Part II - Ch 4 Container terminals

Quist, P.; Wijdeven, B.; Lansen, A.J.; van Koningsveld, M.; de Vriend, H.J.

Publication date
2021

Document Version
Final published version

Published in
Ports and Waterways

Citation (APA)
Quist, P., Wijdeven, B., Lansen, A. J., van Koningsveld, M., & de Vriend, H. J. (2021). Part II - Ch 4 Container terminals. In M. V. Koningsveld, H. J. Verheij, P. Taneja, & H. J. de Vriend (Eds.), *Ports and Waterways: Navigating a changing world* (pp. 115-160). TU Delft OPEN.

4 Container terminals

4.1 Backgrounds of container transport

4.1.1 Historic development

[1]After World War II world trade increased rapidly and sea transport along with it. This led to serious congestion in ports and long waiting times. Until that time, most of the goods used to be shipped in the form of general cargo (Figure 4.1), which was time consuming and labour intensive.

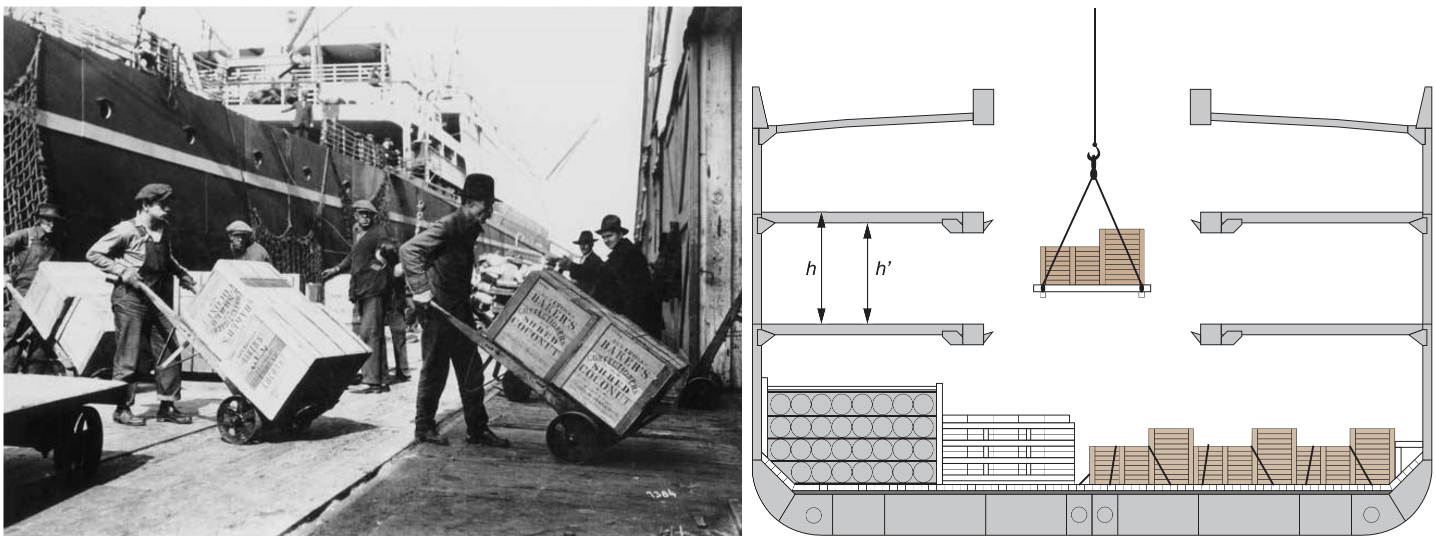


Figure 4.1: General cargo vessel loading and unloading; left: Longshoremen unloading cargo from a freighter by handtruck (by Asahel Curtis is licenced under CC0 1.0); right: a cross section of a general cargo vessel (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

The container had been introduced in the fifties as a standard size box for transport of cargo by truck and rail across the USA. Its use in sea transport followed after some time and reduced turnaround and waiting time in ports substantially (Van Beemen, 2008). In 1955 the White Pass & Yukon Route started operating a fully intermodal service between the Canadian mainland (Vancouver) and Alaska (Skagway). For this purpose a specially built container vessel was used, with a capacity of 4,000 tons or 600 containers.

Malcolm McLean (Figure 4.2) is generally regarded as the godfather of containerisation. His initiatives led more or less to the global application we know today. In 1955 he bought a shipping line (known as Sealand, later taken over by Maersk) and started maritime container transport. In the sixties, McLean's engineers developed technology to further speed up container handling, such as the corner casting, the twist lock, the spreader and the first container gantry crane.

In the sixties parties involved in container shipping finally agreed on a standard for the ISO container. The smallest early ISO container had dimensions of 8 ft x 8 ft x 20 ft (2.44 x 2.44 x 6.10 m^3). This explains why the capacity of a vessel or a container storage yard is still expressed in Twenty Feet Equivalent Units (TEU). Nowadays forty feet long containers are used besides the twenty feet ones, and additional standard sizes for length, width and height have been introduced.

At the end of the sixties, Sealand operated 36 container vessels and 27,000 containers and offered services to 30 ports worldwide. Initially limited to coastal shipping along the US West and East Coast, the first Sealand

[1]This chapter made use of the handout 'Container terminals' (Quist and Wijdeven, 2014) for the Ports and Waterway courses CIE4330 & CIE5306 at TU Delft

Figure 4.2: Malcolm McLean at railing, Port Elizabeth, mid-1960s (by Maersk Line is licenced under CC BY-SA 2.0).

containers arrived in Rotterdam in 1966. Following Sealand's success, many other shipping companies entered the container business. Over the past 45 years container shipping has boomed and spread across the globe, taking over a major share of general cargo transport (Van Beemen, 2008). Figure 4.3 shows how the world container throughput at ports has evolved over the last 50 years. The effect of the 2008 economic crisis is clearly visible, and so will the effect of the 2020 pandemic be.

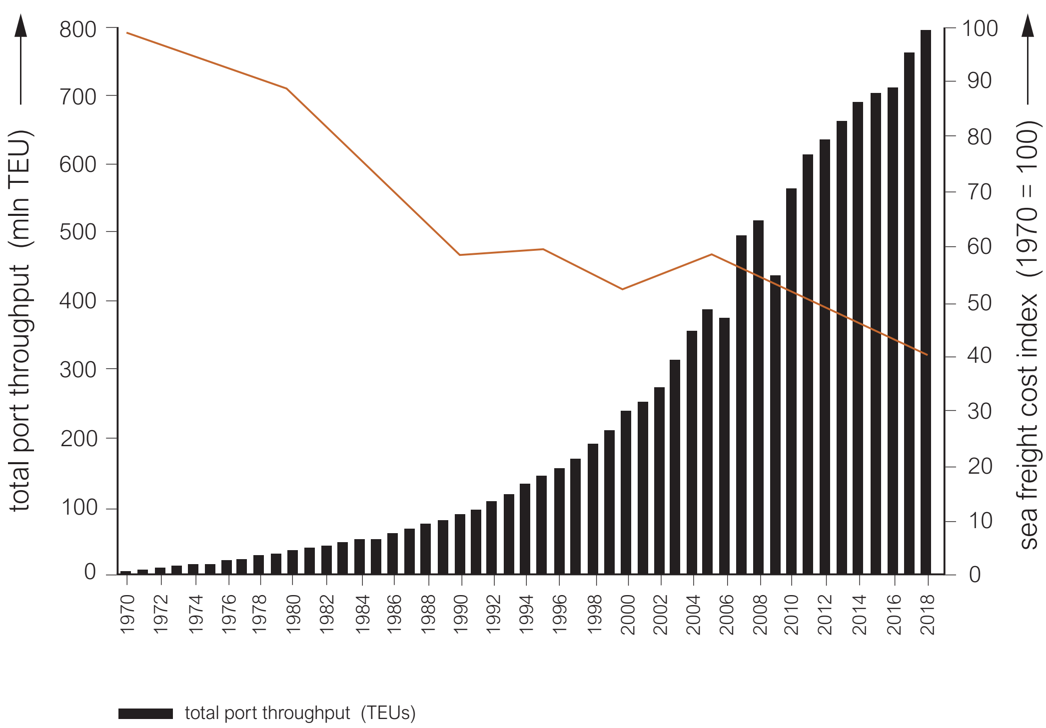


Figure 4.3: Evolution of world container port throughput and sea freight price index (source throughput until 2009: Global Networks; source throughput 2010-2018: UNCTAD; source freight price: Dr. Jean-Paul Rodrigue, Dept. of Global Studies & Geography, Hofstra University, New York, USA, image by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

A similar development has taken place in inland waterborne container transport, where the Netherlands have played a leading role (Figure 4.4).

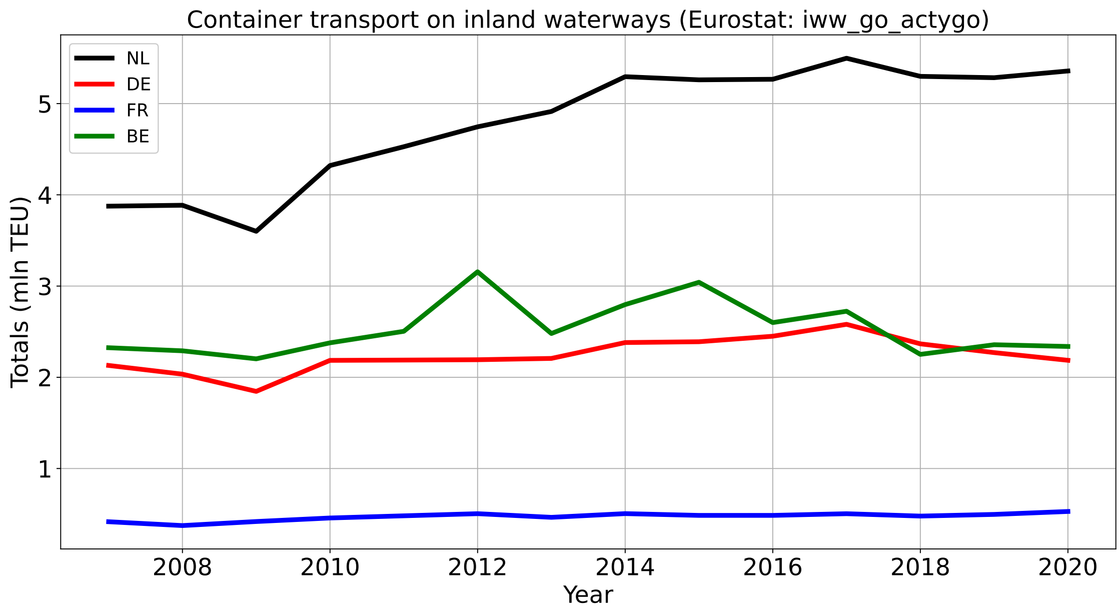


Figure 4.4: Evolution of inland container transport in Europe (source: Eurostat – iww_go_actygo; image by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Containerisation has contributed to significant changes in the global structure of manufacturing and production, and vice versa. Low-cost production has been moved to South-East Asia, India, Central America and Eastern Europe, which required a global transport network and has indeed led to a greater share of the world's production being transported worldwide (also see Part I – Chapter 1). Consequently, shipping lines have grown substantially in terms of geographical coverage, frequency of services and transit times. Mutual competition has driven them to an economy of scale approach, both in vessel size and organizational structure, which has brought down the costs per TEU significantly (Figure 4.5).

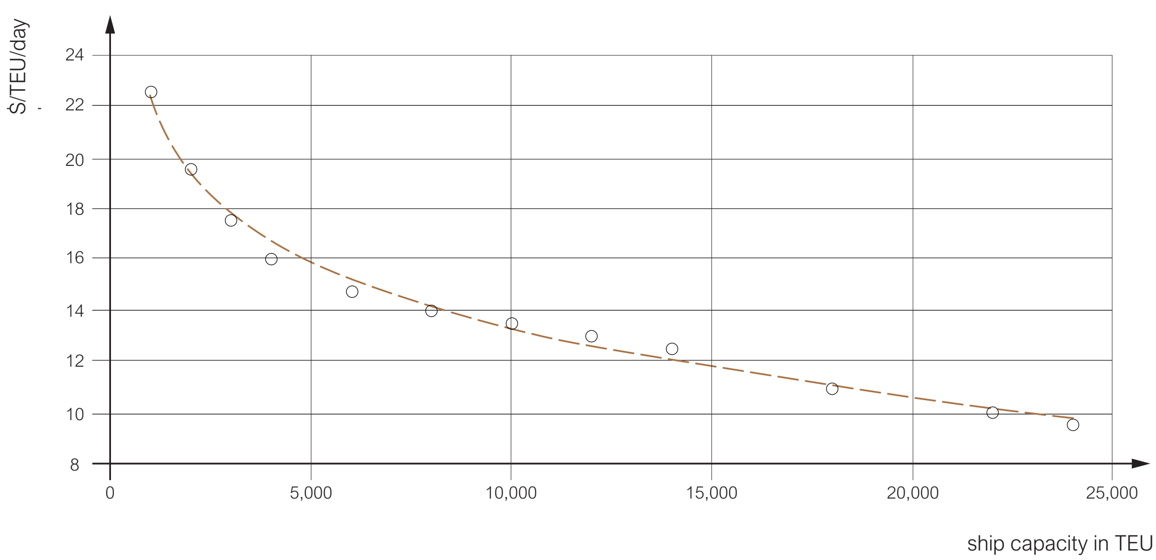


Figure 4.5: Daily operating expenses for container ships per TEU (reworked from https://transportgeography.org by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

4.1.2 Major transport routes

The drive to cost reduction not only led to larger ships, but also to investment sharing and round-the-world services. Ships call at different terminals during a trip, thus ensuring efficient use of their capacity. The two major traffic routes are the Europe – Far East route and the Trans Pacific – North route (Figure 4.6).

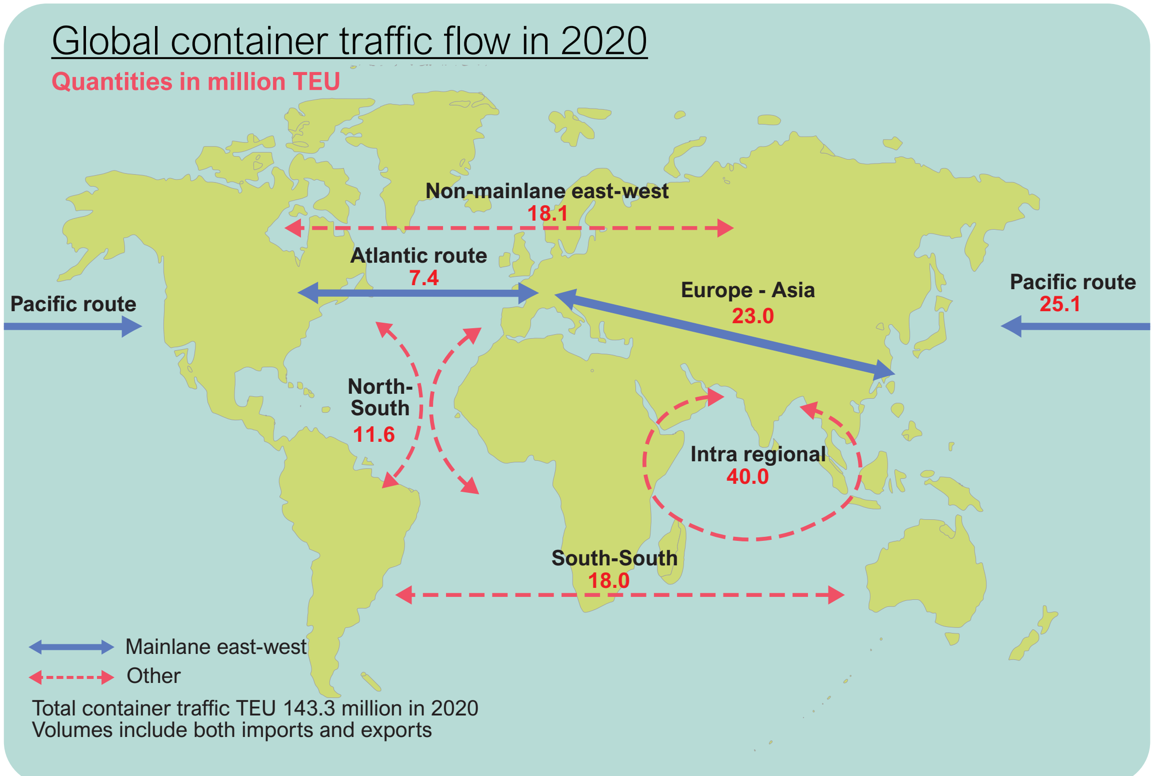


Figure 4.6: Major global container traffic flows, 2020 (source: UNCTAD, 2020, image by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

As an example, Figure 4.7 shows a detailed west- and eastbound schedule for Asia - Northern Europe. The transit time from Shanghai to Rotterdam is 33 days.

Figure 4.7: Example of a ship's schedule on the Mediterranean-Asia route (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Figure 4.8 gives another example, of the Transpacific-North route between China and the US-west coast. The transit time from Shanghai to Long Beach is 14 days.

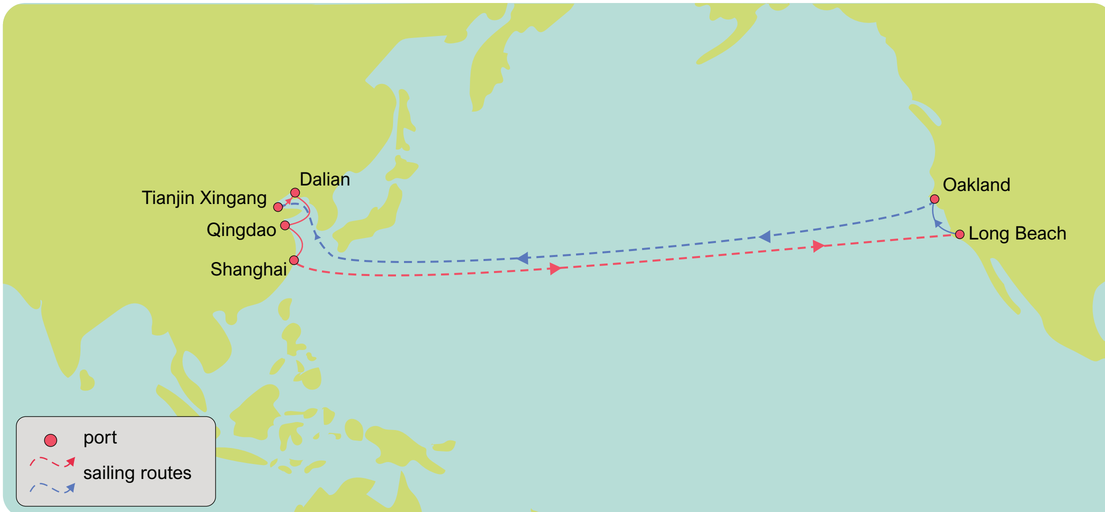


Figure 4.8: Example of a ship's schedule between China and the US west coast (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Figure 4.9 shows a third example, from the Transpacific-North route between China and the US-west coast via the Panama Canal. The transit time between Shanghai and New York is 28 days.

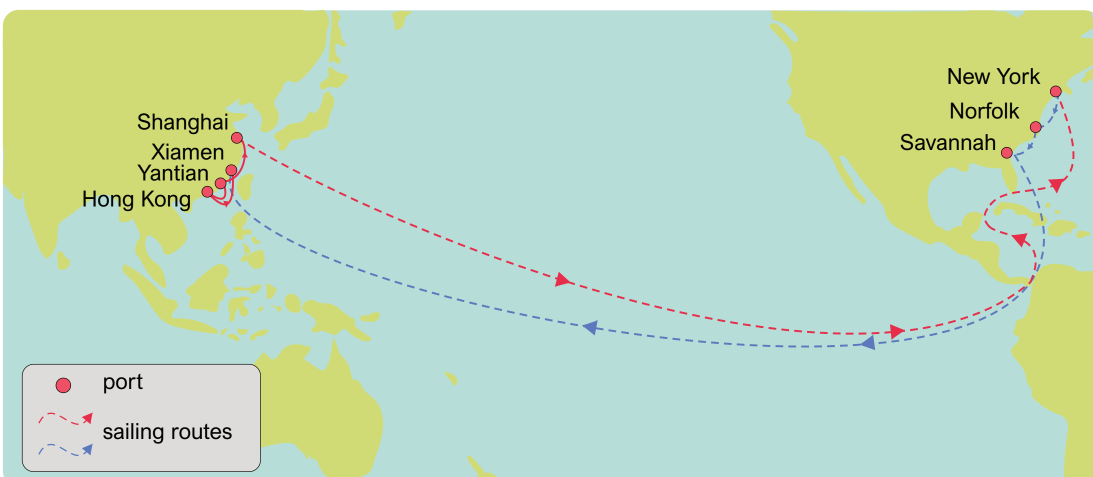


Figure 4.9: Schedule China – US east coast (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

4.1.3 Pros and cons

The worldwide shift to containerisation of almost all general cargo required enormous investments, which were only possible because of great advantages, such as (Van Beemen, 2008):

- *Labour saving* – up to 30 tons of containerised cargo can be discharged or loaded in a minute, by a crew of two to three people. Thanks to containerisation, labour intensive ad costly transfer of boxes, crates, drums, bags, sacks and bales from one mode of transport to another can be avoided.
- *Economies of scale* – for general cargo, larger vessels and larger port facilities were no solution, as loading and discharge time were already disproportionally high compared to actual sailing time and cost. Containerisation

brought the technical solutions and standardisation that enabled scale increase and cost reduction.

- *Time saving* – with containerisation, unloading and loading times of vessels, trains and trucks were reduced considerably. A large container vessel spends 24 hours in port, a much smaller conventional general cargo vessel several days.
- *More transport options* – world-wide container transport infrastructure enables shippers to develop long and complex transport chains that are fast, reliable and economical.
- *Security and damage reduction* – Because a container is packed only once, more attention can be paid to packing it properly, with knowledge of the product.
- *Safety* – general cargo stevedoring was hard, dirty and dangerous work. Container handling is generally a safer activity, although accidents still happen.
- *Cost saving* – cost saving continues with the ongoing scale increase in container transport (see Figure 4.5).

There are also disadvantages, however:

- *High investment cost* – well-equipped container infrastructure requires high investment. For the poorest nations it is difficult to raise the capital required for government-owned container terminals. Hence those countries do not get access to low-cost and efficient transport of goods, which hampers economic development and investment possibilities. Large global terminal operators are now breaching this vicious circle by increasingly investing in terminal facilities in developing countries.
- *Empties* – it is not always possible to find export cargo nearby for an unpacked import container. The empty container must then be stored or transported to a location where export cargo is available, which involves costs without direct revenue. About 20% of the total global port moves are empties. Because the dwell time for empties is higher than for loaded containers, the percentage of empties stored on terminals is often considerably higher. There is a lot of idle capital tied up in empty containers and there is also the cost of storing empties on expensive land close to the quay side. Efficient repositioning of empties can therefore make the difference between a loss or a profit for the shipping line.
- *Labour* – Because of containerisation the large general cargo stevedoring companies in the developed world have all gone, and in some developing countries this process is still ongoing. As a result a huge workforce got unemployed and only part of them could be absorbed by the new container terminals.
- *Theft* – theft in ports used to be widespread, though the scale of individual cases was mostly limited. Because of containerisation, theft in ports now concerns entire containers and is the domain of organised crime.
- *Smuggling* – smuggling of contraband, especially drugs, is a persistent problem in container ports, despite sophisticated detection technology. This, too, is the domain of organised crime, as is trafficking.
- *Security* – Customs have deployed high tech solutions such as X-ray scanning. Yet, experts are concerned that international terrorism may use container infrastructure for terrorist attacks.

Figure 4.10: ISO container dimensions (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

4.2 Container types and container vessels

4.2.1 Container types, sizes and demands

The International Standards Organisation (ISO) issued the official standard dimensions of containers (Figure 4.10):

- The most common standard is the TEU, which is a container with L_c = 20 ft (6.10 m), B_c =8 ft (2.44 m) and H_c = 8 ft 6 inches (2.60 m). Its own weight is about 24 kN. Its internal volume is approximately 32 m^3 and the maximum "payload" amounts to 220 kN. This implies that the container cannot be filled to the limit with high density cargo. In practice the payload is much lower even, on average around 100 kN;
- The forty feet container (2 TEU or 1 Forty Feet Equivalent Units (FEU)) measures twice as long and has the same width and height as the 20 ft container. Its own weight is about 45 kN and the internal volume measures 65 m^3. The maximum payload is only marginally higher than the TEU: 270 kN, but the average payload in practice is 175 kN.

There are several other container types in use, including:

- Oversize containers (longer than 40 ft) (of which in particular the 45 ft is used more often);
- High Cube containers (height 9 ft 6 inches, 2.90 m);
- Over width containers (wider than 8 ft). (Pallet wide containers, often 45 ft in length).

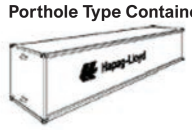
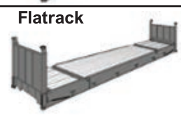
Standard container 	20 ft, 40 ft and 40 ft High-Cube Version Standard container with full steel box top, bottom and sides and end doors
Hardtop Container 	20 ft, 40 ft and 40 ft High-Cube Version Standard container with a removable steel roof. Used for heavy or tall cargoes – with loading from the top or side
Ventilated Container 	20 ft Especially for cargo which needs to be ventilated.
Refrigerated Container 	20 ft, 40 ft and 40 ft High-Cube Version The cooling is provided via a built-in electrically driven unit. Power is supplied either through power grids on board or ashore, or by "clipon" diesel generators during land transport.
Porthole Type Container 	20 ft and 40 ft This container does not have a built in cooling unit. The cooling is provided through openings (port holes) either by the ship's refrigeration system, a land terminal or by a 'clip-on' refrigeration unit during land transit.
Open-Top-Container 	20 ft and 40 ft Provided with removable tarpaulin. Especially for over-height cargo. Loading from the top or side.
Flatrack 	20 ft, 40 ft and 40 ft High-Cube Version Especially for heavy loads and wide loads.
Platform 	20 ft and 40 ft Especially for heavy loads and oversized cargo.
Tank Container 	20 ft For the transport of liquids including foodstuffs, for example: petrochemical products, alcohol, fruit juices, edible oils, food additives.

Table 4.1: Container types (modified from PIANC, 2014b, by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0)

The latter category originally measures 8 ft 2.5 inches (2.50 m), because that width allowed placing two Euro pallets side-by-side inside the container. Moreover, it is the maximum width permitted on the Western European roads. Since this has been relaxed to 2.60 m, the container width of 8 ft 6 inches has become more common.

As can be expected, the use of non-ISO containers gives complications, hence extra costs:

- On the vessel the cell guides in the holds are designed to receive ISO containers. Hence Oversize and Overwidth containers have to be placed on deck, which limits the flexibility of the loading schedule.
- On the terminal the Oversize containers, also known as OOG need their own stacks, which again limits flexibility.
- The "spreader", the frame used under the crane trolley or by the yard equipment to pick up a container by the four twist locks at the corners, must be adjustable to accommodate the different lengths (20, 30, 40 or 45 ft) and widths.
- For the onward transport of containers by road or rail different lengths require special provisions on the trailer or rail wagon to fasten the containers at the corner castings.

Apart from the variation in size there is a range of special purpose containers (see Table 4.1).

Dry ISO containers are used for general purpose transportation. The cargo is loaded via doors at the end of the container. These totally enclosed, box-type containers are also called dry vans.

Thermal or insulated ISO containers are used to transport chilled and frozen goods. They are also used for temperature sensitive products. These containers have insulated walls but they don't have a refrigeration unit.

Refrigerated ISO containers (reefers) are used when a steady temperature must be maintained during transport. They are the same as insulated containers but have a built-in refrigeration unit. Reefers require electricity supply, both on the vessel and on the terminal. In case reefers are stacked in multiple layers, reefer racks are provided (Figure 4.11).

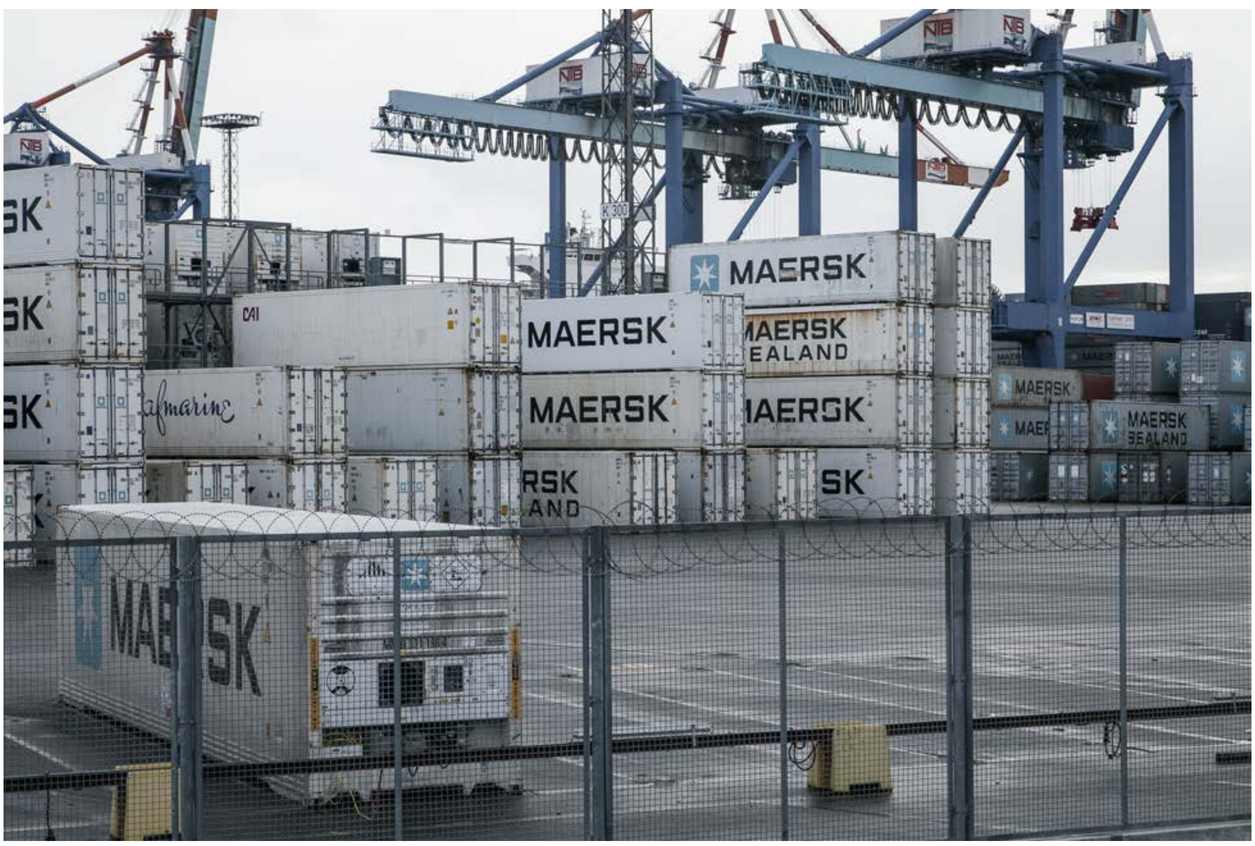


Figure 4.11: Reefer racks in a container storage (by Stefan Georgi is licenced under CC BY-NC-SA 2.0).

Flat racks and platforms are used to transport heavy machinery. They have no side walls, but may have end bulkheads. There are also collapsible flat rack containers. These are open-sided containers with end bulkheads that can be folded down when the rack is empty.

Open top containers are used to transport heavy, tall or hard-to-load cargo, and bulk material, such as coal or grain. These box-type containers with no top can be loaded from the top or from the end.

Tank type containers are used to transport liquid or bulk materials. They have a cylindrical tank mounted within a rectangular steel framework, with the same overall dimensions as other intermodal containers. Heated tank containers are used for wax, for instance.

4.2.2 Container vessels

The "first generation" container vessels were general cargo vessels, converted to carry containers. Since then several classes of container vessels have been built with ever increasing dimensions and capacities (Table 4.2, Figure 4.12 and Figure 4.13).

Vessel class	**TEU-capacity**	**DWT-range**	L_s	D_s	B_s
1^{st} generation	750 – 1,100	14,000	180 – 200	9	27
Feeders	1,500 – 1,800	30,000 – 35,000	225 – 240	11.5	30
Panamax I	2,400 – 3,000	45,000 – 80,000	275 – 300	12.5	32
Panamax II	3,000 – 5,000	80,000 – 100,000	290 – 310	12.5	32.3
Post Panamax	5,000 – 10,000	90,000 – 120,000	270 – 320	12.5 – 16	38 – 42
New Panamax	10,000 – 14,500	120,000 – 150,000	366	15.2	49
ULCV	14,500 – 24,000	157,000 – 235,000	400	15.2 – 16	56 – 61

Table 4.2: Container vessel characteristics (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Figure 4.12: The ULCV MSC Gülsün (23,756 TEU) on its way to the port of Rotterdam (MSC GÜLSÜN by kees torn is licenced under CC BY-SA 2.0).

For port planning purposes the development of the size of container vessels is of great importance. Parties involved are continuously trying to beat competitors by creating the possibility to accommodate vessels bigger than existing ones. Limiting factors in vessel design, such as structural strength, engine capacity, cavitation of propeller and rudder, cargo handling speed and available depth in ports have gradually been resolved. The recently built container vessels enable economies of vessel size due to their large hauling capacity, but diseconomies of scale in their handling capacity (relatively long service times in ports). Hence it makes sense to deploy large vessels at long distance routes (Veldman, 2011).

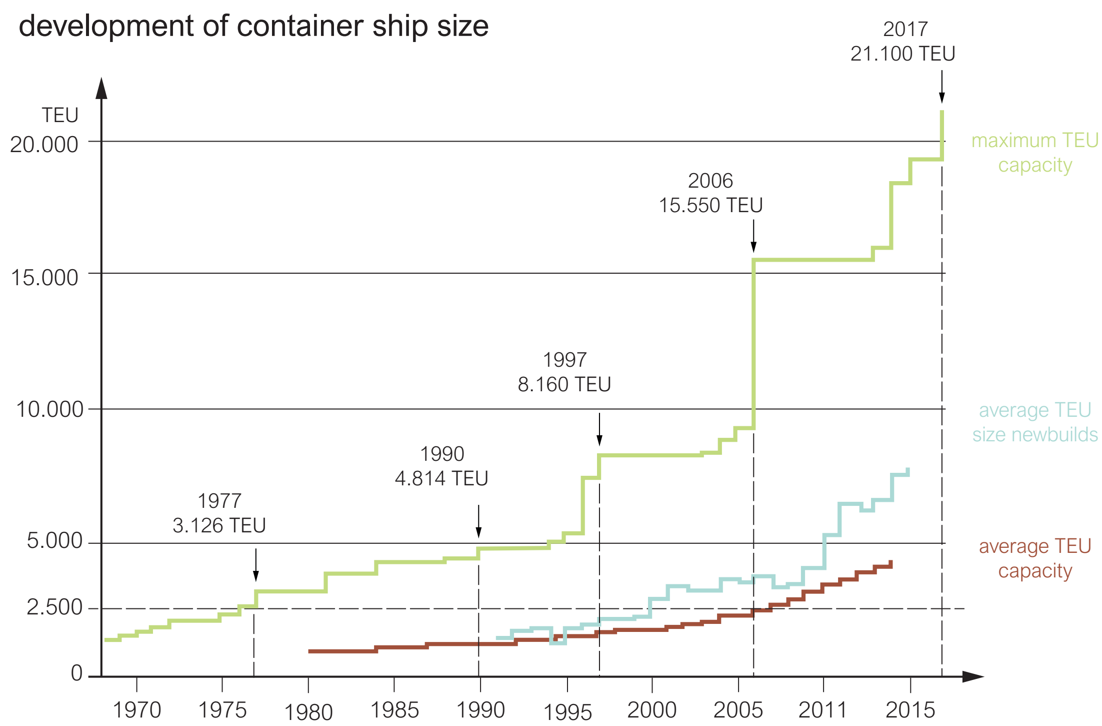


Figure 4.13: Development of container vessel capacities (reworked from Merk, 2018, by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

4.2.3 Container flows and modal split

The yearly averaged throughput of containers is key input into planning and design of a container terminal. It is derived from the so-called modal split, which gives gives the (forecasted) numbers of containers entering and leaving the terminal via the sea (main lines, feeder lines and short-sea lines), road, rail and IWT.

As shown in Figure 4.14, there are various flows of containers:

- *The import flow* – discharged from a seagoing vessel and finding its way the hinterland;
- *The export flow* – coming from the hinterland and loaded onto a seagoing vessel;
- *The sea-to-sea flow* – transhipment containers that are discharged from a deep-sea or feeder vessel and loaded again onto another deep-sea or feeder vessel;
- *The land-to-land flow* – mostly empty containers returned to the empty depot and leaving again for reloading with local export products; other containers come in by one landside modality, e.g. truck, and leave by another, e.g. IWT.

Figure 4.14, furthermore, gives a simplified example of a modal split, with arbitrary numbers. The assumption that the flows are balanced per transport mode is clearly a simplification of reality: in most cases there is a distinct imbalance. The throughput figures shown include the empty containers, which normally are singled out, because they may be stacked and handled more economically than loaded containers.

The modal split gives the transport flows in number of containers per unit time (in this case year). This is relevant for the quay length design, because the container crane production is also expressed in number of container (moves) per unit time (hour). The other capacity calculations are therefore also carried out in TEU per unit time. For the capacity of the storage yard the division between 20 ft and 40 ft containers has to be known, because the surface area depends on this. This is taken into account via the TEU-factor:

$$f_{TEU} = \frac{N_{20} + 2N_{40}}{N_{20} + N_{40}} \tag{4.1}$$

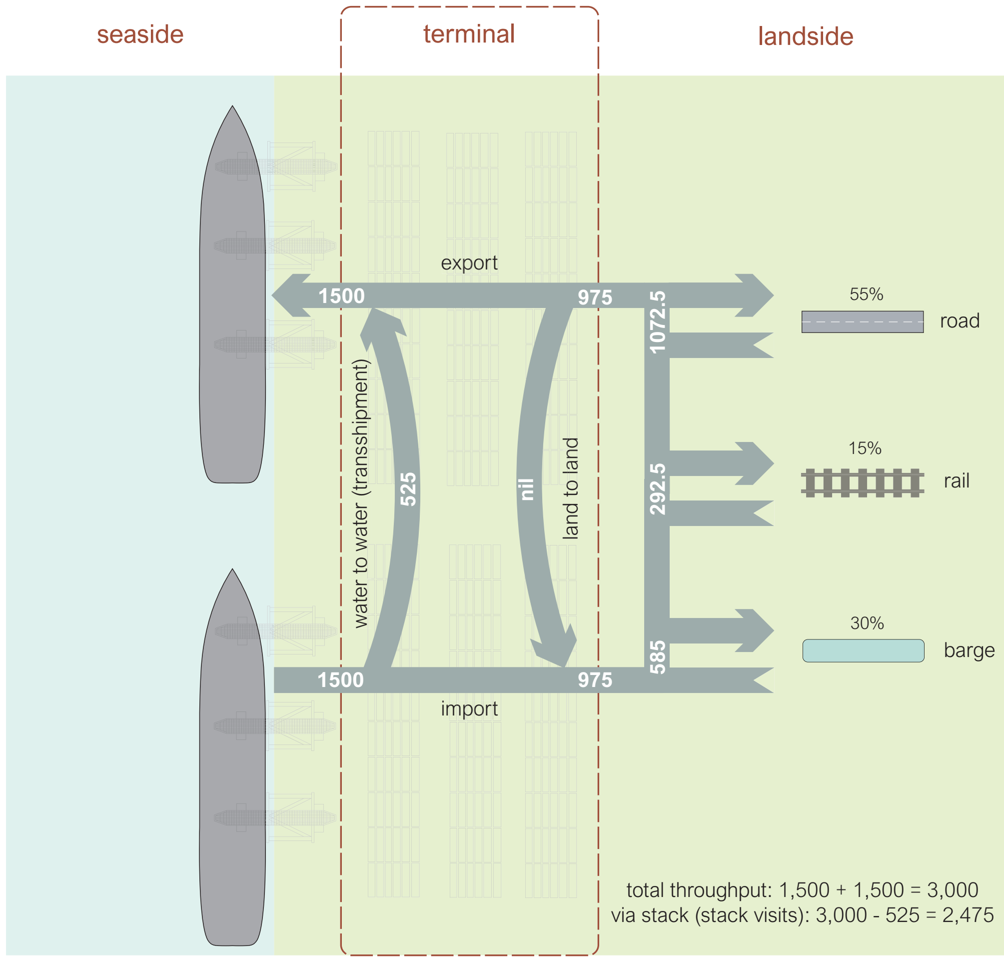


Figure 4.14: Container flows and modal split example (numbers × 1,000 TEU/year) (modified from Quist and Wijdeven, 2014, by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

in which N_{20} is the number of TEUs and N_{40} the number of FEUs. This TEU-factor is often characteristic of the type of port and can be derived statistically from data. In developing countries TEU-factors are often low, indicating that a large percentage of goods is transported in 20 ft containers. On the main routes there is a tendency towards 40 ft containers, a trend that is likely to continue for some time.

The initial planning of a container terminal is often based on rules of thumb or relatively simple design formulae, as presented in the subsequent sections, or on a simple form of queuing theory. The final layout may be optimised by means of simulations, which permit to analyse the complete terminal process, including the stochastic processes such as vessel arrivals, crane and other transport equipment availability, and container arrivals/departures via land. Such sophisticated simulation models, however, require precise and reliable input in order to produce reliable results. Also the stochastic character of vessel arrivals is limited nowadays because of tight sailing schedules. Tramp shipping as occurred during the early years of container shipping hardly occurs anymore. As a consequence, scenario-approaches are replacing black-box stochastic approaches.

4.2.4 Terminal archetypes

The relation between the main container flows as described in Section 4.2.3 is the principal determinant of the type of terminal. There are two categories of container terminals, viz.

- gateway terminals, and
- transhipment or hub terminals.

Gateway terminals form the gate to and/or out of a vast hinterland with emphasis on import and export of captive cargo. The most important containers flows are import and/or export. Examples are the ports of Shanghai (China) and Busan (Korea). Import in these gateway terminals consists for a considerable part of empty containers that are being filled with industrial products coming from the hinterland. It can also be the other way around: import mainly consisting of loaded containers and export of empty containers. This is for instance happening in Jeddah (Saudi Arabia) and Kuwait City.

Historically, the hinterland was the determining factor for port site selection. The development of round-the-world services, however, is one of the reasons why specialised transhipment ports have emerged at places without much of a hinterland. Transhipment ports focus on sea to sea flow of containers, rendering landside facilities of less importance. Examples are the ports of Hong Kong (PRC), Singapore, Aden, Salalah (Oman), Dubai and Gioia Tauro (Italy), Algeciras and Valencia (Spain), Malta, Tanger Med (Morocco) and Port Said (Egypt).

Regarding container handling, the Port of Rotterdam is a mix between a gateway and a transhipment port. Rotterdam has a relatively large hinterland and thus attracts a significant volume of gateway containers. That is the reason why the large container carriers deviate from their round-the-world route to call at the Port of Rotterdam. It makes this port also attractive as a container feeder hub for Scandinavia, the Baltic region and part of the United Kingdom.

4.2.5 Forecasting trade and traffic

Trade forecasting is necessary to estimate the demand for traffic, hence for shipping. Traffic forecasting is key to defining the need for terminal facilities. Thus it provides the basis for assessing the viability of a port development project.

Based on trade forecasts in a port's hinterland, traffic forecasts estimate what traffic this could generate through the port, at present and in the future. Traffic forecasts must include transhipment trade and free trade zone goods.

Several techniques may be used, depending on the circumstances:

- For an existing port, it may be sufficient to start with the existing throughput and assume that the traffic will generally grow in proportion to the GDP. This assumes that there are no significant new developments or industries planned in the region which would generate additional specific traffic.
- For a new port or terminal, it may be necessary to conduct interviews with local key industries to ascertain their potential trade and their specific development plans. In order to have a picture of the potential future traffic to the terminal, studying local and regional plans may also be useful.
- In some cases existing general cargo flows may be transferred into containers, which means that rate of containerisation must be estimated in order to have a useful forecast.

It is important to distinguish import/export traffic from transhipment traffic. Import/export traffic is usually the economic foothold of a terminal. Routing the cargo through a different port involves extra costs, so a terminal is generally assured of a certain basic throughput, provided that the facilities keep pace with the demand. Transhipment cargo, however, is easily switched from one port to another if the shipping line manages to negotiate a better deal. Developing a terminal solely on the basis of transhipment is therefore risky.

Container vessel forecasting requires a proper understanding of the nature of the container trade in the region. Maybe local import/export trade will only justify small feeder vessels, or the strategic location of a terminal may rather make it suitable as a global hub for transhipment. In any case the size of container vessels actually deployed in the region serve as a guide to identify the vessel sizes for which the terminal should be designed.

The future development of vessel sizes should also be taken into account, to ensure that access channels, layout, structures and facilities are adaptable if larger vessels need to be accommodated.

Once the "design vessel" dimensions have been defined, all these aspects can be elaborated in further detail. Apart from these design vessel dimensions, the composition of the fleet, the "vessel mix", is an important input to terminal design. The berth configuration and handling capacity required are not a matter of the largest vessel alone, as illustrated by the time-evolution of the average vessel size in Figure 4.13.

4.3 Container terminal operations

Before going into the development of an actual container terminal layout, it is important to understand the logistic process on container terminals. As far as they are relevant to the terminal design, we describe them in this section.

4.3.1 At the quay

Prior to arrival of a vessel the containers to be unloaded have been identified (and those to be loaded have been arranged in the export stack in such a way that they can be transferred to the vessel in the right order).

Immediately after the vessel has made fast at the berth the lashings are taken off the containers above deck and the STS gantry cranes (or portainers) start unloading. A modern STS gantry crane is as high as a cathedral, especially with its booms up. Figure 4.15 presents Post Panamax STS gantry cranes at container terminal Altenwerder in Hamburg (Germany).

Figure 4.15: Post Panamax STS crane at container terminal Altenwerder, Hamburg, Germany (by www.hippopx.com is licenced under CC0 1.0).

These STS cranes are generally rail-mounted. They are characterised by a boom which extends across the moored vessel. This boom can be lifted (Figure 4.16), or pulled inward (when close to airports, for instance). The cranes are provided with a trolley with a spreader, enabling to pick up a container (or two), bring it onto the quay and place it on a transport vehicle that brings it to the storage yard (or vice versa). As container ships were getting larger, STS cranes had to follow in height and reach. At present, the most common STS crane is based on an A-frame with tip-up boom (Figure 4.16). This figure also shows the typical dimensions of an STS crane suitable to handle Super – Post Panamax vessels. Mobile harbour cranes are also used for the loading and unloading of container vessels, mainly small ones.

Some typical properties of STS cranes are:

- *Lifting capacity* – originally 400 kN, now increasing to 800 kN and above, to allow for twin/tandem handling.
- *Outreach* – going up from 30 m for handling Panamax vessels to 70 m for handling Very Large Container Vessels (VLCVs) and Ultra Large Container Vessels (ULCVs).
- *Rail gauge* – varying from 15 to 35 m.

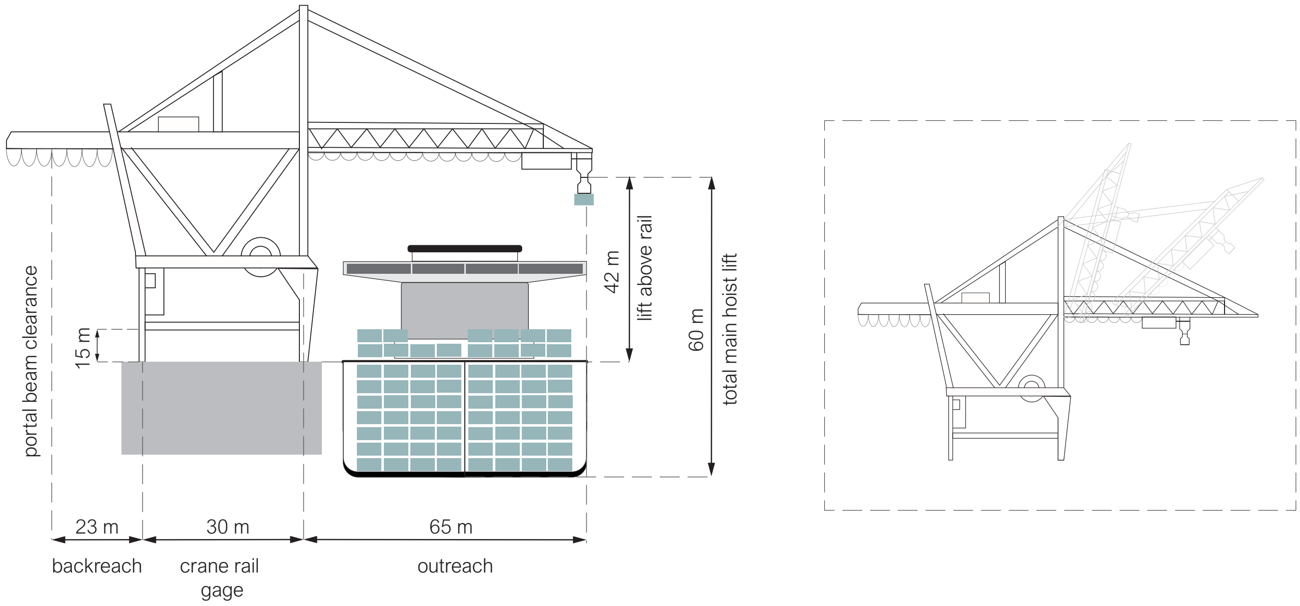


Figure 4.16: A-frame STS crane with typical dimensions for handling Super - Post Panamax vessels (modified from Bartosek and Marek, 2013, by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

- *Width between legs* – min. 16 m, to allow oversized containers to pass.
- *Crane productivity* – peak 40-50 moves/hr, average 20-30 moves/hr.

Crane productivity is a key indicator and one of the critical parts of overall terminal productivity. The productivity of an STS crane is measured by the number of moves per hour. One move equals a move of a container between vessel and transport vehicle or vice versa. Feeder vessels are being served by 1-2 STS cranes, while Super - Post Panamax vessels can be served by 6-8 STS cranes (Figure 4.17). The STS cranes at the ECT Euromax terminal have a reach of 23 containers wide.

Figure 4.17: 21,000 TEU COSCO Development being handled by six STS cranes at Euromax terminal in the port of Rotterdam (SIF W & COSCO NEBULA by kees torn is licenced under CC BY-SA 2.0).

4.3.2 Between quay and storage yard

For the transport between quay and storage areas several options exist, depending on the size and the throughput of the terminal and the preferences of its operator. In increasing order of sophistication these are:

- *Toploaders (Figure 4.18, left)* – In the past Forklift Trucks (FLTs) were used, nowadays toploaders. Toploaders are equipped with a spreader to pick up a container from above and are capable of handling loaded containers. Top loaders need sideway access to a stack, which can therefore be only two containers wide. This requires much space between the stacks. On multipurpose terminals with limited container throughput and much space this type of equipment offers an economic solution. Empty container handlers are used in the empty container depot, their lifting capacity is smaller than that of top loaders. Empty container handlers pick up the containers sideways.
- *Reach Stacker (RS) (Figure 4.18, right)* – The difference from the FLT is that this device handles the container by means of a boom with a spreader. Hence it can reach the second row of containers in a stack, which can therefore be four rows wide. Yet, space efficiency is rather low. Another disadvantage is the relatively high front axle load (up to 100 tons), which asks for strong pavement.

Figure 4.18: Container handling equipment; left: toploader (by Gazouya-japan is licenced under CC BY-SA 4.0); right: reach stacker (by NAC is licenced under CC BY-SA 4.0).

- *Chassis (Figure 4.19, left)* – Single trailers for use in the yard only, where they are moved by tractor units. The containers are stored on the chassis. This approach, quite customary in U.S. ports, has the disadvantage of low space utilisation as compared with the stacking approach applied in Europe and Asia. It is very easy, however, to select containers and remove them from the stack.
- *Straddle Carrier (SC) (Figure 4.19, right)* – For this equipment the stack consists of (not too lengthy) rows of containers, separated by lanes wide enough for the legs and tyres of the SC. Depending on the nominal stack height, 2- or 3-high, the SC can lift a container 1 over 2 or 1 over 3. Certainly in the latter case the SC becomes quite tall and difficult to manoeuvre since the driver cabin is on top. However, for reasons of space efficiency and flexibility the SC is quite popular among terminal operators.

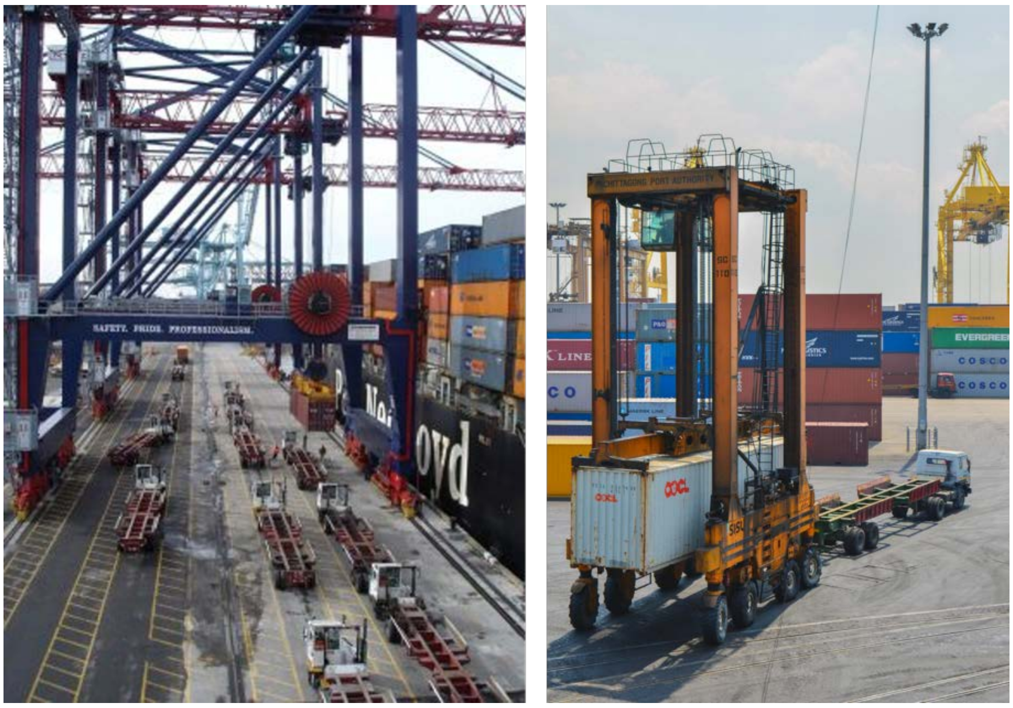


Figure 4.19: Container handling equipment; left: chassis (from www.portstrategy.com, "Take a load off", Copyright by Mercator Media Ltd 2021); right: straddle carrier (SC from Port of Chittagong by Moheen Reeyad is licenced under CC BY-SA 4.0).

The above four types of equipment deal with the transport from quay to storage yard and within the yard. In high capacity terminals the two functions are often separated, with dedicated cranes within the stack and the following types of vehicles for transport between quay and yard:

- *Multi Trailer System (MTS), Figure 4.20, left)* – A series of up to 5 interconnected trailers is pulled by one yard tractor. This offers a substantial reduction of the number of drivers needed. The system, developed and manufactured in The Netherlands, has a special device to keep all trailers in line when making a turn. MTS is not a very common means of horizontal transport on the larger and modern terminals nowadays. On the other hand MTS can be a very suitable on dedicated interconnecting lanes between terminals in a port complex.
- *Automated Guided Vehicle (AGV), Figure 4.20, right)* – Developed and first implemented by ECT on the Delta-SeaLand terminal on the Maasvlakte. They are fully automated and therefore mean a further drastic reduction of manpower.

Figure 4.20: Container transport vehicles; left: Multi Trailer System (MTS) (by Govender et al., 2017, is licenced under CC BY 4.0); right: Automated Guided Vehicle (AGV) (by Europe Container Terminals (ECT) is licenced under CC BY-NC-SA 4.0).

- *Lift AGVs (Figure 4.21* – are a further development of AGV technology. Unlike conventional AGVs, the lift AGV has two active lifting platforms. These enable the vehicle to lift and place containers independently on transfer racks in the interchange zone in front of the stacking cranes. Two 20' containers can be handled independently, as well as one other container of any size. This can result in shorter downtimes and increased working frequency.

Figure 4.21: Lift Automated Guided Vehicle (Lift-AGV) (from www.konecranes.com, "Lift AGV", Copyright by 2021 Konecranes).

Advantages	Disadvantages
Top Loader (TL) / Reach Stacker (RS)	
low investment equipment	much storage capacity needed
simple / flexible in operation	labour intensive
Straddle Carrier (SC)	
high throughput capacity	complicated equipment
one type of equipment for entire terminal	high investment and maintenance costs
	highly qualified personnel needed
	labour intensive
Automated Guided Vehicle (AGV)	
minimal labour costs	high investment and maintenance costs
high throughput capacity	complicated and sensitive equipment

Table 4.3: Quay-to-storage transport and container handling systems (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

4.3.3 Within the storage yard

The MTS and AGVs deliver the containers outside the stacks and for further handling within the stack separate equipment is needed. Various types of gantry cranes are used as described below:

- *Rubber Tyred Gantry (RTG), Figure 4.22* – This type is commonly used in stacks up to about 6 containers wide and about 5 high. They are flexible (can be moved from one stack to another), but require good subsoil conditions or a track with adequate foundation, in view of the relatively high wheel loads;

Figure 4.22: Rubber Tired Gantry crane (RTG) (RTG at Bintulu International Container Terminal (BICT) by R.W. Sinyem is licenced under CC BY 2.0).

- *Rail Mounted Gantry (RMG), Figure 4.23* – Where the subsoil conditions are less favourable or loads are heavier the RMG is preferable, because the rails spread the load better. Notwithstanding the greater span of the crane (up to 10 containers wide) the crane bogies provide for lesser wheel loads. Also, the rail can be more easily supported, if needed.

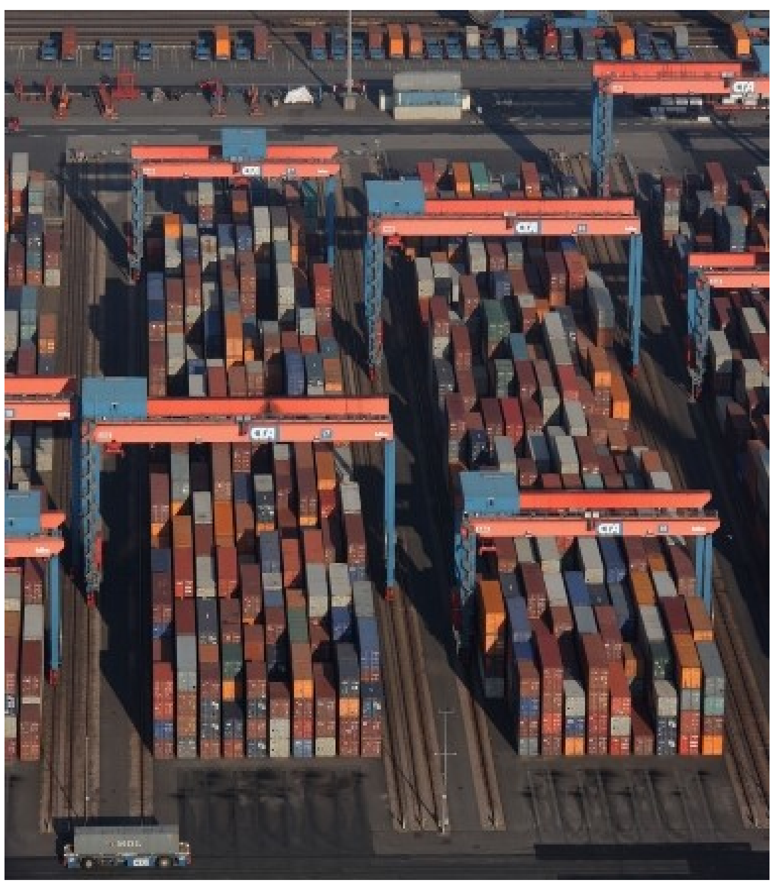


Figure 4.23: Rail mounted gantry cranes (RMGs) at the Altenwerder terminal, Hamburg (Port of Hamburg, Container Terminal Altenwerder by Dirtsc is licenced under CC BY-SA 3.0).

- While most RMGs have the rails at ground level, a terminal in Singapore has an overhead crane running on rails at 18 m above ground level, mounted on beams supported by concrete columns; this type is referred to as Overhead Bridge Crane (OBC);
- *Automated Stacking Crane (ASC), Figure 4.24* – The first cranes of this type were introduced by ECT in conjunction with the AGVs. They reach across about 10 containers and operate 1 over 4 high at most terminals (for instance ECT Euromax terminal at Maasvlakte, Rotterdam).

Figure 4.24: Automated Stacking Cranes (ASCs) (by ECT is licensed under CC BY-NC-SA 4.0).

Advantages	Disadvantages
Rubber Tyred Gantry (RTG)	
good space utilisation	high maintenance costs
flexible, high occupancy rate	labour intensive
reasonable productivity	
Rail Mounted Gantry (RMG)	
good space utilisation	high investment costs
reliable, low maintenance costs	inflexible
automation and relatively high productivity possible	
Automated Stacking Crane (ASC)	
minimal labour costs	higher investment than for RMG
high capacity	

Table 4.4: Equipment within the stacks (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

4.3.4 From storage to hinterland transport

The transport of containers between the stacks and the truck stations (and vice versa) is done mostly by the equipment that is also used in the stack. At a terminal with straddle carriers, for instance, these bring the containers to the truck station and position them on the trucks (see Figure 4.19, right). Depending on the distance, various types of equipment are used for transport from the yard to a rail or inland barge terminal. The same considerations apply as for the equipment between quay and storage yard (see above).

There are basically three modes of container transport to the hinterland:

- *Road transport* – via the truck station and the gate,
- *Rail transport* – via a rail terminal,
- *IWT transport* – via the IWT terminal.

The gate

For road transport the gate is a central element on the terminal (Figure 4.25). Here imported containers leave the terminal and containers to be exported arrive. All entries and departures are recorded and customs formalities are dealt with here. High-capacity terminals require advanced information technology to avoid frequent queues and long waiting times for the trucks.

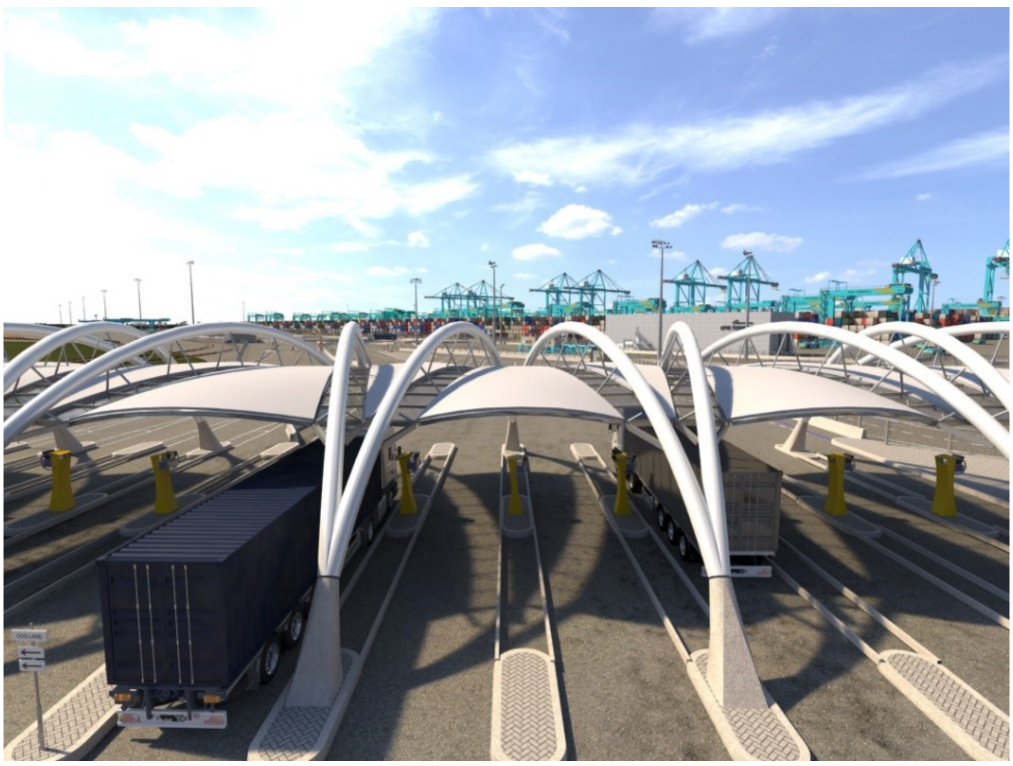


Figure 4.25: The gate (canopy) at APMT Maasvlakte 2 terminal, artist impression (Verkeersportaal APM Terminals by APM Terminals is licenced under CC BY-NC-SA 4.0).

As described in PIANC (2014b), the gate facilities are usually divided into an entrance or receiving gate for trucks entering and a separate exit gate for trucks exiting the terminal. The number of entrance and exit lanes required is determined by the predicted level of traffic for the terminal.

Many modern terminals using Automatic Equipment Identification System (AEIS) (standardised by ISO/TC 104/SC 04/WG 02 "AEI for containers and container related equipment") have a pre-gate entrance system. This divides the gate procedure into two parts, thus reducing the required time at the gate itself and, consequently, the number of lanes and space required:

- At Position 1 (pre-check) the necessary information, such as booking numbers, is exchanged between a clerk in the control room and the truck driver. An AEIS reader puts the container's code into the terminal's computer system.
- Subsequently, the truck is driven to the gatehouse (Position 2) where remaining gate procedures are carried out.

As described in PIANC (2014b), the terminal gate often has to provide space to accommodate additional port functions such as:

- *Port Security and ISPS compliance* – The requirement is to verify the identity of anyone passing the demarcation (usually a fence) between the port and terminal area proper.

- *Radiation Detection* – to incoming and outgoing containers. This check is accomplished by special mobile or fixed equipment called Radiation Portal Monitors.
- *Customs inspections* – Usually an area near the exit gate has to be set aside for the customs officials to be able to selectively inspect the content of incoming containers for contraband and collect the customs duty. At many terminals in the developing world the customs inspection procedure is time consuming, which often constitutes a bottleneck in the flow of containers. In such cases separate facilities ought to be provided. The application of X-ray equipment for customs control is quite common nowadays, also more and more in developing countries.
- *Reefer and agricultural inspections* – This requires an area for trucks to be set aside, similar to the Customs inspection above.
- *Port health inspections* – Ports are locations from where infectious diseases, such as SARS and Covid-19, may spread; a port coming under the World Health Organisation (WHO) International Health Regulations is held to infectious disease control.
- *Weighbridge* – One or more of these may be required for a variety of reasons, such as verifying cargo weights, or checking for vehicle wheel pressures exceeding the highway limit.
- *Damage inspections* – It is normal to have cameras incorporated in the gate complex for the general external inspection of containers for insurance purposes.

Rail terminal

Transfer to and from rail can be done on or outside the container terminal. For logistic reasons, the railroad track inside a terminal often runs parallel to the truck transfer area. Figure 4.26 shows an example of such a rail terminal.

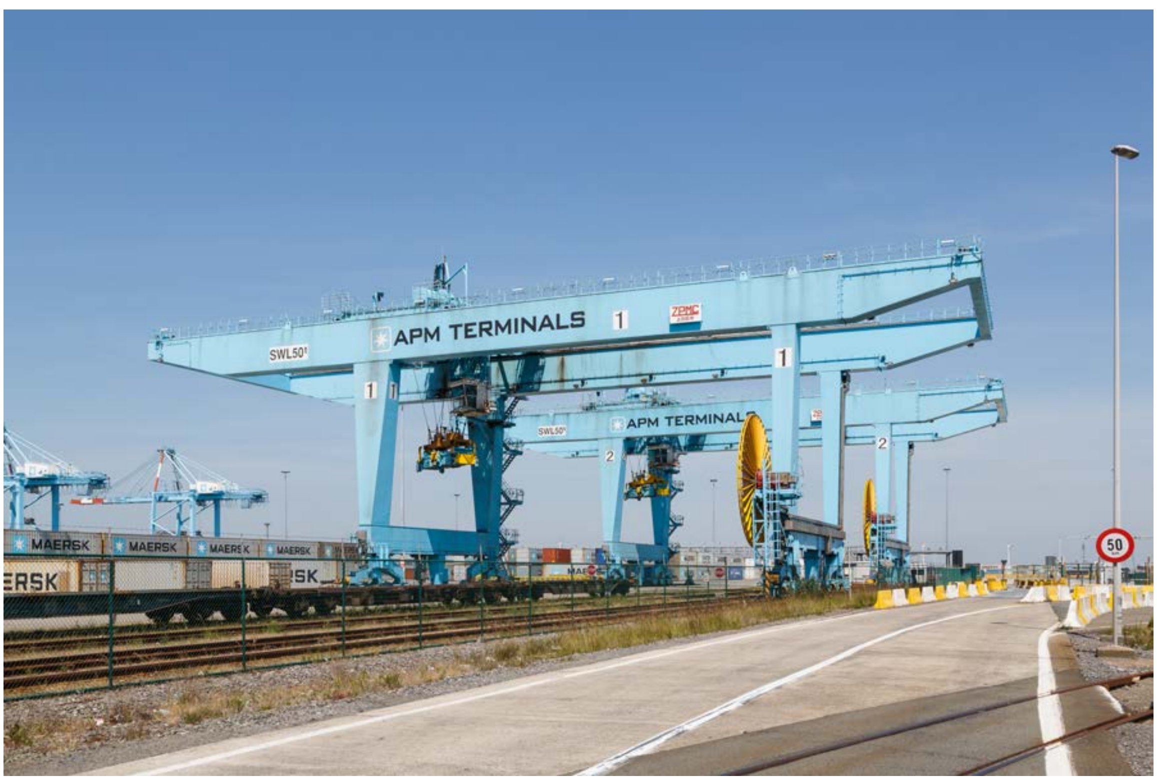


Figure 4.26: APMT Zeebrugge (Belgium) rail terminal with gantry crane (by CEphoto, Uwe Aranas is licenced under CC-BY-SA 3.0).

Not all rail yards are inside a terminal (on-dock). Off-dock ones (also called Rail Service Centre (RSC)) generally serve more than one terminal. Transfer from container terminal to RSC and vice versa is done by trailers which have to pass the gate. On other terminals an internal road may connect to the RSC, thus allowing the use of terminal equipment, such as MTS.

IWT terminal

Depending on the terminal (busy or not busy, large or small vessels) the transfer of containers to and from IWT barges is done along the quays for sea-going vessels, or at separate quays. Handling IWT-barges at quays for sea-going vessels has a number of distinct disadvantages:

- The STS cranes are too large for handling the small barges, whence crane productivity is relatively low.
- When a sea-going vessel arrives, it usually gets priority and handling of the barge is interrupted.
- The barges often collect their cargo at several terminals, which may be time consuming, especially if they have to give priority to sea-going vessels.

A separate barge terminal with suitable equipment and linked to the main one is a way to overcome the former disadvantages. Figure 4.27 shows such a barge terminal, at ECT's Delta Terminal on the Maasvlakte. Note that this one is combined with a rail and a road terminal.

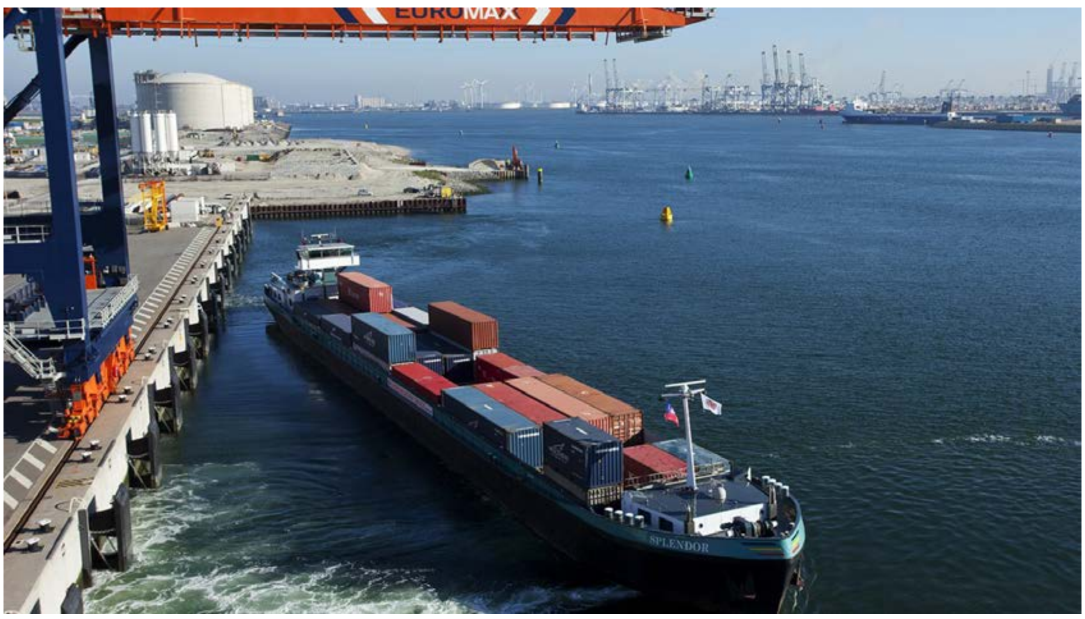


Figure 4.27: IWT-vessel leaving ECT Euromax terminal, Maasvlakte, Rotterdam (image by Eric Bakker and Port of Rotterdam is licenced under CC BY 4.0).

In order to overcome all three disadvantages one might consider building a general barge terminal with connections to the different container terminals. However, this introduces an additional step in the transport process with two times extra handling. The associated extra cost makes this solution unattractive. Yet, the rapid increase of container transport by barge is likely to render a multi-user concept attractive. Such Barge Service Centres (BSCs) could be similar to RSCs, with internal connections to the surrounding container terminals. Such a concept requires co-operation of all users (container terminal operators).

Other buildings

Other buildings encountered on the terminal include the office building and the workshop for repair and maintenance of the equipment. The requirements vary per terminal.

4.4 Estimation of terminal elements and layout

Figure 4.28 gives a typical container terminal layout and Figure 4.29 summarises the most important components. A terminal layout depends to a large extent on the selected yard handling systems. Other determining factors are related to the context in which the terminal is to be realised.

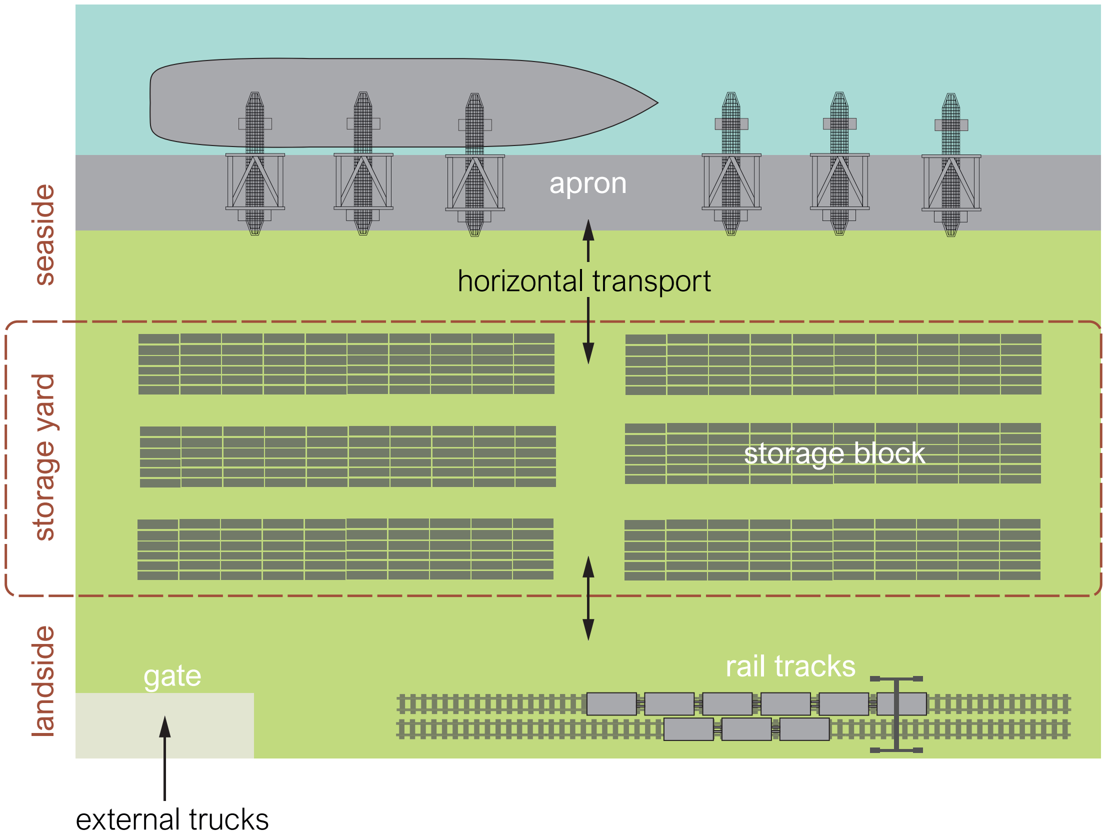


Figure 4.28: Typical container terminal layout (modified from Böse, 2011, by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

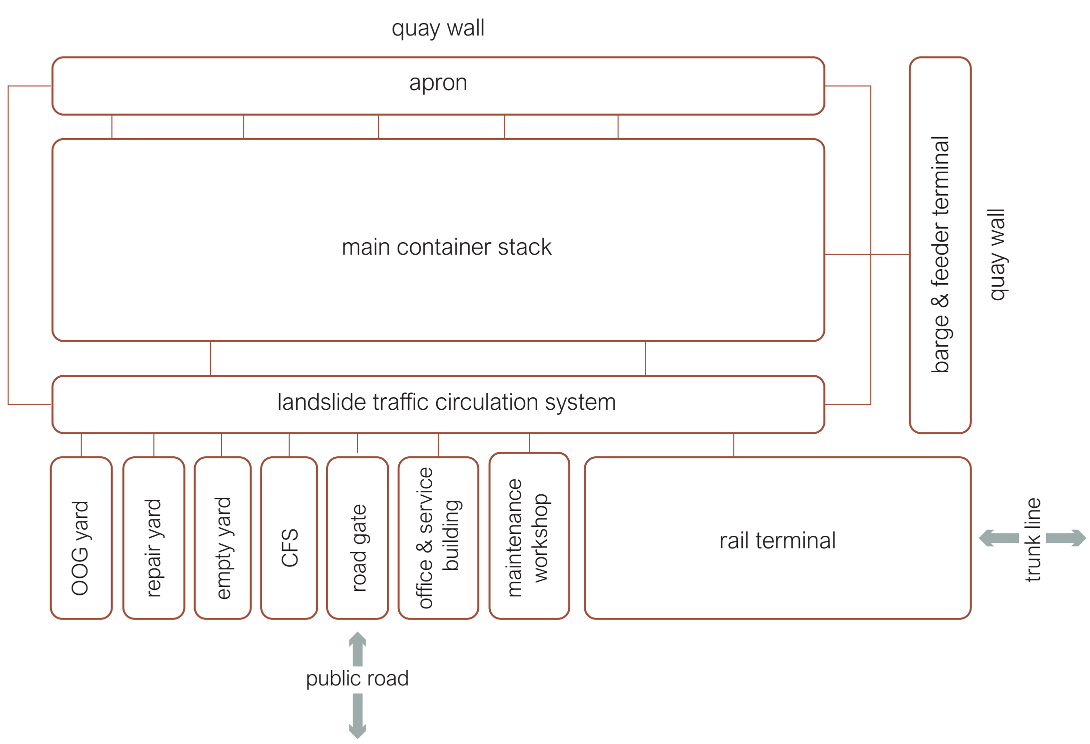


Figure 4.29: Terminal components (modified from PIANC, 2014b, by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

The planning of a new terminal often starts from the operator's preference for a specific stacking system in combination with a specific horizontal transport system. For a first-order functional design and feasibility analysis the following terminal components have to be specified:

- *Seaside* – number of STS cranes, quay length, quay retaining height and apron area,
- *Storage yard* – storage area and yard equipment,
- *Landside* – container transfer area (to truck, rail and IWT), and
- *Other* – supporting buildings such as offices, workshops, a Container Freight Station (CFS), et cetera.

In the following sections we will consider these items one by one and see how they interact with the others in a coherent layout. We will illustrate this by an example, which we will elaborate step by step, following the steps outlined in Section 3.3.3.

4.4.1 Step 1: Cargo forecast

Before we can determine numbers and dimensions of terminal elements, we need to know more about the cargo flows and the vessels to be expected. Table 4.5 shows the values that are used for our example.

Cargo estimates	
Annual cargo throughput	2,460,000 TEU
Percentage import	15%
Percentage export	16%
Percentage transhipment	69%
Peak factor	1.2
TEU-factor	1.6

Table 4.5: Cargo forecast (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

So this is a terminal with a relatively large percentage of transshipment. In order to increase the service level and limit maximum waiting times, the port authority has chosen a peak factor 1.2. The TEU-factor indicates the average container size as compared with the standard twenty-foot container.

4.4.2 Step 2: Fleet composition, cargo distribution

In order to know how often what type of vessels will call how many times per year at the terminal, we need to forecast the vessel mix and the call size. We assume three vessel classes will call on this terminal in a 40-30-30 percent split (see Table 4.6).

Vessel class	Vessel mix	Cargo flow	Call size	Nr. calls
Post Panamax I	40%	984,000 TEU	900 TEU	1094
VLCS	30%	738,000 TEU	2,250 TEU	328
ULCS	30%	738,000 TEU	3,150 TEU	235
Total	**100%**	**2,460,000 TEU**	–	**1657**

Table 4.6: Vessel mix and estimated number of calls per year (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Note that the total cargo throughput obtained by multiplying the number of calls of a vessel type by the call size does not add up to 2,460,000 TEU, but slightly more than that. This is because the number of calls has to be a round number. We use the original throughput C rather than one derived from the number of trips in the further calculations.

4.4.3 Step 3: Cargo specification

Transhipment cargo is handled twice at the quay (once when coming in and once when going out), but it is stored only once. Therefore, we have to distinguish between the throughput over the quay and over the terminal. We use the input values from Table 4.5 to make this distinction. This results in the split presented in Table 4.7.

Annual cargo flow	Quay	Loading	Unloading	Terminal
Import (sea – land)	369,000 TEU	–	369,000 TEU	369,000 TEU
Export (land – sea)	393,600 TEU	393,600 TEU	–	393,600 TEU
Transhipment (sea – sea)	1,697,400 TEU	848,700 TEU	848,700 TEU	848,700 TEU
Total	**2,460,000 TEU**	**1,242,300 TEU**	**1,217,700 TEU**	**1,611,300 TEU**

Table 4.7: Annual cargo flow (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Both for the capacity of the quay operations and for the configuration of the storage area we need a further specification of the cargo by type (ladens, reefers, empties, OOGs) and a translation of the quay and terminal throughputs from TEU to boxes to be handled. Table 4.8 shows the split percentages and TEU-factors we assume, and how this translates to throughput quantities in terms of TEU and boxes.

	Laden	Reefer	Empty	OOG
Percentage	70%	10%	19%	1%
TEU-factor	1.6	1.75	1.55	1.55
Quay throughput (TEU)	1,722,000 TEU	246,000 TEU	467,400 TEU	24,600 TEU
Quay throughput (boxes)	1,076,250 boxes	140,571 boxes	301,548 boxes	15,871 boxes
Terminal throughput (TEU)	1,127,910 TEU	161,130 TEU	306,147 TEU	16,113 TEU
Terminal throughput (boxes)	704,944 boxes	92,074 boxes	197,514 boxes	10,395 boxes

Table 4.8: Cargo type specification (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

The annual quay throughput in boxes is obtained by dividing the annual throughput in TEU (adding up to 2,460,000 TEU) by the TEU-factor. This leads to a total number of 1,534,240 boxes that need to be handled at the quay annually.

Similarly, the terminal or stack throughput is found by dividing the annual terminal throughput in TEU (adding up to 1,611,300 TEU) by the TEU-factor. This gives a total number of 1,004,927 boxes to be handled at the terminal annually.

4.4.4 Step 4: Berth configuration

Vessel properties The dimensions of a single berth depend on the size of the vessels to be accommodated. The times needed for mooring and unmooring may also depend on the vessel type (here selected to be equal).

Vessel class	Length (L_{OA})	Draught (D_s)	Beam (B_s)	Mooring	Unmooring
Post Panamax I	300 m	13 m	40 m	1 hr	1 hr
VLCS	397 m	15.5 m	56 m	1 hr	1 hr
ULCS	400 m	16 m	59 m	1 hr	1 hr

Table 4.9: Vessel properties (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Cargo handling equipment In order the determine the berth and quay configuration, we need information on the cargo handling equipment at the quay. Here we assume the loading/unloading to be done with STS-cranes and the transport to and from the storage yard by tractor trailers. Empties are handled by special equipment.

Quantity	Number	Units
Operational hours	8592	hours/year
Hourly cycles per STS crane	30	lifts/hour
Lifting capacity	2	TEU/lift
Max. nr. of crane slots per berth	4	crane slots/berth
Tractor trailers	5	tractor trailers/crane
Empty handlers	40,000	moves per handler/year

Table 4.10: Cargo handling equipment (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

The number of lifts per hour and the capacity per lift determine the crane productivity, though a widely accepted productivity definition is lacking. Here we use the average number of lifts per hour between the moment that berthing is completed and the moment that de-berthing starts. This period includes all sorts of 'unproductive' time intervals, such as the time needed for crane repositioning from one bay to another, for removal of hatches and placing them back, for changing shifts and for simple repairs to the cranes. A potential peak production of 40-50 lifts per hour is easily reduced to a net value of 30 lifts per hour due to these losses.

Step 4.1: Number of berths, quays and unloading equipment needed

With the information we now have available we can work out how many berths / quay sections and pieces of unloading and transporting equipment we need to handle the cargo throughput (see also Section 3.3.3). The determining factor is the waiting time to service time (WT/ST) ratio. We select 0.1 as a maximum acceptable value of this ratio which is common for container terminals (see also PIANC, 2014b). In the present example we use the E2/E2/n table from queueing theory to determine the required number of berths and the corresponding berth occupancy (see Table 3.10).

We start from a greenfield situation and increase the number of berths step by step until we have achieved the required WT/ST ratio. The total (un)mooring time is 3314 hours in this example (Nr. calls × 2 hours). The berth occupancy factor follows from:

$$\text{occupancy} = (\text{Total (un)loading time} + \text{Total (un)mooring time})/\text{operational hours} \qquad (4.2)$$

For this example 4 berths and 14 STS cranes are sufficient to achieve an acceptable service level.

In practice the number of STS cranes per berth depends on several additional factors, such as:

- the range of vessel sizes and the (weighted) average size,
- the number of berths,
- the stowage plan, and
- the maximum number of cranes that can operate on one vessel.

Along a conventional linear quay cranes can work on any berth. For practical reasons (including the transport between the STS cranes and the storage yard) Post Panamax vessels have not more than 5 cranes working simultaneously. Smaller vessels have fewer cranes. If a new terminal would start with just one berth and had to handle Post Panamax vessels efficiently, 5 cranes would be needed for that single berth. For the latest generation of vessels this is not even enough (see, for instance, Figure 4.17). If, on the other hand, a quay consists of several berths and the berth occupancy is low, it is possible to reduce the average number of cranes per berth.

Step 4.2: Quay length

Now that we know how many berths are needed, we can work out the total quay length. We assume a linear arrangement, with all berths in line, and with a berthing gap of 15 m for all vessels and at either end of the quay structure (PIANC, 2014b, p. 98, suggests 15-30 m; Table 3.2 gives numbers differentiated by vessel type). One may choose to dimension one berth for the largest vessel calling at the terminal; all other berths are designed

Iteration	Action	Configuration		(Un)loading	Occupancy	WS/ST
		Berths	Cranes			
0	greenfield	–	–	–	–	–
1	add berth	1	–	–	–	–
2	add crane	1	1	30750.0	3.96	> 4.3590
3	add crane	1	2	15375.0	2.18	> 4.3590
4	add crane	1	3	10250.0	1.58	> 4.3590
5	add crane	1	4	7687.5	1.28	> 4.3590
6	add berth	2	–	–	–	–
7	add crane	2	5	6150.0	1.10	> 2.0000
8	add crane	2	6	5125.0	0.98	> 2.0000
9	add crane	2	7	4392.9	0.90	1.9647
10	add crane	2	8	3843.8	0.83	1.2169
11	add berth	3	–	–	–	–
12	add crane	3	9	3416.7	0.78	0.4213
13	add crane	3	10	3075.0	0.74	0.3289
14	add crane	3	11	2795.5	0.71	0.2532
15	add crane	3	12	2562.1	0.68	0.2087
16	add berth	4	–	–	–	–
17	add crane	4	13	2365.4	0.66	0.1128
18	**add crane**	**4**	**14**	**2196.4**	**0.64**	**0.0971**

Table 4.11: Number of berths, quays and cranes (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

on the basis of the average vessel length. This leads to the following formula for the total quay length (see also Section 3.3):

$$L_q = 15 + L_{s,max} + 1.1(n-1)(15 + L_{s,av}) + 15 \tag{4.3}$$

in which n is the total number of berths.

The factor 1.1 follows from a study carried out by (UNCTAD, 1985). They determined, for a number of actually observed vessel length distributions and berth lengths, the probability of occurrence of additional waiting time due to simultaneous berthing of above-average vessels (Figure 4.30).

The correction of the total port time in this figure accounts for additional waiting time. The diagram shows that with an average berth length of 10% above the average sum of ship length plus berthing gap no additional waiting time occurs.

As the number of berths in a row increases, the correction factor will theoretically tend to 1.0. In practice this is not the case, because vessels will seldom be shifted during operations, in view of the additional delays this causes. For more complex arrangements see Section 3.1.3. For our current example we arrive at a total quay length required of 1579.7 m (see Table 4.12).

Quay length calculations	
Largest vessel length ($L_{s,max}$)	400 m
Average vessel length ($L_{s,av}$)	333.4 m
Number of berths (n)	4
Total quay length	**400 + 3.3 * (333.4 + 15) + 30 = 1579.7 m**

Table 4.12: Quay length calculation (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

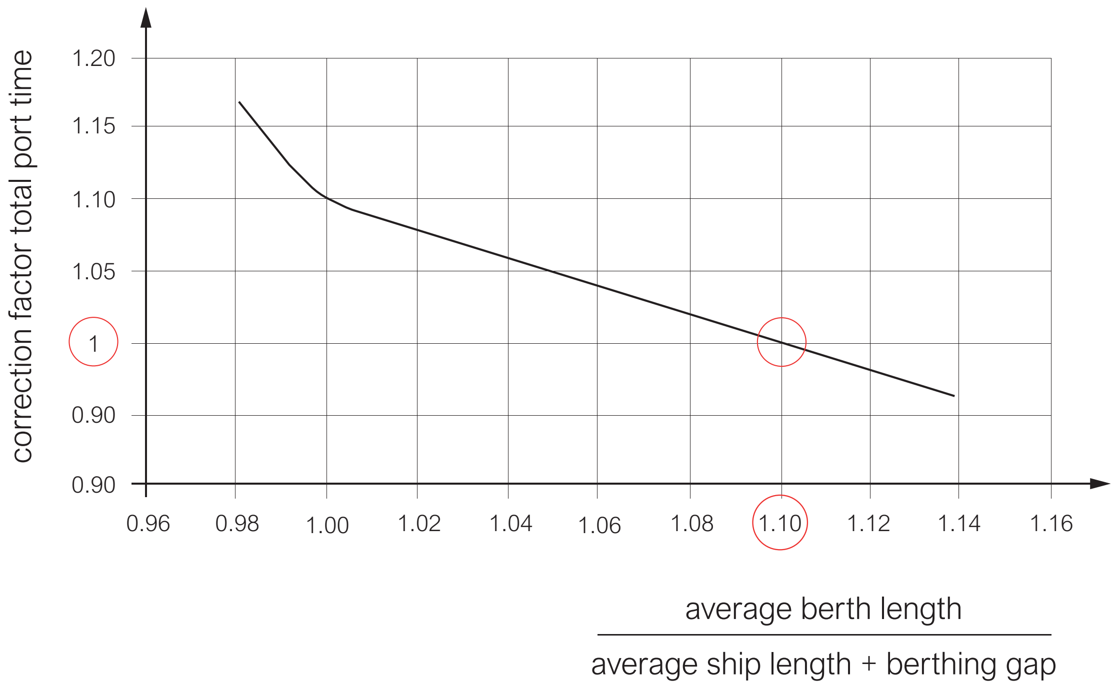


Figure 4.30: Correction factor for the total port time (reworked from UNCTAD, 1985, by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Step 4.3: Quaywall retaining height

The vertical distance from the quay platform to the bottom level of the berth is a relevant design parameter for the quay structure, such as an earth retaining quaywall. Starting from the bottom it consist of the underkeel clearance of the vessel, its draught, its sinkage (including the wave-induced vertical motion) and the freeboard.

Retaining height	
Under Keel Clearance (UKC)	0.5 m
Max sinkage	0.5 m
Wave motion	0.5 m
Freeboard	4.0 m
Max draught	16.0 m
Total quay retaining height.	**0.5 + 0.5 + 0.5 + 4.0 + 16.0 = 21.5 m**

Table 4.13: Quay wall retaining height (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

If the quay platform is built on an earth-retaining quay wall in soft soil, a rule of thumb for the required length of anchored sheetpiles is twice this retaining height.

Step 4.4: Apron surface area

Once the quay length has been determined, one can address the layout of the apron area. Moving from the waterfront inwards one encounters (Figure 4.31):

1. a setback of 3 – 5 m between the coping and the waterside crane rail, to provide access to the vessels for crew, supplies and services. This space is also necessary to prevent damage to the crane by the flared bow of the vessel during berthing under some angle. In the setback area are bollards and shore power connection pits.

2. the crane track spacing, which is primarily determined by considerations of crane stability. A second aspect is the space required for the transport equipment and ATL removal/application. On most terminals the containers are dropped off or picked up by the STS crane within the space between the crane rails. When four STS cranes are working on one vessel, each has transport equipment lining up, preferably on separate lanes for safety reasons. Depending on the number of crossings of the landward rail over the length of the quay, there may be need for additional lanes. The space between the rails of cranes should accommodate a number of truck lanes depending on how many cranes are on the quay. The three lanes are 16 m for smaller terminals (two lanes for trucks waiting containers, one for overtaking) or four lanes are 20 m. Large Post Panamax cranes now have 30.48 m - 35 m rail spacing. In the end there is also a feedback between crane designer, marine civil engineer and operational planning of number of lanes.
3. the space immediately landward of the landside rail, which is used to place the hatch covers and/or to lift special containers, such as flats with bulky or hazardous cargo.
4. a traffic lane for the SC, the Tractor-Trailer (TR-TR)/MTS or AGV which commute between the storage yard and the quay. The width depends on the transport system adopted. For SC 2 lanes are usually sufficient, whereas for AGV's a width equal to that between the crane rails is required.

Note that no hinterland connections are allowed on the apron, contrary to the conventional general cargo terminals, where truck- and rail access to the quay was customary. For reasons of efficiency and safety this is not common on modern container terminals.

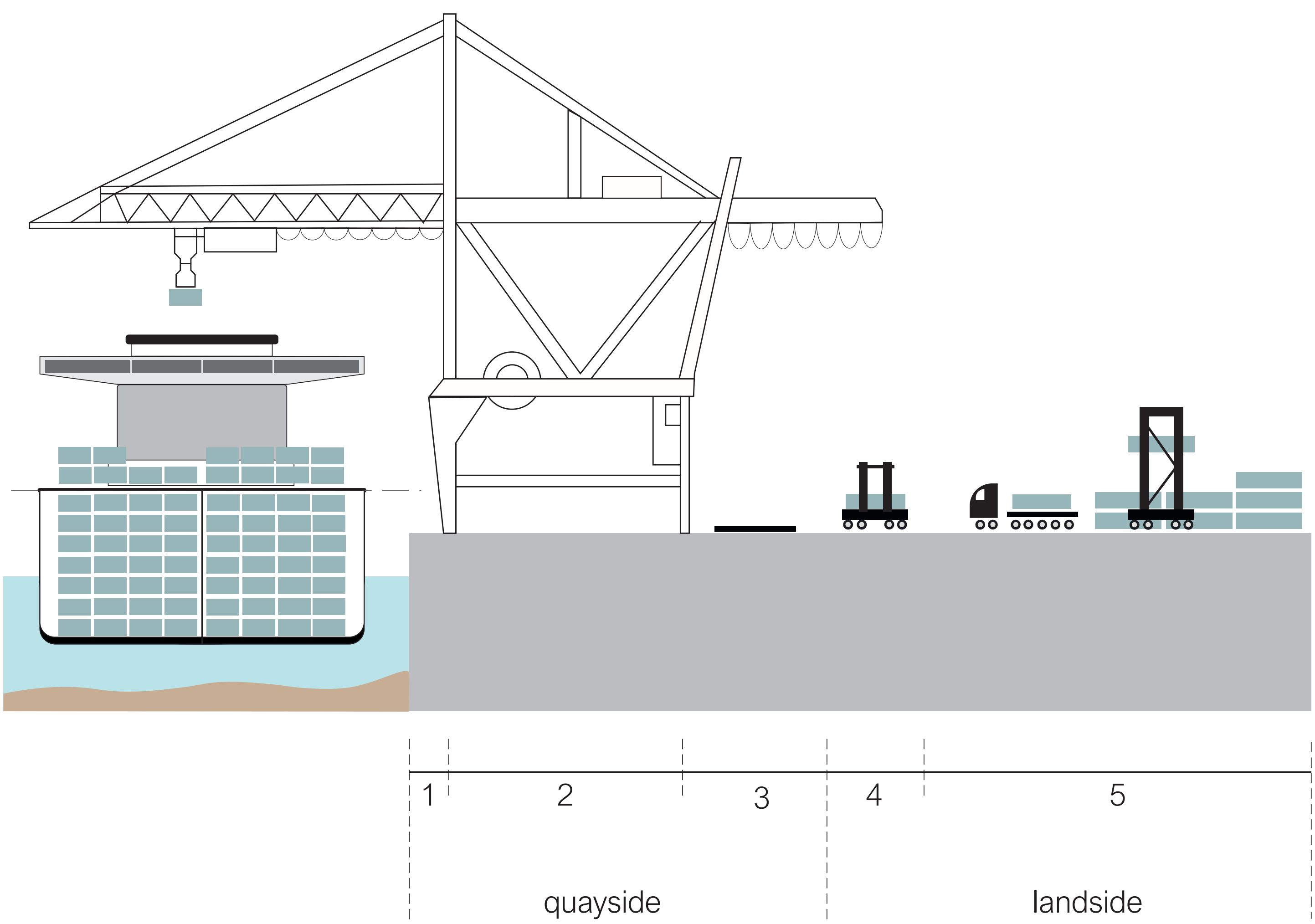


Figure 4.31: Apron lanes (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

In this example we assume a total apron width of 82 m. Multiplying the apron width with the apron lenght (assumed here to be equal to the quay lentgh) yield the apron area (see Table 4.14).

Apron surface area	
Total apron width	82 m
Apron length (= quay length)	1579.7 m
Total apron area	**82 * 1579.7 = 129,533 m^2**

Table 4.14: Apron surface area (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

4.4.5 Step 5: Quay to storage transport equipment

Next, we need to specify the transport equipment between quay and storage and the container handling equipment at the storage yard. In order to prevent congestion, the amount of transport equipment has to correspond with the crane capacity at the quay. Proportionality with the number of cranes therefore makes sense (see also Table 4.10). Table 4.15 shows the number of tractor trailers that is needed in this example.

Number of tractor trailers	
Nr of STS cranes	14
Trailers per STS crane	5
Total nr of tractor trailers	**14 * 5 = 70**

Table 4.15: Number of tractor trailers (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

At the storage yard, the first important choice is the stacking direction, as this influences the need for transport equipment. On the other hand, the type of transport equipment determines the space between the stacks and the maximum width and height of the stack (see also Part IV – Section 3.1).

4.4.6 Step 6: Storage area

An important factor when determining the area required for storage is the dwell time.

The average dwell time, $t_{d,av}$, has to be considered separately for import/export containers and empties. Dwell times for the latter are usually much longer. Also, fluctuations in dwell times may have to be considered, although $t_{d,av}$ is averaged over a large number of containers, so it will not vary much.

By definition, the average dwell time can be written as:

$$t_{d,av} = \frac{1}{S(0)} \int_0^\infty S(t)dt \tag{4.4}$$

in which $S(t)$ is the number of containers of a call at time $t = 0$ which is still on terminal.

ECT found that for their home-terminal the following dwell time function applies (see Figure 4.32):

$$\frac{S(t)}{S(0)} = \begin{cases} 1 & \text{for } 0 < t \leq 1 \\ \left(\frac{t_{d,max}-t}{t_{d,max}-1}\right)^2 & \text{for } 1 < t \leq t_{d,max} \\ 0 & \text{for } t > t_{d,max} \end{cases} \tag{4.5}$$

in which $t_{d,max}$ is the time at which 98% of the containers of the call have left the terminal again.

Substitution into Equation 4.4 yields:

$$t_{d,av} = (t_{d,max} + 2)/3 \tag{4.6}$$

A typical value of $t_{d,max}$ for terminals with a high turnover is 10 days, whereas in case of a low turnover it may amount to 30 days.

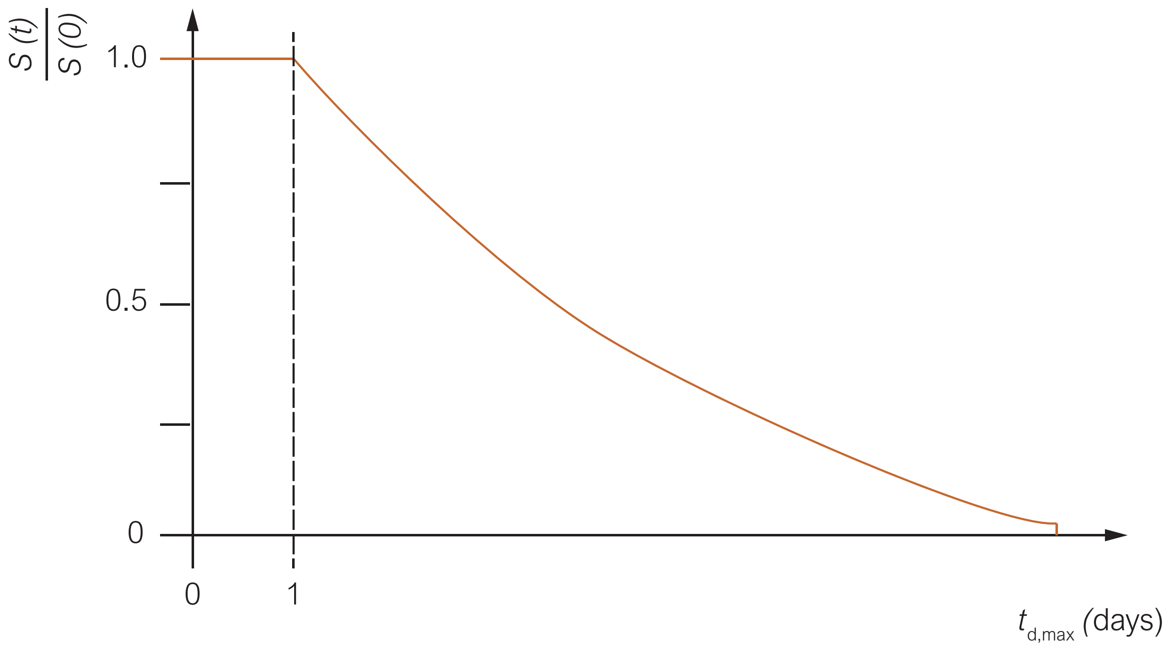


Figure 4.32: Typical dwell time function (at ECT) (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

For each container category (index k) we can now evaluate the number of TEU to be stacked from:

$$N_{s,k} = (C_k \cdot f_p \cdot t_{d,av})/d_{yr} \tag{4.7}$$

in which:

$N_{s,k}$ = number of TEU of category k to be stacked [TEU],
C_k = throughput of category k over the storage area [TEU/yr],
f_p = peak factor [-],
d_{yr} = number of operational days per year [days/yr].

Then the number of ground slots for containers of this category amounts to

$$N_{tgs} = N_{s,k}/(r_{st} \cdot m_c \cdot H_{n,st}) \tag{4.8}$$

in which:

N_{tgs} = number of ground slots required for this category of containers,
r_{st} = ratio of average stacking height over the nominal stacking height (usually 0.6 to 0.9),
m_c = occupation rate (usually 0.65 to 0.70),
$H_{n,st}$ = nominal stacking height.

The factor r_{st} in Equation 4.8 reflects the fact that the sequence in which the containers will leave the stack is partly unknown (mostly so for the import stack) and that extensive intermediate re-positioning of containers is expensive. Statistically, the need for re-positioning will increase as the stacking height increases. If the acceptable degree of re-positioning can be defined (e.g. 30% additional moves), as well as the degree of uncertainty in the departure of containers from the stack, the optimum value of r_{st} can be found through computation or simulation. The uncertainty of departure depends, among other things, on the mode of through transport. Rail and IWT can generally be programmed rather well, in contrast with road transport.

The occupancy m_c has to be introduced because the pattern of arrivals and departures of containers is stochastic by nature. The optimum value of m_c depends on the frequency distribution of these arrivals and departures, and on the acceptable frequency of occurrence of a saturated stack. The number of container departures per unit of time may be more or less constant, at least for large terminals, but the number of arrivals is not. The container arrival distribution can have different forms and depends, in its turn, on the vessel arrival distribution and on the variation of the number of containers per vessel.

The gross surface area A_{TEU} per ground slot (including traffic lanes in the stack) is expressed in Twenty-feet Ground Slots (TGS). It is empirically established and depends on the handling equipment and the nominal stacking height. Table 4.16 gives some typical values.

Gross TGS area	
Reach Stacker (RS)	18.0 m^2
Rail Tired Gantry (RTG)	18.0 m^2
Rail Mounted Gantry (RMG)	18.7 m^2
Straddle Carrier (SC)	27.4 m^2

Table 4.16: Gross TGS area for different stacking equipment (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Figure 4.33 illustrates the reason for the differences between the various types of equipment. The additional space that a RMG-stack requires over the RS- and RTG-stacks is associated with the space occupied by the rails. The main reason that a SC-stack needs a larger gross TGS area is that a SC needs space between the container rows to manoeuvre.

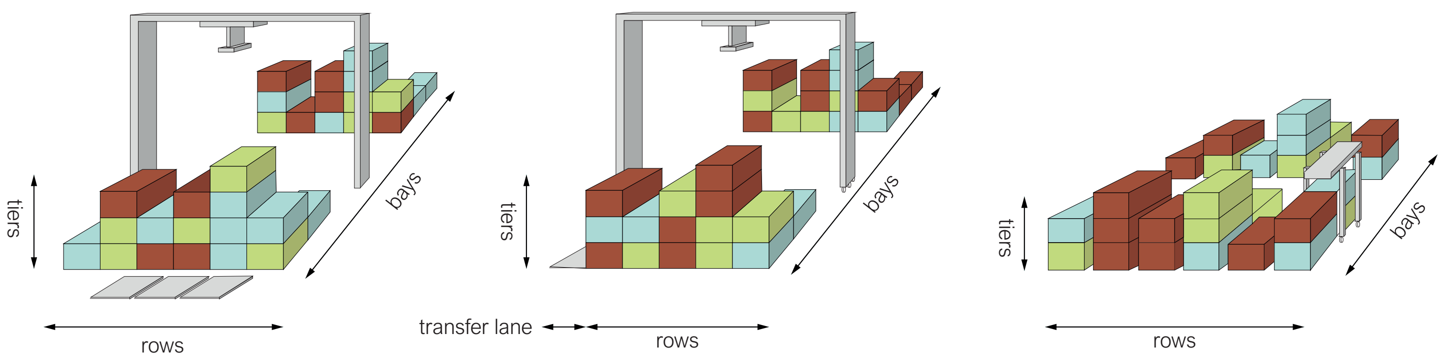


Figure 4.33: Block structures stacking equipment, from left to right RMG, RTG and SC operation (reworked from Böse, 2011, by TU Delft – Ports and Waterways is licenced by CC BY-NC-SA 4.0).

Part IV – Section 3.1 elaborates an example that illustrates the effect of container terminal equipment selection. For our current example we assume that SCs are selected as stack equipment of choice.

Ladens The majority of the container throughput will generally be ladens. In the example we assume straddle carriers to be used for their stacking. Using the input from Table 4.8, Table 4.16 and Equation 4.8 we can calculate the number of stack required and the area that needs to be allocated to this.

Quantity	**Symbol**	**Magnitude**	**Units**
Gross ground slot area for SC	A_{TEU}	27.4	m^2/tgs
Throughput of ladens	C_{laden}	1,127,910	TEU/year
Peak factor for ladens	f_p	1.2	–
Average dwell time	$t_{d,av}$	7.5	days
Number of operational days	d_{yr}	358	days/year
Nominal stacking height	$H_{n,st}$	4	TEU-heights
Stacking width	W_{st}	45	TEU-widths
Stacking length	L_{st}	20	TEU-lengths
Average stacking fraction	r_{st}	0.8	–
Occupancy rate	m_c	0.7	–

Table 4.17: Basic data: ladens (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Quantity	**Operation**	**Magnitude**	**Units**
Total slots required	N_{tgs}	12,659	tgs
Total capacity required	$N_{tgs} \cdot H_{n,st} = C_{req}$	50,636	TEU
Total ground slots per stack	$W_{st} \cdot L_{st} = N_{tgs,st}$	900	tgs/stack
Total capacity per stack	$N_{tgs,st} \cdot H_{n,st} = C_{st}$	3,600	TEU/stack
Gross area per stack	$N_{tgs,st} \cdot A_{TEU} = A_{st}$	24,660	m^2/stack
Number of stacks required	$\text{ceil}(C_{req}/C_{st}) = N_{st}$	**15**	**stacks**
Total storage area for ladens	$A_{st} \cdot N_{st} = A_{ladens}$	**369,900**	$\mathbf{m^2}$

Table 4.18: Results: ladens (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

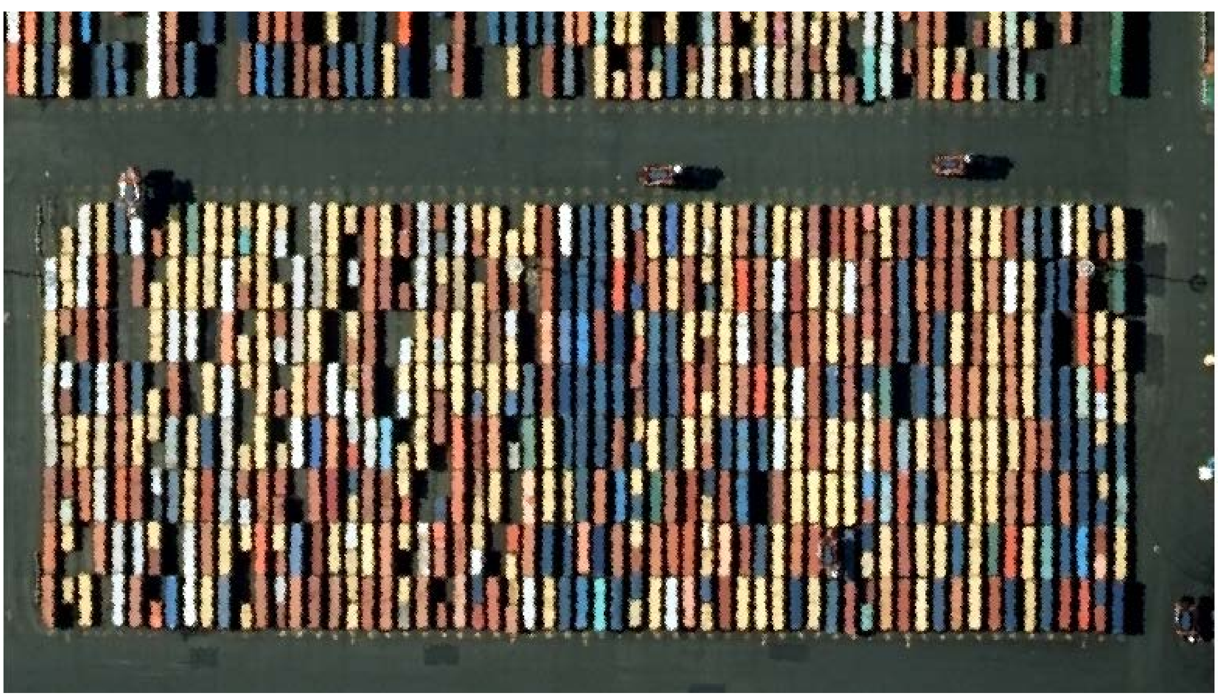


Figure 4.34: Example: ladens stack operated by straddle carriers (aerial imagery by the National Georegister (NGR) is licenced under CC BY 4.0).

Reefers We can apply the same procedure for the reefers, but here we have to take another factor into account, viz. the stack reefer factor, which is a combination of the TEU-factor and a multiplier for the reefer rack. It is a way to translate the FGSs, since reefers are often 40 ft long, to required surface area using the estimate A_{TEU}.

Quantity	Symbol	Magnitude	Units
Gross ground slot area for SC	A_{TEU}	27.4	m^2/tgs
Throughput of reefers	C_{reefer}	161,130	TEU/year
Peak factor for reefers	f_p	1.2	–
Average dwell time	$t_{d,av}$	6.5	days
Number of operational days	d_{yr}	358	days/year
Nominal stacking height	$H_{n,st}$	4	TEU-heights
Stacking width	W_{st}	22	TEU-widths
Stacking length	L_{st}	4	TEU-lengths
Average stacking fraction	r_{st}	0.8	–
Occupancy rate	m_c	0.7	–
Stack reefer factor	f_{reef}	2.35	–

Table 4.19: Basic data: reefers (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Quantity	Operation	Magnitude	Units
Total slots required	N_{tgs}	1,568	tgs
Total capacity required	$N_{tgs} \cdot H_{n,st} = C_{req}$	6,272	TEU
Total ground slots per stack	$W_{st} \cdot L_{st}/2 = N_{fgs,st}$	44	fgs/stack
Total capacity per stack	$2 \cdot N_{fgs,st} \cdot H_{n,st} = C_{st}$	352	TEU/stack
Gross area per stack	$N_{fgs,st} \cdot f_{reef} \cdot A_{TEU} = A_{st}$	2833.2	m^2/stack
Number of stacks required	$\text{ceil}(C_{req}/C_{st}) = N_{st}$	**18**	**stacks**
Total storage area for reefers	$A_{st} \cdot N_{st} = A_{reefers}$	**50,997**	$\mathbf{m^2}$

Table 4.20: Results: reefers (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Figure 4.35: Example: reefers stack operated by straddle carriers (aerial imagery by the National Georegister (NGR) is licenced under CC BY 4.0).

Empties For empties and OOGs we follow a similar calculation procedure as for ladens and reefers, be it that the average stacking factor is equal to 1 in both cases and a different value for A_{TEU} is used (associated with different handling equipment). Furthermore the dwell time $t_{d,av}$ of empty containers is typically large.

Figure 4.34, Figure 4.35, and Figure 4.36 respectively depict loaded-, reefers-, and empties stacks.

Quantity	**Symbol**	**Magnitude**	**Units**
Gross ground slot area for SC	A_{TEU}	16.7	m^2/tgs
Throughput of empties	$C_{empties}$	306,147	TEU/year
Peak factor for empties	f_p	1.2	–
Average dwell time	$t_{d,av}$	11	days
Number of operational days	d_{yr}	358	days/year
Nominal stacking height	$H_{n,st}$	6	TEU-heights
Stacking width	W_{st}	35	TEU-widths
Stacking length	L_{st}	24	TEU-lengths
Average stacking fraction	r_{st}	1	–
Occupancy rate	m_c	0.8	–

Table 4.21: Basic data: empties (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Quantity	**Operation**	**Magnitude**	**Units**
Total slots required	N_{tgs}	2,352	tgs
Total capacity required	$N_{tgs} \cdot H_{n,st} = C_{req}$	14,112	TEU
Total ground slots per stack	$W_{st} \cdot L_{st} = N_{tgs,st}$	840	tgs/stack
Total capacity per stack	$N_{tgs,st} \cdot H_{n,st} = C_{st}$	5040	TEU/stack
Gross area per stack	$N_{tgs,st} \cdot A_{TEU} = A_{st}$	14,028	m^2/stack
Number of stacks required	$\text{ceil}(C_{req}/C_{st}) = N_{st}$	**3**	**stacks**
Total storage area for empties	$A_{st} \cdot N_{st} = A_{reefers}$	**42,084**	$\mathbf{m^2}$

Table 4.22: Results: empties (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Figure 4.36: Example: empties stack operated by empty handlers (aerial imagery by the National Georegister (NGR) is licenced under CC BY 4.0).

OOGs The gross ground slot area for OOGs deviates from that for the other container types. OOGs are often transported and stored on carrier chassis, which means that the ground slot is the parking area needed for the chassis (roughly 16 x 4 m), rather than the TEU-slot. If the OOGs are handled with a reach stacker, a similar space is required.

Quantity	**Symbol**	**Magnitude**	**Units**
Gross ground slot area for SC	A_{TEU}	64	m^2/tgs
Throughput of OOG's	$C_{OOG's}$	16,113	TEU/year
Peak factor for OOG's	f_p	1.2	–
Average dwell time	$t_{d,av}$	7	days
Number of operational days	d_{yr}	358	days/year
Nominal stacking height	$H_{n,st}$	1	TEU-heights
Stacking width	W_{st}	10	TEU-widths
Stacking length	L_{st}	10	TEU-lengths
Average stacking fraction	r_{st}	1	–
Occupancy rate	m_c	0.8	–

Table 4.23: Basic data: OOG's (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Quantity	**Operation**	**Magnitude**	**Units**
Total slots required	N_{tgs}	473	tgs
Total capacity required	$N_{tgs} \cdot H_{n,st} = C_{req}$	473	TEU
Total ground slots per stack	$W_{st} \cdot L_{st} = N_{fgs,st}$	100	tgs/stack
Total capacity per stack	$N_{tgs,st} \cdot H_{n,st} = C_{st}$	100	TEU/stack
Gross area per stack	$N_{tgs,st} \cdot A_{TEU} = A_{st}$	6,400	m^2/stack
Number of stacks required	$\text{ceil}(C_{req}/C_{st}) = N_{st}$	**5**	**stacks**
Total storage area for OOG's	$A_{st} \cdot N_{st} = A_{OOG's}$	**32,000**	$\mathbf{m^2}$

Table 4.24: Results: OOG's (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Stacking yard summary The gross slot areas include room for traffic of transport equipment, but that is within the stack. As an estimate, an additional 20% is taken into account for roads around the stacks.

Container type	**Nr. of stacks**	**Area per stack [m²]**	**Total area [m²]**
Ladens	15	24,660	369,900
Reefers	18	2,833	50,997
Empties	3	14,028	42,084
OOG's	5	6,400	32,000
Total area stacks			**494,981**
20% extra for roads			98,996
Total area storage yard			**593,977**

Table 4.25: Storage yard summary (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

The 'throughput – storage yard area' ratio of this terminal is approximately 41,500 TEU/ha. It is interesting to compare this ratio with other terminals. Singapore, for instance, has 22,000 TEU/ha, and Hongkong 40-50,000 TEU/ha. The differences are mainly caused by differences in the efficiency of the storage yard and the dwell time. To shorten the dwell time, the stevedoring company must introduce incentives for shorter dwell times and penalties for longer dwell times than average, for instance by applying a variable tariff.

4.4.7 Step 7: Storage to hinterland transport

Container transport to and from the hinterland goes by road, by rail or over water, or by a combination of these. As an illustration, Figure 4.37 shows the recent evolution of this modal split for the port of Rotterdam. Although transport by road is still the largest fraction, growth (25% in total) mainly takes place in IWT (+ 48%) and rail transport (+ 40%)

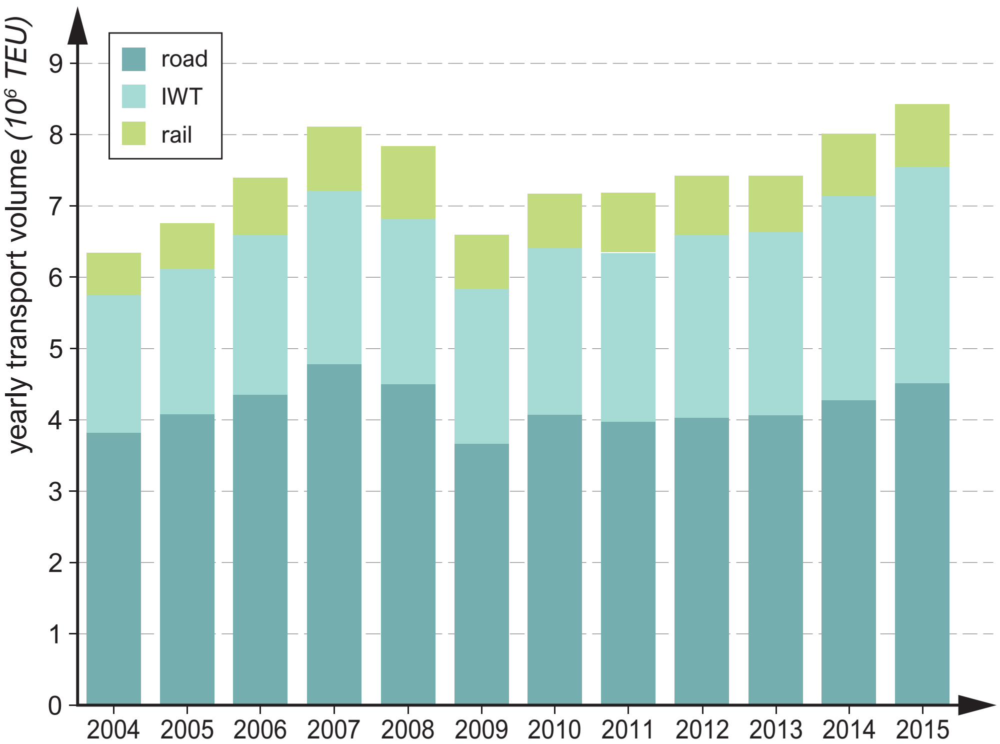


Figure 4.37: Modal split for container transport via the port of Rotterdam (by Monitor logistiek & Goederenvervoer voor Nederland 2016 is licenced under CC0 1.0).

Gate Trucks bringing or collecting containers enter and leave the terminal through the gate. Here three functions are executed:

- Administrative formalities related to the cargo, including customs inspection and clearance;
- Inspection of the boxes themselves (for possible damage); and
- Direction of the drivers to the location in the container transfer area.

The gate used to create long queues, due to the distinct peaks in the truck arrivals during the day. The introduction of electronic data processing and automated inspection of the boxes has shortened the delays at the gate considerably. Moreover, gates are presently designed for (statistically) the busiest hour of the year, such that waiting times can be kept within reasonable bounds (further see Section 4.3.4).

In the calculation example below we assume the transport to and from the hinterland to be exclusively by road. This means that the entire import and export throughput (369,000 and 393,600 TEU/year, respectively, see Table 4.7) has to pass by the road gate. We assume the TEU-factor to be 1.6, again.

import		export	
TEU/year	boxes/year	TEU/year	boxes/year
369,000	230,625	393,600	246,000

Table 4.26: Cargo flow specification (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Assuming one box per truck, the number of terminal exit and entry moves per year is equal to the number of import and export boxes per year, respectively. The peak load of a gate is calculated from:

$$M_{max} = M_y \cdot pf_{week} \cdot pf_{day} \cdot pf_{hour}/n_w \tag{4.9}$$

in which:

M_{max}	= peak number of moves per hour,
M_y	= number of moves per year,
pf_{week}	= peak factor for the busiest week of the year,
pf_{day}	= fraction of peak week moves at peak day.
pf_{hour}	= fraction of peak day moves at peak hour.
n_w	= number of operational weeks.

Then the design time required for gate operations follows from:

$$t_{d,g} = M_{max} \cdot \text{reloading fraction} \cdot \text{inspection time} \cdot \text{design capacity} \tag{4.10}$$

for exit and entry moves separately. The reloading percentage indicates which part of the trucks entering loaded will be reloaded and leave the terminal loaded, again. Trucks leaving empty are assumed not to need checking at the gate. The design capacity is the fraction of M_{max} for which the terminal is designed. This fraction is usually rather high (0.95 – 1.0). Once the required time for gate operation, $t_{d,g}$, is estimated, the number of required gates can be derived by taking the next higher integer of $t_{d,g}$/gate service time.

Table 4.27 provides some basic data that we can use in our current example. Table 4.28 shows how many entry and exit gates are needed to accommodate the export and import volumes respectively.

Quantity	**Symbol**	**Magnitude**	**Units**
Peak-week factor	pf_{week}	1.2	–
Peak-day percentage	pf_{day}	0.25	week/day
Peak-hour percentage	pf_{hour}	0.125	day/hr
Number of operational weeks	n_w	51.1	weeks/yr
Reloading fraction		0.75	–
Entry inspection time		1	min/move
Exit inspection time		2	min/move
Design capacity		0.98	–
Gate service time		60	min/hr

Table 4.27: Basic data: Gates (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Entry (handling export box moves)			**Exit (handling import box moves)**		
M_{max}	180	moves/hr	M_{max}	169	moves/hr
$t_{d,g}$	133	min/hr	$t_{d,g}$	249	min/hr
Nr. entry gates	**3**	**gates**	**Nr. exit gates**	**5**	**gates**

Table 4.28: Results: Gates (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Figure 4.38 shows an example of a gate. Once through the gate the trucks take their assigned position at the container transfer area. For container imports this area is usually located immediately behind the import stacks and the truck's position is chosen to minimise the distance to the import containers to be picked up. For container exports the trucks bring their containers straight to the export stacks, where they are picked up by the stack equipment for placement in the designated stack.

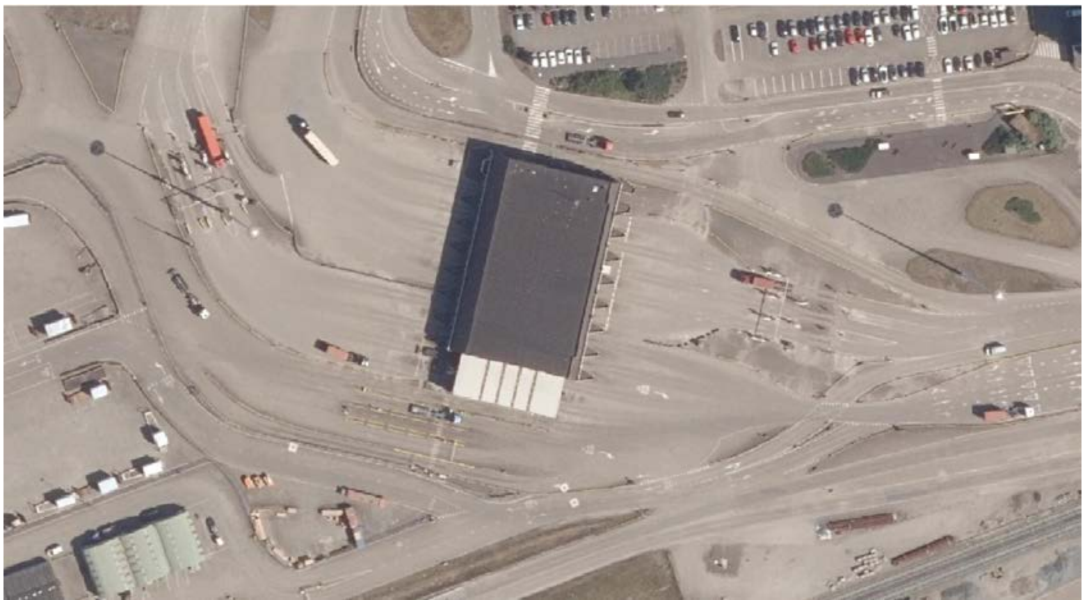


Figure 4.38: Example: road gates (aerial imagery by the National Georegister (NGR) is licenced under CC BY 4.0).

IWT terminal Dimensioning of an IWT-terminal follows a similar procedure as already described in design Steps 2, 3 and 4: once the amount of cargo to be shipped via IWT and the associated vessel mix are known, a berth configuration can be designed for a desired minimum service level. IWT container vessels are typically much smaller than their sea-going counterparts. As a result smaller (un)loading equipment is involved, which in turn leads to lower (un)loading capacities. Depending on the modal split, and the resulting cargo volume that needs to be shipped over water into the hinterland, a large number of IWT-vessels may be involved. The ever-increasing sea-going container ships can deliver a huge supply of containers at once. This causes peaks in the number of containers that arrive at a terminal, which can make their timely departure to the hinterland challenging. Congestion problems associated with this are not uncommon. Due to the many similarities we will not present a quantified design of the IWT-terminal in this example. Figure 4.39 gives an example of an IWT-quay (on the right), adjacent to the sea-shipping quay (on the left).

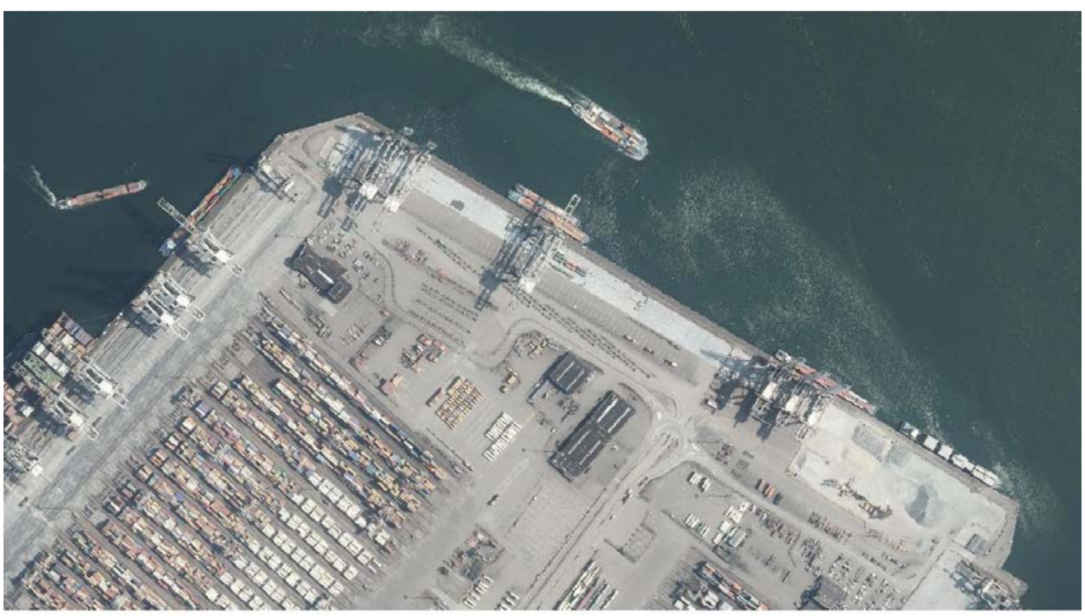


Figure 4.39: Example: IWT-quay, part of a larger container terminal (aerial imagery by the National Georegister (NGR) is licenced under CC BY 4.0).

Rail terminal Hinterland transport via rail can be done via on-terminal as well as via off-terminal rail stations. The rail terminals outside the container terminal are also called RSCs. Both on- and off-terminal the formation of so-called block trains, i.e. wagons which all have the same hinterland destination, will be promoted. Transfer from the container terminal to the RSC is done by trailer, which passes via the gate. On modern terminals an internal road may connect to the RSC, allowing use of terminal equipment such as MTS.

The layout of these RSCs falls outside the scope of this book. However, by-enlarge a functional design of a rail terminal can be derived in a similar manner as for quays and gates. Based on the amount of cargo that a rail station should be able to handle, and a given maximum train length, you can derive the number of tracks that should be installed to conform to a given performance criterion. The train length times the track width and the number of tracks provides a first order estimate of the surface area required. Figure 4.40 gives an example of a rail terminal. In this case 4 tracks of approximately 750 m long have been implemented.

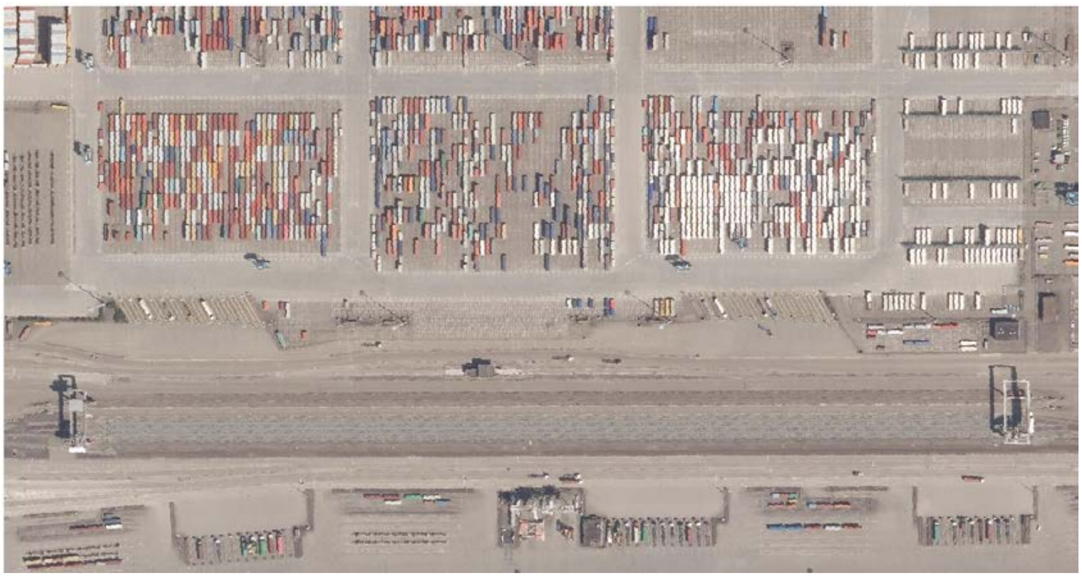


Figure 4.40: Example: rail terminal (aerial imagery by the National Georegister (NGR) is licenced under CC BY 4.0).

4.4.8 Step 8: General services

There is a range of general services that belong to a container terminal. We briefly discuss the so-called Container Freight Station (CFS) and a number of 'other facilities'.

Container Freight Station (CFS) Sometimes cargo imported in one container has different inland destinations. This means that it has to be redistributed at the terminal ("stripping"). Similarly, export cargo from different inland sources may have to be packed in one container ("stuffing"). After an import container has been stripped and before an export container is stuffed, the cargo is stored in the so-called Container Freight Station (CFS). In some cases the CFS and/or the empties yard are located outside the terminal property. The surface area of the CFS, A_{cfs}, is calculated from:

$$A_{cfs} = \frac{N_c \cdot V \cdot t_d \cdot f_{area} \cdot f_{bulk}}{h_c \cdot m_c \cdot 365} \tag{4.11}$$

in which:

- N_c = number of TEU moved through the CFS [TEU/yr], (also called Less than Container Load (LCL)),
- V = contents of 1 TEU container with the average capacity of 90% (= 0.9 times the available capacity of 32 m^3 = 29 m^3),
- t_d = average dwell-time [d],

f_{area} = ratio of gross and net area [-] (accounting for internal travel lanes and containers),
f_{bulk} = bulking factor [-],
h_c = average height of cargo in the CFS [m],
m_c = acceptable occupancy rate [-],

The containers are positioned around the CFS during actual transfer of cargo, which is also reflected in the value of f_{area} (≈ 1.4). The factor f_{bulk} accounts for additional space needed for cargo requiring special treatment or repairs. One often finds values of 1.1 – 1.2. The factor m_c again reflects the random character of arrivals and departures of this cargo, and the need to avoid a full CFS. Normal values are 0.6 – 0.7. At large container terminals less and less CFS facilities are present. Therefore, we ignore it in the calculation example.

Other facilities Next to the quay wall and apron, the main container stack, and the hinterland facilities (road, IWT, rail) there is a range of other facilities that are generally part of a container terminal:

- general offices + parking space,
- one or more workshops,
- a repair building,
- parking space for trailers, and
- an area for scanning and inspection.

Rather than designing these to a similar detail as we did the other terminal elements, we will assume a set of surface area values for each component (see Table 4.29). The numbers are loosely based on obeservations derived from aerial photographs and an estimate that roughly 15% of the total terminal surface area consists of items other than the apron area and the storage yard.

General office + parking space	12,500	m^2
Workshop + parking space	20,000	m^2
Repair building + parking space	61,000	m^2
Trailer parking	30,000	m^2
Scanning and inspection area	2,700	m^2
Total	**126,200**	$\mathbf{m^2}$

Table 4.29: Surface area estimates for other facilities (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

4.4.9 Step 9: Summary

In the previous steps we systematically investigated which terminal elements are involved in the handling of an annual throughput of 2,460,000 TEU at a minimum prescribed service level. Based on a range of explicitly stated assumptions we elaborated a functional design to derive the number of system elements required, and to estimate their order-of-magnitude dimension. Table 4.30 presents an aggregated summary of the main terminal elements and how they contribute to the overall surface area.

Quay length	1,579.7	m	
Apron area	129,533	m^2	15%
Storage yard	593,787	m^2	70%
Other facilities	126,200	m^2	15%
Total	**849,520**	$\mathbf{m^2}$	**100%**

Table 4.30: Total terminal surface area (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

The apron area plus the storage yard surface area divided by the quay length yields the so-called 'terminal depth'. For this example this results in a terminal depth of 458 m. For a modern container terminal, this depth typically lies between 400 – 500 m. A value of 458 m gives some confidence that our terminal is of reasonable dimensions.

Systematically following the terminal design steps, as done above, provides valuable information that can feed back into the port layout process. Where layout efforts were first based on rough rule-of-thumb estimates, we now have a better picture of what kind of surface area is required to accommodate a desired annual throughput, and what kind of infrastructure this requires in terms of quay length, STS-cranes, tractor trailers, et cetera. It is good to realise that selecting a different type of terminal equipment can have significant effect on the required surface area. However, accommodating a given throughput on a smaller surface area, is generally offset with higher CAPEX associated with STS-cranes and more efficient yard equipment (see also Part IV – Section 3.1).

4.5 Developments

The container transport market is highly competitive. New technology is continuously developed, resulting in larger and more efficient vessels, more efficient terminals and consequently more container transport. In this process of ongoing competition and improvement, a number of recognisable developments can be identified.

4.5.1 Simulation models

Simulation is increasingly applied to container terminals worldwide. It enables consultants, designers and terminal operators to accomplish strategic and tactical planning related to existing and new-to-develop container terminals. Simulation models can be of use to:

- analyse and optimise the operation of existing terminals,
- develop a conceptual/functional design of a container terminal extension and/or a new terminal,
- identify and solve capacity bottlenecks;
- improve a terminal's performance and service level.

4.5.2 Terminal automation

Shipping lines are pressing terminals to increase their service level, and at the same time to reduce their handling costs. As labour expenses form a large part of the latter, automated container handling has proven to be an effective way to reduce operational costs of large terminals.

In terminal operations, automation is possible at three levels (Rademaker, 2007):

- *Level 1* – sharing information, i.e. electronic exchange of information between shipper, carrier, haulier, receiver and terminal operator.
- *Level 2* – planning and control of operational processes at the terminal. Automation at this level means using information systems for planning decisions and control of terminal operations.
- *Level 3* – the actual handling of containers, meaning partly or fully robotised operation of equipment.

An example of a large, fully automated terminal is the APMT terminal on Maasvlakte 2 (Figure 4.41), with a capacity of 2.7 million TEU per year. The terminal concept is based on using STS cranes, remotely operated from a central control room. They unload containers from the vessel and place them directly onto a fleet of Lift Automated Guided Vehicles (Lift AGVs). The Lift AGVs can carry two 20 ft containers at a time and shuttle them at a speed of 22 km/h from the quay to the container yard using an on-board navigation system that follows a transponder grid. Once the Lift AGV arrives at its programmed destination it lifts the containers onto storage racks. Next, an Automated Rail-Mounted Gantry (ARMG) crane (Figure 4.42) takes the container from the rack to its designated location in the stack (APM-Terminals, 2012).

Figure 4.41: Overview of the container terminal AMPT Maasvlakte 2 (APM Terminals MVII: 2018 by APM Terminals is licenced under CC BY-NC-SA 4.0).

Figure 4.42: ARMG and truck transfer docks, AMPT Maasvlakte 2 (APM Terminals Maasvlakte II, Rotterdam by APM Terminals is licenced under CC BY-NC-SA 4.0).

Another example of a fully automated terminal is Altenwerder Container Terminal in Hamburg, Germany. It became operational in 2002 (Figure 4.43).

Figure 4.43: Overview of the container terminal Altenwerder, Hamburg, Germany (Phb dt 8107 CTA by Dirtsc is licenced under CC BY-SA 3.0).

4.5.3 Terminal Operating System (TOS)

Maximising terminal performance and operational efficiency can hardly be done without a computerised Terminal Operating System (TOS). Terminal operators use the information from a TOS to optimise the use of equipment at the quayside and in the container yard. It can also help managing the terminal's business transactions, including gate operations, invoicing, finance, accounting and management reports.

A real-time TOS provides up-to-date information on events throughout the terminal, including data on productivity and time lost on cranes or in the yard. With this information planners can quickly and easily determine vessel loading/unloading plans and the best allocation of manpower, equipment and yard space. A real-time TOS also enables an immediate response to exceptional events and accidents.

The TOS can help minimise unused yard space, unnecessary container and equipment moves, lost containers and excessive dwell times. Detailed graphic visualisation enables real-time monitoring of berth space, vessel stowage and equipment activity, thus allowing to change operations if necessary.

The TOS can automatically assign gangs and cranes to vessels, sequence the cranes and track their productivity real-time. It can also predict vessel loading and unloading times and can alert the operator to factors relevant to the service commitment, such as time-sensitive customer delivery or transhipment to another vessel.

The system can usefully generate an automated stowage plan and will consider the trade-off between vessel and yard efficiency, such as the impact of RMG/RTG crane movements and lane changes and the effects of retrievals from more remote parts of the container yard.

TOS-supported yard planning and control can include:

- a detailed yard model and real-time views,
- utilisation and maintenance reporting,

- flexible allocations for yard planning and equipment utilisation,
- automated tracking and notification of planning errors.

TOS-supported vessel planning and control can include:

- advanced stowage validation,
- real time tracking of vessel planning execution.

Last, but not least, the TOS gives access to a wealth of very detailed historical data. This data can be most useful for layout and operational rearrangements of the terminal.

4.5.4 Security

A new comprehensive security regime came into force in July 2004 with the intention of strengthening maritime security to prevent and suppress acts of terrorism against shipping. Both the International Ship and Port Facility Security (ISPS) Code and the Container Security Initiative (CSI) have represented the culmination of work by the IMO's Maritime Safety Committee and the United States Custom and Border Protection Service in the aftermath of terrorist atrocities in the United States in September 2001.

The ISPS Code takes the approach that the security of ships and port facilities is basically a risk management activity. To determine what security measures are appropriate, a risk assessment must be undertaken for each particular case.

Container movements are considered particularly sensitive in this respect, and are therefore subject to some specific regulations. In particular the CSI seeks to use Non-Intrusive Inspections (NII) and radiation detection technology before containers are shipped to the United States of America.

The ISPS Code was adopted by the IMO on July 1^{st} 2004 as an amendment of the International Convention for the Safety of Life at Sea (SOLAS). The objectives of the ISPS Code (NeRF-Maritime, 2004) are:

- to establish an international framework involving contracting governments, government agencies, local administrations and the shipping and port industries to detect security threats and take preventive measures against security incidents affecting vessels and port facilities used in international trade;
- to establish the respective roles and responsibilities of the contracting governments, government agencies, local administrations and the shipping and port industries, at the national and international level, for ensuring maritime security;
- to ensure the early and efficient collection and exchange of security-related information;
- to provide a methodology for security assessments so as to have in place plans and procedures to react to changing security levels;
- to ensure confidence that adequate and proportionate maritime security measures are in place.

In order to achieve its objectives the ISPS Code embodies a number of functional requirements. These include but are not limited to the following:

- gathering and assessing information with respect to security threats and exchanging such information with appropriate contracting governments;
- requiring the maintenance of communication protocols for vessels and port facilities;
- preventing unauthorised access to vessels, port facilities and their restricted areas;
- preventing the introduction of unauthorised weapons, incendiary devices or explosives to vessels or port facilities;
- providing means for raising the alarm in reaction to security threats or security incidents;
- requiring vessel and port facility security plans based upon security assessments;
- requiring training drills and exercises to ensure familiarity with security plans and procedures.

Under CSI, high-risk containers receive security inspections, including X-ray and radiation scans (Figure 4.44), before being loaded on board vessels destined for the USA. Once high-risk containers are inspected at CSI ports, they are not ordinarily inspected again upon arrival at the US seaport. This means that the containers inspected at CSI ports actually move faster, more predictably and efficiently through USA seaports.

Figure 4.44: Fast Scan Vehicle and Container inspection system ("Douane Vervoer Controle" by Willem van Kasteren is licenced under CC BY-SA 4.0).