,000	1,849	2,404
Total	100%	-	200,000	180,000	3,871	11

Landside handling capacity

The transhipment ratio of 20% indicates landside handling capacity is very important factor for the terminal. Unlike the waterside operations the landside services are no 24/7 operation. Road haulers operate only six days of the week during the day, with clear peaks in the early morning and late afternoon. Assuming 6 days per week, 12 hrs per day operations, with 40% equipment utilisation to account for daily peaks, the following landside handling capacity is determined.

$$P_{land} = \frac{\left(1-\mu\right) \cdot C}{f \cdot u \cdot 52 \cdot 72} = \frac{\left(1-0.2\right) \cdot 200{,}000 \, {}^{TEU}\!/_{yr}}{1.4 \, {}^{TEU}\!/_{mv} \cdot 0.4 \cdot 3744 \, {}^{hr}\!/_{yr}} = 77 \, {}^{mvs}\!/_{hr} \qquad (8.3)$$

8.3.2 Evaluation criteria

Terminal and handling systems are assessed and compared by four key elements. Each concept presented in this chapter is assessed on the criteria discussed next

Service level

The measure to which client service demands are met is decisive for attracting shipping lines. Client demands were mentioned earlier in chapter 4, some of these are also for evaluation of different concepts:

- Quay productivity; service time
- Reliability of services
- Flexibility; last minute changes

Operations

- Flexibility; break downs and equipment allocation
- Presence of potential bottlenecks
- Maintenance requirements
- Travelling distances
- Equipment efficiency
- Health and safety considerations
- Environmental impact

Costs

- Investment costs
- Operating costs
- Area requirements
- Risks

Implementation

- Phased start of operations
- Phased introduction of automation
- Flexibility of design
- Expansion

8.3.3 Concepts

From figure 5.2 it can be concluded that many different types of terminal equipment can be combined to a container handling system. The table blow gives an overview of the possible combination.

Table 8.4 Overview possible terminal concepts

Quay handling		Internal transport		Stacking			Comment
		AGV	Shuttle	AutoStrad	RMG	OBC	
Ship to shore gantry	1	+			+		Operated in Rotterdam and Hamburg
	2	+				+	Originally planned Singapore
	3		+		+		In consideration for Busan and Felixtowe
	4		+			+	
	5			+			Operated in Brisbane
Mobile harbour crane	6	+			+		Mobile harbour crane may be used to place boxes directly in (front of) stacks
	7	+				+	
	8		+		+		
	9		+			+	
	10			+			
Widespan gantry	11				+		Widespan RMGs with overlapping outreaches

From the table above, the following concepts have been selected for each type of yard handling equipment combining it with suitable equipment for quay handling and horizontal transport.

- Automated straddle carrier terminal
- RMG terminal
- Overhead bridge crane
  - Quay handling by mobile harbour cranes and no horizontal transport
  - Quay handling by ship-to-shore gantries and horizontal transport

- Widespan RMG terminal

For each considered handling system a possible terminal design is outlined to meet the functional requirements set earlier in this paragraph.

8.4 Automated straddle carriers (Autostrad)

The Autostrads can be combined with either mobile cranes or quay gantry cranes. Both combinations are evaluated as alternative concepts. To determine the required number of equipment units the benchmarks of chapter 5 are used. For the required number of quay cranes conservative benchmarks are used.

8.4.1 Handling system

Quay handling

- Mobile harbour cranes
  - Industry benchmarks:
    Gross productivity : 15 $^{mvs}/_{hr}$
    Max throughput per crane : 50,000 $^{TEU}/_{yr}$
  - Required number of cranes : 200,000 / 50,000 = 4 cranes
    Berth productivity : 3 · 15 $^{mvs}/_{hr}$ = 45 $^{mvs}/_{hr}$
    Quay productivity : 4 · 15 $^{mvs}/_{hr}$ = 60 $^{mvs}/_{hr}$
- STS gantry cranes
  - Industry benchmarks:
    Gross productivity : 25 $^{mvs}/_{hr}$
    Throughput per crane : 70,000 $^{TEU}/_{yr}$
  - Required number of cranes : 200,000 / 70,000 = 3 cranes
    Berth productivity : 2 · 25 $^{mvs}/_{hr}$ = 50 $^{mvs}/_{hr}$
    Quay productivity : 3 · 25 $^{mvs}/_{hr}$ = 75 $^{mvs}/_{hr}$
    Throughput per quay crane : 200,000 TEU / 3 = 67,000 $^{TEU}/_{yr}$

Yard handling

- Benchmarks for Autostrad:
  - Gross productivity (estimated)
    Waterside operations : 10 $^{mvs}/_{hr}$
    Landside operations : 15 $^{mvs}/_{hr}$
  - Units per quay crane
    MHC : 2
    STS : 3
- Waterside operations
  - 2 Autostrads per MHC : 8 Autostrads
    Productivity : 8 x 10 $^{mvs}/_{hr}$ = 80 $^{mvs}/_{hr}$
  - 3 Autostrads per STS : 9 Autostrads
    Productivity : 9 x 10 $^{mvs}/_{hr}$ = 90 $^{mvs}/_{hr}$
- Landside operations
  - 75 $^{mvs}/_{hr}$ / 15 $^{mvs}/_{hr}$ = 5 Autostrads
- Annual throughput per equipment unit
  - MHC : 200,000 TEU / (8+5) = 15,500 $^{TEU}/_{unit}$
  - STS : 200,000 TEU / (9+5) = 14,300 $^{TEU}/_{unit}$

For the Autostrad no benchmarks are available to verify the annual throughput per unit.

Storage capacity
Autostrads can stack containers only 2 high, max filling rate is estimated at around 85%. A minimum of 2900 TEU ground slots (TGS) is required to meet the 5033 TEU storage capacity during peaks.

8.4.2 Concept layout

Mobile harbour cranes

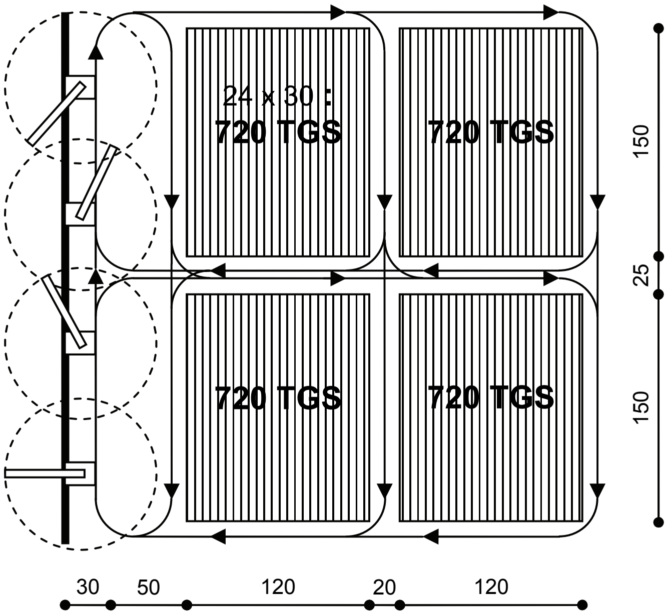


Figure 8.1 Autostrad concept with quay handling by MHC

STS gantry cranes

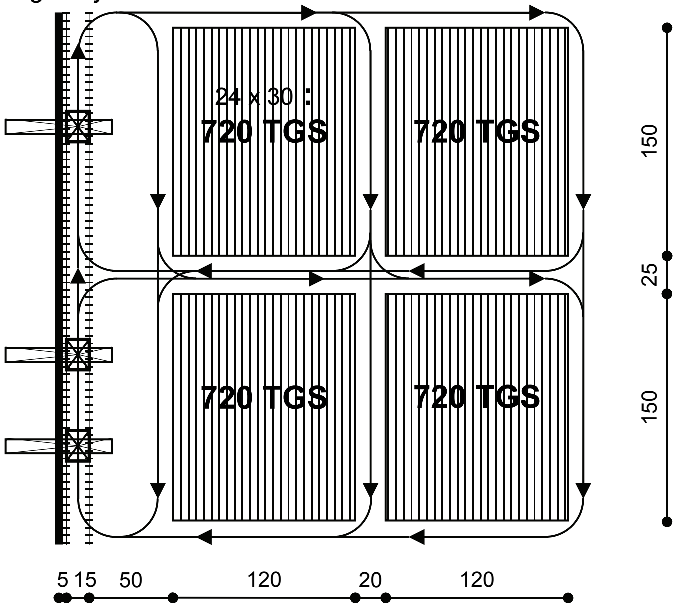


Figure 8.2 Autostrad concept with STS gantry cranes

Comments
One way traffic in combination with parallel stack orientation is chosen to create a circular flow of traffic in one direction. Below the systems cycles diagram, as shown in figure 5.1 in chapter 5, is revised for the straddle carrier operation to provide an overview of the possible container handling cycles in the concept. Note that boxes arriving at the gate can be transported straight to the quay and vice versa.

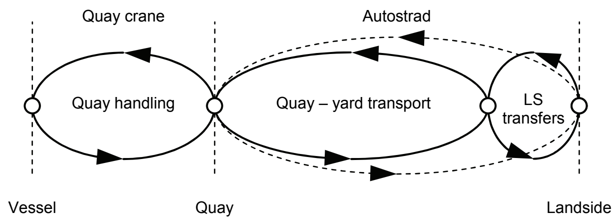


Figure 8.3 System cycles diagram straddle carrier

8.4.3 Evaluation

Service level

- Quay productivity
  With a limit of 2 to 3 mobile cranes that can work on one vessel at same time berth productivity is therefore lower than for the STS gantry crane.
- Reliability of services
  Reliability of both types of quay crane is high. Impact of broken down mobile crane is very low.
- Flexibility; last minute changes
  Last minute arrivals and changes in schedule pose no problems.

Operations

- Flexibility; break downs and equipment allocation
  Autostrads perform any yard operation and, additionally, large numbers limit impact of breakdown single unit.
- Presence of potential bottlenecks
  None
- Maintenance requirements
  High maintenance requirements limit availability and require permanent workshop for on-site maintenance.
- Travelling distances
  Large travelling distances for Autostrads, due to large yard area limit equipment productivity.
- Equipment efficiency
  Difference between system capacity and required capacity is limited.
- Health and safety considerations
  Clear separation of automated and manned operations; airlock system for areas where people come (loading bays, reefer stacks)
- Environmental impact
  Energy consumption of electrically powered Autostrad is high, but clean and silent. Diesel powered mobile crane emits exhaust fumes and noise.

Costs

- Investment costs
  ad MHC: Considerable savings in equipment costs and structural requirements on quay from much lower weight of crane (~350 Tons).
  ad STS: High cost of equipment and quay structure for crane (1000 – 1500 Tons)
- Operating costs
  High cost of maintenance, no statement on energy consumption.
- Area requirements
  Very high area requirements increase land costs.
- Risks
  Low risks from minimal investments in civil infrastructure and saleability of mobile cranes and straddle carriers.

Implementation

- Phased start of operations
  Excellent opportunities of early start of operations with half quay and yard
- Phased introduction of automation
  Not suitable for evolutional introduction of automation.
- Flexibility of design
  Arrangement of yard layout and equipment numbers is highly flexible.
- Expansion
  Although area requirements are high, yard area is well suited for expansion in either direction.

8.5 Rail mounted gantry cranes (Automated stacking cranes)

8.5.1 Handling system

Quay handling

- 3 STS gantry cranes
  Quay productivity : 75 $^{mvs}/_{hr}$
  Throughput per quay crane : 67,000 $^{TEU}/_{yr}$

Yard handling

- Benchmarks for RMG crane
  - Gross productivity : 25 $^{mvs}/_{hr}$
  - Units per quay crane : 2 (incl. LS operations)
- Required equipment numbers
  - Waterside operations : 75 $^{mvs}/_{hr}$ / 25 $^{mvs}/_{hr}$ = 3 RMGs
    Landside operations : 75 $^{mvs}/_{hr}$ / 25 $^{mvs}/_{hr}$ = 3 RMGs
  - Yard productivity : 6 x 25 $^{mvs}/_{hr}$ = 150 $^{mvs}/_{hr}$
- Annual throughput per yard crane : 200,000 TEU / 6 = 33,500 $^{TEU}/_{yr}$

Horizontal transport

- AGV
  - Industry benchmarks
    Goss productivity AGV (est.) : 5 $^{mvs}/_{hr}$
    Units per quay crane : 5
  - 5 AGVs per STS : 15 AGVs
    Productivity : 15 x 75 $^{mvs}/_{hr}$ = 75 $^{mvs}/_{hr}$
- Shuttle carrier (alternative option)

- Benchmarks (estimated)
  Goss productivity : 10 $^{mvs}/_{hr}$
  Units per quay crane : 3
- 3 SHCs per STS : 9 SHCs
  Productivity : 9 x 10 $^{mvs}/_{hr}$ = 90 $^{mvs}/_{hr}$

As discussed in chapter 4, horizontal transport capacity must at least match quay productivity. The estimated minimum of 15 AGVs complies with the industry benchmark of 5 transport units per quay crane. For the estimated number shuttle carriers, no benchmarks are available. As the estimation seems rather low, a requirement of at least 10 units is set.

Storage capacity
For a maximum stacking height of 4 boxes and a maximum filling rate of 85% (Rijsenbrij and Wieschemann, 2004), a minimum of 1480 TEU ground slots (TGS) is required to meet the 5033 TEU maximum storage capacity. This height is the current industry standard for automated stacking cranes, although higher stacking is possible.

8.5.2 Concept layout

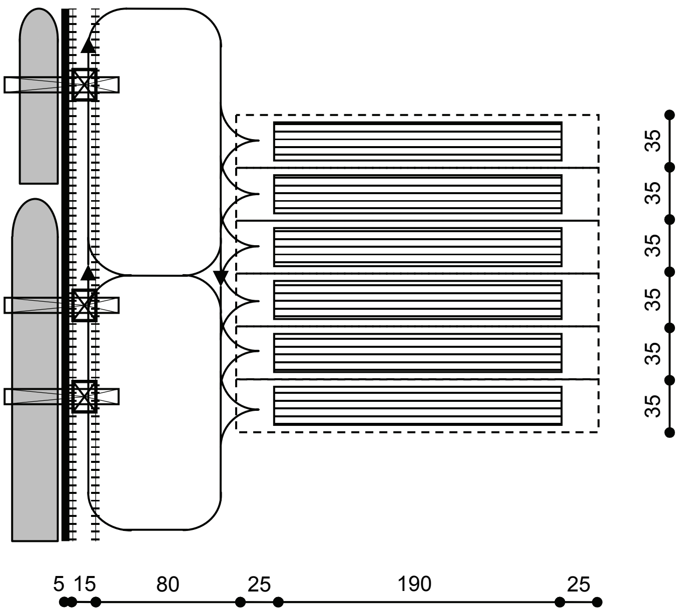


Figure 8.4 RMG concept

The layout above shows a possible terminal layout with six stacks each operated by a single automated RMG. More conventional would be a configuration of 3 stacks, twice as long, each operated by two RMGs. The configuration above however had the advantage of providing twice as many transfer points. Below the systems cycles diagram is given.

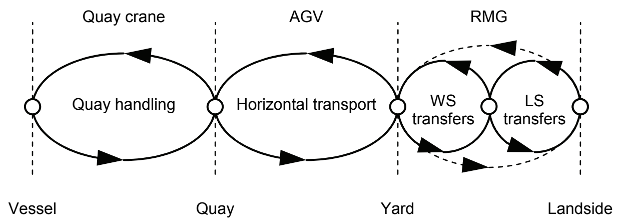


Figure 8.5 System cycles diagram RMG and horizontal transport

8.5.3 Evaluation

Service level

- Quay productivity
  High productivity, 3 STS cranes have combined handling capacity well above the requirements.
- Reliability of services
  Reliability is very high, breakdowns may impact on productivity of system by blocking quay handling operations.
- Flexibility; last minute changes
  Low impact of last minute changes, late arrivals must pas through stacks and horizontal transport.

Operations

- Flexibility; break downs and equipment allocation
  Impact unavailable equipment on productivity is limited, unavailable RMG makes entire stack inaccessible.
- Presence of potential bottlenecks
  None
- Maintenance requirements
  Low maintenance requirements of very reliable equipment, AGVs require small workshop near apron area and RMGs require maintenance zone at landside end of stack.
- Travelling distances
  Relatively long travelling distances for RMGs covering entire stack.
- Equipment efficiency
  Difference between system capacity and required capacity is limited.
- Health and safety considerations
  Clear separation, remote controlled (un-)loading of road transport. Airlock for reefer stacks
- Environmental impact
  No emissions from electrically powered RMG and STS cranes. Diesel electric AGVs have minimal emissions.

Costs

- Investment costs
  High investment costs for equipment, quay structure, rail tracks for RMG and transponders for AGV.
- Operating costs
  Low maintenance requirements and efficient energy consumption.
- Area requirements
  Low area requirements from compact yard layout.

- Risks
  Considerable risk from high investments in civil infrastructure and limited saleability of RMGs.

Implementation

- Phased start of operations
  Some opportunities of early start of operations.
- Phased introduction of automation
  Evolutional introduction automated yard handling possible, horizontal transport can not be gradually automated.
- Flexibility of design
  Limited flexibility, additional equipment units can intensify operations.
- Expansion
  Possibility of expansion in inland direction by lengthening stacks or in direction parallel to quay by adding stacks.

8.6 Overhead bridge crane with mobile quay cranes

The concept of the OBC combined mobile harbour cranes for quay handling was previously elaborated by Rijsenbrij and Dobner (2001).

8.6.1 Handling system

Quay handling

- 4 Mobile harbour cranes
  Quay productivity : 60 $^{mvs}/_{hr}$
  Throughput per quay crane : 50,000 $^{TEU}/_{yr}$

Yard handling

- Benchmarks for OBC
  Gross productivity (est.) : 25 $^{mvs}/_{hr}$
  Units per quay crane : n.a.
- Required equipment numbers
  - Waterside operations : 60 $^{mvs}/_{hr}$ / 25 $^{mvs}/_{hr}$ = 3 OBCs
    Landside operations : 75 $^{mvs}/_{hr}$ / 25 $^{mvs}/_{hr}$ = 3 OBCs
    Internal movements : 2 OBCs (estimated)
  - Yard productivity : 6 x 25 $^{mvs}/_{hr}$ = 150 $^{mvs}/_{hr}$
- Annual throughput per yard crane : 200,000 TEU / 8 = 25,000 $^{TEU}/_{yr}$

Industry benchmarks for overhead travelling cranes are not available. Gross crane productivity reduced proportional with reduced accessibility from increasing stacking height.

Storage capacity
A maximum stacking height of 4 boxes is assumed in this stage. This is relatively low compared to the advertised ability to stack as high as 8 boxes (Paceco Corp.). Stacking 4 high, assuming a maximum filling ratio of 85% for this concept are 1480 TEU ground slots are required.

8.6.2 Concept layout

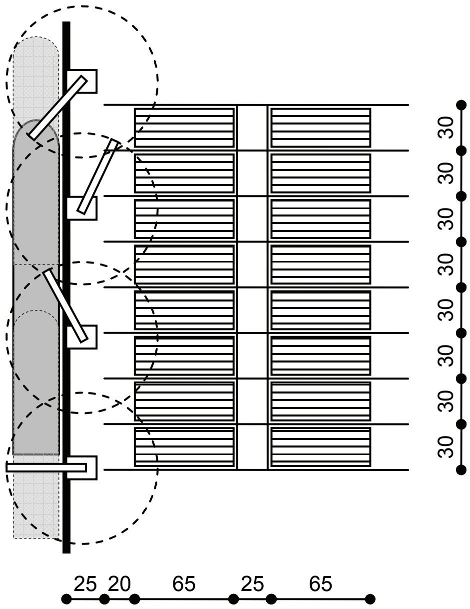


Figure 8.6 OBC concept with MHC

Comments
To keep outer stacks within reach of cranes at end of quay a additional stacks are required to avoid dependency on horizontal transport. As a result more stacks are built than is needed to meet capacity requirements. In a central transport artery one or two cranes travel on a lower bridge to exchange boxes between stacks. Contrary to the original concept of Rijsenbrij and Dobner, this artery is not suitable for landside transfers.

The overview of the systems cycles in the diagram below shows the complex logistics of pre-stacking containers in the correct waterside transfer point, within the reach of the mobile harbour crane.

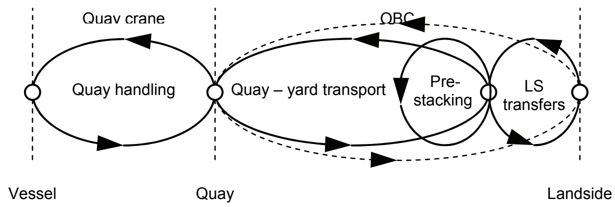


Figure 8.7 System cycles for OBC concept with MHC

8.6.3 Evaluation

Service level
- Quay productivity
  No more than 2 to 3 mobile cranes can work simultaneously on one vessel. Actual berth productivity is further limited by increased cycle distances to skip horizontal transport, reducing quay crane productivity.

- Reliability of services
  Equipment reliability is high.
- Flexibility; last minute changes
  Required level of pre-stacking reduces flexibility to cope with last minute changes. Direct transfers of late arrivals between quay and road going transport are however possible.

Operations

- Flexibility; break downs and equipment allocation
  Usable quay length depends on availability of stacks within back reach of quay crane. Impact of unavailable yard equipment is high.
- Presence of potential bottlenecks
  Pre-stacking and internal artery create potential bottlenecks, drastically reducing productivity of entire system.
- Maintenance requirements
  Maintenance requirements are very low. OBCs require maintenance area on landside end of crane bridge.
- Travelling distances
  Short travelling distances for yard cranes.
- Equipment efficiency
  Low throughput per bridge crane (8 + 2) indicates sub-optimal efficiency
- Health and safety considerations
  Minimal workspace, high above ground, is available for maintenance on bridge cranes. Collision risk of quay crane (sway) and bridge structure.
- Environmental impact
  Small, electrically powered, overhead cranes are silent and without emissions. Diesel powered mobile crane emits exhaust fumes and noise.

Costs

- Investment costs
  Very high investment costs for construction of crane bridges, are only partially compensated by cost savings from mobile cranes and quay structure.
- Operating costs
  Low operating costs form low maintenance requirements and limited energy consumption.
- Area requirements
  Low area requirements.
- Risks
  High risk from very high investment costs of cane bridge construction.

Implementation

- Phased start of operations
  Opportunities of phased start-up are limited by internal transport artery.
- Phased introduction of automation
  Good possibility of phased introduction of automation through remote controlled crane operation.
- Flexibility of design
  Only flexibility is available in form of additional equipment.
- Expansion
  Feasibility of expansion in any direction is limited by direct transfers between quay and yard and by risk of clogging of internal artery.

8.7 Overhead bridge cranes with STS and horizontal transport

8.7.1 Handling system

Quay handling

- 3 STS gantry cranes
  Quay productivity : 75 $^{mvs}/_{hr}$
  Throughput per quay crane : 67,000 $^{TEU}/_{yr}$

Yard handling

- Benchmarks for OBC
  Gross productivity (est.) : 25 $^{mvs}/_{hr}$
  Units per quay crane : n.a.
- Required equipment units
  - Waterside operations : 75 $^{mvs}/_{hr}$ / 25 $^{mvs}/_{hr}$ = 3 OBCs
    Landside operations : 75 $^{mvs}/_{hr}$ / 25 $^{mvs}/_{hr}$ = 3 OBCs
    Internal movements : 1 OBC (estimate)
  - Yard productivity : 7 · 25 $^{mvs}/_{hr}$ = 175 $^{mvs}/_{hr}$
- Annual throughput per yard crane : 200,000 TEU / 7 = 29,000 $^{TEU}/_{yr}$

Horizontal transport AGV

- Industry benchmarks
  Goss productivity AGV (est.) : 5 $^{mvs}/_{hr}$
  Units per quay crane : 5
- 5 AGVs per STS : 15 AGVs
  Productivity : 15 x 75 $^{mvs}/_{hr}$ = 75 $^{mvs}/_{hr}$

Similar to the RMG concept, the estimated minimum of 15 AGVs to achieve required handling capacity matches the industry benchmark of 5 transport units per quay crane.

Storage capacity
To make full use of the high density stacking abilities of the OBC, 6 high stacks are used. At a maximum filling ratio of 85% the required number of TEU ground slots is reduced to 990.

8.7.2 Concept layout

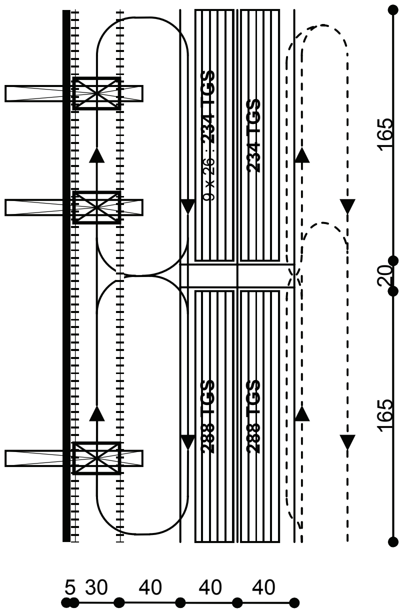


Figure 8.8 OBC concept with STS and AGVs

Comments
The reduced accessibility of stored containers, due to high stacking, is partially compensated by reduced crane travel and more flexible allocation of yard equipment. A short transport artery handling internal transport to landside stacks has a reduced risk of clogging and becoming a bottleneck.

The diagram below shows the separation of landside and waterside yard operations. No shown is the internal artery that may be used for direct transfers between landside and waterside of the stack.

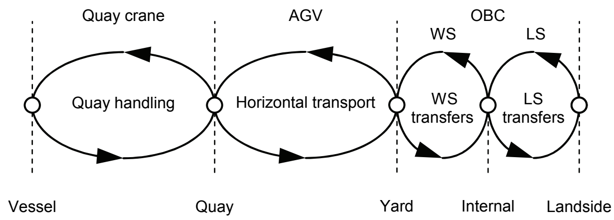


Figure 8.9 System cycles for OBC and STS concept

8.7.3 Evaluation

Service level

- Quay productivity
  High productivity, 3 STS cranes have combined handling capacity well above the requirements.
- Reliability of services
  Reliability is very high, breakdowns may impact system productivity by blocking quay handling operations.

- Flexibility; last minute changes
  Low impact of last minute changes, late arrivals must pas through stacks and horizontal transport.

Operations

- Flexibility; break downs and equipment allocation
  More flexible allocation handling capacity from several cranes on one bridge. Impact on system of unavailable equipment is reduced but equipment may be in each others way.
- Presence of potential bottlenecks
  Internal transport between stacks poses low risk of becoming bottleneck.
- Maintenance requirements
  Low maintenance requirements of very reliable equipment, AGVs require small workshop near apron area and OBCs require maintenance area on landside end of crane bridge.
- Travelling distances
  Short travelling distances for yard cranes and horizontal transport equipment.
- Equipment efficiency
  OBCs for internal transport increase difference between system capacity and required capacity.
- Health and safety considerations
  For landside transfers road vehicles enter storage yard where cranes pass overhead. Actual transfers take place remote controlled.
- Environmental impact
  No emissions from electrically powered OBCs and STS cranes clean. Diesel electric AGVs have minimal emissions.

Costs

- Investment costs
  High costs for equipment and construction of quay and crane bridges.
- Operating costs
  Low maintenance requirements and efficient energy consumption.
- Area requirements
  Low area requirements form compact terminal layout.
- Risks
  Considerable risks from high investments in civil infrastructure.

Implementation

- Phased start of operations
  Due to construction of crane bridge, limited opportunities
- Phased introduction of automation
  Good possibility of phased introduction of automation through remote controlled crane operation.
- Flexibility of design
  Some flexibility in operation, additional equipment units can intensify operations and arrangement of stacks under OBC can be altered.
- Expansion
  Possibility to add stacks away from quay, but requires change of logistic process horizontal transport to landside stacks.

8.8 Widespan yard gantry cranes

Widespan RMG cranes with overlapping outreach and directly within back reach of quay crane is an alternative solution for eliminating horizontal transport on the terminal. On inland barge terminals widespan quay gantry cranes are often used for such terminals, but on a sea terminal STS gantry cranes or mobile cranes are required.

8.8.1 Handling system

Quay handling

- 4 Mobile harbour cranes
  Quay productivity : 60 $^{mvs}/_{hr}$
  Annual throughput per quay crane : 50,000 $^{TEU}/_{yr}$
- 3 STS gantry cranes
  Quay productivity : 75 $^{mvs}/_{hr}$
  Annual throughput per quay crane : 67,000 $^{TEU}/_{crane}$

Yard handling

- Benchmarks for WRMG crane
  - Gross productivity (estimated)
    Waterside operations : 20 $^{mvs}/_{hr}$
    Landside operations : 25 $^{mvs}/_{hr}$
  - Units per quay crane : ≥ 1
- Required equipment units
  - Waterside operations by MHC
    Required equipment units : 60 $^{mvs}/_{hr}$ / 20 $^{mvs}/_{hr}$ = 3 WRMGs
    1 WRPC per MHC : 4 WRMGs
  - Waterside operations by STS:
    Required equipment units : 75 $^{mvs}/_{hr}$ / 20 $^{mvs}/_{hr}$ = 4 WRMGs
  - Landside operations
    Required equipment units : 75 $^{mvs}/_{hr}$ / 25 $^{mvs}/_{hr}$ = 3 WRMGs
  - Yard productivity (MHC / STS) : $4 \cdot 20 + 3 \cdot 25$ = 155 $^{mvs}/_{hr}$
- Annual throughput per equipment unit
  - 200,000 TEU / 7 = 29,000 $^{TEU}/_{unit}$

Industry benchmarks for the widespan RMGs are not available. Slower gantry travel of the larger crane and pre-stacking in the backreach of the quay cranes are limiting factors of the productivity of the WRMG.

Storage capacity
To limit the number of stacks away from the quay, while maintaining good accessibility of the stored containers, containers are stacked 12 wide and 4 high under the WRMGs, requiring 1480 TEU ground slots.

8.8.2 Concept layout

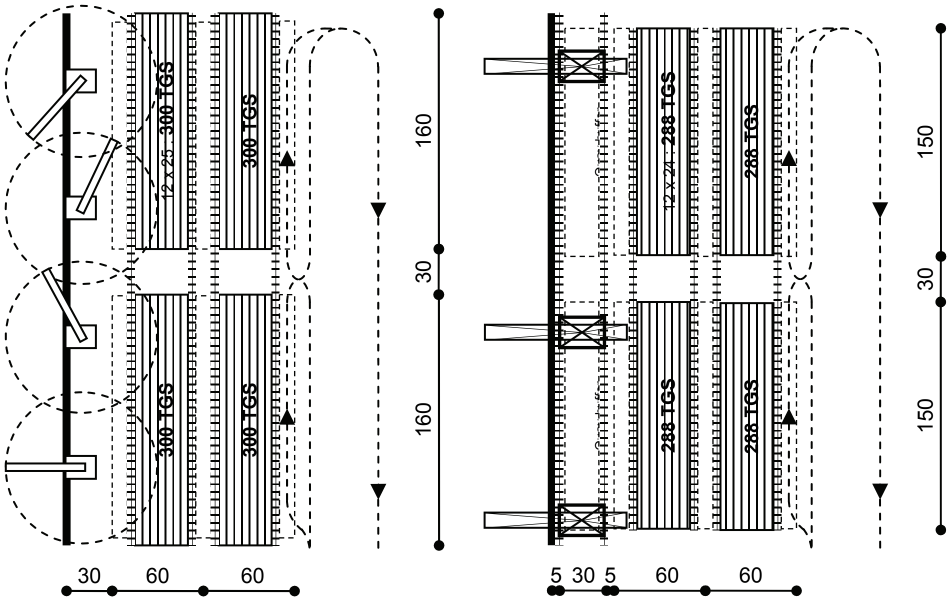


Figure 8.10 WRMG concept with MHC (left) and STS (right)

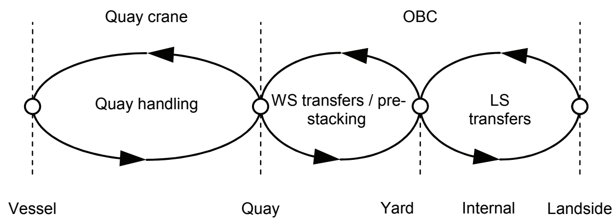


Figure 8.11 System cycles for WRMG concept

8.8.3 Evaluation

Service level

- Quay productivity
  No more than 2 to 3 mobile cranes can work simultaneously on one vessel limiting actual berth productivity of the alternative operating mobile harbour cranes. Crane productivity is also limited by cycle distances to stacks.
- Reliability of services
  Reliability of both quay cranes is high. Impact of broken down mobile crane is very low.
- Flexibility; last minute changes
  Low impact of last minute changes, late arrivals must pas through both and handover zones between quay and landside transfer point.

Operations

- Flexibility; break downs and equipment allocation
  4 cranes per 2 stacks appears to allow flexible allocation of handling capacity. In practice the configuration causes a high number of encounters with other equipment that is in the way.

- Presence of potential bottlenecks
  Internal transport through buffer zones may form capacity limiting bottleneck.
- Maintenance requirements
  Low maintenance requirements, RMGs require maintenance zone at outside and middle of stack.
- Travelling distances
  Relative short travelling distances for yard equipment, compensate slower crane travel.
- Equipment efficiency
  Low efficiency due to high re-handling requirement and considerable difference between system capacity and required capacity.
- Health and safety considerations
  For landside transfers road vehicles enter storage yard where cranes pass overhead. Actual transfers take place remote controlled.
- Environmental impact
  Energy consumption of large quay and yard gantry crane is high, but electrical propulsion clean and silent. Diesel powered mobile crane emits exhaust fumes and noise.

Costs

- Investment costs
  Considerable cost savings on quay construction and equipment for MHC. Large and heavy WRMG is expensive and has increased structural requirements on crane track.
- Operating costs
  Low maintenance costs but energy consumption of larger equipment may be high.
- Area requirements
  Low area requirements form compact terminal layout.
- Risks
  Considerable risks from high investments in equipment and limited saleability.

Implementation

- Phased start of operations
  Good opportunities of early start of operations with half quay and one stack
- Phased introduction of automation
  Good opportunities for evolutional introduction of automation.
- Flexibility of design
  Some flexibility may be gained by using taller crane, allowing to increase stacking heights in later stages.
- Expansion
  Limited suitability for expanding operation due to risk of bottlenecks in container transport in inland direction.

8.9 Selection of handling system

8.9.1 Multi criteria analysis

About MCA

To select the most favourable handling system the concepts discussed in this chapter are compared by means of a multi criteria analysis. The multi criteria analysis was developed for objective selection of alternative solutions on the basis of selected criteria.

Each solution is awarded a score for each of these criteria, which are given a weighing factor to discriminate between more and less important selection criteria.

Selection criteria and weighing factors
The multi criteria analysis is based on the criteria on which each concept was evaluated. The main criteria have been awarded a weighing factor and within each criterion the sub-criteria are awarded a relative weight.

For this case the level of services and the costs criteria have been awarded the highest weight.

Sensitivity analysis
The reliability of the MCA can be assessed by performing a sensitivity analysis. This is done by evaluating the impact on the results, by varying scores and weigh factors. A low sensitivity of the MCA is to these variations indicates a good degree of objectivity of the analysis.

8.9.2 Comparison

In the table below the score card for the multiple criteria analysis is given. Each alternative has been awarded a score per selection criterion. Below the total score of the alternative is calculated using its weighed score relative to the maximum score that could be awarded.

Table 8.5 Score table multi-criteria analysis

Criteria	W	Straddle carriers		RMG	OBC		WSG	
		MHC	STS	STS AGV	MHC	STS AGV	MHC	STS
Service level	**0.25**							
Productivity	0.6	o	++	++	-	++	o	o
Reliability	0.2	+	+	++	+	++	+	++
Flexibility	0.2	++	+	+	-	o	+	o
Operations	**0.25**							
Flexiblity	0.2	++	++	o	--	+	o	o
Bottlenecks	0.2	++	++	+	--	-	o	o
Maintenance	0.2	--	--	+	+	+	+	+
Distances	0.1	-	-	+	o	++	++	++
Efficiency	0.2	o	+	+	-	+	o	o
H&S	0.05	+	+	+	o	-	-	-
Environment	0.05	o	+	+	+	+	o	+
Costs	**0.40**							
Investment	0.4	+	o	-	--	--	o	-
Land use	0.1	--	--	+	+	++	++	++
Operating	0.3	-	-	+	+	+	o	o
Risk	0.2	++	+	o	--	--	o	--
Implementation	**0.10**							
Phased costr.	0.4	++	++	+	--	--	+	+
Phased auto.	0.1	-	-	+	++	+	+	+
Flexiblity	0.3	++	++	o	-	o	-	-
Expansion	0.2	+	+	+	--	-	--	--
Total %	**100%**	76%	77%	**81%**	49%	69%	71%	64%

Sensitivity analysis
In general, results of the MCA are most sensitive to changes for those criteria which have been awarded the highest weight and those for which awarded scores show large differences.

For the selection of handling system the key criteria are quay productivity, investment costs and operating costs. Large differences in the scores that have been awarded are found for the presence of potential bottlenecks, land use and the financial risks. The sensitivity analysis however shows no major changes in the results occur when changes are mad in the weigh factors.

8.9.3 Results

Based on the multi-criteria analysis and the sensitivity analysis the concept of automated rail mounted gantry cranes for yard handling and ship-to-shore gantry cranes is the most favourable concept for Risavika container terminal. The concepts involving automated straddle carriers form a very good alternative, with a preference of quay handling by means of ship-to-shore gantry cranes. Biggest differences between both concepts are high maintenance and area requirements of the Autostrad concept and the high investment costs of the handling equipment for the RMG concept.

8.10 Conclusion

Based on the conclusions of the multi-criteria analysis the concept of automated rail mounted gantry cranes and ship-to-shore gantry cranes is selected to be further developed for the Risavika container terminal.

Key issues in the selection are the high maintenance demands of the straddle carrier, requiring an on-site workshop and maintenance crew, going against the labour reducing motive for automation. Furthermore the automated straddle carrier has only just come on the market, offered by one manufacturer only and still in a stage of development. The automated rail mounted gantry on the other hand has been through a long development process and has been in operation for over a decade. At least four equipment manufacturers are offering automated gantry cranes on the market.

9 PRELIMINARY DESIGN

9.1 Functional design: Quay and Apron

9.1.1 Overview of areas

Below are listed the different areas parallel to the quay wall in which the quay and apron area can be divided. It is complemented with an overview of the functions and an indication of the required width of each sub area.

Area	Function	Dimensions
Quay wall	• Mooring • Vessel access	2 – 3 m
Service lane	• Quay traffic	5 – 10 m
Rail span	• Twistlock handling • Specials transfer (non-containerised cargo) • Traffic lanes for quay transfers	15 – 25 m
Crane back reach	• Hatch cover storage • Quay – yard transport (traffic lanes –|)	15 – 30 m
Apron area	• Quay – yard transport (traffic lanes //) • Access WS transfer points	15 – 25 m

Within these areas the following assets can be located:
- Lashers and mooring gang hut (vicinity)
- Crane rails + buffer stops
- Fence / barrier automated yard (access point for equipment recovery)
- Bunker station AGVs (near transit area between quay and stacks)
- Power supply quay cranes, cable slots and turnover pit
- Locking and tie-down points quay cranes

9.1.2 Handling equipment

Quay crane
Key asset of the quay and apron area is the quay cranes. Panamax sized ship to shore gantry cranes are well within the design requirements of the terminal. Many manufacturers offer cranes of this size on the market, with each their individual specifications and equipment. No specific model is selected, but below an overview is given for the crane requirements and some the performance data.

Table 9.1 Panamax STS gantry crane: performance data and characteristics

Rows on deck	Max 13
Outreach	41 m
Rail span	25 m
Backreach	15 m
Height of beam	30 m
Hoisting speed	75/150 m/min
Trolley travel speed	150 m/min
Gantry travel speed	50 m/min

Lifted load	65 MT
Crane mass	900 MT

AGV
For internal transport between yard and quay the AGV is selected. The automated shuttle carrier is not considered as this equipment is still in the prototyping phase. The Gottwald E-Drive Diesel-electric AGV is preferred for its low maintenance requirements, high level of reliability and its overall track record on existing terminals. Some of its performance data and characteristics are listed in the table below.

Table 9.2 Gottwald E-Drivel D/e AGV performance data and characteristics

Load types		20' / 40' / 45' 2 x 20'
Load capacity	single unit maximum	40 t 60 t
Length (depending on bumper)		14.8 m
Width		3 m
Mass (unloaded, in operation)		25 MT
Travelling speed	maximum cornering crab mode	6 $^{m}/_{s}$ 3 $^{m}/_{s}$ 1 $^{m}/_{s}$
Braking distance	controlled emergency	8 m < 6 m
Fuel tank		1,200 l
Fuel consumption		12 – 14.5 $^{l}/_{hr}$

9.1.3 Overview

Below the specific dimensions of the sub areas of the quay and apron area are listed.

Quay wall (Mooring, access, vehicle parking)	:	2.5 m
WS Rail + crane structure	:	1.0 m
Traffic lane (single lane, one-way)	:	4.0 m
Service area (twistlock handling , special)	:	4.5 m
Barrier	:	0.5 m
AGV traffic lanes (3 x 4.25 m, one per crane)	:	15 m
LS Rail + crane structure	:	1.0 m
Backreach area (hatch cover storage, AVGs)	:	20.0 m
AGV traffic lanes	:	15 m

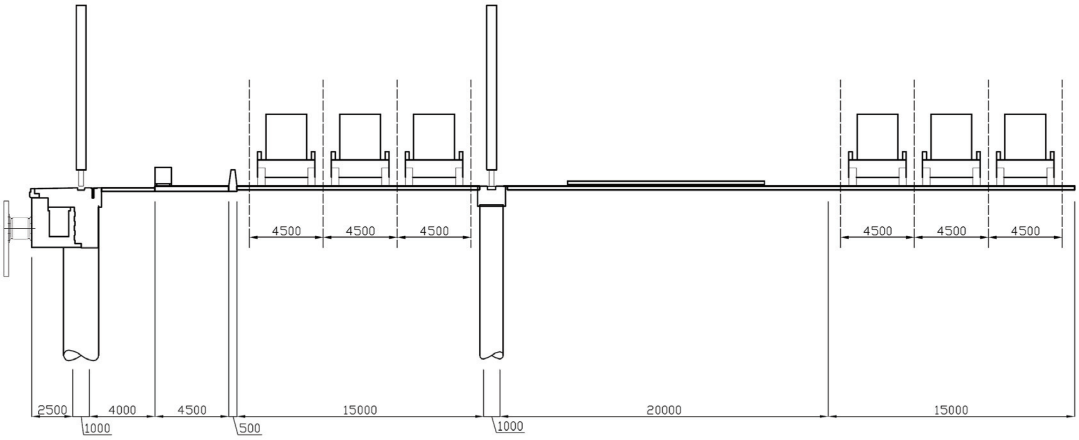


Figure 9.1 Cross-section of quay area

9.2 Functional design: Storage yard

9.2.1 Functional overview

Waterside transfers to and from AGVs
Container storage

- Standard + IMO containers : General stacks
- Refrigerated containers : Reefer gantries within general stacks
- Empty containers : Within general stacks and separate depot

Landside transfers to road transport

9.2.2 Storage capacity

Maximum storage capacity is calculated using the higher peaking factor proposed by Saanen (2004) of 1.5 instead of the 1.3 used earlier. The maximum storage demand is then build up as follows below:

		Average	Peak
Standard cargo	:	1,775	2,663 TEU
Dangerous cargo	:	148	222 TEU
Refrigerated cargo	:	99	148 TEU
Empty containers	:	1,849	2,774 TEU

The longer dwell times of empty containers (MT) causes empty containers to take up half of the storage demand of the terminal. Actual throughput of these containers is relatively low. To increase efficiency, many terminals store empty containers in special empty depots in a separate area on the terminal or even outside the terminal. For the case a maximum of 1,000 TEU MT shall be stored in the general stacks. Furthermore an operational strategy is set for period peak storage demand to reduce the number of empty containers in the general stacks to 500 TEU. By doing so the average stacking height of containers in the general stacks is reduced, improving accessibility and thus crane performance.

Storage capacity:

General stacks			
Std / IMO / MT	:	3,385 TEU	
Reefers	:	148 TEU	
MT depot	:	2,274 TEU	+
Total	:	5,807 TEU	

9.2.3 Handling equipment

Automated RMG
Automated RMGs can be designed to stack containers from 6 up to 12 wide and up to 6 high. By staking more containers side by side, crane travel is reduced, but the increased size of the crane means it is more expensive and imposes a large load on the subsoil.

For the case 4 high stacking, 10 units wide is selected similar to the cranes operated at the Altenwerder terminal in Hamburg.

Table 9.3 Stack dimensions

Stacking width	10 units
Stacking height	4 units (9'6")
Container spacing (//)	300 mm
Container spacing (--)	300 mm
TGS (lxb)	6,396 x 2,738 mm
Stack width (10 wide)	27,380 mm

Table 9.4 Automated RMG performance data and characteristics

Rail span (stack width + 3,000mm)	30,380 mm
Stack spacing / service lane	5,000 mm
Hoisting speed	30/60 m/min
Trolley travel speed	150 m/min
Gantry travel speed	240 m/min
Load capacity under spreader	500 kN
Crane mass	250 MT

9.2.4 General stacks

The general stacks, operated by automated RMGs are assigned to handle and store standard dry containers, dangerous cargo containers (IMO) and empty containers (MT). Reefer containers are plugged into power points on reefer gantries. These reefer gantries are located in a separate area within the general stacks.

Stack capacity

Standard / IMO / MT		: Peak demand / maximum peak filling ratio
		: 3,385 / 0.85 = 3,985 TEU slots
Reefers		: Peak demand (in boxes) / maximum peak filling ratio
	Boxes	: 148 / 1.4 = 106 reefer points

Max filling : 80 %
Reefer slots : 108 / 0.8 = 134(54 x 40ft, 80 x 20 ft)

Alternative stack arrangement

- 6 short stacks with 1 RMG per stack
- 3 full length stacks with 2 RMGs per stack

Reefer storage
107 reefer points with a 40ft ground slot each → 3 Gantries required:
8 wide: 192 points = 56%

Optional arrangements stack:

- 3 general stacks : 1 reefer gantry per stack (8 wide)
  : 3 x 64 = 192 reefer points
- 6 general stacks : 3 stacks with 1 gantry
  : 1 stack with 3 gantries

Stack layout

3 stacks, each 1 reefer gantry:

Stack width		10 wide
Rows		34
TEU slots		4,080
Reefer points		192
Length	standard	217.6 m
	reefer	28.0 m
	total	245.6 m
Width	track	30.4 m
	service lane	5.0 m
	total	35.4 m
avg. height	standard	2.9
	reefer	1.5

6 stacks, 3 x 1 gantry:

Stack width		10 wide
Rows		17
TEU slots		4,080
Reefer points		192
Length	standard	108.8 m
	reefer	27.8 m
	total	136.6 m
Width	track	30.4 m
	service lane	5.0 m
	total	35.4 m
avg. height	standard	2.9
	reefer	1.5

Loading bays (LS / WS)

Transfer points are located at the end of each stack in the shape of loading bays. At the quay side of the terminal six loading bays are assigned to allow for 6 AGV to wait for their turn to be (un-)loaded. At the landside only 4 loading bays are assigned to allow plenty of manoeuvring space for lorries backing up into the stacks.

To allow for maintenance works on a crane and have a second crane continuing to serve the transfer points, the loading bays have a length of 25 meters.

In the vicinity of the landside transfer points on the general stacks an operator cabin is required for a remote operator to handle the human controlled loading and unloading process of manned vehicles on all stacks.

9.2.5 Empty depot

In the Empty depot containers are separated, sorted and stored in block stacks. Density of these block stacks is high and accessibility of containers is low. Because empty containers are sorted by size and owner, this is no serious problem. As a result, in practice sometimes, containers at the bottom of the stack may end up never leaving the terminal.

Empty (MT depot)	: (2,774 – 500) / 0.9	= 2,530 TEU slots
Block stacks	: 2 stacks 8 wide, 8 high	
	: (height outer rows dependant on wind conditions)	
	: 52 containers per block	
	: Minimal 20 bays	

Traffic land between stacks at least 15.0 m

Area	width	: 15.0 m + 2 x 21.9 m	= 58.8 m
	length	: 20 x 6.4 m	= 128 m
	total	: 58.8 m x 128 m	= 7,526.4 m^2

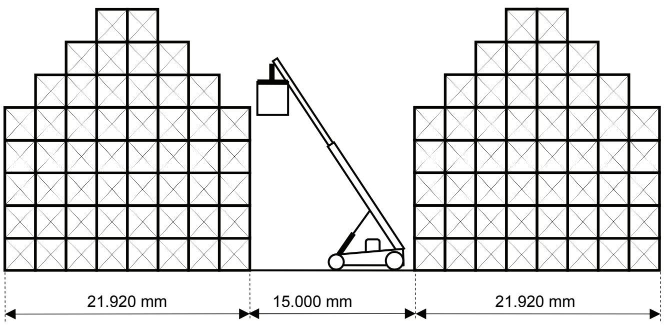


Figure 9.2 Empty block stacks

For handling empty containers one or more forklift trucks or straddle carriers are necessary. Specialised forklift trucks for handling empty containers can stack containers up to 8 units high. The maximum stacking height depends on local wind conditions, as empty containers have a relative low weight and, due to their shape, are relatively easy blown away. A stacking height of 6 units high is common.

9.2.6 Container freight station

Optionally a container terminal can offer less-than car load (LCL) handling. In a container freight station general cargo from different origin with the same port destination is loaded (“stuffed”) into a container to make a full container load FCL. Imported containers with cargo for different destinations are unloaded (“stripped”).

CFS: stripping / stuffing area
Covered storage area for cargo

Often the CFS is owned and operated by carriers and not by the terminal operator. Therefore is not part of the actual terminal, but located in direct vicinity outside the terminal. For these reasons a CFS is not considered for the purposes of the case study

9.3 Container handling system

The handling system of container terminal is the integrated chain of equipment handling containers at the quay, in the yard and the horizontal transport in between. To determine the required number of equipment units and integration of the separate operation, quay handling, internal transport and yard handling is regarded as in integrated system build up from separate modules.

For the case study the selected modules are Panamax-sized STS gantry cranes, AGVs and automated RMGs. In this paragraph the required number of equipment units and the arrangement of the yard operations are determined.

For detailed calculations of equipment performance is referred to appendix II.

9.3.1 Equipment performance

STS gantry crane

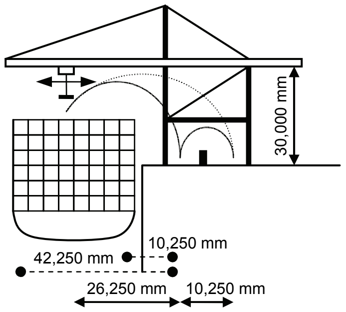


Figure 9.3 Cycle and distances STS gantry crane

Operation	Possible delay
Connect to container	lashing
	hatch cover handling
	sway
hoisting and transfer to quay	waiting for other crane
twistlock handling	sway
	no handlers (unloading)
	no twistlocks (loading
handover	sway
	waiting for transportation system
empty travel next container	waiting for other crane
	crane repositioning (bay changes)

Cycle times
For the STS gantry crane the minimal operational cycle times, without operational delays such as waiting times and interaction with other terminal traffic, are calculated as the sum of the of the minimal times necessary for each step in the cycle. The time necessary for each step of the cycle is assumed to have a normal distribution, with a mean value and a standard deviation. The sum of these steps is the operational cycle time and is assumed to be Erlang-k distributed. The results of these calculations are given below.

$T = N(\mu,\sigma)$
$T_{QC}(\text{unloading}) = N(97.8\ s,\ 9.4\ s)$
$T_{QC}(\text{loading}) = N(118.8\ s,\ 10.7\ s)$
$T_{QC}(\text{average}) = N(108.3\ s,\ 14.2\ s)$

The average cycle time without delays can be converted into the operational productivity per hour:

$P_{QC}(\text{ops}) = 3600 / \mu = 33.2\ ^{mvs}/_{hr}$

For 2 cranes per berth this gives a berth productivity of:

$P_{berth} = N_{QC} \cdot P_{QC} = 2 \cdot 33.2 = 66.4\ ^{mvs}/_{hr}$

AGV

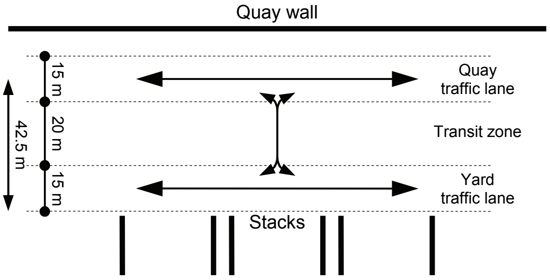


Figure 9.4 Cycle and distances AGV

Operation (*unloading at quay*)	Possible delay
Cont. loaded onto AGV by quay crane	waiting for quay crane
Travel to stack	congestion
	queuing in front of stack
Cont. unloaded from AGV by RMG	waiting for yard crane
Travel to quay (empty)	congestion
	queuing on quay

Operation (*loading at quay*)	Possible delay
Cont. loaded onto AGV by RMG	waiting for yard crane
Travel to quay	congestion
	queuing in quay
Cont. unloaded from AGV by RMG	waiting for quay crane
Travel to stack (empty)	congestion
	queuing in front of stack

Cycle times

$T = N(\mu,\sigma)$

$T_{AGV}(\text{unloading}) = T_{AGV}(\text{loading})$

$T_{AGV}(\text{average}) = N(262.8\text{ s}, 12.9\text{ s})$

Converted into the operational productivity per hour this gives for a single unit:

$P_{AGV}(\text{ops}) = 3600 / \mu$

$= 13.7\ ^{\text{cycles}}/_{\text{hr}}$

RMG

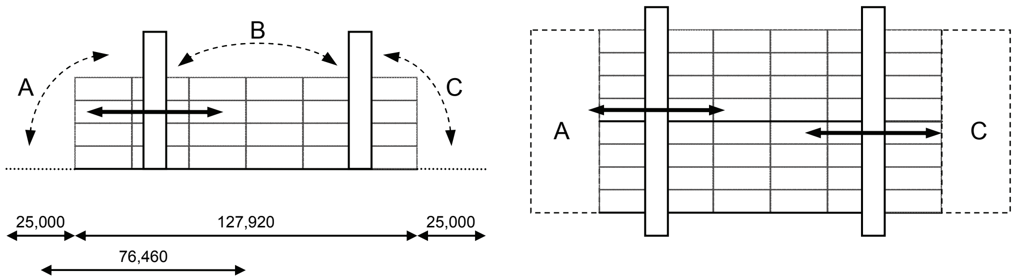


Figure 9.5 Cycle and distances RMG

Operation (unloading at quay)	Possible delay
Pick up container from horizontal transport	Waiting for transport unit
Travel to empty container slot	Waiting for other crane
Place container in stack	Sway
Empty travel to transfer point	

Operation (loading at quay)	Possible delay
Travel to assigned ground slot	Waiting for other crane
Pick-up container	Access handling
	Sway
Travel to transfer point	
Handover to horizontal transport / truck	Waiting for transport unit / truck
	Transfer point full (no space for container)

Cycle times
T_{RMG}(unloading) = N(117.2 s, 11.0 s)
T_{RMG}(loading) = N(127.2 s, 12.7 s)
T_{RMG}(average) = N(122.2 s, 16.8 s)

Converted into the operational productivity per hour this gives:
P_{RMG}(ops) = 3600 / μ
= 29.5 $^{mvs}/_{hr}$

9.3.2 Queuing theory

The queuing theory is an excellent tool for initial assessment of the terminal handling system and to get an indication of its performance and equipment productivity. The queuing theory was developed by Kendall to determine waiting times in a system in which customers require a single service.

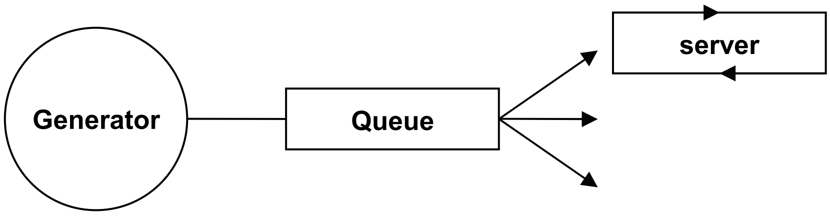


Figure 9.6 Visualisation of queuing theory

In ports the queuing theory can be used to determine waiting times for customers on either side of the terminal. With the queuing theory an average waiting time can be calculated by comparing the average rates and distributions of the generated service calls and the service time. Different algorithms are available to determine average waiting times in units of the service time. The applicable algorithm depends on the type of distribution of the arrival rate of service calls and the service rate.

The terminals handling system can also be modelled as a number of queuing systems of generating and serving different parts of the handling process. The queuing theory is used to get an indication of the required equipment number and waiting times for equipment during interactions with other equipment.

The arrival and service rates of queuing objects on a container terminal depend on equipment productivity. This is the inverse of the cycle times, which is assumed to be Erlang-k distributed. The following algorithm is an interpolation between three different distributions to calculate waiting times for Erlang-k distributed multiple server queuing systems (Groenveld, 2002):

$$W_n = \left(v_a, v_s, u\right) = \left(1 - v_a\right) \cdot v_s \cdot W_n\left(0,1,u\right) + v_a \cdot \left(1 - v_s\right) \cdot W_n\left(1,0,u\right) + v_a \cdot v_s \cdot W_n\left(1,1,u\right) \quad (9.1)$$

n : number of servers / number of generators
v_a : 1/k = variability of E_k distribution of inter arrival times
v_s : 1/m = variability of E_m distribution of service times
u : server utilisation

W(0,1,u) : Waiting time in D/M/n system (derived from reference table)
W(1,0,u) : Waiting time in M/D/n system (derived from reference table)
W(1,1,u) : Waiting time in M/M/n system (derived from reference table)

The variability v_a and v_s and the server utilisation u are calculated as follows:

$$v_a = \frac{1}{k} = \left(\frac{\sigma_a}{\mu_a}\right)^2 \quad (9.2)$$

$$v_s = \frac{1}{m} = \left(\frac{\sigma_s}{\mu_s}\right)^2 \quad (9.3)$$

$$u = \frac{\mu_s}{\mu_a \cdot n} \quad (9.4)$$

μ_a / μ_s : mean value inter arrival time / service time [μ] = s
σ_a / σ_s : standard deviation inter arrival time / service time [σ] = s

Application of queuing theory in system design
The system cycles diagram in section 8.5.2 (Figure 8.5) can be used to identify the different queuing systems that are present on the terminal.

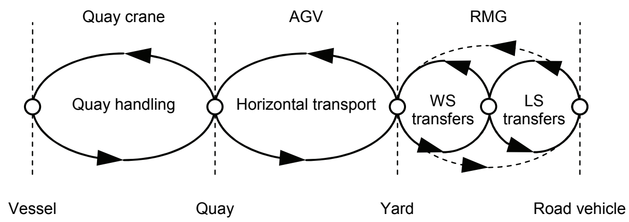


Figure 9.7 System cycles diagram

The diagram above can be separated into a waterside system and a landside system. In both systems the yard cranes are considered servers. At the landside, service calls are generated by the gate. From there road vehicles are directed to the yard, either to collect, or to deliver containers. At the waterside the quay cranes generate a flow of AGVs that are either delivering a container to the stack, or have to be loaded with a container retrieved from the stack.

Table 9.5 Queuing systems on terminal

Subsystem	Generator	Generated objects in queue	Server
Waterside	Quay crane	AGV to be loaded / unloaded in yard	RMG
Land side	Gate	Lorries delivering / collecting boxes	RMG

For the systems design of a terminal, the queuing theory can be used to determine the required numbers of RMGs and AGVs. Aim is to optimising quay productivity by minimising waiting times for quay cranes. The number of AGVs required is influenced by the number of RMGs. The entire process is iterative, requiring several iterations before a selection is made.

Landside operations have a negative influence on the waterside service capacity. To prevent landside operations from interfering with waterside operations, the minimum required number of RMGs for landside services is determined as well.

System 1: Required number of RMGs for waterside operations
Generator : Quay cranes (STS)
Server : Yard cranes (RMG)
Queue : Quay crane waiting to load next AGV

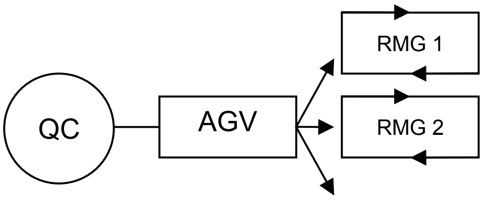


Figure 9.8 Queuing model for waterside operations

The initial estimate of the required number of RMGs is calculated on the basis of a constant generation of AGVs on the quay at maximum capacity. If sufficient AGVs are in operation, the arrival rate of AGVs in the yard is equal to the quay productivity. A maximum waiting time of 10% of the average RMG's crane cycle is used as a limit.

T_{QC}(average) = N(108.3 s, 14.2 s)
N_{QC} = 3
T_{AGV}(average) = N(262.8 s, 12.9 s)
T_{RMG}(average) = N(122.2 s, 16.8 s)
N_{RMG} = 4

Input parameters:

$$\mu_a = \frac{T_{QC}\left(average\right)}{N_{QC}} = \frac{108.3}{3} = 36.1s$$

$$\sigma_a = \sqrt{\sigma_{QC}^{\ 2} + \sigma_{AGV}^{\ 2}} = \sqrt{14.2^2 + 12.9^2} = 19.2s$$

$$\mu_s = \mu_{RMG} = 122.2s$$

$$\sigma_s = \sigma_{RMG} = 16.8s$$

Utilisation (u):

$$u = \frac{\mu_s}{\mu_a \cdot n} = \frac{122.2}{36.1 \cdot 4} = 0.846$$

E_k/E_m/m system:

$$W_n = \left(v_a, v_s, u\right) = \left(1 - v_a\right) \cdot v_s \cdot W_n\left(0,1,u\right) + v_a \cdot \left(1 - v_s\right) \cdot W_n\left(1,0,u\right) + v_a \cdot v_s \cdot W_n\left(1,1,u\right)$$

$$v_s = \frac{1}{m} = \left(\frac{\sigma_a}{\mu_a}\right)^2 = \left(\frac{19.2}{36.1}\right)^2 \quad = 0.282 \qquad m = 3.5$$

$$v_s = \frac{1}{k} = \left(\frac{\sigma_s}{\mu_s}\right)^2 = \left(\frac{16.8}{122.2}\right)^2 \quad = 0.0189 \qquad k = 52.9$$

Using the values from the waiting time tables in appendix III, a linear interpolation is made for between the Ek/Em/n system with u = 0.8 and u = 0.9.

W(0,1,0.8)	= 0.2725	W(0,1,0.9)	= 0.8612
W(1,0,0.8)	= 0.3860	W(1,0,0.9)	= 0.9340
W(1,1,0.8)	= 0.7455	W(1,1,0.9)	= 1.9693

$$W_n = (v_a, v_s, 0.846) \quad = 0.192 \qquad (= 19.2\%)$$

$$T_{AGV}\left(waitng\right) = 0.1728 \cdot 122.2\, s \quad = 23.4\, s$$

The average waiting time per AGV arriving in the yard is rather high, but not unacceptable. An iteration step for 5 RMGs is made. The calculations of this step are given in appendix IV. The results of this iteration are given below:

$$u \quad = 0.677$$

$$W_n \quad = 0.0351 \qquad (= 5\%)$$

$$T_{AGV}(waiting) \quad = 0.0351 \cdot 122.2 = 4.3s$$

System 2: Required number of RMGs for landside operations
Generator : Gate
Server : Yard cranes (RMG)
Queue : Road vehicles waiting to collect / deliver boxes

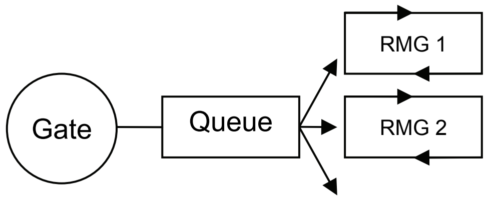


Figure 9.9 Queuing model for landside operations

72 hours per week, the gate of the terminal is open. 80% of the annual throughput (transhipment is 20%) is processed through the gate. For every service call generated by the gate, the probability of waterside operations taking place at the time is equal to the 41% quay utilisation as determined in section 8.2. Additional yard cranes may be required to prevent long delays for road transport. Distribution is of the inter arrival time of trucks at the gate is determined for number of vehicles that are served on average and during peaks.

$$Average \quad : \frac{0.8 \cdot 200,000 \, {}^{TEU}\!/_{yr}}{1.4 \, {}^{TEU}\!/_{move} \cdot 52 \, {}^{wk}\!/_{yr} \cdot 72 \, {}^{hr}\!/_{wk}} \qquad = 30.5\, h^{-1}$$

$$Peak \quad : \frac{30.5\, h^{-1}}{0.4} \qquad = 76.3\, h^{-1}$$

$$\mu_a = \frac{1}{30.5} \qquad = 117.9\, s$$

$$\sigma_a = \sqrt{2\left(117.9 - \frac{1}{76.3}\right)} \qquad = 35.4\, s$$

$$\mu_s = \mu_{RMG} \qquad = 122.2\, s$$

$$\sigma_s = \sigma_{RMG} \qquad = 16.8\, s$$

In appendix IV the calculations for this system are given. The results of these are given below:

$$n = 1$$

$$u = \frac{122.2\, s}{117.9\, s} \geq 1 \left(unsufficient\ capacity\right)$$

$$n \qquad = 2$$

$$u \qquad = 0.518$$

$$W_n \qquad = 0.0195 \qquad (= 2\%)$$

$$T_{LS}(waiting) \quad = 0.0195 \cdot 122.2 = 2.4\, s$$

Combining the results of the waterside and landside estimates, it is found that, during simultaneous operations on either side, 4 to 5 RMGs are required for waterside operations and an additional 2 RMGs for landside operations.

For a total of 7 RMGs, the average waiting times of both AGVs and road vehicle are very low. Only during 41% of landside operations, the terminal is also operating on the waterside. During these periods, an increase in waiting times at the landside is accepted. The total number of RMGs in the yard is then set a 6 cranes.

Required number of AGVs
In section 4.3.2 it was stated that the horizontal transport capacity must equal the quay handling capacity during peaks in productivity. During these periods, an average waiting time of 10% of the total cycle time is accepted.

The average waiting time in the yard as calculated earlier is added to its estimated cycle time. The number of AGVs is calculated for both 4 and 5 RMGs for waterside operations

4 RMGs:

$$N_{AGV} = \frac{\overline{T}_{AGV}(net)}{\overline{T}_{QC}(peak)}$$

$$\overline{T}_{AGV}(net) = 262.8s + 23.4s = 286.2s$$

$$\overline{T}_{QC}(peak) = \frac{T_{QC}(min)}{0.9} = \frac{54s}{0.9} = 60s$$

$$\Leftrightarrow N_{AGV} = \frac{286.2}{60} = 4.77$$

5 RMGs:

$$\overline{T}_{AGV}(net) = 262.8s + 4.3s = 267.1s$$

$$N_{AGV} = \frac{267.1}{60} = 4.45$$

The average waiting time of AGVs in the yard is used in the calculations. During peaks in quay production, it can be assumed this waiting time is actually longer. Because this calculation is merely an estimate, this iteration is omitted and it is assumed that yard productivity is also at its peak.

Results of equipment requirements
The results of the estimate of the equipment requirements are a total of 6 RMGs and 15 AGVs. A comparison with the two operational AGV/RMG terminals in Hamburg and Rotterdam indicates the calculated number of 15 AGVs and 6 RMG is of the correct order. Industry benchmarks for PTT/RTG terminals suggest the same.

9.4 Simulation study

The layout of the terminal and the way the different terminal operations are linked has a great influence on the handling capacity of the terminal systems. The queuing theory and other methods that have been used in the systems design of the case study are all largely based on assumptions and simplifications. The effect of the terminal layout on equipment performance and the interaction with other terminal operations are only partly taken into account.

By actually simulating the terminal's operations and processes within a proposed layout, the terminals performance can be assessed to confirm expected performance and possibly identify faulty design elements limiting the terminals actual performance.

Posport CT
Within Royal Haskoning software has been developed under the name of Posport CT to simulate container terminal operations. Posport software package allows its user to build a model of a proposed terminal design and assess its operations. The modelling consists of modules, like for example for quay operations, gate operations and yard operations.

A main problem with the use of Posport for this study is however the “black-box” type of simulation. For specific simulations there are limitations on its use and the modules have to be adjusted to reflect the handling processes and the possible design parameters that can be given. This will in many cases require extensive modelling and will therefore not be feasible within the scope of this study. Therefore assumptions and simplifications have to be made which are outlined in section 9.5.2.

In general however, Posport is very useful for identifying potential bottlenecks in the terminal design and providing a good indication of the potential performance of a terminal design.

Aim of the study
A simulation study of the proposed terminal layout up to this point is carried out to confirm system design calculations and selections made on the basis of these calculations. The simulation will be carried out on a high level with some simplifications in order to arrive at these conclusions within the short time frame. The results of the study shall be compared in a qualitative way, rather than quantitative.

9.4.1 Model input – output

Input

- Berthing schedule
    - Vessel arrival schedule
    - Call mixture (DRY / IMO / RF / MT)
    - Transhipment ratio
- Container storage
    - Stacking strategy
    - Container dwell
- Equipment properties
    - Dimensions
    - Operating speeds
- Gate operations
    - Opening hours
    - In / out delays
    - Arrival pattern

Output

- Performance
    - Berth performance per vessel
    - Equipment productivity (average / peak)
    - Stack occupancy
    - Queuing times gate operations

Limitations

- No idle times yard equipment (AGV / RMG)
  Al periods during which AGVs and RMGs are not operating are recorded as waiting
- No housekeeping
- No empty depot

9.4.2 Terminal simulation

Simulation runs have been carried out for both the concept with 6 short stacks and the concept with three long stacks. A period of 2 weeks was simulated.

A scheduled arrival pattern is assumed with 2 feeders calling at the terminal each work day and twice a week a mainline vessel calling at the terminal.

Table 9.6 Overview vessel arrival pattern and call sizes

	LOA	callsize		discharge		load		day of arrival							total	
	m	*TEU*	*Boxes*	*TEU*	*Boxes*	*TEU*	*Boxes*	mo	tu	we	th	fr	sa	su	*TEU*	*Boxes*
Feeder A	60	140	100	70	50	70	50	x	x	x	x	x			700	500
Feeder B	120	280	200	140	100	140	100	x	x	x	x	x			1400	1000
Mainline	220	840	600	420	300	420	300				x			x	1680	1200
Total															3780	2700

The mixture of import-export and transhipment containers is given in the table below. The assumption is made that transhipment only takes place from mainline to feeder vessel.

Table 9.7 Break-up of destinations (I/E or transhipment)

	import / export		transhipment		total
	%	TEU	%	TEU	
Feeder A	82%	574	18%	126	700
Feeder B	82%	1148	18%	252	1400
Mainline	77.5%	1302	22.5%	378	1680
Total	80%		20%		3780

For the purpose of modelling some simplifications have been made:

- All containers standard dry containers
  - The transition between automated AGV yard and manually operated (empty handler) MT depot can not easily be incorporated into the model.
  - The software does not allow assigning separate reefer slots within general stacks in combination with end-loading. In the model reefers will be stacked in the general full stacks, while in practise these are stacked separately.
- Reduced dwell times of containers
  - No housekeeping algorithms are included. By reducing the dwell time of containers, the average stack height is reduced to emulate improved accessibility of containers from housekeeping.
- Tractor-trailer combinations instead of AGVs

An AGV module is under development. At the time of simulation conventional tractor-trailer combinations are used with the specifications of AGVs.

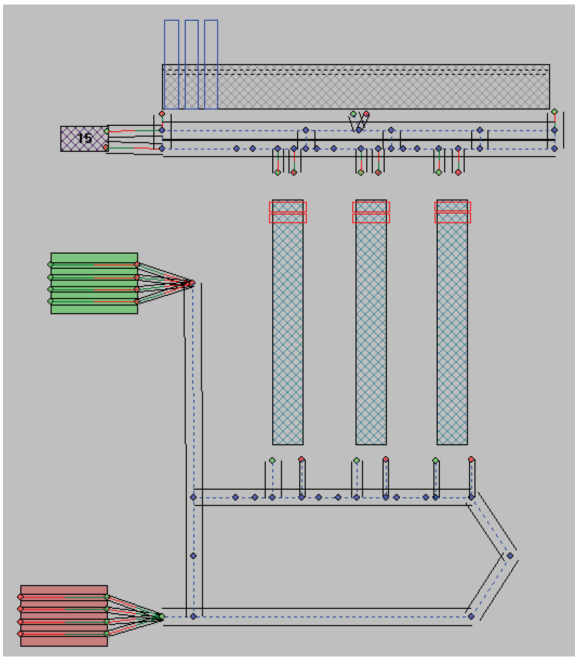


Figure 9.10 Terminal layout in Posport of 3 stacks concept

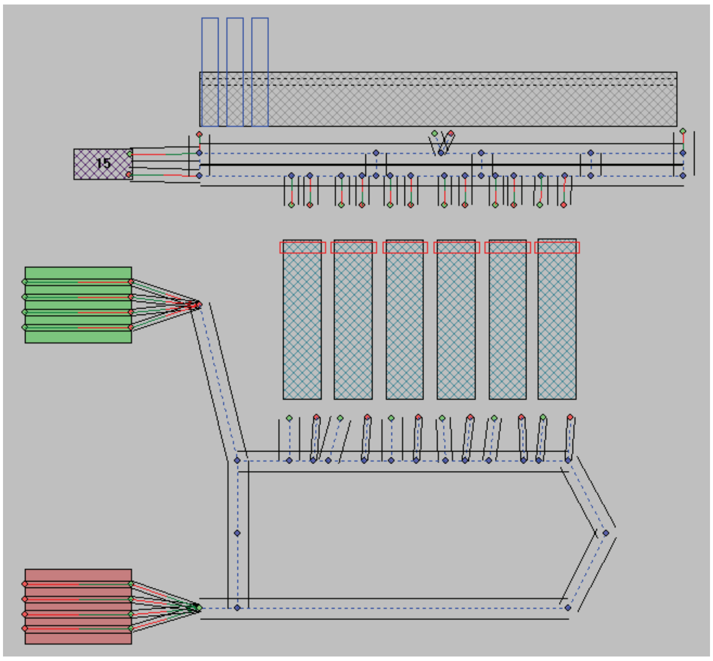


Figure 9.11 Terminal layout in Posport of 6 stacks concept

9.4.3 Simulation runs

Running the simulation for both terminal designs has provided the following results.

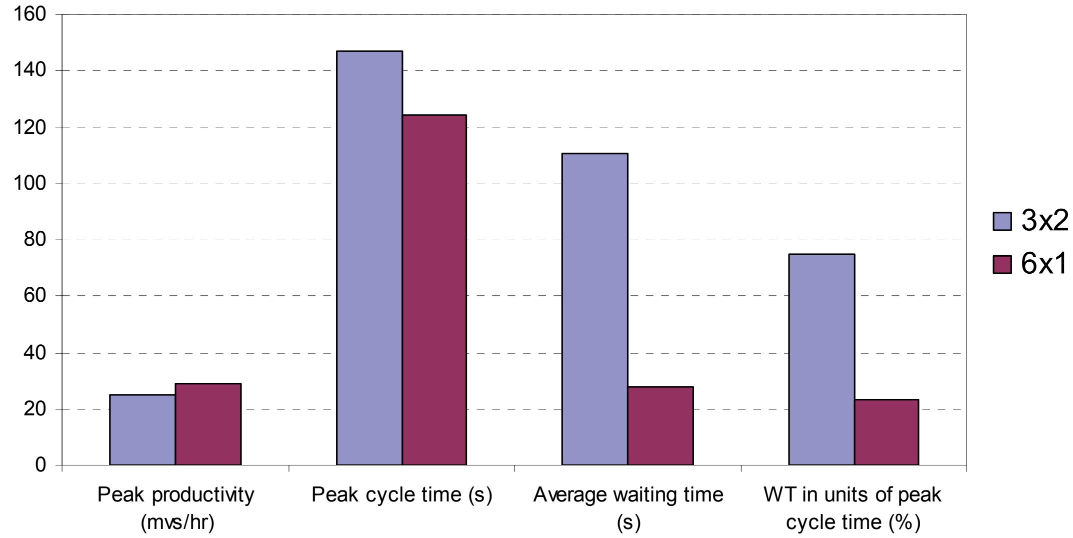


Figure 9.12 Quay crane performance indicators

Table 9.8 Overview performance indicators from simulation

	unit	2 x 3	1 x 6
Berth :			
Discharged	TEU	2700	2700
Loaded	TEU	2616	2634
Total handled	TEU	5316	5334
Total time operations	hh:mm:ss	183:38:00	124:34:00
Average crane productivity	mvs/ hr	17.2	24.3
STS crane			
Peak productivity	mvs/ hr	24.7	29
Peak cycle time	s	147	124.2
Average waiting time	s	110.7	28
WT in units of peak cycle time	%	75	23
RMG crane			
Peak productivity	mvs/hr	29.2	29.5
Peak cycle time	s	123.6	122.6
AGV			
Average cycle distance	m	680.1	645.3
Gate			
Peak queue	-	12	8
Average time in terminal	min	18.8	13.0
Storage yard			
Peak occupancy	%	61%	56%
Average stack height	TEU	2.2	2

The overview of the simulation output shows the effect the systems performance of a different layout of the yard. The impact of number of stacks on quay productivity is large. A similar but less significant impact can be seen at the landside services.

Peak performance of the yard cranes in either configuration is in the same range as was determined by analysis of the crane cycles.

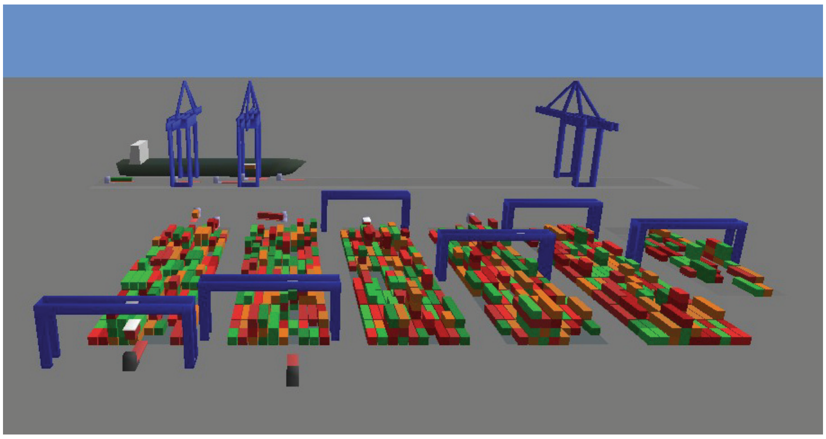


Figure 9.13 Graphic output Posport

Effect of IMV

To reduce waiting times for quay cranes, additional AGVs may be deployed. However, the added benefit of additional units reduces as more AGVs are assigned per quay crane.

To evaluate this reduction, the simulation is ran several times with varying numbers of AGVs assigned to each quay crane.

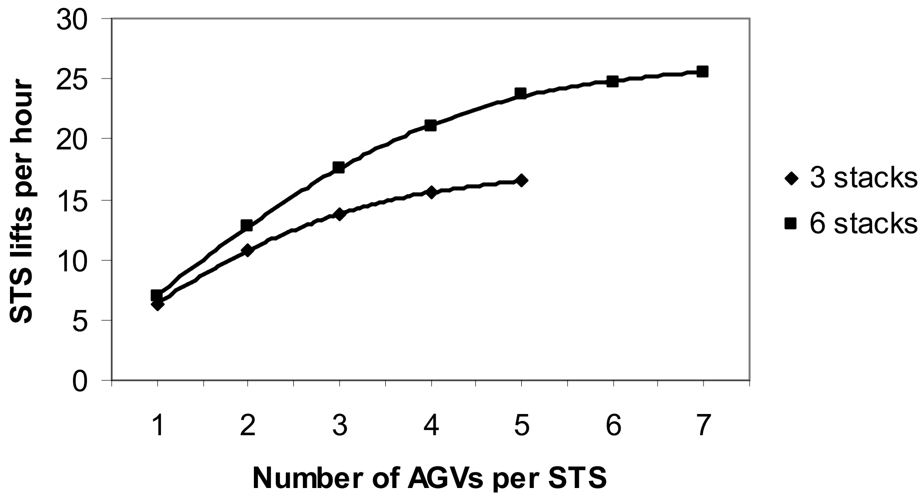


Figure 9.14 Crane performance development

From the graph above it becomes visible that the added benefit of additional AGVs per crane reduces less quickly for the system operating 6 short stacks. The simulation running only a single AGV per quay crane gives an indication of the productivity of a single AGV, indicating a minimum cycle time per AGV larger than the determined 240 s.

9.4.4 Results from simulation study

Optimisation

The results of the systems calculations in section 9.4 are compared with a number of simulation runs o assess the required equipment units as determined by means of the queuing theory, the simulation is ran with different combinations of equipment numbers. The table below is an overview of the output of these simulation runs.Are the The code for each run indicated the number of equipment units (STS / AGV / RMG).

Table 9.9 Results of simulation runs for different equipment numbers

	a	b	c	d	e	f
STS / AGV / RMG	3 / 15 / 6	3 / 15 / 5	2 / 12 / 6	2 / 10 / 6	2 / 12 / 5	2 / 10 / 5
Berth :						
Discharged	2700	2700	2700	2700	2700	2700
Loaded	2613	2648	2609	2617	2630	2611
Total handled	5313	5348	5309	5317	5330	5311
Total time operations	126:38:00	135:45:00	125:18:00	131:53:00	133:36:00	138:41:00
Quay productivity	42,0	39,4	42,4	40,3	39,9	38,3
STS crane						
Average lifts / hour	25,2	23,0	26,2	25,1	24,5	23,8
Average cycle time	02:22,8	02:36,3	02:17,2	02:23,3	02:27,0	02:31,1
Peak lifts / hour	30,3	29,0	30,5	30,5	30,5	30,5
Peak cycle time	01:58,7	02:04,2	01:58,1	01:58,1	01:58,1	01:58,1
Average waiting time	00:28,7	00:39,3	00:18,4	00:25,1	00:28,9	00:32,5
in % of peak cycle time	20%	25%	13%	18%	20%	22%
RMG crane						
Peak lifts / hour	29,8	33,2	28,8	30,7	32,4	31,6
Peak cycle time	02:02,6	01:48,8	02:07,8	01:57,9	01:51,2	01:54,4
AGV						
Average travelled distance	603,7	582,4	592,3	576,5	578,0	566,7
Gate						
Peak queue	9	10	11	13	9	11
Average time in terminal	0:12:57	0:13:29	0:12:54	0:13:01	0:13:29	0:13:51
Storage yard						
Peak occupancy	55%	56%	56%	56%	53%	54%
Average stack height	1,92	1,98	1,97	1,97	1,92	1,96

Variations in equipment numbers in each step of the terminal handling process have the following effect on quay productivity:

- Quay cranes: The very limited effect of reducing the number of quay cranes can be noticed when comparing run A with runs C and D and comparing run B with runs D and F.

- Yard cranes: The impact of varying the number of yard cranes is much bigger. This can be seen when comparing runs A and B, C and E and runs D and F.
- AGVs: Quay productivity increases considerable by increasing the number of AGVs per quay crane. This effect is not as large that of variations in yard cranes. The effect is visible when comparing runs C and D and runs E and F.

Based on the results of the simulation it might be concluded that the configuration C (2/12/6) would be the optimal system. The output of the simulation runs clearly indicates that higher quay productivity can be expected from that configuration.

However, these results are considerably influenced by the way the vessel arrival schedule was modelled as input of the simulation software. The vessel arrival schedule that was put in the model, does not correspond to the previously used E_2-distribution. As a result, during the simulation runs, no two vessels are ever served at the same time.

Furthermore, the results can be explained the minimal crane spacing used by the software. As a result, even during operations on mainline vessels, not all three quay crane are used for the complete service time. This leads to underutilisation of the quay crane. Whether this is in correspondence with reality would require more detailed information on vessel calling pattern and a non-deterministic vessel arrival rate.

Conclusion
As indicated by the initial calculations, performance of the system with three longer stacks fails to meet service requirements on the berth productivity.

The additional stacks improve waterside productivity as more cranes can be assigned to handle waterside transfers, improving overall terminal performance. During peaks in service demand on the landside of the terminal, waterside handling capacity decreases. By prioritising waterside operations and / or spreading landside arrivals by means of a Vehicle Booking System (VBS), the drop in productivity may be reduced.

Furthermore it is recommended that operations will with only 2 STS gantry cranes. The simulation study has brought to light that with two cranes berth productivity is such, that a third crane may not be needed if 12 AGVs are assigned per crane.

9.5 Functional design: Landside areas and buildings

- Gate area
- Workshop and stores
- Terminal offices

9.5.1 Gate area

Pre-gate area
Before road vehicle collecting of delivering containers can actually enter the terminal area a number of administrative procedures is completed. Upon arrival and submitting all necessary documentation a work order is created and a driver is provided with a swipe card and a time slot during which he can enter the terminal area to perform his

collection or delivery. Depending on the time of day, week, or even year, waiting times can run up as high as an hour. A vehicle booking system to spread peaks may in such cases be advisable.

Main road access
For indicative purposes the guidelines of the British Freight Transport Association are used to determine basic dimensions of road surfaces, such as lane widths and corner radii.

Design vehicle : Articulated vehicle (max 40 tonne, 2.55 m wide, 16.5 m overall length)
lane width : 3.5 m (<30 m before corner: 3.7 m)
Swept path : 5.4 m

Parking area for at least 20 road going lorries:
One-way parking system with stalls at 45 degrees
Aisle width : 11 m
Length of stalls : 19 m

Gate reception building:
Reception area for handing out swipe cards to enter terminal area
Customs office
Waiting room lorry drivers

Reception	:	4 x 5 m	=	24 m^2	
Customs office	:	3 x 4 m	=	16 m^2	
Waiting area	:	5 x 4 m	=	20 m^2	
Facilities	:	3 x 4 m	=	20 m^2	+
Total				80 m^2	

Terminal gate
Before accessing or exiting the terminal area each vehicle is weighed and photographed. Containers are photographed to document the state in which they were arrived or left the terminal. To improve the level of customs control a terminal may be equipped with one or more x-ray scanner to scan all containers or at random intervals.

These gate processes can completely automated with the use of pre-gate registration as proposed. The whole procedure can then be completed as little as 90 seconds. Accounting for drive up and waiting times a capacity of 30 vehicle per hour can be assumed.
Given the peak rate of landside service calls of 70 vehicles per hour, 3 gates are required for both access and exit of the terminal.

Lane width : 3.5 m
Aisle : 2.0 m
Drive up area : 25 m
Drive off area : 25 m

Total area:
Width : $6 \cdot (3.5 + 2)$ = 33 m

Length : 2 · 25 + 20 = 70 m

9.5.2 Workshop and stores

In the workshop repair and maintenance works are carried out on equipment. AGVs and spreaders are brought into the workshop to work in optimal conditions. Work on yard and quay cranes however is carried out on site and required only a small area to maintain and repair separate parts.

Workshop area	:	20 x 15 m	=	300 m^2	
Stores	:	5 x 10 m	=	50 m^2	
Washing area	:	20 x 5 m	=	100 m^2	
Engineers office	:	6 x 4 m	=	24 m^2	
Facilities	:	8 x 4 m	=	32 m^2	+
Total				506 m^2	

9.5.3 Offices

Compared to a large terminal the office facilities required for the smaller terminal are limited. A staff at least 20 people should still be expected to manage operations, finances, vessel planning, vehicle booking and customs administrations.

Assuming 15 m^2 of office space per staff member, a two storey building with a 15 by 20 meter surface area offering a 600 m^2 of office area should suffice to accommodate planned staff and leave some room for expansion of operations.

9.5.4 Roads

Inside the terminal area the FTA guidelines are continued to be used.
Freight transport association:
lane width : 3.7m
Outside radius corner : 20 m
Lane width at apex : 6.4 m

9.6 Terminal layout

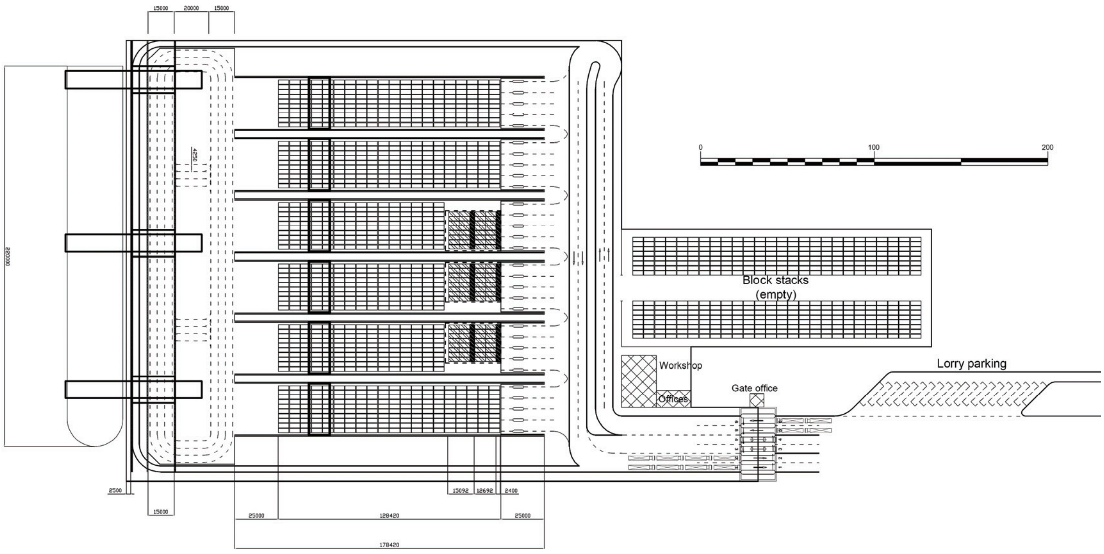


Figure 9.15 Overview terminal layout

The figure above is a smaller version of the drawing which can be found in appendix V. It gives an overview of the layout of the Risavika container terminal. The following comments are to clarify the chosen layout.

- The access to the quay area runs around the yard area and gives direct access to the quay for terminal personnel, last minute cargo and anyone else that has been granted access to the quay and terminal area.
- To allow queuing of lorries during peak periods in landside operations, the road for accessing vehicles has been made longer, than that of vehicle departing from the terminal.
- The terminal offices, workshops and personnel parking are located In the direct vicinity of the gate with separate access to the main road.
- The empty depot has been included in the drawing to indicate the area taken up by it. Its location may be varied.
- To allow for lengthening of the container stacks in the future, it may be considered not to locate the terminal gate, office and workshops in the extended path of the stacks.

9.7 Civil works

9.7.1 Quay

Structural concepts
Depending on the operational requirements and site conditions (marine climate, soil conditions and environment considerations) a variety of alternative structural concepts may be considered for quay design. Typically the solutions will range from gravity structures, (blockwork or caissons type) through suspended decks on piles to sheet piled or combi-type constructions.

The combi-wall is a type of embedded wall. It is a combination of steel tubes with sheet piles between the tubes. For increased load bearing capacity, as in the case of a crane track for a STS gantry crane, the tubes may be filled concrete.

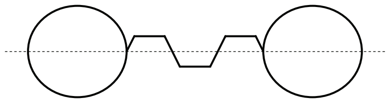


Figure 9.16 Profile of combi-wall

Loads working on quay wall
A key factor in quay wall design is the analysis of the loading on the wall. Besides the resulting loads from soil and water pressures on both sides of the wall the following loads can be identified on the construction:

- Live terrain loads including loads from quay traffic
- Live loads from quay cranes
- Mooring loads on the bollards
- Fender loads

In appendix VI the loads above are determined. The following values are found.

Table 9.10 Overview of loads on quay wall

Type of load	Unit	Load
Terrain loads	kN/m^2	20
Quay crane		
Vertical loads		
Dead weight	t	900
Max. vertical corner load WS	kN	5,760
Max. vertical corner load LS	kN	4,350
Max. vertical wheel load WS	kN/m	720
Max. vertical wheel load LS	kN/m	600
Horizontal loads		
Perpendictular to rail (10 %)	kN/m	72
In direction of rail (15 %)	kN/m	108
Bollard		
Line pull force	kN	800
Fender		
Impact energy	kNm	930
Resulting impact force	kN	1,550

The external loads imposed on the quay structure are shown in the scheme below. The high wheel loads on the crane rail of the STS crane require piling for both the waterside and the landside crane track.

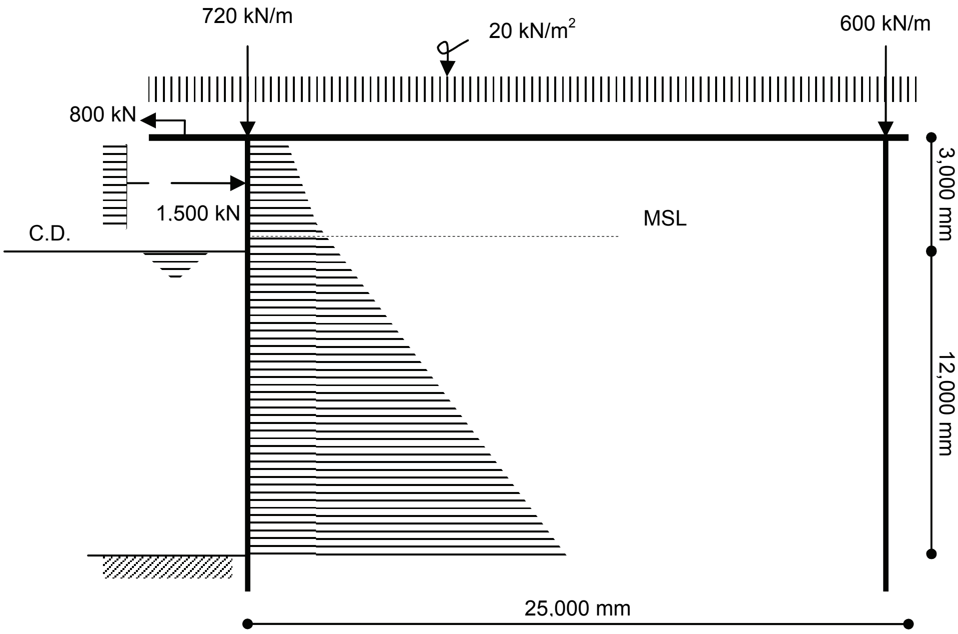


Figure 9.17 Overview of loads working on construction

Quay wall concept
The figure below shows an overview of the quay wall structure and the capping beam. The piling for the landside crane track can be used for anchoring the quay wall. In the case unexpected horizontal settlements of the quay wall, the rail gauge will remain the same.

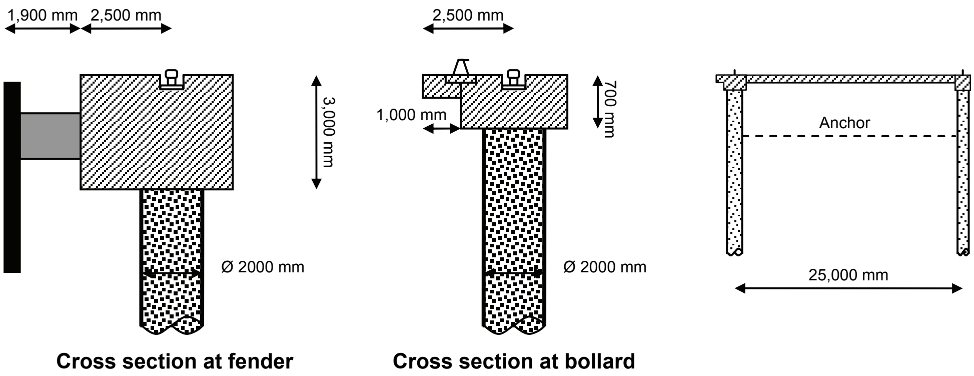


Figure 9.18 Quay wall cross sections

Construction steps quay wall
- Land preparation
- Piling (Tubes, sheet piles)
- Piling LS
- Anchoring combi-wall to LS piles
- Fill up steel tubes
- Fill up land behind wall
- Capping beam

  - Head blocks (fender / normal)
  - Turnover pit
- Crane rails
- Paving
- Fenders + bollard
- Crane installations

9.7.2 Pavement

The terminal surface area can be divided into a number of areas with differing requirements on load capacity and performance of the pavement. Roughly the following types of area can be identified:

- Yard and quay area
- Service and access roads
- Stack area
- MT-depot
- Secondary paved areas

Concrete slabs, block paving, asphalt and gravel are examples of pavement types that can be found on a container terminal.

Table 9.11 Representative pavement loads (EAU 2004)

Weight, 20 ft container	200 kN
Weight, 40 ft container	300 kN
Light traffic (cars)	5 kN/m2
General traffic (HGV's)	10 kN/m2
General Cargo	20 kN/m2
Container empty, stacked 4 high	15 kN/m2
Container full, stacked 2 high	35 kN/m2
Container full, stacked 4 high	55 kN/m2

Yard and quay areas
The most intensively used area of the terminal stretches out from directly behind the quay wall up to the container stacks. High terrain loads are imposed on the pavement by intensive, AGV traffic, temporarily stored cargo, containers and hatch covers. Due to the large numbers of equipment and the intensive use, the risk of spillage from fuel and hydraulic oil is relatively high.

Concrete block pavement is a very suitable type of pavement for this area. Rather than the more flexible, but viscous, bitumen based asphalt pavement it has a high resistance to concentrated loads and is not influenced by hydraulic oils and fuel. Its long lifetime, low and easy maintenance requirements make it very suitable for the closed of area where AGVs operate.

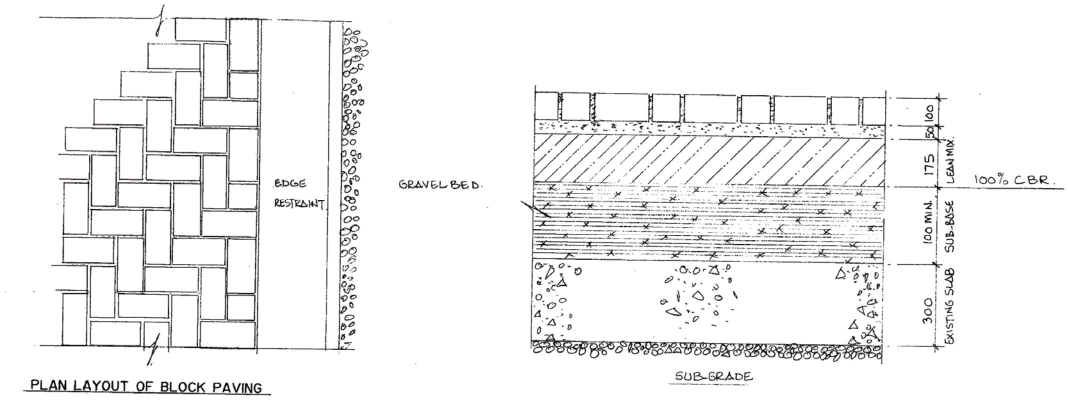


Figure 9.19 Typical cross section of block paving and bed

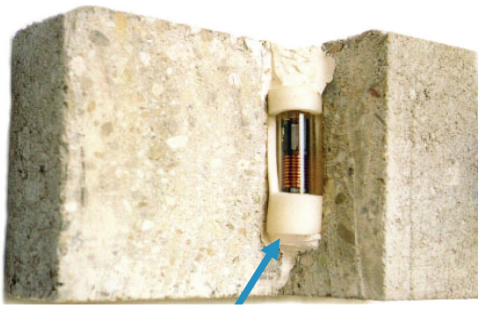


Figure 9.20 Transponder for AGV

Service and access roads

Although intensively used, load bearing requirements on the terminal roads is reduced compared to the apron area. Quicker and less labour intensive to lay, asphalt is a well suitable pavement that is not as expensive to lay offering smooth ride conditions.

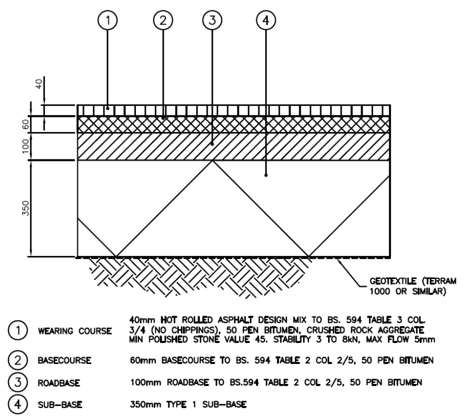


Figure 9.21 Typical cross-section of a asphalt road

Stacks areas

The areas under the RMG cranes where containers are stack have a specific load requirement. As can be noted from the EAU 2004 table surface loads for four high stacks can be assumed as high as 55 kN/m^2. Loads on a flat and hard pavement are however concentrated in the corner castings of stacked containers, imposing hardly any load on the rest of the surface. The EAU 2004 guideline indicates a maximum container weight of 300 kN for a 40 ft unit. For a 4 high stack this indicated a corner load of 300 kN per corner.

An effective and cost efficient pavement method is the gravel bed. Concrete pads are often used at the four corners of each ground slot to prevent gravel from clogging the twistlock slots of grounded containers. This solution however does not allow mixing of 20 and 40ft units. Gravel beds without corner pads for containers are used at several ports including Thamesport.

The main advantages of a gravel bed are the very low cost of laying, easy maintenance and good drainage, while offering sufficient stability for placing containers.

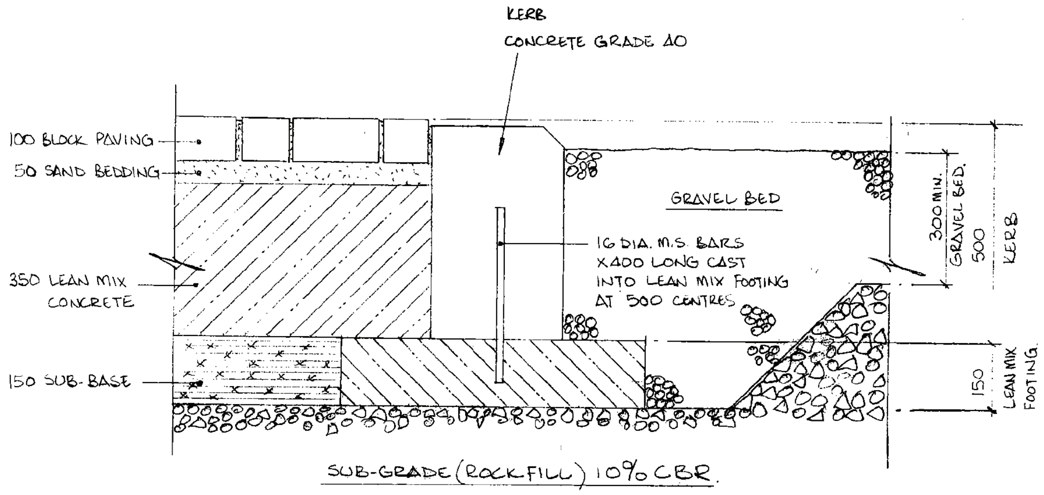


Figure 9.22 Cross-section with both gravel and block paving

An alternative for gravel bed pavement is to continue the concrete block paving to include the stacking area.

Empty depot
Table 9.11 indicates a pavement load for loads for empty containers, stacked four high, of 15 kN/m^2. Loads from the 8 high stacks in the empty deport are therefore assumed to be 30 kN/m^2.

The decision for the type of pavement for the empty depot is left to the detailed design of the terminal.

9.7.3 Crane tracks RMG

In the terminal yard 6 pairs of crane tracks are needed for the automated RMGs. These tracks can be laid on sleepers on a gravel bed, but on sites with very poor soil conditions piling may be required significantly adding to the construction costs.

The loads the crane imposes on its crane track a given in the table below.

Table 9.12 Vertical loads on RMG crane track

Type of load	Unit	Load
Crane dimensions		
Crane mass	MT	250
Wheels per corner		4
Wheel spacing	mm	1,000
Vertical loads		
Max. vertical corner load	kN	850
Max. vertical wheel load	kN/m	215
Horizontal loads		
Perpendictular to rail (10 %)	kN/m	85
In direction of rail (15 %)	kN/m	32

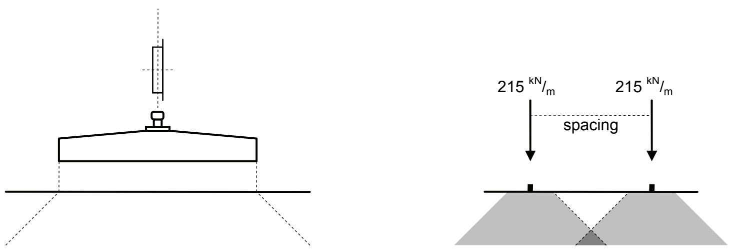


Figure 9.23 Crane track on sleepers and transfer of loads to subsoil

As indicated in the drawing above spacing of the tracks of two separate stacks influences the loads on the subsoil and must be taken into account in the detailed design of the terminal.

9.8 Cost estimations

The following paragraph provides an overview of the estimated investment costs for the Risavika container terminal. The estimates have been divided into the investment costs for the civil works and terminal installations and equipment costs.

9.8.1 Civil works

The civil works of have been divided into four subsections, the quay wall, the civil works on the terminal area, terminal buildings and other terminal facilities.

Quay wall

Table 9.13 Cost break-up quay

	ratum	pro ratum (€)			cost (€)
Combi-wall	per lin. m	30,000.00		250	7,500,000.00
Capping beam	per lin. m	2,500.00		250	625,000.00
Quay pavement	per sqr. m	75.00	250 x 25	6,250	468,750.00
Crane rails	per lin. m	1,000.00		500	500,000.00
Piling LS crane rail	per lin. m	4,500.00		250	1,125,000.00
Panzerbelt cable cover	per lin. m	150.00		250	37,500.00
Furniture (fenders, bollards, turnover pit)	per lin. m	4,500.00		250	1,125,000.00
Sub-total quay		*45,525.00*		*250*	*11,381,250.00*

Terminal area

Table 9.14 Cost break-up yard area

	ratum	pro ratum (€)			cost (€)
Block paving	per sqr. m	75.00			
Apron	per sqr. m	75.00	250 x 35	8,750	656,250.00
Loading bays	per sqr. m	75.00	12 x 30 x 25	9,000	675,000.00
MT stacks	per sqr. m	50.00	70 x 140	9,800	490,000.00
Gravel bed	per sqr. m	30.00	6 x 30 x 130	23,400	702,000.00
Rail track (incl. sleepers)	per lin. m	1,500.00	180 x 12	2,160	3,240,000.00
Service and access roads	per sqr. m	45.00			
Quay acces		45.00	2 x 250 x 3.5	1,750	78,750.00
Transfer area		45.00	250 x 25	6,250	281,250.00
Gate area		45.00	250 x 35	8,750	393,750.00
Sub-total yard area		*96.26*		*67,700*	*6,517,000.00*

Buildings

Table 9.15 Cost break-up terminal buildings

	ratum	pro ratum (€)			cost (€)
Gate office	per sqr. m	2,250.00		64	144,000.00
Gate	unit	750,000.00		1	750,000.00
Offices	per sqr. m	2,250.00		400	900,000.00
Workshop	per sqr. m	2,000.00		482	964,000.00
Shelters etc	unit	15,000.00		5	75,000.00
Sub-total buildings					*2,833,000.00*

Facilities

Table 9.16 Cost break-up terminal facilities

	ratum	pro ratum (€)		cost (€)
Reefer stations (platforms, substations)	unit	900,000.00	6	5,400,000.00
Power substation quay	unit	225,000.00	1	225,000.00
Power substation yard	unit	75,000.00	6	450,000.00
Power substation general	unit	75,000.00	1	75,000.00
Drainage	per ha	115,000.00	10	1,150,000.00
Others (fences, watersystem, etc	per ha	50,000.00	10	500,000.00
Sub-total facilities				*7,800,000.00*

Cost summary civil works

A summary is made of the total investment costs of the terminal. The result of the estimate is multiplied by two factors. Preliminary costs account for all expenses that are made before a single spade is put in the soil. These include consulting and engineering costs. The result including the preliminary costs is multiplied by a contingency factor to account for unexpected additional costs. Both factors are set at 15% together these add almost a third to initial estimate.

Sub-total quay	€	11,381,250.00
Sub-total terminal area	€	6,517,000.00
Sub-total buildings	€	2,833,000.00
Sub-total facilities	€	7,800,000.00
Sub-total	**€**	**28,531,250.00**
Peliminaries (15%)	€	4,279,687.50
Sub-total	**€**	**32,810,937.50**
Contingency (15%)	€	4,921,640.63
Total	**€**	**37,732,578.13**

9.8.2 Equipment purchase

In section 9.4 and 9.5 the required number of quay cranes, AGVs and RMGs have been determined. Besides this equipment a considerable number of support equipment is needed. The overview below gives a full overview of the required equipment and the costs.

As for the civil works, the costs estimate of the required terminal equipment is multiplied with a contingency factor of 20%. It is assumed that preliminary costs are included in the equipment price.

	Lifetime	price (€)	units	cost (€)
Quay cranes				
STS gantry cranes	20	5.000.000,00	2	10.000.000,00
Spreaders	4	140.000,00	3	420.000,00
Yard cranes				
Automated RMG cranes	20	2.500.000,00	6	15.000.000,00
Spreaders	4	140.000,00	8	1.120.000,00
Terminal transport				
AGV	10	400.000,00	12	4.800.000,00
Miscellaneous equipment				
Empty handler	8	400.000,00	2	800.000,00
Tractor unit	10	130.000,00	2	260.000,00
Chassis	4	25.000,00	3	75.000,00
Service vehicles	4	15.000,00	2	30.000,00
Service van	4	30.000,00	1	30.000,00
Sub-total equipment				**32.535.000,00**
Contingency		20%		6.507.000,00 +
Total				**39.042.000,00**

10 FINANCIAL EVALUATION

10.1 Introduction

In this chapter the feasibility of the proposed automated container terminal at Risavika Havn is studied a commercial investment. First step is an estimate of the operating costs per year and per container that is handled. The required investment costs were determined in the final section of the previous chapter. The income of the terminal is determined by the average charge for handling a container. These three elements are the basis of the financial assessment.

Available industry information on terminal handling charges is used to determine the payback period of the required investments for the terminal. The net present value (NPV) and the internal rate of return (IRR) of the proposed design are calculated and compared with those of an alternative design for manned equipment.

10.2 Terminal operating costs

The main reason for terminal operators to go for terminal automation is the expected reduction of operating costs. The operating costs of a container terminal can be divided into the following categories:

- Labour costs
- Repair and maintenance costs
- Energy and fuel consumption
- Support costs (TOS, insurances, marketing, general overhead)
- PA charges and land lease

Little information is made available by terminal operators concerning operating costs of container terminals. Studies made by Drewry (1998 and 2002) provide some indicative figures to determine terminal operating costs. Rough indicators of operating costs per TEU are also provided by Drewry and Saanen (2004), who refers to an earlier study by Dobner, Rijsenbrij and himself (2002). The figures from both studies however are somewhat dated.

To estimate the operating costs of the proposed terminal design a detailed cost estimate is made based on the available figures from the industry. Next the saved labour hours per TEU and per year determined to indicate the savings in labour costs from terminal automation. Finally the estimated operating costs of the automated terminal and the savings in labour costs are compared to the available benchmarks figures for non-automated container terminals to validate the results of the calculations.

10.2.1 Initial estimate of terminal operating costs

An estimate is made of the operational costs of the terminal. These costs have been split up in labour costs, maintenance and repair costs on terminal installations and civil works, energy consumption and other periodical costs. The estimated figures are based on benchmark figures from the industry (Drewry 1998), reference material used by Royal Haskoning and own estimates that have been verified with industry experts.

The estimate was made for a terminal with an annual throughput on the waterside of 200,000 TEU. In appendix VII a full overview of the estimate is given. A summary of the results of this estimate is given below.

Table 10.1 Summary of estimated operating costs Risavika CT

	Annual costs	
Labour	€ 3,940,000.00	
Repair and maintenance	€ 1,047,675.16	
Fuel, energy costs	€ 1,038,000.00	
Other expenses	€ 3,558,372.81	+
Total	€ 9,584,047.97	

The result of the estimate is used to determine the operating cost per TEU. This is done by dividing the estimate by 200,000. This approach is not entirely correct as no distinction is made between fixed operating costs (e.g. land lease) and variable operating costs. Because it has been assumed that terminal throughput of the Risavika terminal will reach 200,000 TEU by the end of year 3, the impact of this simplification is limited.

Based on the total estimate the operating costs per TEU is 47,92 Euro per TEU.

10.2.2 Indicators for operating costs per TEU

Benchmarks of operational costs per TEU for conventional container terminals provided by Drewry in 1998 estimate operating costs per TEU handled at 58 to 72 US Dollar, respectively for a terminal handling 600,000 and 210,000 TEU per year in a developed economy. With an average inflation rate of 2.5% per year and the exchange rate of the dollar in 1998 (1 USD = 0.90 EUR) these figures can be recalculated to 2007. This gives and operating cost per TEU of 65 to 80 Euro.

Saanen (2004), referring to a study by Dobner, Rijsenbrij and himself (2001), estimates average labour costs per TEU for a terminal in Northwest Europe to 30 to 38 Euro. This amount accounts for 51% of the operating costs of the terminal. For 2007 these figures can be recalculated to an operating cost per TEU of 65 to 85 Euro (66.55 € / 84.30 €).

The benchmark figures provided above are very similar. For large conventional container terminals operating costs per TEU are estimated at 65 Euro per TEU. For a small terminal the estimate is 80 to 85 Euro per TEU.

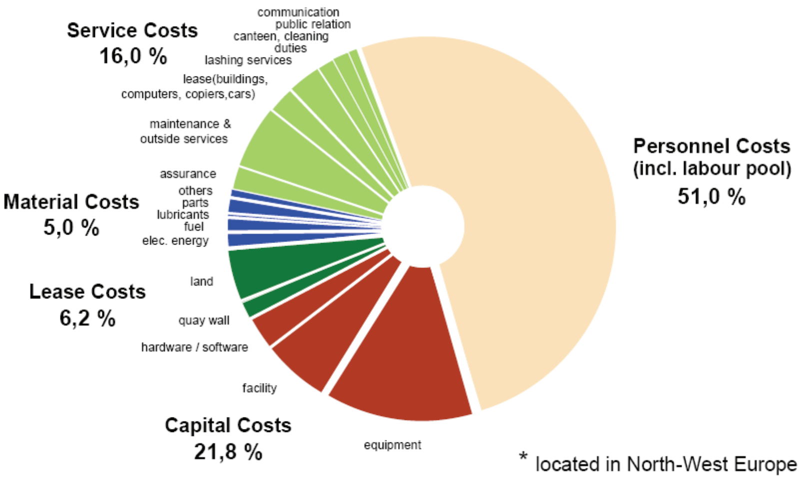


Figure 10.1 Distribution of operational costs (Dobner et al., 2001)

10.2.3 Labour savings from automation

Due to the deployment of automated container handling equipment considerable savings on labour expenses are achieved. Figure 5.1 is used once more to identify which processes are automated.

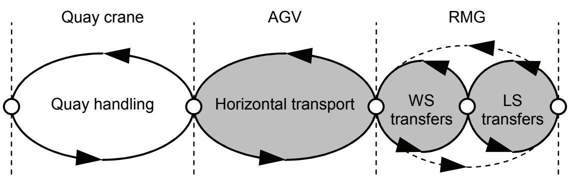


Figure 10.2 Savings in labour hours from automation

The total savings on labour expenses of the proposed automated terminal can be estimated in a number of ways. Two methods with different approached will be followed for the estimate in this section. Both methods determine the saved human labour during container handling operations. The cost of equipment operators during idle periods of the terminal is not included in the calculation.

The first method provides a minimal figure for labour savings per handled container. It is assumed that while a quay crane is in operation a proportional number yard equipment is in operating. The second method is based on the assumption that during any hour of terminal operations, all equipment is being manned and either being operated or standing by.

Proportional equipment running hours
For each quay crane in operation it is assumed a proportional numbers of AGVs and RMGs are in operation. For the case terminal this means 6 AGVs and 3 RMGs are in operation for each moment a single quay crane is working on a vessel.

The average cycle time of the quay cranes is derived from the results of the simulation study. To account for the difference between the equipment productivity as determined by the simulation software and the gross productivity including all delays simulated a factor of 0.95 is assumed.

For each container that is handled at the landside of the terminal a RMG is in operation. These running hours per container, minus the transhipment factor, should therefore be added to the results of the calculations. The assumption is made that landside operations are carried out by cranes that are not being used for waterside operations.

Operational hours of terminal
A different approach is to determine the total operating hours of the terminal, assuming al equipment is either operating or standing by. The total operating hours of the container terminal are calculated on the basis of the average quay productivity as provided by the simulation study.

Because all terminal systems are considered to be in operation during waterside operations, no all landside operating hours of yard cranes may be added to the result of the calculation. The average utilisation ratio of the quay can be used as a probability of waterside operations taking place, while a landside transfer is carried out.

Results from calculations
In appendix VII the full calculations of saved labour hours are given, the results of which are given in the table below.

Table 10.2 Labour cost reductions from automated container handling

	Method I	Method II
Reduced hours of human labour	0.283 $^{hr}/_{TEU}$	0.334 $^{hr}/_{TEU}$
Reduced labour hours saved per year (based on 200,000 TEU per year)	56,600 $^{hr}/_{yr}$	66,800 $^{hr}/_{yr}$
Cost savings per TEU on hourly wage		
gross hourly salary 30 $^{€}/_{hr}$	8.49 $^{€}/_{TEU}$	10.02 $^{€}/_{TEU}$
gross hourly salary 40 $^{€}/_{hr}$	11.32 $^{€}/_{TEU}$	13.36 $^{€}/_{TEU}$

As mentioned before the calculations that have been made do not take into account the savings from workers that have to be paid for standing by for operations. For a terminal handling 200,000 TEU per year labour utilisation is estimated at 70%. This corresponds to a total of maximum 1,200 effective working hours per employee per year. Now the following savings on labour costs are found

	Method I	Method II
Eliminated work places	48	56
Total annual labour cost savings (based on 45,000 Euro per year)	2,160,000 $^{€}/_{yr}$	2,520,000 $^{€}/_{yr}$
Cost saving per TEU (based on 200,000 TEU per year)	10.80 $^{€}/_{TEU}$	12.60 $^{€}/_{TEU}$

The results of the two methods to calculate the labour cost savings are both relatively low estimates. The results from the calculation based on operational hours of the terminal account for most additional labour cost. For the cost savings per TEU, the result based on hourly wage and that based on the number of full time contracts are averaged to 13 TEU per handled container.

Subtracting the found costs saving from the benchmarks gives an indication of benchmark operating costs per TEU for an automated terminal. For the found figures this would be in the order of 50 to 70 Euros per TEU.

10.2.4 Estimate of operating cost per TEU

There is a substantial difference between the estimated operating costs and the obtained benchmark figures. This is partially explained by the exclusion of capital costs in the estimate. These may amount to as much as 21% of operating costs of the terminal (Figure 10.1). A correction of the benchmark now gives an operating cost of about 55 Euros per TEU for a terminal handling 200,000 TEU per year. This figure is very close to the initially estimated 48 Euros per TEU. For the financial calculations, operating costs per TEU are set at 55 Euros.

10.3 Cash flow analysis

In the long term the profitability of a container terminal depends on the operating costs of the terminal. The required investment costs however determine the payback period. The longer the longer period to earn back the made investments, the higher the risk of those investments will be.

For the proposed automated container terminal for Risavika the feasibility of the required investment is evaluated on the basis of a Discounted-Cash-Flow model (DCF). The Net Present value (NPV) and the Internal Rate of Return (IRR) are two widely applied methods for evaluation of investment opportunities. These two methods will be used for this evaluation.

10.3.1 Net present value and Internal Rate of Return

The Net Present Value (NPV) and the Internal Rate of Return (IRR) are the two main variations if Discounted-cash-flow models (DCF). DCF models focus a project's cash inflows and outflows. They are based on the old saying that a bird in the hand is worth two in the bush – money in the pocket today is worth more than money received (or spend) 5 years from now. Because of the cost of money (interest) this saying applies. Both the NPV and the IRR focus on expected the expected cash flow and not on income.

The Net Present Value (NPV) discounts the value a series of future earnings and expenses (cash flows) to the present using a minimum desired rate of return. The minimum desired rate if return is determined by the cost of capital and is called the discount rate. It depends on the risks of the investment. If the sum of the present values of the cash flows is positive, the project is desirable. If not, it's undesirable.

The NPV is calculated by the following formula:

$$NPV = \sum_{t=0}^{i} \frac{C_i}{\left(1+r\right)^{t_i - t_0}} \qquad (10.1)$$

C_i	Net cash flow over a year	(€)
r	Discount rate	(%)
t_i	Year of cash flow	
t_0	Year of the investment	

The selection of a correct discount rate for NPV calculations is crucial for the value the conclusions drawn from it. The following factors should be considered when selecting the discount rate:

- Currency inflation
- Interest rate
- Income risk
- Rate of return on other investments

Similar to the NPV, the Internal Rate of Return expresses the discount rate for which at a certain point in time, the NPV is equal to zero.

The IRR is iteratively calculated by the following formula:

$$IRR = \sum_{t=0}^{i} \frac{C_i}{(1+r)^{t_i}} \qquad (10.2)$$

10.3.2 Discounted cash flow calculations

For the container terminal the annual cash flow is composed of the following components:

- Investment costs; In the period before the start of operations these are the sum of the construction costs of the civil works and equipment costs as determined in the previous chapter. After the start of operations these are the replacement costs of equipment that has come at the end of its economical life time.
- Operating costs; annual costs as determined per TEU.
- Terminal handling charges (THC); income from handling operations of 100 Euro per move.

Terminal operating costs are subject to inflation. Operating costs increase under the influence of, for example, rise of labour costs and fuel prices. A terminal operator will try to recover these increasing costs by raising its tariffs. It depends on the market situation whether or not the terminal operator will be able to do so.

In the NPV and IRR calculation in this chapter the following rates have been considered:

- Discount rate : 8%
  The discount rate has been determined as the sum of the current long term interest rate (4%), the average inflation (2%) and a risk factor (2%).
- Operational cost inflation : 3%
- Annual increase of THC : 1.5%

The NPV and IRR calculations are made for three different investment scenarios. First scenario is the BOT investment structure is used to determine the overall financial performance. Regardless of how invested capital was obtained the value of the project is evaluated. The influence of the initial capital outlay on the value of the cash flow is studied. This is done by removing the costs of the quay wall from the required investments. Instead an annual lease is paid to the port authority. This scenario is similar to the ownership structure of a lease terminal or a concession agreement. Finally the influence of financing the investment costs of the terminal with outside capital is studied. By getting a loan for (part of) the investment costs, the expenditure is postponed and spread in time. The difference between the discount rate and the interest rate may have a positive effect on the present value of the required future interest and amortisation payments.

To determine the benefits of automated container handling, the NPV and IRR calculations are also made for an alternative conventional terminal design. The required equipment costs are determined on the basis of a similar systems design with manned equipment. The cost estimate of the civil works is made on the basis of the rough assumption these are 80% of those of the proposed automated terminal.

A complete overview of the DCF calculations is given in appendix VIII.

Basic cash flow analysis
The first cash flow calculation is based on the assumption all necessary capital for the project is provided by the owner. This means there are no postponed payments. The per

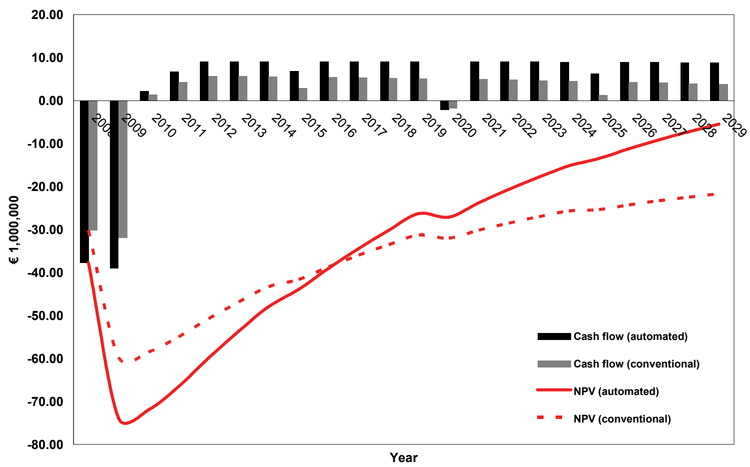


Figure 10.3 Net present value (r = 8%)

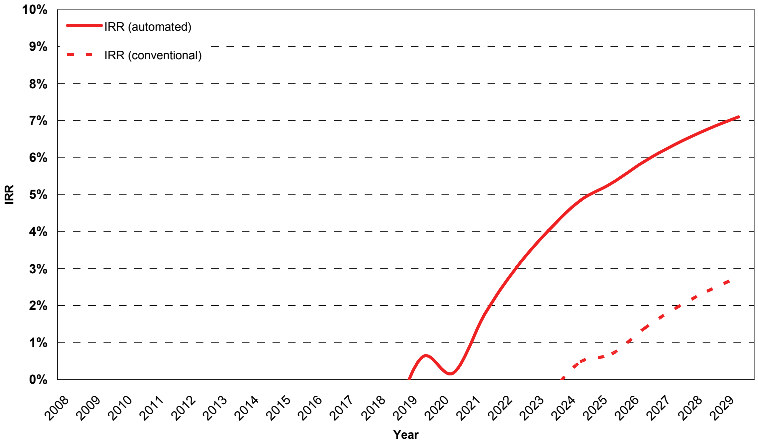


Figure 10.4 Internal rate of return

Leased quay wall

The high construction costs of the quay wall are a heavy load on the projects finances. To reduce the investment risk for the terminal operator, a port authority can therefore decide to include the quay wall in the annual lease fee for the terminal area.

In the cash flow calculations a fixed annual lease fee is set. At the end of a 25 year lease the total costs of the terminal will have been paid back at 5% interest per year.

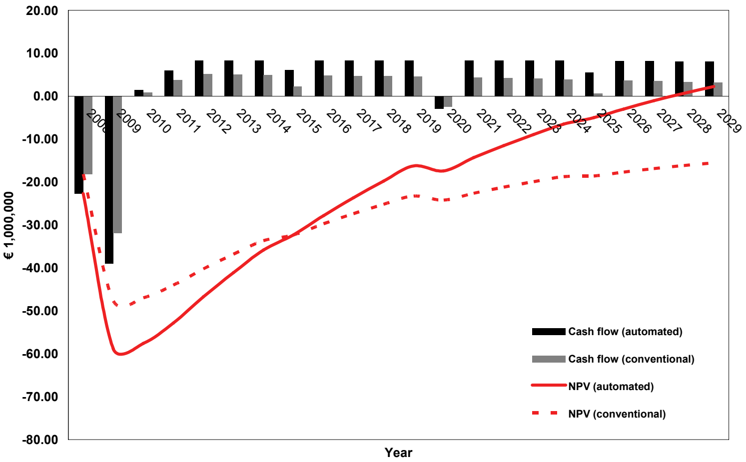


Figure 10.5 NPV for leased quay wall (r = 8%)

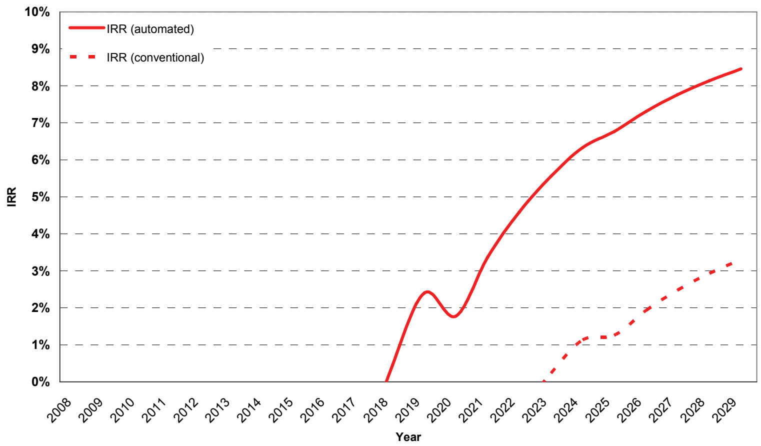


Figure 10.6 IRR for leased quay wall

Outside capital investment
The investment cost of the terminal can be spread over a period by paying part of investment costs of the terminal with outside capital. The difference between the discount rate and the interest the loan has a positive effect on the NPV.

For the terminal it is assumed that 50% of all required investments are paid with a loan. In the cash flow calculations the annual interest and amortisation payments are fixed with a running period equal to the expected life time of the investment.

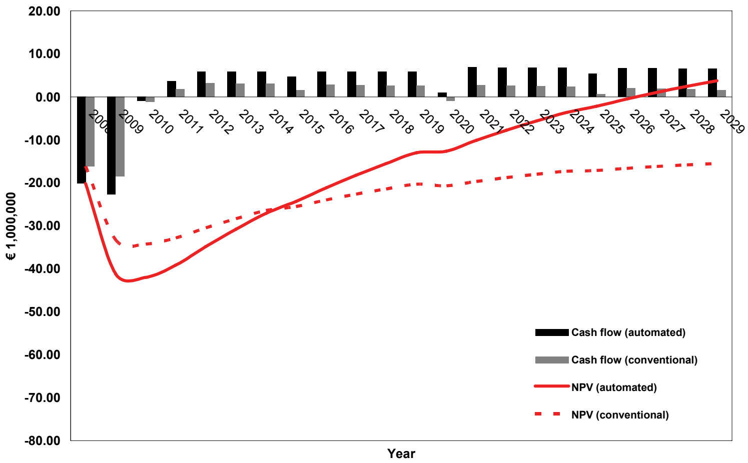


Figure 10.7 NPV for 50% finananced investment (r = 8%, i = 6%)

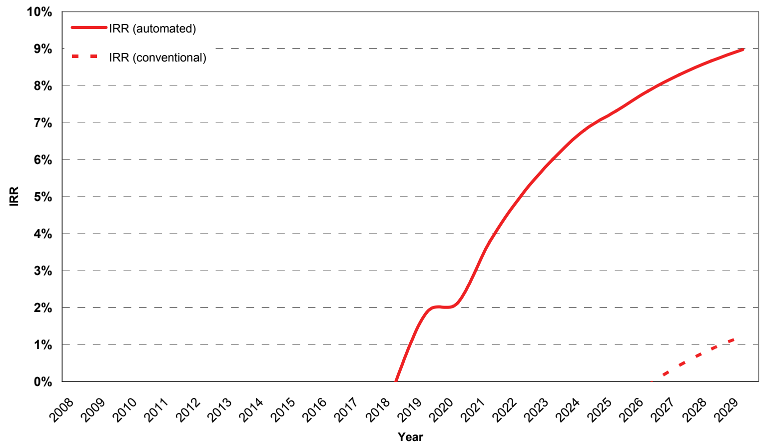


Figure 10.8 IRR for 50% financed investment (i = 6%)

10.3.3 Results from DCF calculations

As a rule of thumb for container terminals, investors require an IRR of 10 to 15% within 15 years of operation for investments in a container terminal. Furthermore the payback periods are limited to 10 years after the start of operations.

The table below gives a summarised overview of the calculations that were made in this section.

Table 10.3 Overview of DCF calculations

			BOT structure	**Leased quay wall**	**Financed investment**
Foreign capital			-	-	50%
Quay wall part of lease			no	yes	no
Payback period automation			10	9	7
After 10 years of operation					
	NPV	Automated (€)	-26,264,276.50	-16,229,773.65	-13,012,892.04
		Conventional (€)	-27,374,014.48	-19,346,412.20	-18,629,677.37
	IRR	Automated (€)	1%	2%	2%
		Conventional (€)	-3%	-2%	-6%
After 15 year of operation					
	NPV	Automated (€)	-15,161,402.56	-6,509,714.01	-3,640,104.43
		Conventional (€)	-26,670,828.51	-19,051,675.59	-15,711,633.47
	IRR	Automated (€)	5%	6%	7%
		Conventional (€)	-1%	-1%	0%
After 20 year of operation					
	NPV	Automated (€)	-5,457,314.28	2,253,254.07	3,769,430.12
		Conventional (€)	-22,796,560.88	-16,628,106.20	-12,381,945.96
	IRR	Automated (€)	7%	8%	9%
		Conventional (€)	2%	2%	3%

10.4 Conclusions for financial evaluation

The financial evaluation of the proposed Risavika Container Terminal demonstrates the financial benefits of terminal automation over conventional container handling. The large savings in operational expenses, allow the terminal to earn back the required investments within 7 to 10 years of operations, depending on the investment structure.

From the discounted cash flow calculations it also becomes apparent that the Build Operate and Transfer (BOT) ownership structure as assumed in section 7.1 would not be feasible as a commercial investment.

In its proposed BOT-structure, it is expected that none of the requirements for commercial investments will be met by the terminal. This caused by the high initial capital outlay that is required to the expected annual return. This has a strong, negative influence on the Net Present Value of the project. A higher level of public sector involvement would increase the commercial value of the project.

The commercial value of the project can be improved by reducing the required initial capital outlay. The public sector can get involved in the project in two ways. Instead of a BOT-ownership structure, including the (some of) the terminal infrastructure in the lease has a positive effect on the NVP of the project..

Investors could also spread the initial capital outlay themselves by financing part of the investments with outside capital. The public sector can get involved in the project by having the national government to provide financial guarantees to outside financiers. Because of the long life of the project and large uncertainties of the development of terminal income, the financial risks are substantial. Outside investors may not be inclined to provide loans without financial guarantees.

11 CONCLUSIONS AND RECOMMENDATIONS

11.1 Goal of the study

Leading throughout the research were the following two research questions:
- How can automated container handling be implemented on small terminals with "off-the-shelf" technology?
- Is automation of container handling operations in small terminals feasible as a commercial investment and by what factors is this feasibility affected?

Based on the research and case study, each question will be answered in the following section.

11.2 Conclusions

11.2.1 How can automated container handling be implemented on small terminals with "off-the-shelve technology?

Off-the-shelf automated handling concepts
The fully proven AGV-RMG concept and the flexible Autostrad concept are the most favourable concepts for automation of container terminals. The AGV-RMG has proven its productivity and reliability over a period of 15 years. The operational flexibility of the Autostrad is a big advantage. However, the Autostrad concept is relatively new on the market. A multi criteria analysis of the AGV-RMG and Autostrad concepts concluded a slightly better match with decision criteria in favour of the AGV-RMG concept. Main decision criteria were area requirements, reliability and maintenance requirements.

Terminal system systems design
The terminal systems are quantified; both by manual calculation involving the queuing theory, as by a simulation study using Posport CT, the required equipment numbers are estimated. From the combined results is the following system is selected:
- 2 STS gantry cranes (Panamax design)
- 12 AGVs
- 6 automated RMGs

11.2.2 Is automation of container handling operations in small terminals feasible as a commercial investment and by what factors is this feasibility affected?

The additional investment costs of automated equipment are recovered within 10 years. The discounter cash flow calculations indicate the rate of return for the automated terminal concept is 5% higher than that of a conventional terminal concept.

As a commercial investment, the rate of return on large investments required, is not sufficient for the project to be feasible.

Influences on feasibility
The reason for the negative result of the financial feasibility study lays in the high initial capital outlay that is required. From an accounting perspective, the results of the calculation can be positively influenced by spreading that outlay over a longer period. Instead of the BOT-ownership structure the public sector could increase the level of

involvement. This can, for example take place in the form of leasing (part) of the terminal infrastructure to the operator, or by providing financial guarantees to help attract outside investors.

An obvious, but worth mentioning, influencing factor on the feasibility, is the handling charge per TEU. Terminal operators are not always able to follow the annual increases in labour, energy and other costs.

Last influencing factor on feasibility of automation is terminal throughput. The smaller a terminal is, the fewer the scale advantages. Larger terminals can achieve a higher throughput per equipment unit. For small automated container terminals, equipment is expensive. For each handled container addition profit is made due to the reduced operating costs.

11.2.3 Challenges for small and medium sized terminals

- Strong competition from an increasing number of terminals serving the same
- Flexible routes of regional and short-sea services.
- High pressure from shipping lines to offer high level of services, e.g. 24 hours a day waterside operations, waiting times for vessels, storage capacity.
- Few opportunities to profit from scale advantages lead to relatively high investment costs and operating costs.

To stay ahead of the competition, terminal operators are pushed to improve their terminals productivity and efficiency. At the same time the uncertain development of terminal throughput and handling charges increase the risks of the required investments to achieve this. As a result, terminal operators have no margin for error. They are only able to invest cautiously and conservatively

11.3 Recommendations

Application of queuing theory on terminal operations
In port planning the queuing theory can be very useful tool for determining berth length or quay handling capacity. For terminal operations, and equipment calculations in specific, its applicability is limited. The queuing theory has been developed for situations where there is no relation between rates of generated calls and the service rate. Especially on smaller terminals, this requirement is not met.

Furthermore, for the validity of the obtained results, the queuing theory relies on the quality of the input, which is very loosely based on assumptions

Market analysis
A big limitation of discounted cash flow models is the assumption of a world of certainty. Terminal income is assumed as certain. Especially on small and medium sized terminals, in reality throughput development has many uncertainties. A thorough analysis of the market is therefore a must.

Threshold of feasibility
Although the benefits of automated container handling have been established, the feasibility of the studied project is limited. The studied terminal with an annual

throughput of 200,000 TEU, is perhaps a bit too small. Although at the start of this study placed in the same category, terminals like Risavika CT can hardly be compared with terminals handling volumes close to 500,000 TEU. It is quite plausible that an annual throughput of 300,000 TEU already proam the owner provides sufficient scale advantages that investing in automation would be commercially feasible.

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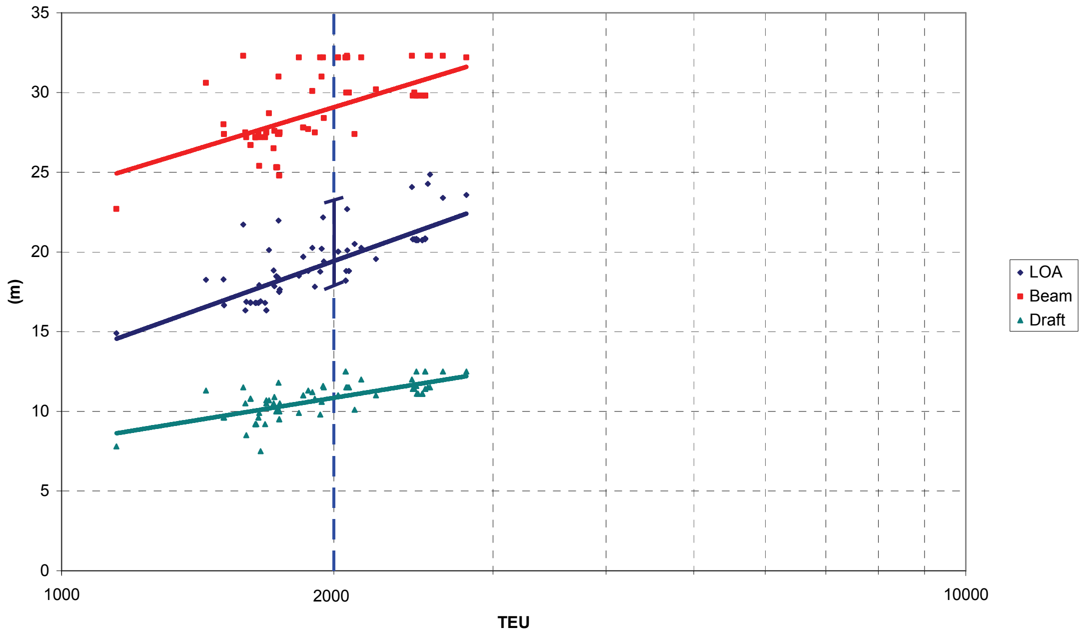
- Liebherr
- Promo-Teus
- ZPMC

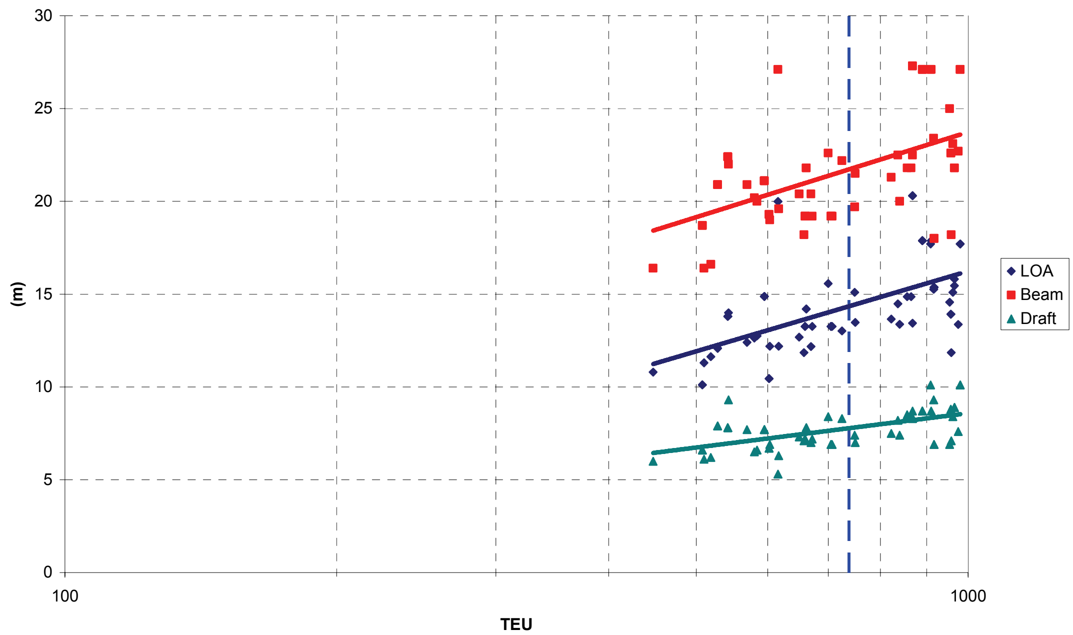
APPENDIX I VESSEL SIZE

Audit of vessel dimensions versus load capacity
(data obtained from website www.containership-info.net.tc)

Container vessels: 1,500 – 2,500 TEU



Container vessels: 0 – 1000 TEU



APPENDIX II EQUIPMENT CYCLE TIMES

$$T(cycle) = T_1 + \ldots + T_n$$

$$T_i = (\mu_i, \sigma_i)$$

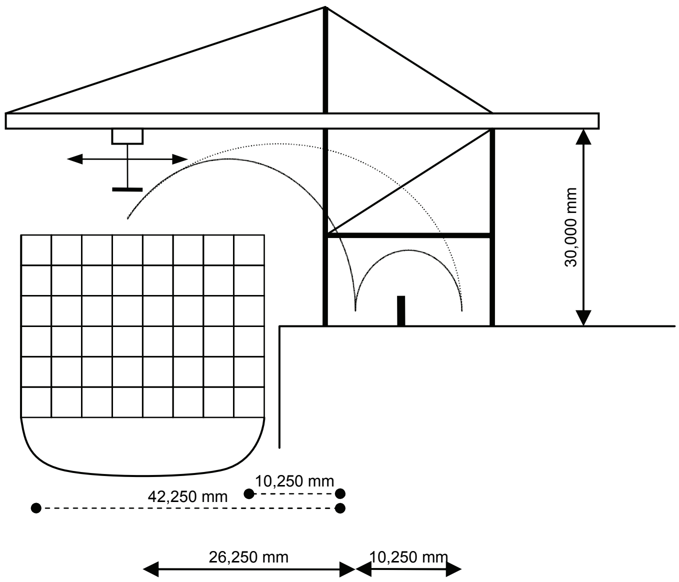
$$\mu_i = \overline{T_i}$$

$$\sigma_i = \sqrt{Var(T_i)}$$

$$\mu_{cycle} = \mu_1 + \ldots + \mu_n$$

$$\sigma_{cycle} = \sqrt{\sigma_1^2 + \ldots + \sigma_n^2}$$

Quay crane



UNLOADING	Δx (m)	v max ($^m/_s$)	t min (s)	t max (s)	μ (s)	σ^2 (s^2)	σ (s)
spreader up	10 m	150	4	6	5	2	1.4
travel to vessel	26.25 m	150	10	23	16.4	13	3.6
connect	-		10	30	20	20	4.5
hoist + travel to quay	10	75	10	20	15	10	3.2
travel to quay	26.25 m	150	10	23	16.4	13	3.6
load AGV	-		10	40	25	30	5.5
Full cycle	-		54	142	97.8	88	9.4

LOADING	Δx (m)	v max ($^m/_s$)	t min (s)	t max (s)	μ (s)	σ² (s²)	σ (s)
unload AGV	-		20	40	30	20	4.5
hoist	10 m	75	8	20	14	12	3.5
travel to vessel	26.24 m	150	10	22.8	16.4	12.8	3.6
loading container	-		10	50	30	40	6.3
spreader up + travel to quay	-	150	4	20	12	16	4
travel to quay	26.24 m	150	10	22.8	16.4	12.8	3.6
Full cycle	71 m		62	175.6	118.8	113.6	10.7

Unloading : T(μ,σ)= (97.8 s, 9.4 s)
Loading : T(μ,σ) = (118.8 s, 10.7 s)

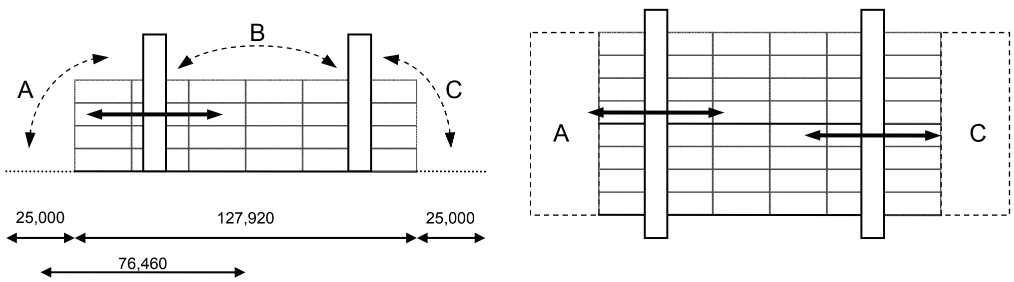
Average :

$$\mu_{average} = \tfrac{1}{2}\left(\mu_{loading} + \mu_{unloading}\right)$$

$$\sigma_{average} = \sqrt{\sigma^2_{loading} + \sigma^2_{unloading}}$$

T(μ,σ) = (108.3 s, 14.2 s)

Yard gantry crane

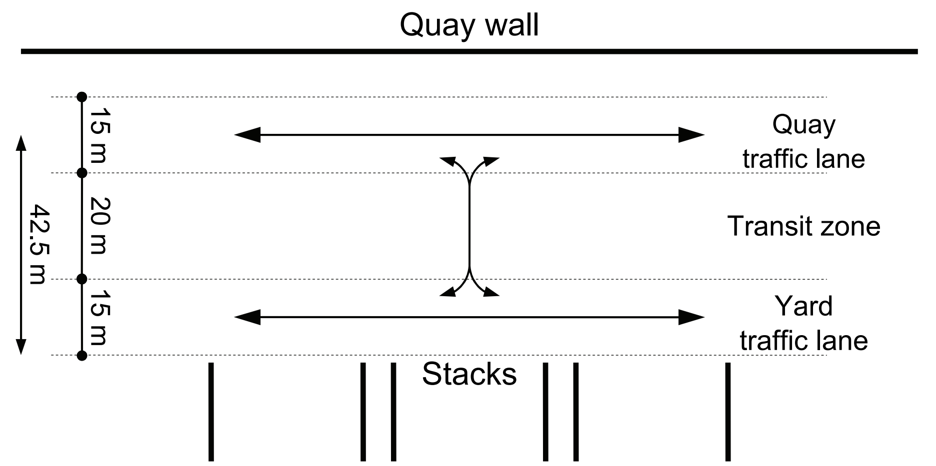


UNLOADING	Δx (m)	v max ($^m/_{min}$)	t min (s)	t max (s)	μ (s)	σ² (s²)	σ (s)
Collection at TP	-	-	20	40	30	20	4.5
Travel to slot	76.5	210	11	46.2	28.6	35.2	5.9
Unloading in stack	-	30 / 60	15	45	30	30	5.5
Travel to TP	76.5	210	11	46.2	28.6	35.2	5.9
Full cycle	140		57	177.4	117.2	120.4	11.0

LOADING	Δx (m)	v max ($^m/_{min}$)	t min (s)	t max (s)	μ (s)	σ² (s²)	σ (s)
Travel to cont.	76.5	210	11	46.2	28.6	35.2	5.9
Pick up from stack	-	60 / 30	15	75	45	60	7.5
Travel to TP	76.5	210	11	46.2	28.6	35.2	5.9
Loading AGV	-	30 / 60	10	40	25	30	5.5
Full cycle	153		47	207.4	127.2	160.4	12.7

Unloading : $T(\mu,\sigma)$ = (117.2 s, 11.0 s)
Loading : $T(\mu,\sigma)$ = (127.2 s, 12.7 s)
Average : $T(\mu,\sigma)$ = (122.2 s, 16.8 s)

AGV



Parallel travel quay	: 0.5 · 350 m	= 175.0 m
Parallel travel yard	: 1.5 · 35.4 m	= 53.1 m
Quay stack travel	: (0.5 · 15 + 15) +20	= 42.5 m
Entry in transfer point	:	= 25.0 m +
Total	:	= 295.6 m

Travel speeds	: Loaded	: $v_{avg}(min) = 2.0\ ^m/_s$	↔ $v_{avg}(max) = 4.0\ ^m/_s$
	: Empty	: $v_{avg}(min) = 2.5\ ^m/_s$	↔ $v_{avg}(max) = 4.5\ ^m/_s$

UNLOADING	Δx (m)	v_{max} ($^m/_s$)	t_{min} (s)	t_{max} (s)	μ (s)	σ^2 (s^2)	σ (s)
Collection quay	-		20	40	30	20	4.5
Travel to stack	295.6	6	73.9	147.8	110.9	73.9	8.6
Delivery to stack	-		20	40	30	20	4.5
Travel to quay	295.6	6	65.9	118.2	91.7	52.6	7.2
Full cycle	593.2		179.6	346.0	262.8	166.5	12.9

LOADING	Δx (m)	v_{max} ($^m/_s$)	t_{min} (s)	t_{max} (s)	μ (s)	σ^2 (s^2)	σ (s)
Collection yard	-		20	40	30	20	4.5
Travel to quay	295.6	6	73.9	147.8	110.9	73.9	8.6
Delivery to crane	-		20	40	30	20	4.5
Travel to yard	295.6	6	65.9	118.2	91.7	52.6	7.2
Full cycle	593.2		179.6	346.0	262.8	166.5	12.9

$T_{AGV}(average) = T_{AGV}(loading) = T_{AGV}(unloading)$ = (262.8 s, 12.9 s)

APPENDIX III TABLES QUEUING THEORY

$E_2/E_2/n$ system

utilisation (u)	number of servers (n) 1	2	3	4	5	6	7	8	9	10
0.1	0.0166	0.0006	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.2	0.0604	0.0065	0.0011	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.3	0.1310	0.0235	0.0062	0.0019	0.0007	0.0002	0.0001	0.0000	0.0000	0.0000
0.4	0.2355	0.0576	0.0205	0.0085	0.0039	0.0019	0.0009	0.0005	0.0003	0.0001
0.5	0.3904	0.1181	0.0512	0.2530	0.0142	0.0082	0.0050	0.0031	0.0020	0.0013
0.6	0.6306	0.2222	0.1103	0.0639	0.0400	0.0265	0.0182	0.0128	0.0093	0.0069
0.7	1.0391	0.4125	0.2275	0.1441	0.0988	0.0712	0.0532	0.0407	0.0319	0.0026
0.8	1.8653	0.8300	0.4600	0.3300	0.2300	0.1900	0.1400	0.1200	0.0900	0.0900
0.9	4.3590	2.0000	1.2000	0.9200	0.6500	0.5700	0.4400	0.4000	0.3200	0.3000

D/M/n system

utilisation (u)	number of servers (n) 1	2	3	4	5	6	7	8	9	10
0.1	0.0556	0.0062	0.0009	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.2	0.1250	0.0242	0.0066	0.0021	0.0007	0.0002	0.0001	0.0000	0.0000	0.0000
0.3	0.2143	0.0553	0.0201	0.0085	0.0039	0.0019	0.0009	0.0005	0.0002	0.0001
0.4	0.3333	0.1033	0.0450	0.0227	0.0124	0.0072	0.0043	0.0026	0.0017	0.0011
0.5	0.5000	0.1767	0.0872	0.0497	0.0307	0.0199	0.0135	0.0093	0.0066	0.0047
0.6	0.7500	0.2930	0.1584	0.0984	0.0661	0.0467	0.0342	0.0257	0.0197	0.0154
0.7	1.1667	0.1936	0.2862	0.1897	0.1355	0.1016	0.0788	0.0627	0.0505	0.0419
0.8	2.0000	0.9030	0.5537	0.3860	0.2890	0.2265	0.1833	0.1519	0.1282	0.1098
0.9	4.5000	2.0138	1.2887	0.9340	0.7237	0.5848	0.4894	0.4164	0.3606	0.3175

M/M/n system

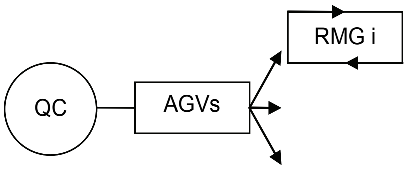
utilisation (u)	number of servers (n) 1	2	3	4	5	6	7	8	9	10
0.1	0.1111	0.0101	0.0014	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.2	0.2500	0.0417	0.0103	0.0030	0.0010	0.0003	0.0001	0.0000	0.0000	0.0000
0.3	0.4286	0.0989	0.0333	0.0132	0.0058	0.0027	0.0013	0.0006	0.0003	0.0002
0.4	0.6667	0.1905	0.0784	0.0378	0.0199	0.0111	0.0064	0.0039	0.0024	0.0015
0.5	1.0000	0.3333	0.1579	0.0870	0.0521	0.0330	0.0218	0.0145	0.0102	0.0072
0.6	1.5000	0.5625	0.2956	0.1794	0.1181	0.0819	0.0589	0.0436	0.0330	0.0253
0.7	2.3333	0.9608	0.5470	0.3572	0.2519	0.1867	0.1432	0.1128	0.0906	0.0739
0.8	4.0000	1.7778	1.7870	0.7455	0.5541	0.4315	0.3471	0.2860	0.2401	0.2046
0.9	9.0000	4.2632	2.7235	1.9693	1.5250	1.2335	1.0285	0.8769	0.7606	0.6687

The decision D/M/n system

utilisation (u)	number of servers (n) 2	3	4	5	6	7	8	9	10
0.1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.2	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.3	0.0048	0.0008	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.4	0.0223	0.0060	0.0019	0.0007	0.0002	0.0001	0.0000	0.0000	0.0000
0.5	0.0649	0.0239	0.0103	0.0049	0.0024	0.0013	0.0007	0.0004	0.0002
0.6	0.1520	0.0685	0.0360	0.0206	0.0125	0.0079	0.0051	0.0034	0.0023
0.7	0.3257	0.1696	0.1020	0.0665	0.0458	0.0327	0.0240	0.0180	0.0137
0.8	0.7111	0.4114	0.2825	0.1947	0.1461	0.1134	0.0903	0.0734	0.0605
0.9	1.9330	1.2112	0.8612	0.6567	0.5238	0.4310	0.3629	0.3110	0.2703

APPENDIX IV QUEUING THEORY

Quay – Yard system



	QC	AGV	RMG
function	Server		Generator
μ (s)	108.3	262.8	122.2
σ (s)	14.2	12.9	16.8

# Generators	N_a	:	1
# Severs	N_s	:	4
	n	:	4

Inter arrival time

mean	μ_a	:	36.1 s
std dev.	σ_a	:	19.2 s

$$\mu_a = \frac{T_{QC}(average)}{N_{QC}}$$

$$\sigma_a = \sqrt{\sigma_{QC}^2 + \sigma_{AGV}^2}$$

Service time

mean	μ_s	:	122.2 s
std dev.	σ_s	:	16.8 s

Utilisation

u	:	0.8463
u_1	:	0.80
u_2	:	0.90

$$u = \frac{\mu_s}{\mu_a \cdot n}$$

Variability

v_a	:	0.282
k	:	3.5
v_s	:	0.0189
m	:	52.9

$$v_a = \left(\frac{\sigma_a}{\mu_a}\right)^2 = \frac{1}{k}$$

$$v_s = \left(\frac{\sigma_s}{\mu_s}\right)^2 = \frac{1}{m}$$

Waiting time: $W_n = (v_a, v_s, u) = (1 - v_a) \cdot v_s \cdot W_n(0,1,u) + v_a \cdot (1 - v_s) \cdot W_n(1,0,u) + v_a \cdot v_s \cdot W_n(1,1,u)$

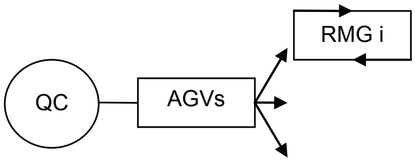
$W(0,1,u_1)$	:	0.2725	$W(0,1,u_2)$	:	0.8612
$W(1,0,u_1)$	:	0.3860	$W(1,0,u_2)$	:	0.9340
$W(0,1,u_1)$	:	0.7455	$W(0,1,u_2)$	:	1.9693
$Wn(u_1)$	:	0.1146	$Wn(u_2)$	:	0.2810

$W_n(v_a,v_s,0.846)$: 0.1916

$T_{AGV}(waiting)$: 23.41 s

$$T(waiting) = W_n(v_a, v_s, n) \cdot T(cycle)$$

Quay – Yard system II



	QC	AGV	RMG
function	Server		Generator
μ (s)	108.9	262.8	122.2
σ (s)	14.2	12.9	16.8

# Generators	N_a	:	1
# Severs	N_s	:	5
	n	:	5

Inter arrival time

mean	μ_a	:	36.1 s
std dev.	σ_a	:	19.2 s

$$\mu_a = \frac{T_{QC}(average)}{N_{QC}}$$

$$\sigma_a = \sqrt{\sigma_{QC}^2 + \sigma_{AGV}^2}$$

Service time

mean	μ_s	:	122.2 s
std dev.	σ_s	:	16.8 s

Utilisation

u	:	0.6770
u_1	:	0.60
u_2	:	0.70

$$u = \frac{\mu_s}{\mu_a \cdot n}$$

Variability

v_a	:	0.282
k	:	3.5
v_s	:	0.0189
m	:	52.9

$$v_a = \left(\frac{\sigma_a}{\mu_a}\right)^2 = \frac{1}{k}$$

$$v_s = \left(\frac{\sigma_s}{\mu_s}\right)^2 = \frac{1}{m}$$

Waiting time: $W_n = (v_a, v_s, u) = (1 - v_a) \cdot v_s \cdot W_n(0,1,u) + v_a \cdot (1 - v_s) \cdot W_n(1,0,u) + v_a \cdot v_s \cdot W_n(1,1,u)$

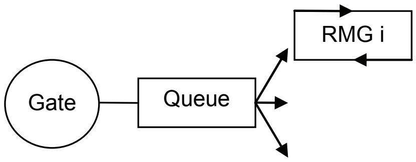
$W(0,1,u_1)$	:	0.0206	$W(0,1,u_2)$	:	0.0665
$W(1,0,u_1)$	:	0.0661	$W(1,0,u_2)$	:	0.1355
$W(0,1,u_1)$	:	0.1181	$W(0,1,u_2)$	:	0.2519
$Wn(u_1)$	:	0.0192	$Wn(u_2)$	:	0.0398

$W_n(v_a,v_s,0.846)$: 0.0351

T_{AGV}(waiting) : 4.28 s

$$T(waiting) = W_n(v_a, v_s, n) \cdot T(cycle)$$

Gate – Yard system



	Gate	RMG
function	Generator	Server
μ (s)	117.9	122.2
σ (s)	35.4	16.8

# Generators	N_a	:	1
# Severs	N_s	:	2
	n	:	2

Inter arrival time

mean	μ_a	:	117.9 s
std dev.	σ_a	:	35.4 s

Service time

mean	μ_s	:	122.2 s
std dev.	σ_s	:	16.8 s

Utilisation	u	:	0.5182
	u_1	:	0.50
	u_2	:	0.60

$$u = \frac{\mu_s}{\mu_a \cdot n}$$

Variability

v_a	:	0.090
k	:	11.1
v_s	:	0.0189
m	:	52.9

$$v_a = \left(\frac{\sigma_a}{\mu_a}\right)^2 = \frac{1}{k}$$

$$v_s = \left(\frac{\sigma_s}{\mu_s}\right)^2 = \frac{1}{m}$$

Waiting time: $W_n = (v_a, v_s, u) = (1 - v_a) \cdot v_s \cdot W_n(0,1,u) + v_a \cdot (1 - v_s) \cdot W_n(1,0,u) + v_a \cdot v_s \cdot W_n(1,1,u)$

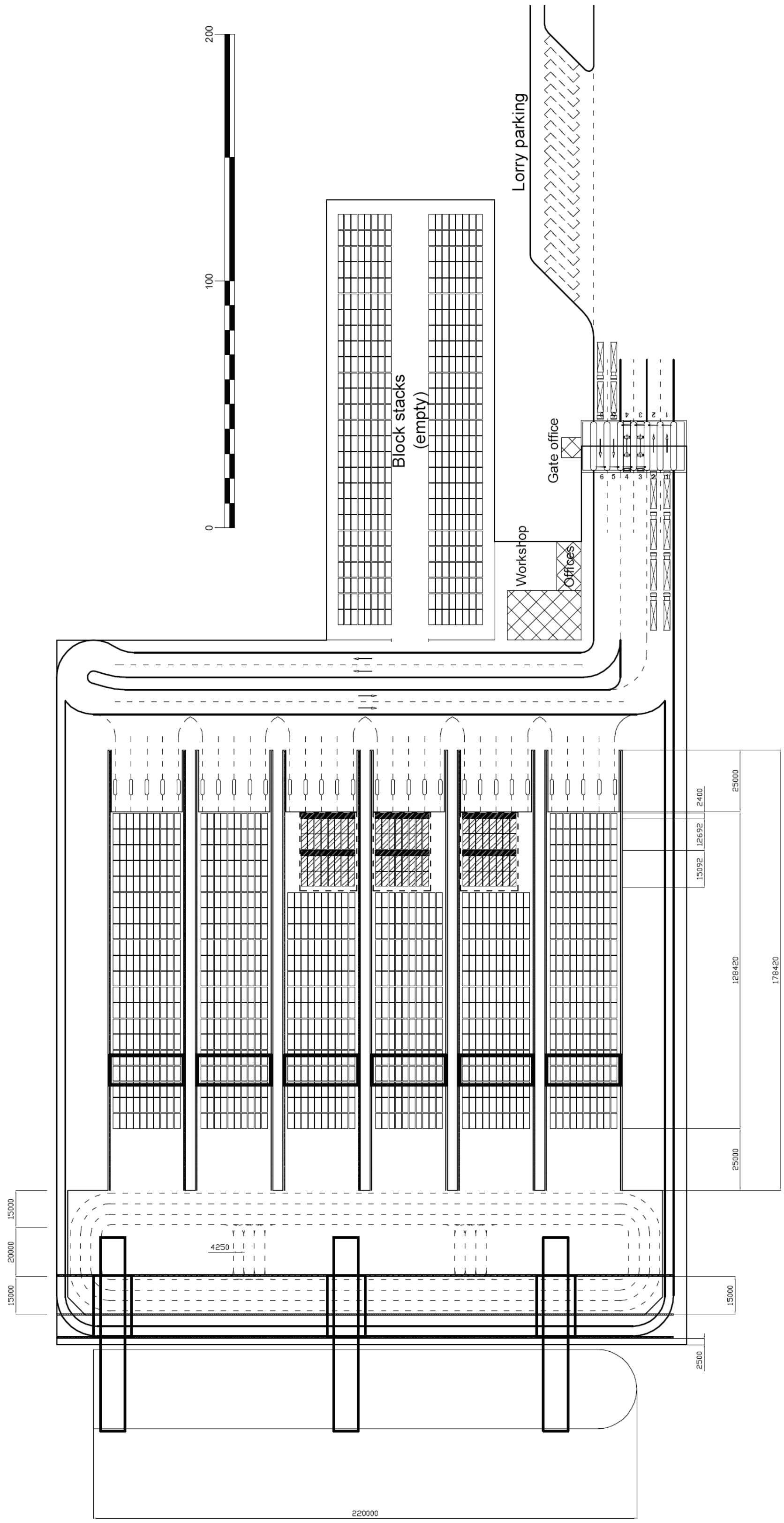
$W(0,1,u_1)$	:	0.0649	$W(0,1,u_2)$	:	0.152
$W(1,0,u_1)$	:	0.1767	$W(1,0,u_2)$	:	0.293
$W(0,1,u_1)$	:	0.3333	$W(0,1,u_2)$	:	0.5625
$Wn(u_1)$	:	0.0173	$Wn(u_2)$	:	0.0295

$W_n(v_a,v_s,0.518)$: 0.0195

T_{LS}(waiting) : 2.39 s

$$T(waiting) = W_n(v_a, v_s, n) \cdot T(cycle)$$

APPENDIX V TERMINAL LAYOUT



APPENDIX VI QUAY WALL DESIGN

Mooring loads bollard

Combined overview of line pull force for vessel displacement, derived from CUR 166, Handsbook Quay Walls, EAU 2004 (Meijer, 2006)

Vessel displacement (MT)	**Line pull force** (kN)
< 2,000	100
< 10,000	300
< 20,000	600
< 50,000	800
< 100,000	1000
< 200,000	1500
> 200,000	2000

Design vessel:

- Dimensions:
  - LOA : 220 m
  - Beam : 32.2 m
  - Draft : 12 m
- Displacement : $0.5 \cdot \rho_w \cdot V_{block} = 42{,}504$ MT
- Line pull force : 800 kN

Fender loads

The maximum fender load on a quay wall follows from the impact energy absorbed by a fender. This is calculated by the following formula:

$$E = \tfrac{1}{2} \cdot M \cdot v^2 \cdot C_m \cdot C_e \cdot C_s \cdot C_c$$

In which:

M	Mass of the ship	(MT)	
v	Berthing velocity	($^m/_s$)	(under unfavourable conditions: 0.25 $^m/_s$)
C_m	Virtual mass coefficient	(-)	
C_e	Eccentricity coefficient	(-)	
C_s	Stiffness coefficient	(-)	(stiff fender: 0.9, soft fender: 1.0)
C_c	Configuration coefficient	(-)	(jetty : 1.0 , closed : 0.8)

In a simplified calculation for the impact energy the factor C_b is used to represent the combined effects of virtual mass, eccentricity, stiffness and configuration.

$$C_b = C_e \cdot C_m \cdot C_s \cdot C_c \approx 0.7$$

Then: $E = \tfrac{1}{2} \cdot 42{,}504 \cdot 0.25^2 \cdot 0.7 = 930 kNm$

The reaction force that is transferred from the fender to the quay is determined from tables provided fender manufacturers.

Reaction force kone fender (Maritime International)

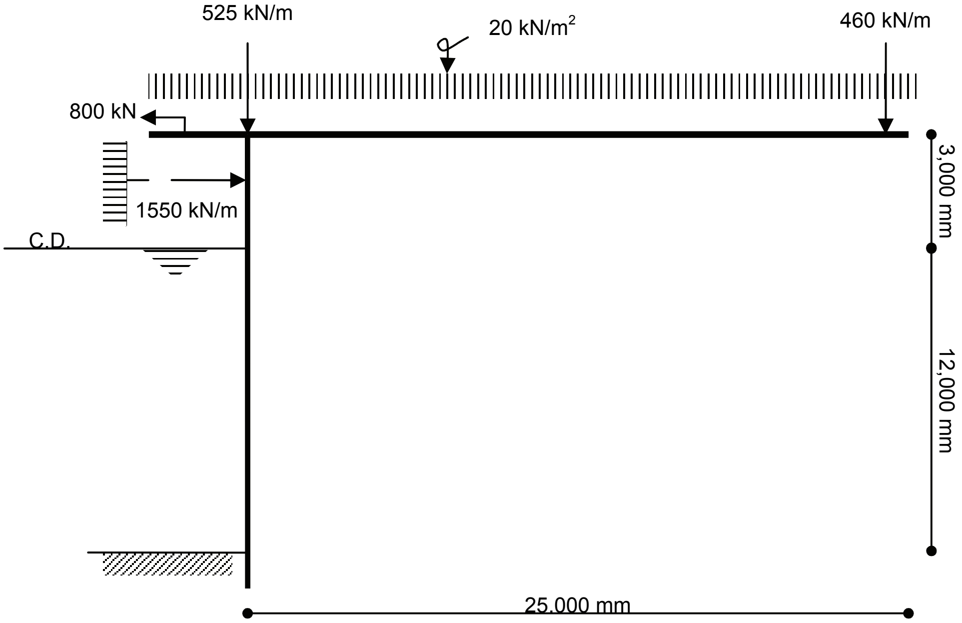
Model	Rubber Grade								Weight (kg)
	G4		G3		G2		G1		
	R (kN)	E (kN-m)	R (kN)	E (kN-m)	R (kN)	E (kN-m)	R (kN)	E (kN-m)	
MCN 500	307	81	245	65	196	55	157	44	131
MCN 600	441	140	353	112	282	94	226	76	227
MCN 700	601	223	481	179	384	150	308	120	360
MCN 800	785	333	628	267	502	224	402	179	538
MCN 900	993	474	794	380	636	319	508	255	765
MCN 1000	1226	650	981	521	785	437	628	350	1050
MCN 1150	1621	989	1297	792	1038	665	830	532	1597
MCN 1200	1765	1124	1412	900	1130	756	904	605	1814
MCN 1300	2072	1428	1657	1144	1326	961	1061	769	2307
MCN 1400	2403	1784	1922	1429	1538	1200	1230	961	2881
MCN 1600	3139	2663	2511	2133	2009	1792	1607	1434	4301

Maximum reaction force from design vessel impact: 930 · (1621 / 989) = 1550 kN

STS-grantry crane

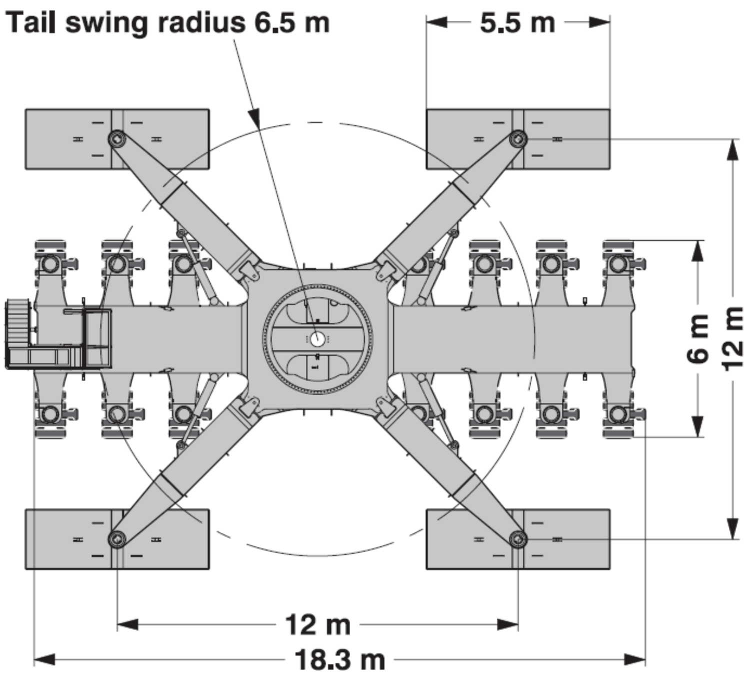
Dimensions and loads from ship-to-shore gantry crane

	Unit	Load
Crane dimensions		
Crane mass	MT	900
Rail gauge	mm	25,000
Corner spacing	mm	15,500
No. wheels per corner	-	8
Wheel spacing	mm	1,000
Vertical loads (operational conditions)		
Max. vertical corner load WS	kN	3,200
Max. vertical corner load LS	kN	2,800
Max. vertical wheel load WS	kN/m	400
Max. vertical wheel load LS	kN/m	350
Vertical loads (extreme conditions)		
Max. vertical corner load WS	kN	4,200
Max. vertical corner load LS	kN	3,700
Max. vertical wheel load WS	kN/m	525
Max. vertical wheel load LS	kN/m	460
Horizontal loads		
Perpendictular to rail (10 %)	kN/m	53
In direction of rail (15 %)	kN/m	79



Load configuration quay wall for STS-crane

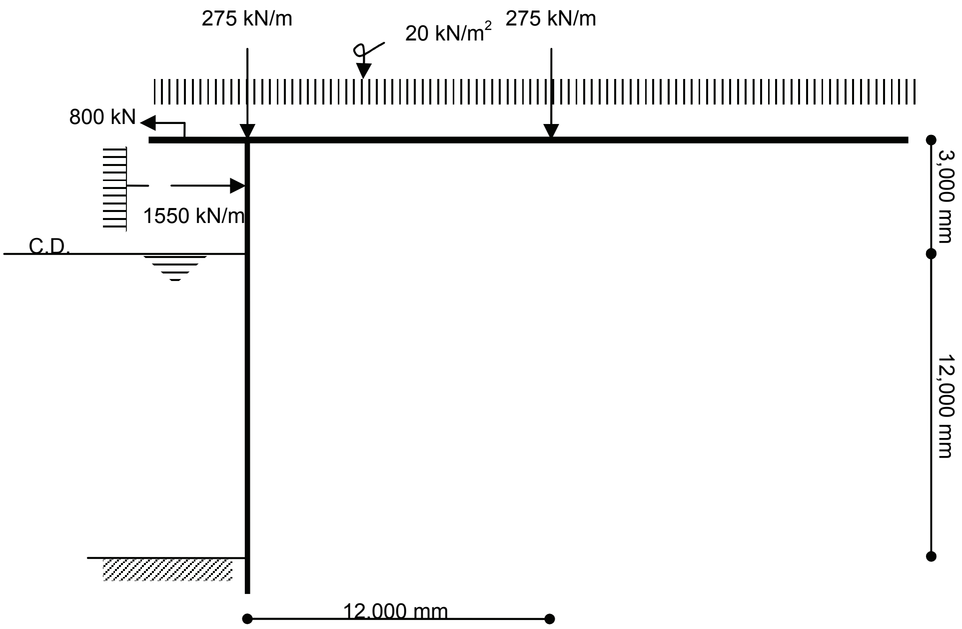
MHC



Topview Liebherr 320 mobile harbour crane (Liebherr)

Dimensions and surface loads mobile harbour crane (Liebherr 320)

	Unit	Load
Crane dimensions		
Crane mass (incl. counterweight)	MT	325
Counterweight	MT	70
Crane radius	mm	43,000
Lifting capacity (at max radius)	MT	16
Lifting capacity (max, excl. spreader)	MT	41
No. of axles	-	7
Axle spacing	mm	1,575
Surface corner pad (min / max)	m^2	5.5 / 16.5
Vertical loads (operational conditions)		
Max load on corner pad	kN	1,204
Max surface load	kN/m^2	220
Vertical loads (extreme conditions)		
Max load on corner pad	kN	1,505
Max surface load	kN/m^2	275
Horizontal loads		
Perpendictular to quay (10 %)	kN/m	28
In transit (15 %)	kN/m	22
Wheel load (transit)	kN/m	150



Load configuration quay wall for MHC

APPENDIX VII TERMINAL OPERATING COSTS

Estimated terminal operating costs

Labour costs

	# Employees	Annual salary (€)	Expenditure (€)
Management	4	75000	300,000.00
Administation and finance	12	45000	540,000.00
Operations	50	35000	1,750,000.00
Engineering and maintenance	30	45000	1,350,000.00
Total	96		3,940,000.00

Maintenance and repair costs

	Annual costs	Value (€)	Expenditure (€)
Quay cranes	2.8%	10,420,000.00	291,760.00
RMG	2.5%	16,120,000.00	403,000.00
Tractor/trailers	7.0%	335,000.00	23,450.00
AGV	4.0%	4,800,000.00	192,000.00
FLT	7.0%	800,000.00	56,000.00
Engineering services vehicles	5.0%	60,000.00	3,000.00
other vehicles	5.0%	60,000.00	3,000.00
civil works	0.2%	37,732,578.13	75,465.16
Total			1,047,675.16

Energy consumption

		Unit price (€)	Expenditure (€)
Electricity			
Variable (25 kWh/TEU)	per teu	3.75	750,000.00
Fixed	per ha per yr	12,000.00	120,000.00
Fuel	per teu	0.84	168,000.00
Total			1,038,000.00

Other periodical costs

		Unit price (€)	Expenditure (€)
Land lease	per sqr. m	8.00	800,000.00
Insurance	per year	1,358,372.81	1,358,372.81
Computer system	per year	2,000,000.00	2,000,000.00
General overheads	per teu	2.00	400,000.00
Total			4,558,372.81

Total operating costs

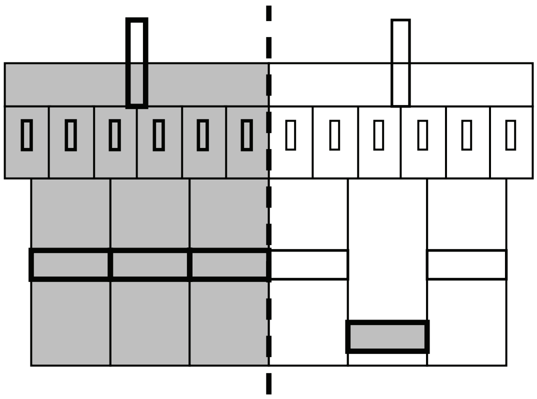
	Annual costs	Cost per TEU
Labour costs	€ 3,940,000.00	€ 19.70
Repair and maintenance	€ 1,047,675.16	€ 5.24
Fuel, energy costs	€ 1,038,000.00	€ 5.19
Other expenses	€ 4,558,372.81	€ 22.79
Total	€ 6,025,675.16	€ 52.92

Labour cost savings from automation

Results simulation study

		$^{moves}/_{hr}$	$^{TEU}/_{hr}$ (f =1.4 $^{TEU}/_{move}$)
Quay	$P_{quay}(average)$	42.4	59.4
STS crane	$P_{QC}(peak)$	30.5	42.7
	$P_{QC}(average)$	26.2	36.7
RMG	$P_{RMG}(peak)$	28.8	40.3

Method I: proportional equipment running hours



1. Quay crane operating hours per TEU

$$P_{QC}(gross) = P_{QC}(average) \cdot 0.95$$
$$= 36.7\ ^{TEU}/_{hr} \cdot 0.95$$
$$= 34.9\ ^{TEU}/_{hr}$$
$$\Leftrightarrow T_{QC} = \frac{1}{34.9\ ^{TEU}/_{hr}} = 0.287\ ^{hr}/_{TEU}$$

2. Waterside operating hours of terminal equipment per TEU

$$\begin{aligned} T_{yard}(waterside) &= (N_{AGV} + N_{RMG}) \cdot T_{QC} \\ &= (6+3) \cdot 0.0287 \\ &= 0.258 \, {}^{hr}/_{TEU} \end{aligned}$$

3. Landside operating hours of terminal equipment per TEU

a. Gross crane productivity of RMG (assuming P(gross) = 0.81 · P(peak))

$$\begin{aligned} P_{RMG}(gross) &= P_{RMG}(peak) \cdot 0.81 \\ &= 40.3 \, {}^{TEU}/_{hr} \cdot 0.81 \\ &= 32.7 \, {}^{TEU}/_{hr} \end{aligned}$$

b. RMG operating hours per container handled at quay (μ = 0.2)

$$\begin{aligned} T_{RMG}(landside) &= \frac{1-\mu}{P_{RMG}(gross)} \\ &= \frac{1-0.2}{32.7} \\ &= 0.0245 \, {}^{hr}/_{TEU} \end{aligned}$$

4. Total saved labour hours per TEU handled at quay

$$\begin{aligned} T(labour) &= T_{yard}(waterside) + T_{RMG}(landside) \\ &= 0.258 + 0.0245 \\ &= 0.283 \, {}^{hr}/_{TEU} \end{aligned}$$

Method II: aterminal operating hours

1. Terminal operating hours per TEU

$$\begin{aligned} P_{quay}(gross) &= P_Q(average) \cdot 0.95 \\ &= 59.4 \, {}^{moves}/_{hr} \cdot 0.9 \\ &= 56.4 \, {}^{TEU}/_{hr} \end{aligned}$$

$$\Leftrightarrow T_{quay} = \frac{1}{56.4 \, {}^{TEU}/_{hr}} = 0.0177 \, {}^{hr}/_{TEU}$$

2. Waterside operating hours of terminal equipment per TEU

$$\begin{aligned} T_{yard}(waterside) &= (N_{AGV} + N_{RMG}) \cdot T_{quay} \\ &= (12+6) \cdot 0.0177 \\ &= 0.319 \, {}^{hr}/_{TEU} \end{aligned}$$

3. Landside operating hours of terminal equipment per TEU

a. Quay utilization (for 200,000 TEU)

$$u = \frac{200{,}000 \, {}^{TEU}/_{yr} \Big/ 56.4 \, {}^{TEU}/_{hr}}{8760 \, {}^{hr}/_{yr}} = 0.405$$

Probability of no waterside operations during landside call is 1 – u = 0.595

b. RMG operating hours per container handled at quay

$$T_{RMG}(landside) = (1-u)\cdot\frac{1-\mu}{P_{RMG}(gross)}$$
$$= 0.595\cdot\frac{1-0.2}{32.7}$$
$$= 0.0146\ {}^{hr}\!/_{TEU}$$

4. Total saved labour hours per TEU handled at quay

$$T(labour) = T_{yard}(waterside) + T_{RMG}(landside)$$
$$= 0.319 + 0.0146$$
$$= 0.334\ {}^{hr}\!/_{TEU}$$

Results from calculations

Reduced labour expenditure due to automation

	Method I	Method II
Reduced hours of human labour per TEU	0.283 $^{hr}/_{TEU}$	0.334 $^{hr}/_{TEU}$
Reduced labour hours saved per year	56,600	66,800
Cost savings based on hourly wage		
per TEU based on 30 €/hr	8.49 $^{€}/_{TEU}$	10.02 $^{€}/_{TEU}$
per TEU based on 40 €/hr	11.32 $^{€}/_{TEU}$	13.36 $^{€}/_{TEU}$

APPENDIX VIII FINANCIAL ANALYSIS

Terminal cash flow

Overview of annual expenses and income for automated terminal design

	Note	Present value (€)
Investment costs		
Civil works	Investment made in first year	37,732,578.13
Equipment	Investment made in second year	39,042,000.00
Replacement costs	2% price inflation and 20% contingency	
every 5 years	Spreaders, chassis and service vehicles	1,645,000.00
every 10 years	AGVs, empty handlers and tractors	5,890,000.00
every 20 years	Quay and yards cranes	25,000,000.00
Operating costs	Calculated per TEU (3.0% annual increase)	55.00
Handling charges	Calculated per TEU (1.5% annual increase)	100.00

Overview of annual expenses and income for convention terminal design

	Note	Present value (€)
Investment costs		
Civil works	First year, est. @ 80% of automated design	30,186,062.50
Equipment	Second year, 8 RTGs and 14 PTTs	27,450,000.00
Replacement costs	2% price inflation and 20% contingency	
every 5 years	Spreaders, chassis and service vehicles	2,225,000.00
every 10 years	RTGs, empty handlers and tractors	10,650,000.00
every 20 years	Quay and yards cranes	10,000,000.00
Operating costs	Calculated per TEU (3.0% annual increase)	70.00
Handling charges	Calculated per TEU (1.5% annual increase)	100.00

Discounted Cash flow table, NPV and IRR for Automated terminal (r = 8%)

Year		Throughput (TEU)	Capital cost (€)	Operating costs (€)	Income (€)	Cash flow (€)	PV (€)	NPV (€)	IRR (%)
2008	*0*	-	-37,732,578.13	0.00	0.00	-37,732,578.13	-37,732,578.13	-37,732,578.13	0%
2009	*1*	-	-39,042,000.00	0.00	0.00	-39,042,000.00	-36,150,000.00	-73,882,578.13	0%
2010	*2*	50,000	0.00	-2,889,218.75	5,151,125.00	2,261,906.25	1,939,220.04	-71,943,358.09	0%
2011	*3*	150,000	0.00	-8,884,347.66	15,685,175.63	6,800,827.97	5,398,716.51	-66,544,641.58	0%
2012	*4*	200,000	0.00	-12,141,941.80	21,227,271.01	9,085,329.22	6,677,988.20	-59,866,653.39	-39%
2013	*5*	200,000	0.00	-12,445,490.34	21,545,680.08	9,100,189.74	6,193,436.22	-53,673,217.16	-26%
2014	*6*	200,000	0.00	-12,756,627.60	21,868,865.28	9,112,237.68	5,742,255.42	-47,930,961.74	-17%
2015	*7*	200,000	-2,223,044.62	-13,075,543.29	22,196,898.26	6,898,310.35	4,025,097.83	-43,905,863.91	-12%
2016	*8*	200,000	0.00	-13,402,431.87	22,529,851.73	9,127,419.86	4,931,260.95	-38,974,602.96	-7%
2017	*9*	200,000	0.00	-13,737,492.67	22,867,799.51	9,130,306.84	4,567,426.57	-34,407,176.40	-4%
2018	*10*	200,000	0.00	-14,080,929.99	23,210,816.50	9,129,886.51	4,228,903.98	-30,178,272.42	-1%
2019	*11*	200,000	0.00	-14,432,953.24	23,558,978.75	9,126,025.51	3,913,995.92	-26,264,276.50	1%
2020	*12*	200,000	-11,242,590.50	-14,793,777.07	23,912,363.43	-2,124,004.13	-843,471.27	-27,107,747.77	0%
2021	*13*	200,000	0.00	-15,163,621.49	24,271,048.88	9,107,427.39	3,348,782.15	-23,758,965.62	2%
2022	*14*	200,000	0.00	-15,542,712.03	24,635,114.61	9,092,402.58	3,095,608.85	-20,663,356.77	3%
2023	*15*	200,000	0.00	-15,931,279.83	25,004,641.33	9,073,361.50	2,860,301.95	-17,803,054.82	4%
2024	*16*	200,000	0.00	-16,329,561.83	25,379,710.95	9,050,149.13	2,641,652.26	-15,161,402.56	5%
2025	*17*	200,000	-2,709,878.98	-16,737,800.87	25,760,406.62	6,312,726.76	1,706,134.04	-13,455,268.51	5%
2026	*18*	200,000	0.00	-17,156,245.89	26,146,812.72	8,990,566.82	2,249,880.62	-11,205,387.90	6%
2027	*19*	200,000	0.00	-17,585,152.04	26,539,014.91	8,953,862.87	2,074,718.05	-9,130,669.85	6%
2028	*20*	200,000	0.00	-18,024,780.84	26,937,100.13	8,912,319.29	1,912,122.13	-7,218,547.72	7%
2029	*21*	200,000	0.00	-18,475,400.36	27,341,156.63	8,865,756.27	1,761,233.44	-5,457,314.28	7%

Discounted Cash flow table, NPV and IRR for conventional terminal (r = 8%)

Year		Throughput (TEU)	Capital cost (€)	Operating costs (€)	Income (€)	Cash flow (€)	PV (€)	NPV (€)	IRR (%)
2008	*0*	-	-30,186,062.50	0.00	0.00	-30,186,062.50	-30,186,062.50	-30,186,062.50	0%
2009	*1*	-	-27,114,000.00	0.00	0.00	-27,114,000.00	-25,105,555.56	-55,291,618.06	0%
2010	*2*	50,000	0.00	-3,677,187.50	5,151,125.00	1,473,937.50	1,263,663.84	-54,027,954.22	0%
2011	*3*	150,000	0.00	-11,307,351.56	15,685,175.63	4,377,824.06	3,475,257.89	-50,552,696.33	0%
2012	*4*	200,000	0.00	-15,453,380.47	21,227,271.01	5,773,890.54	4,243,981.92	-46,308,714.42	-42%
2013	*5*	200,000	0.00	-15,839,714.98	21,545,680.08	5,705,965.10	3,883,383.97	-42,425,330.45	-29%
2014	*6*	200,000	0.00	-16,235,707.85	21,868,865.28	5,633,157.42	3,549,844.71	-38,875,485.74	-20%
2015	*7*	200,000	-2,628,463.09	-16,641,600.55	22,196,898.26	2,926,834.62	1,707,779.89	-37,167,705.85	-17%
2016	*8*	200,000	0.00	-17,057,640.57	22,529,851.73	5,472,211.17	2,956,465.42	-34,211,240.42	-11%
2017	*9*	200,000	0.00	-17,484,081.58	22,867,799.51	5,383,717.93	2,693,199.33	-31,518,041.09	-8%
2018	*10*	200,000	0.00	-17,921,183.62	23,210,816.50	5,289,632.88	2,450,123.51	-29,067,917.58	-5%
2019	*11*	200,000	0.00	-18,369,213.21	23,558,978.75	5,189,765.54	2,225,801.48	-26,842,116.10	-3%
2020	*12*	200,000	-18,792,359.30	-18,828,443.54	23,912,363.43	-13,708,439.41	-5,443,809.90	-32,285,926.00	-18%
2021	*13*	200,000	0.00	-19,299,154.63	24,271,048.88	4,971,894.25	1,828,155.20	-30,457,770.80	-7%
2022	*14*	200,000	0.00	-19,781,633.49	24,635,114.61	4,853,481.12	1,652,421.24	-28,805,349.56	-4%
2023	*15*	200,000	0.00	-20,276,174.33	25,004,641.33	4,728,467.00	1,490,610.00	-27,314,739.57	-2%
2024	*16*	200,000	0.00	-20,783,078.69	25,379,710.95	4,596,632.26	1,341,713.14	-25,973,026.42	-1%
2025	*17*	200,000	-3,204,081.84	-21,302,655.66	25,760,406.62	1,253,669.13	338,827.84	-25,634,198.58	-1%
2026	*18*	200,000	0.00	-21,835,222.05	26,146,812.72	4,311,590.67	1,078,971.38	-24,555,227.21	0%
2027	*19*	200,000	0.00	-22,381,102.60	26,539,014.91	4,157,912.31	963,438.44	-23,591,788.76	1%
2028	*20*	200,000	0.00	-22,940,630.16	26,937,100.13	3,996,469.97	857,435.47	-22,734,353.30	2%
2029	*21*	200,000	0.00	-23,514,145.92	27,341,156.63	3,827,010.71	760,257.67	-21,974,095.62	2%

Leased quay wall: DCF table, NPV and IRR for automated terminal (r = 8%)

Year		Throughput (TEU)	Capital cost (€)	Operating costs (€)	Income (€)	Cash flow (€)	PV (€)	NPV (€)	IRR (%)
2008	*0*	-	-22,680,875.00	0.00	0.00	-22,680,875.00	-22,680,875.00	-22,680,875.00	0%
2009	*1*	-	-39,042,000.00	0.00	0.00	-39,042,000.00	-36,150,000.00	-58,830,875.00	0%
2010	*2*	50,000	-807,527.65	-2,889,218.75	5,151,125.00	1,454,378.60	1,246,895.23	-57,583,979.77	0%
2011	*3*	150,000	-807,527.65	-8,884,347.66	15,685,175.63	5,993,300.31	4,757,675.02	-52,826,304.75	0%
2012	*4*	200,000	-807,527.65	-12,141,941.80	21,227,271.01	8,277,801.56	6,084,431.26	-46,741,873.49	-38%
2013	*5*	200,000	-807,527.65	-12,445,490.34	21,545,680.08	8,292,662.08	5,643,846.47	-41,098,027.02	-24%
2014	*6*	200,000	-807,527.65	-12,756,627.60	21,868,865.28	8,304,710.02	5,233,376.02	-35,864,651.00	-15%
2015	*7*	200,000	-3,030,572.27	-13,075,543.29	22,196,898.26	6,090,782.70	3,553,913.20	-32,310,737.80	-10%
2016	*8*	200,000	-807,527.65	-13,402,431.87	22,529,851.73	8,319,892.20	4,494,978.88	-27,815,758.92	-6%
2017	*9*	200,000	-807,527.65	-13,737,492.67	22,867,799.51	8,322,779.18	4,163,461.69	-23,652,297.23	-2%
2018	*10*	200,000	-807,527.65	-14,080,929.99	23,210,816.50	8,322,358.86	3,854,862.43	-19,797,434.80	0%
2019	*11*	200,000	-807,527.65	-14,432,953.24	23,558,978.75	8,318,497.86	3,567,661.15	-16,229,773.65	2%
2020	*12*	200,000	-12,050,118.15	-14,793,777.07	23,912,363.43	-2,931,531.79	-1,164,151.61	-17,393,925.26	2%
2021	*13*	200,000	-807,527.65	-15,163,621.49	24,271,048.88	8,299,899.73	3,051,855.91	-14,342,069.35	3%
2022	*14*	200,000	-807,527.65	-15,542,712.03	24,635,114.61	8,284,874.93	2,820,677.15	-11,521,392.20	5%
2023	*15*	200,000	-807,527.65	-15,931,279.83	25,004,641.33	8,265,833.85	2,605,735.55	-8,915,656.65	6%
2024	*16*	200,000	-807,527.65	-16,329,561.83	25,379,710.95	8,242,621.47	2,405,942.64	-6,509,714.01	6%
2025	*17*	200,000	-3,517,406.64	-16,737,800.87	25,760,406.62	5,505,199.11	1,487,884.39	-5,021,829.62	7%
2026	*18*	200,000	-807,527.65	-17,156,245.89	26,146,812.72	8,183,039.17	2,047,797.61	-2,974,032.02	7%
2027	*19*	200,000	-807,527.65	-17,585,152.04	26,539,014.91	8,146,335.21	1,887,604.15	-1,086,427.87	8%
2028	*20*	200,000	-807,527.65	-18,024,780.84	26,937,100.13	8,104,791.63	1,738,868.52	652,440.64	8%
2029	*21*	200,000	-807,527.65	-18,475,400.36	27,341,156.63	8,058,228.61	1,600,813.43	2,253,254.07	8%

Leased quay wall: DCF table, NPV and IRR for conventional terminal (r = 8%)

Year		Throughput (TEU)	Capital cost (€)	Operating costs (€)	Income (€)	Cash flow (€)	PV (€)	NPV (€)	IRR (%)
2008	*0*	-	-18,144,700.00	0.00	0.00	-18,144,700.00	-18,144,700.00	-18,144,700.00	-
2009	*1*	-	-27,114,000.00	0.00	0.00	-27,114,000.00	-25,105,555.56	-43,250,255.56	-
2010	*2*	50,000	-646,022.12	-3,677,187.50	5,151,125.00	827,915.38	709,803.99	-42,540,451.56	-
2011	*3*	150,000	-646,022.12	-11,307,351.56	15,685,175.63	3,731,801.94	2,962,424.70	-39,578,026.87	-
2012	*4*	200,000	-646,022.12	-15,453,380.47	21,227,271.01	5,127,868.42	3,769,136.37	-35,808,890.50	-
2013	*5*	200,000	-646,022.12	-15,839,714.98	21,545,680.08	5,059,942.97	3,443,712.17	-32,365,178.33	-
2014	*6*	200,000	-646,022.12	-16,235,707.85	21,868,865.28	4,987,135.30	3,142,741.19	-29,222,437.14	-
2015	*7*	200,000	-3,274,485.21	-16,641,600.55	22,196,898.26	2,280,812.50	1,330,832.19	-27,891,604.96	-
2016	*8*	200,000	-646,022.12	-17,057,640.57	22,529,851.73	4,826,189.04	2,607,439.77	-25,284,165.18	-
2017	*9*	200,000	-646,022.12	-17,484,081.58	22,867,799.51	4,737,695.80	2,370,027.43	-22,914,137.75	-
2018	*10*	200,000	-646,022.12	-17,921,183.62	23,210,816.50	4,643,610.76	2,150,890.26	-20,763,247.49	-
2019	*11*	200,000	-646,022.12	-18,369,213.21	23,558,978.75	4,543,743.42	1,948,733.67	-18,814,513.82	-
2020	*12*	200,000	-19,438,381.42	-18,828,443.54	23,912,363.43	-14,354,461.53	-5,700,354.17	-24,514,867.99	-
2021	*13*	200,000	-646,022.12	-19,299,154.63	24,271,048.88	4,325,872.13	1,590,614.20	-22,924,253.79	-
2022	*14*	200,000	-646,022.12	-19,781,633.49	24,635,114.61	4,207,459.00	1,432,475.87	-21,491,777.92	-
2023	*15*	200,000	-646,022.12	-20,276,174.33	25,004,641.33	4,082,444.88	1,286,956.88	-20,204,821.03	-
2024	*16*	200,000	-646,022.12	-20,783,078.69	25,379,710.95	3,950,610.14	1,153,145.44	-19,051,675.59	-
2025	*17*	200,000	-3,850,103.96	-21,302,655.66	25,760,406.62	607,647.00	164,228.12	-18,887,447.47	0%
2026	*18*	200,000	-646,022.12	-21,835,222.05	26,146,812.72	3,665,568.55	917,304.97	-17,970,142.50	1%
2027	*19*	200,000	-646,022.12	-22,381,102.60	26,539,014.91	3,511,890.18	813,747.32	-17,156,395.18	1%
2028	*20*	200,000	-646,022.12	-22,940,630.16	26,937,100.13	3,350,447.84	718,832.58	-16,437,562.60	2%
2029	*21*	200,000	-646,022.12	-23,514,145.92	27,341,156.63	3,180,988.59	631,921.67	-15,805,640.93	2%

50% Outside capital: DCF table, NPV and IRR for automated terminal (r = 8%)

Year		Throughput (TEU)	Capital cost (€)	Operating costs (€)	Income (€)	Cash flow (€)	PV (€)	NPV (€)	IRR (%)
2008	*0*	-	-20,149,635.04	0.00	0.00	-20,149,635.04	-20,149,635.04	-20,149,635.04	0%
2009	*1*	-	-22,728,219.34	0.00	0.00	-22,728,219.34	-21,044,647.54	-41,194,282.58	0%
2010	*2*	50,000	-3,207,219.34	-2,889,218.75	5,151,125.00	-945,313.09	-810,453.61	-42,004,736.19	0%
2011	*3*	150,000	-3,207,219.34	-8,884,347.66	15,685,175.63	3,593,608.63	2,852,722.39	-39,152,013.79	0%
2012	*4*	200,000	-3,207,219.34	-12,141,941.80	21,227,271.01	5,878,109.88	4,320,586.24	-34,831,427.56	-40%
2013	*5*	200,000	-3,207,219.34	-12,445,490.34	21,545,680.08	5,892,970.40	4,010,656.63	-30,820,770.92	-25%
2014	*6*	200,000	-3,207,219.34	-12,756,627.60	21,868,865.28	5,905,018.34	3,721,163.20	-27,099,607.72	-16%
2015	*7*	200,000	-4,381,894.13	-13,075,543.29	22,196,898.26	4,739,460.84	2,765,429.88	-24,334,177.84	-11%
2016	*8*	200,000	-3,270,371.82	-13,402,431.87	22,529,851.73	5,857,048.04	3,164,380.81	-21,169,797.03	-6%
2017	*9*	200,000	-3,270,371.82	-13,737,492.67	22,867,799.51	5,859,935.02	2,931,426.44	-18,238,370.59	-3%
2018	*10*	200,000	-3,270,371.82	-14,080,929.99	23,210,816.50	5,859,514.70	2,714,089.05	-15,524,281.54	0%
2019	*11*	200,000	-3,270,371.82	-14,432,953.24	23,558,978.75	5,855,653.69	2,511,389.50	-13,012,892.04	2%
2020	*12*	200,000	-8,137,900.83	-14,793,777.07	23,912,363.43	980,685.53	389,443.72	-12,623,448.32	2%
2021	*13*	200,000	-2,252,734.19	-15,163,621.49	24,271,048.88	6,854,693.20	2,520,456.46	-10,102,991.86	4%
2022	*14*	200,000	-2,252,734.19	-15,542,712.03	24,635,114.61	6,839,668.39	2,328,640.62	-7,774,351.24	5%
2023	*15*	200,000	-2,252,734.19	-15,931,279.83	25,004,641.33	6,820,627.31	2,150,146.18	-5,624,205.06	6%
2024	*16*	200,000	-2,252,734.19	-16,329,561.83	25,379,710.95	6,797,414.93	1,984,100.62	-3,640,104.43	7%
2025	*17*	200,000	-3,637,996.10	-16,737,800.87	25,760,406.62	5,384,609.65	1,455,292.80	-2,184,811.63	7%
2026	*18*	200,000	-2,283,056.61	-17,156,245.89	26,146,812.72	6,707,510.21	1,678,547.92	-506,263.71	8%
2027	*19*	200,000	-2,283,056.61	-17,585,152.04	26,539,014.91	6,670,806.26	1,545,706.29	1,039,442.58	8%
2028	*20*	200,000	-2,283,056.61	-18,024,780.84	26,937,100.13	6,629,262.68	1,422,296.42	2,461,739.00	9%
2029	*21*	200,000	-2,283,056.61	-18,475,400.36	27,341,156.63	6,582,699.66	1,307,691.12	3,769,430.12	9%

50% Outside capital: DCF table, NPV and IRR for conventional terminal (r = 8%)

Year		Throughput (TEU)	Capital cost (€)	Operating costs (€)	Income (€)	Cash flow (€)	PV (€)	NPV (€)	IRR (%)
2008	*0*	-	-16,119,708.03	0.00	0.00	-16,119,708.03	-16,119,708.03	-16,119,708.03	-
2009	*1*	-	-16,141,235.13	0.00	0.00	-16,141,235.13	-14,945,588.08	-31,065,296.12	-
2010	*2*	50,000	-2,584,235.13	-3,677,187.50	5,151,125.00	-1,110,297.63	-951,901.26	-32,017,197.37	-
2011	*3*	150,000	-2,584,235.13	-11,307,351.56	15,685,175.63	1,793,588.94	1,423,808.72	-30,593,388.65	-
2012	*4*	200,000	-2,584,235.13	-15,453,380.47	21,227,271.01	3,189,655.42	2,344,491.95	-28,248,896.70	-
2013	*5*	200,000	-2,584,235.13	-15,839,714.98	21,545,680.08	3,121,729.97	2,124,596.96	-26,124,299.73	-
2014	*6*	200,000	-2,584,235.13	-16,235,707.85	21,868,865.28	3,048,922.30	1,921,338.23	-24,202,961.51	-
2015	*7*	200,000	-3,973,136.32	-16,641,600.55	22,196,898.26	1,582,161.39	923,175.97	-23,279,785.53	-
2016	*8*	200,000	-2,658,904.78	-17,057,640.57	22,529,851.73	2,813,306.39	1,519,941.91	-21,759,843.63	-
2017	*9*	200,000	-2,658,904.78	-17,484,081.58	22,867,799.51	2,724,813.15	1,363,084.96	-20,396,758.66	-
2018	*10*	200,000	-2,658,904.78	-17,921,183.62	23,210,816.50	2,630,728.10	1,218,536.13	-19,178,222.54	-
2019	*11*	200,000	-2,658,904.78	-18,369,213.21	23,558,978.75	2,530,860.76	1,085,442.80	-18,092,779.74	-
2020	*12*	200,000	-10,509,851.04	-18,828,443.54	23,912,363.43	-5,425,931.15	-2,154,711.91	-20,247,491.65	-
2021	*13*	200,000	-801,677.56	-19,299,154.63	24,271,048.88	4,170,216.70	1,533,380.02	-18,714,111.63	-
2022	*14*	200,000	-801,677.56	-19,781,633.49	24,635,114.61	4,051,803.56	1,379,481.26	-17,334,630.36	-
2023	*15*	200,000	-801,677.56	-20,276,174.33	25,004,641.33	3,926,789.45	1,237,887.80	-16,096,742.56	-
2024	*16*	200,000	-801,677.56	-20,783,078.69	25,379,710.95	3,794,954.71	1,107,711.10	-14,989,031.46	-
2025	*17*	200,000	-2,439,570.81	-21,302,655.66	25,760,406.62	2,018,180.15	545,451.43	-14,443,580.03	1%
2026	*18*	200,000	-837,529.90	-21,835,222.05	26,146,812.72	3,474,060.77	869,380.34	-13,574,199.69	2%
2027	*19*	200,000	-837,529.90	-22,381,102.60	26,539,014.91	3,320,382.41	769,372.66	-12,804,827.03	2%
2028	*20*	200,000	-837,529.90	-22,940,630.16	26,937,100.13	3,158,940.07	677,744.93	-12,127,082.10	3%
2029	*21*	200,000	-837,529.90	-23,514,145.92	27,341,156.63	2,989,480.82	593,877.55	-11,533,204.56	3%

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