Chapter 2
Operations Systems of Container Terminals: A Compendious Overview

Birgitt Brinkmann

Abstract
This section contains an overview of the different functional areas of a marine container terminal and a summary of the main types of container handling systems. The main advantages and disadvantages of each type of handling system are also summarized without focusing on technical details.

2.1 Functional Areas of Terminal Operations

As every other terminal, a container terminal is a complex system that functions only efficiently when its layout is designed in such a way that the loading and discharging process of vessels runs smoothly. A container terminal consists of at least three operational areas:

1. operational area between quay wall and container yard (apron or the area just behind the berth front)
2. container yard (terminal storage = stacking area)
3. terminal area of landside operations (including the gate, parking, office buildings, customs facilities, container freight station with an area for stuffing and stripping, empty container storage, container maintenance and repair area etc.)

The importance of the container freight station has decreased within the past decades as more and more containers are sent directly from the originator to the addressee without being transhipped. Nevertheless, a lot of terminals are provided with a container freight station for storage purposes. Figure 2.1 shows the schematic layout of

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a container terminal with the different operational areas. The transport between the areas is carried out using handling equipment for horizontal container transport. The layout and choice of equipment for the above mentioned areas and their interfaces depend on, amongst others, the

- number of containers to be handled,
- available area and
- mode of hinterland transport.

The combination of terminal equipment used

- at the vessel,
- for transport tasks between quay and stacking yard (or vice versa),
- for container stacking,
- for transport from stacking yard to and from the landside operation area and
- for landside operation itself

is called operations system.

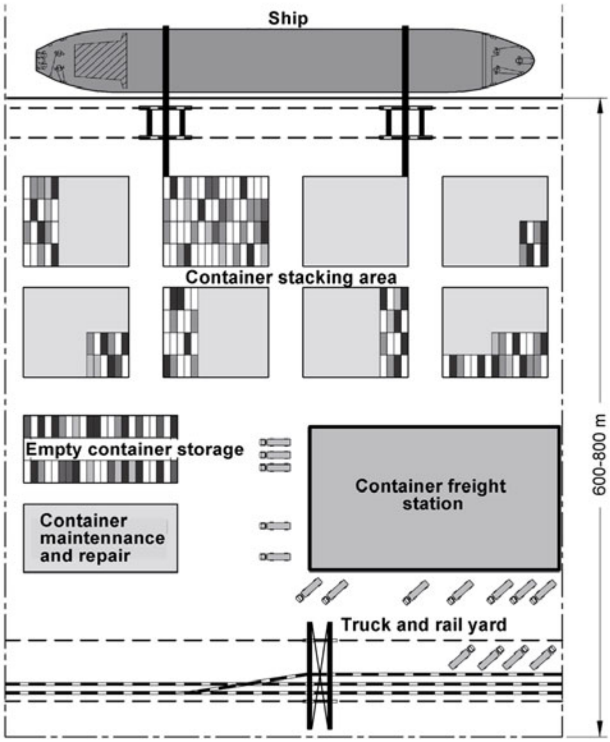

Fig. 2.1 General layout of a container terminal (see Brinkmann (2005))

Independent from the selected terminal operations system, specific processes are performed on the different areas.

On the apron area the ship-to-shore operations (loading and discharging of vessels) are carried out. In the beginning of the container shipping the cargo handling on this area was mainly carried out with on-board lifting gear of the vessels or a regular quay crane. Nowadays this type of handling is only used on terminals with a comparatively low container throughput. On medium and large sized terminals the ship-to-shore handling of containers is usually carried out with gantry cranes specialized in this purpose.

Container vessels are the only ships that can be loaded and discharged at the same time. The *S*hip-*T*o-*S*hore gantry crane (so-called "STS crane") discharges a container moving landwards and on its way back loads a container on to the vessel. This handling procedure requires good planning of the terminal equipment for the container delivery as well as for the container stacking in the yard and on the vessel. Landwards, the full container yard borders on the apron, used for

- storing inbound (discharged from vessels) and outbound (to be loaded on vessels) container as well as for
- storing export containers delivered by train or truck, and forwarding import container to these modes of transport.

These operations usually do not happen at the same time. Therefore, the container yard is an intermediate storage facility, in which the containers remain from a couple of hours to some weeks (container dwell time = containers in the same position or area during this period of time, *e.g.* within the terminal area). There are different possibilities for the layout of this intermediate storage area (= stacking yard). If the stacking area is a compact, low ground area consuming stack without spacing, it is called block stack (see Figure 2.2; HHLA (2010)). In this case, yard gantry cranes are used for the stacking of containers being delivered by terminal equipment of horizontal transport. An alternative is the linear stack (see Figure 2.3) where the containers are stacked by *S*traddle *C*arriers (SC). This type of stacking requires spacing between the container rows and relatively wide terminal roads. Export and import containers are segregated within the yard area), piled up to 4 containers high and (relating to import boxes) pre-sorted for the different hinterland transport modes. The third rarely applied stacking alternative is the high-bay racking, used for terminals with high throughput requirements but very small available area. An example is Hong Kong with high-bay racks up to 12 container tiers.

The configuration of the area for landside operation, as third main functional area of container terminals, is determined by the hinterland transport modes or related interfaces, respectively. In case of predominant truck operations, this functional area is often integrated in the yard area. The trucks are loaded and unloaded on dedicated spaces at the end of the stacking yard or in the middle of the yard, *e.g.* by SCs or yard cranes. In case of railway transport the loading/unloading should take place outside the stacking area to avoid the crossing of rail tracks by the yard equipment. This would increase the terminal efficiency and performance as well as the safety on the terminal. The loading/unloading is carried out directly by the yard equipment or by gantry cranes being combined with appropriate vehicles for horizontal transport between railway station and terminal yard.

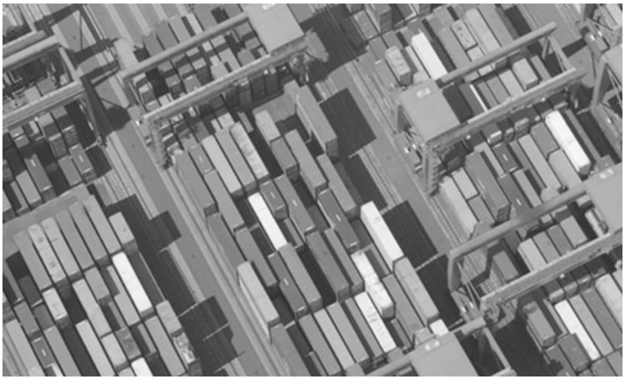

Fig. 2.2 Block stacking

Fig. 2.3 Linear stacking

As only a traveling vessel makes money, the berthing time at the terminal quay wall should be as short as possible. First and foremost this can be achieved by a fast loading / discharging process of the vessel. To ensure this, the operational areas have to be tuned to each other.

The length of a container terminal depends on the planned number of berths and the length of the design vessel as well as local restrictions (*e.g.* given geographic conditions). The (minimum) depth of the terminal depends on the operations system. The available area is a crucial factor for its selection. As a guide value, 600m–800m should be appropriate for new constructions of terminals.

The remainder of this paper is organized as follows. Section 2.2.1 provides a brief overview of common equipment types and meaningful factors for equipment choice. In Section 2.2.2 to 2.2.5, various operations systems are introduced regarding their use of handling equipment for container stacking and transport in the operational terminal areas mentioned above. Additionally, the main operational and economic advantages and disadvantages are outlined system-related. Lastly, Section 2.3 concludes the paper with an overview of functional system capabilities.

2.2 Operations Systems

2.2.1 Determinants of Operations System Choice

To design and operate a successful container terminal is a challenging task with the objective to decrease the cost of operation while at the same time service quality and effectiveness of operation have to be increased. The new large container terminals being under construction, the ones already being designed and the future ones are ambitious projects (due to complexity and given economic/capacity requirements) and will challenge the terminal operators to further increase the efficiency and/or performance of loading/discharging processes. To achieve this, not only larger and faster STS cranes are required but also logistic capabilities of horizontal transport equipment to cope with augmentation of STS cranes. Therefore, the right selection of the operations system is a key factor to a successful terminal. The decision for an operations system depends, inter alia, on the following factors:

- size of vessels
- traffic forecast (annual container volume)
- container volume in peak hours
- available land area
- required stacking density of the containers per ha (configuration of stacking yard)
- cost structure (wages, financial facilities, dues)
- aimed STS productivity (*i.e.* TEU / crane / hour)
- geographic restrictions of the terminal area
- contingent restrictions due to soil conditions
- environmental impacts like wind, ice, noise, light and snow
- mean dwell time of containers in the stacking yard
- TEU factor (*e.g.* 1,6 implies 60% of all containers are 40 ft long)
- percentage of reefer containers
- percentage of empty containers (short: MTs)
- percentage of LCL (*L*ess than *C*ontainer *L*oad)
- the connections to the hinterland transport modes road, railway and inland waterways

The number of determinants shows that there is no "general ideal" container terminal. The usual equipment to fulfil the tasks in the three mentioned functional terminal areas (see Section 2.1) are:

- quay cranes at the vessel:
  - STS crane

  - conventional quay crane
  - mobile harbor crane

- for container transfer (horizontal transport):
  - SC (max. stacking capability: 1-over-3-high)
  - reachstacker
  - terminal tractor with trailer (so-called *T*ractor-*T*railer *U*nit (TTU))
  - multi-trailer (terminal tractors with several trailers)
  - empty/loaded container handler
  - *Sh*uttle *C*arrier (ShC stacking capability: 1-over-1-high)
  - *A*utomated *G*uided *V*ehicles (AGV)
  - automated SC (max. stacking capability: 1-over-2-high)
- for container transport and stacking within the yard:
  - SC
  - *R*ubber-*T*yred *G*antry crane (RTG crane)
  - *R*ail-*M*ounted *G*antry crane (RMG crane)
  - container handler (like reachstacker or top lifter)
  - *O*ver*H*ead *B*ridge crane (OHB crane)
- for the landside operation:
  - SC
  - RTG crane
  - RMG crane
  - reachstacker
  - TTU
- at the inland navigation vessel:
  - STS crane
  - conventional quay crane
  - mobile harbor crane

Considering the fact that the above-mentioned equipment is available in different sizes and special designs (*e.g.* one or two trolley STS cranes, SCs for 3- or 4-high stacking (*i.e.* 1-over-2- or 1-over-3-high), yard cranes of different heights and widths, reachstackers with different lifting heights and loading capacities) and the possibilities of various combinations, it is obvious that special care has to be paid to the analysis and choice of the "optimal" operations system comprising the qualitative (kind of equipment) and quantitative (number of equipment) dimensioning of system resources.

Notwithstanding the mentioned variety there are some commonly used systems being explained below with their main pros and cons listed briefly. Representing possible types of quay cranes only the most efficient one, the STS crane, is being considered. Due to operational and economic restrictions not all types of horizontal and vertical transport equipment can (or should) be combined.

Because of the diversities of equipment types, the choice of the operations system results in considerable different terminal layouts.

2.2.2 Reachstacker System with Tractor-Trailer Units

The STS crane drops down containers on TTU that transport the containers to the stacking area (see Pirhonen (Chapter 3 of this Handbook)) where the boxes are stacked by reachstackers (see Figure 2.4) or forklift trucks fitted with appropriate spreader frames for container top or side lifting. Traditionally heavy fork lifts were used but nowadays most operators use reachstackers because of their higher operational productivity and flexibility enabling a higher stacking density as well.

- due to their versatility in operation, reachstackers are often the best choice for small and medium size container terminals and for multi-purpose terminals. As they are easy to handle reachstackers in particular are a good choice for countries with little trained labor.
- reachstackers can be used for stacking in the yard, loading and unloading of TTUs, road trucks and rail cars on first rail.
- TTUs are used for the transport of the containers between the vessel and the container yard.
- reachstackers can also be used for short distance transportation, so that no additional equipment is required on small terminals.

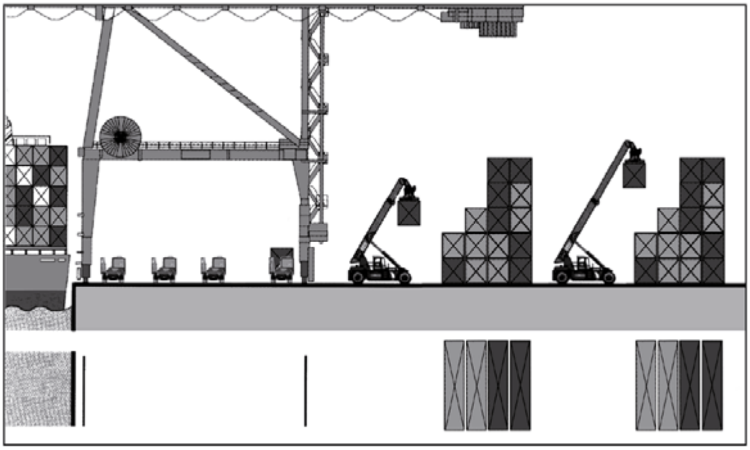

Fig. 2.4 Stacking example of operations system with reachstackers and TTUs (see Kalmar Industries (2010))

- including landside operation, an estimate of 3–4 reachstackers and 4–5 TTUs are required per STS crane (rough rule of thumb of operations practitioners noticing that *e.g.* the specific number of TTUs in particular depends on the distance between the berth and the stacking area of the respective application case).

- a storage capacity of approx. 350 TEU per hectare for 3-high stacking and 500 TEU per hectare for 4-high stacking are common figures for this type of yard equipment. The maximum stacking height is 5, container blocks can be kept 4-deep due to second row access. Among others, another stacking possibility is a depth of 8 when stacked in pyramid shape. To avoid too much reshuffling of the stack, the stacking is often limited to 2 deep and 3–4-high.
- in case of relocation of capacities reachstackers could be easily transported to another terminal or used for other cargo handling. Because of their easy transportation between terminals (or terminal areas) reachstackers could be used to cover temporary peak requirements.

System advantages

- low investment and capital costs as reachstackers and TTUs cause relatively low purchase expenses per equipment unit
- low operating costs of equipment in comparison to other operations system alternatives (prerequisite: low-wage country)

System disadvantages

- container transports between STS crane and yard area require two handover procedures due to the use of different terminal equipment for transport and stacking tasks
- comparatively high manning requirements due to the large number of vehicles and low level of automation, and therefore the impact of labor or operating cost respectively is considerable in high-wage countries
- the TTUs can not pick up or set down the containers self-acting
- disturbance of operation by trucks being loaded/unloaded in the stacking area

2.2.3 Straddle Carrier System

The STS crane places the containers onto the apron from where the SCs transport them to the stacking yard (see Figure 2.5 and Figure 2.6) and stack the containers. The SCs are independent from any other equipment and are able to perform all the different handling operations: transport, stacking and the loading/unloading of trucks and rail cars (see Figure 2.6b).

- SC systems are often the optimal system for medium and large size terminals, when high flexibility in the yard and accessibility of the boxes are required. Within this system it is easy to alter the layout of the terminal.
- due to the required traffic lanes the system allows only a medium stacking density. Based on practical experience a storage capacity of approx. 500 TEU per hectare stacking 2-high (3-high SC) and 750 TEU per hectare stacking 3-high (4-high SC) can be achieved. The maximum stacking height is 4-high.

- including landside operation, an estimate of 4–5 SCs are required per STS crane – without considering specific conditions.
- on some terminals the system is supported by container handlers stacking MT boxes and/or RMGs for container handling in the rail yard.

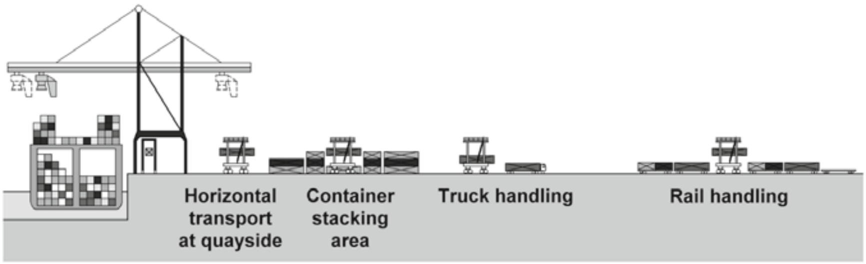

Fig. 2.5 Pure SC system

System advantages

- SC are able to cover all kinds of horizontal and vertical transports being necessary to perform container moves from the landside terminal interfaces (including truck handling and rail operation) via the container yard to handover positions below the STS cranes at quayside (and vice versa). Thus, pure SC operations systems (not considering the STS cranes) are viable and combinations with other (compatible) equipment types are facultative only or are induced by particular logistics or economical requirements, respectively
- the containers can be dropped on the ground so that no (or only short) waiting times for handling equipment occur. This kind of container handover enables STS cranes to operate with a high productivity while using a comparatively low number of SCs per crane.
- high number of concurrent container movements
- the breakdown of one SC has a comparatively low impact on the total handling process
- compared to the systems with TTUs the labor costs are lower due to the smaller number of vehicles
- no disturbance of the operation by trucks because these are loaded/unloaded outside the stacking yard
- the system is flexible to changes based on operational requirements and terminal layouts can be simply altered as SCs can be easily moved within the terminal since no pre-set routes or tracks are needed

System disadvantages

- high investment and capital costs for the SCs

- high maintenance and energy costs
- high labor costs compared to (semi-)automated transport and stacking systems (see Section 2.2.5)
- high area requirement in comparison to yard cranes as a result of a lower stacking height and a large proportion of traffic (within the yard area)
- when traveling distances are far, SCs are not the first choice as they are considerably slower compared to TTUs and more costly

a) b)

Fig. 2.6 SC operation: a) Container transport and stacking; b) Loading / unloading of rail cars

2.2.4 *Rubber-Tyred Gantry Crane System with Tractor-Trailer Units*

The STS gantry crane places the container on a TTU unit that transports the container to the storage area where the RTG crane stacks the containers in long blocks (see Figure 2.7). A RTG can be used for TTUs and road trucks as well. The size and structure of the RTG crane is determined according to the requirements of the terminal operator.

Very heavy concrete paving is required in the wheel tracking areas to support the heavy wheel loads. Besides, there are concrete/steel pads necessary for turning purposes of the cranes to travel to adjacent storage areas (or blocks) to perform stacking operations. RTGs are generally smaller and lighter than RMGs (see Section 2.2.5). Therefore, they are sometimes to be favored for terminals built on reclaimed marshland, where reinforced piling would be too costly.

- RTG cranes are often used on large and very large terminals. The system has a very high stacking density because of the high stacking capability and the block

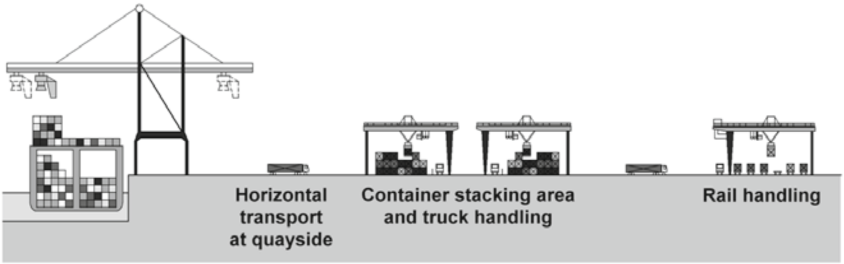

Fig. 2.7 *R*ubber *T*yred *G*antry (RTG) cranes and TTUs in the stacking yard, rail yard operation by RMGs

stacking. Long traveling distances on the terminal are less problematic as TTUs transport the containers

- RTG cranes can also be effectively used for the handling of containers on road trucks or rail cars. According to manufacturers, up to four tracks can be covered and containers can be stored at the side of the rail tracks
- RTG cranes can be allocated from the yard to the landside operation and vice versa, if necessary
- including landside operation 2–3 RTGs and 4–5 TTUss (depending on the distance between berth and stacking area) are required per STS crane (rule of thumb based on practical experience)
- RTGs stack the container in blocks 1-over-4- to -7-high and 5 to 8 container rows plus 1 lane for container handover lane
- as a rule of thumb based on practical experience, the capacity of the yard is approx. 1,000 TEU per hectare (stacking 4-high)

System advantages

- low space requirement in the stacking area because of the high storage capacity in a small area (high stacking density). The containers can be stacked up to 8-high (*i.e.* 1-over-7-high)[1] without spacing for traveling lanes between the rows. To avoid reshuffling of the containers, an efficient administration of the yard is required.
- relatively high flexibility as the RTGs can be transported to other storage blocks
- medium investment capital costs per piece of equipment

System disadvantages

- container transports between STS crane and yard area require two handover procedures due to the use of different terminal equipment for transport and stacking tasks

[1] Common RTG systems offer nowadays max. stacking capability of 1-over-6-high, but systems with seven tier stacks for container storage are available.

- disturbance of TTU operations by trucks being also loaded/unloaded in the stacking area (mixed traffic)

2.2.5 Rail-Mounted Gantry Crane System

2.2.5.1 Rail-Mounted Gantry Crane System with Tractor-Trailer Units (blocks parallel to quay)

The system generally complies with the RTG system, but the cranes are mounted on fixed rail tracks with a cantilever outside the portal of cranes (see Figure 2.8).

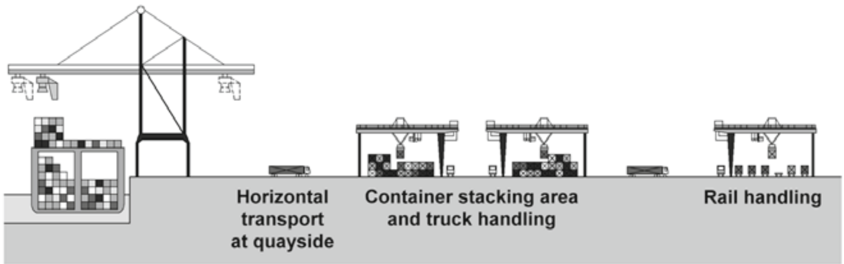

Fig. 2.8 RMG cranes with TTUs

System advantages (compared to RTGs)

- RMGs generally stack higher and span wider, with up to 1-over-7-high and 12 containers wide
- based on practical experience stacking density of the yard is higher with RMG cranes and can exceed 1,000 TEU per hectare (stacking 4-high)
- more durable and reliable than RTGs
- higher availability with moderate maintenance and repair costs
- Medium operating costs because of relatively low maintenance costs
- Easier to automate than RTGs

System disadvantages (compared to RTGs)

- more expensive to install because of required tracks
- high disturbance of terminal operation in case of crane failure
- high investment and capital costs due to equipment and construction costs (rail tracks) in comparison to other types of block stacking systems
- rigid system in operation because of rail mountings and more difficult to change the layout in the yard

2.2.5.2 Rail-Mounted Gantry Crane System with Automated Guided Vehicles or Shuttle Carriers (blocks perpendicular to quay)

The horizontal transport of the containers is performed with AGVs (see Rijsenbrij and Wieschemann (Chapter 4 of this Handbook)) or ShCs (see Pirhonen (Chapter 3 of this Handbook)). For safety and operational reasons, the automation requires a strict separation between the AGV area and the area with manned equipment (see Figure 2.9).

Hence, the handover positions for trucks are located at the top-end of the stacking blocks. The stacking of the containers is usually carried out by automated RMGs. The ShC is designed primarily to convey containers between the ship's side (due to stacking capability of only 1-over-1-high machines are considerably smaller than conventional SC and therefore more manoeuvrable) and container stacks served by RMG cranes. As it is able to stack containers two high it can also be used for loading and unloading road trucks and rail cars. The shuttle carrier is an alternative for terminals that aim at more efficiency to handle the container transport between the stacks and the quay cranes, and still maintain high density stacking by RTG or RMG yard cranes.

System advantages

- very low labor costs because of automation
- high system availability
- very high productivity of horizontal transport

System disadvantages

- very high investment and capital costs
- very well trained labor required
- rigid system

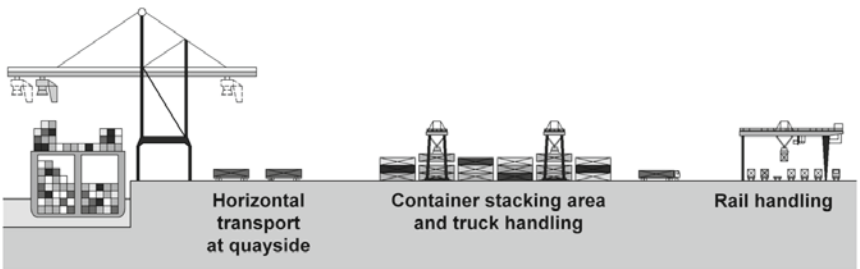

Fig. 2.9 RMG cranes with AGVs

2.3 Summary of Main Data

The data summarized in Table 2.1 is based on practical experience and averaged from a multitude of terminals operated in different countries around the world and does not include allowances for maintenance and repair.
The data should be used only as rule of thumb for plausibility checks and must not be used for planning a container terminal (*e.g.* required area and number of handling equipment) as each terminal is different and the boundary conditions like area layout, operational requirements, legal restrictions etc. vary from location to location. Therefore, the design of each container terminal requires an individual solution.

Table 2.1 Main data of operations systems

Operations System	Required equipment per Quay Crane[(2+3)]	Stacking Tiers [1-over-*n*-high]	Yard Capacity [TEU / ha]
Reachstacker & TTU	3–4 Reachstackers + 4–5 TTUs	3	350
		4	500
		5	950–1,000[4]
Pure SC	4–5	2	500
		3	750
RTG & TTU	2–3 RTGs 4–5 TTUs	4–5[5]	1,000
RMG & TTU (blocks parallel to quay)	2 RMGs 4–5 TTUs	4–5	1,000[6] (or more)
RMG & ShC (blocks perpendicular to quay)	2 RMGs 2–3 ShCs	4–5	1,000[6] (or more)
RMG & AGV	5–6	4–5	1,000[6] (or more)

[2] Generally, the number of equipment per STS crane depends on the distance between stacking yard and berth, the productivity of the STS crane, the locations of the containers within the yard, the quality of stacking in regard to export containers (sorting with respect to destination ports and weight classes), the interaction between vessel stowage planning and yard planning.

[3] The required number of equipment refers only to the horizontal transport between berth (STS cranes) and stacking yard and should be considered more differentiated, particularly with respect to RTGs and RMGs which in a lot of cases also handle the delivered export containers as well as import containers to be loaded on road trucks and additionally carry out reshuffling of containers in the yard.

[4] Only empty containers.

[5] Max. 1-over-7-high (high costs for reshuffling of containers which decreases the productivity and increases the number of required RTGs).

[6] Independent from space requirements of horizontal transport equipment.

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