Study

Optimized Modern Multi-Purpose Terminals

Client: Hamburg Port Authority AöR

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IAPH International Association of Ports and Harbors

Sellhorn Ingenieurgesellschaft

Fraunhofer CML

Study "Optimized Layout of Modern Multi-Purpose Terminals"

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Abbreviations

AGV	Automated Guided Vehicle
ASC	Automated Stacking Crane
CML	Fraunhofer Center for Maritime Logistics and Services
CNG	Compressed Natural Gas
EDI	Electronic Data Interchange
ERP	Enterprise Resource Planning
FDM	Fused Deposition Modeling
GPS	Global Positioning System
HPA	Hamburg Port Authority
IMDG	International Maritime Code for Dangerous Goods
IT	Information Technology
LiDAR	Light detection and ranging
LNG	Liquefied Natural Gas
LSP	Logistics Service Provider
OCR	Optical Character Recognition
PCS	Port Community System
RoRo	Roll on - Roll off
RTG	Rubber Tired Gantry Crane
SIG	Sellhorn Ingenieurgesellschaft mbH
SLA	Stereolithography
SLS	Selective Laser Sinterling
TEU	Twenty-foot-equivalent unit
TOS	Terminal Operating System
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VIS	Visual Information System
VRS	Visual Recognition System
WLAN	Wireless Local Area Network

1 Introduction

A strong specialization of land use and terminal operations took place across the world over the past decades. This development has been influenced by the increase of containerized trade and optimization of bulk, gas and oil terminals. Mainly, only break bulk cargo, dry cargo or cargo-mixed ship loadings remained to be handled on multi-purpose terminals, which still form an important pillar of the port industry. However, recent trade numbers indicate that the trend towards increasing containerization seems to slow down or even stop. The market for containerized transport flows seems to be saturated. Further cost reductions and efficiency improvements in container handling can only be achieved at a marginal level. Significantly more optimization potentials exist for multi-purpose terminals.

A multi-purpose terminal offers infrastructure, equipment and services for different types of cargo and vessels. A certain degree of flexibility is needed to cope with users from different cargo markets. The operators of ‘traditional’ multi-purpose terminals overtake a service provider role for a large number of functions. In most ports, the structures of terminals have been gradually adapted to the requirements of a broad-based service portfolio. The question arises which optimization potentials can be generated for these often historically grown structures. Anticipated advantages may justify a restructuring or even the construction of new terminal areas.

From a macroeconomic point of view, there is a trend towards stronger networking between individual actors along the transport chain. The ongoing globalization, the availability of innovative technologies as well as the rapidly changing market requirements are changing the maritime supply chains. In the port sector as well as in the production sector, the degree of automation continues to increase and digitalization of the economy takes place. Future multi-purpose terminal developments will certainly also profit from a greater degree of networking, automation and the use of innovative IT systems.

Current trends and innovations in maritime logistics, both on terminal/port level and with a broader industry perspective are of particular interest for development projects. On behalf of the Hamburg Port Authority AöR (HPA) the two cooperation partners Sellhorn Ingenieurgesellschaft mbH (SIG) and Fraunhofer Center for Maritime Logistics and Services (CML) follow the objective to provide recommendations for the improvement of multi-purpose terminals considering efficient use of financial and natural resources. Among other things, the following pre-specified questions are considered:

- What is the optimal layout of a multi-purpose terminal under the focus of area efficiency?
- Which innovative transport and logistics processes are recommended?
- How do multi-purpose terminals benefit from advanced information technology?
- What are the possibilities for optimization through enhanced digitalization?
- How can the utilization of multi-purpose terminals be enhanced by cooperation between different operators and/or users?
- How can energy efficiency and emission reduction be promoted?
- How is the development of the demand for multi-purpose terminals assessed in the light of future technologies?
- What is an indication for the investment costs?

2 Goal and Course of the Study

The overall objective of this study is to identify optimization potentials for the restructuring of existing (brownfield) multi-purpose terminals or the planning and construction of new (greenfield) multi-purpose terminals and to provide recommendations for the improvement of multi-purpose terminals considering efficient use of financial and natural resources. To achieve this overall objective, the work is carried out in two consecutive steps. The course of the study is illustrated in Figure 1.

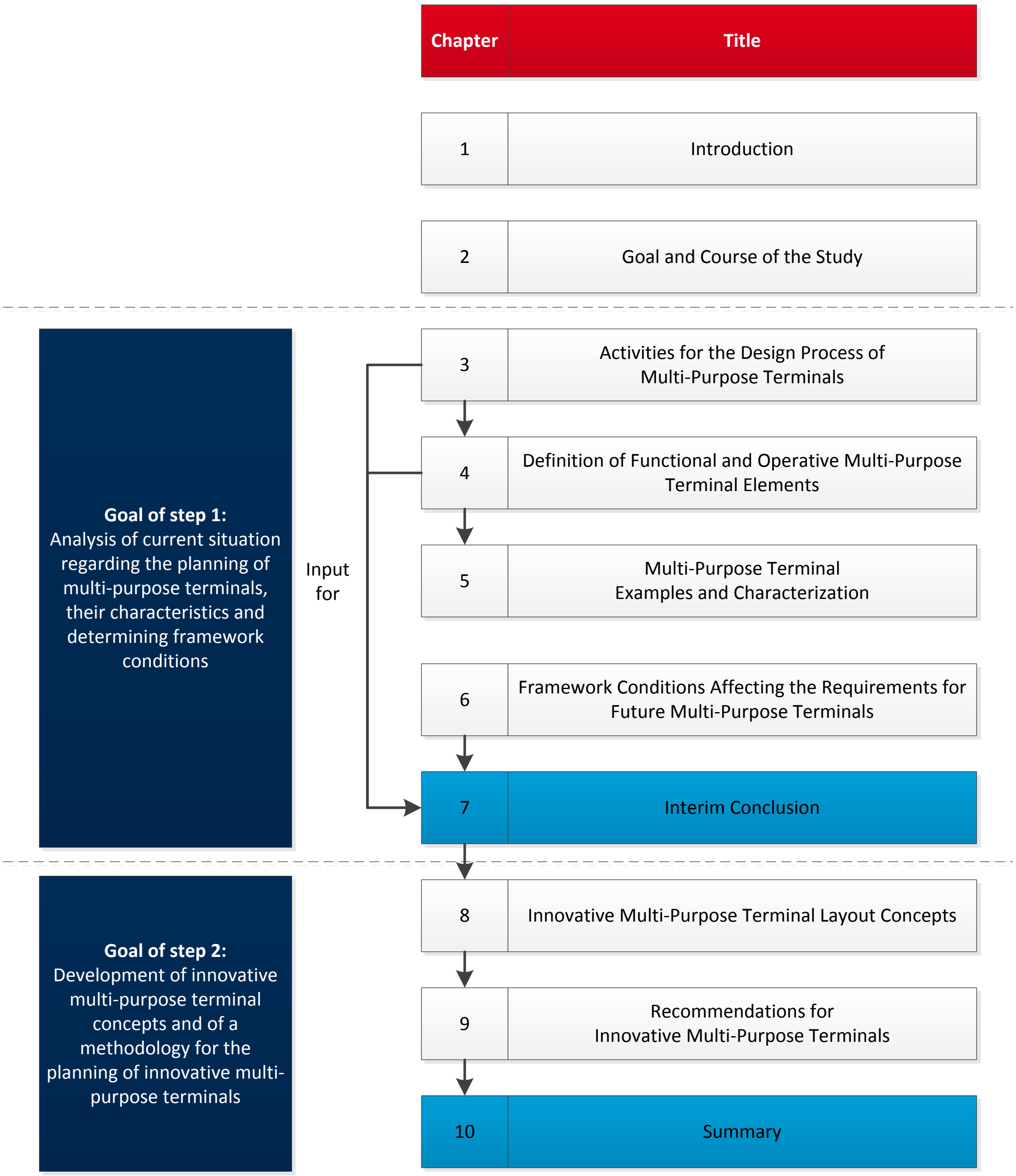

Figure 1: Goal and course of the study

The first step aims to describe the current situation regarding the steps necessary for the planning of multi-purpose terminals (chapter 3) and to define functional and operative multi-purpose terminal elements (chapter 4). Further, a methodology to compare multi-purpose terminals in a structured way is developed. This methodology is used to describe existing multi-purpose terminals (chapter

5). The first step also aims to identify global trends and resulting challenges multi-purpose terminals need to meet to remain competitive (chapter 6). The results of the first step are summarized in an interim conclusion (chapter 7).

Based on the results from the first step, the second step aims to develop innovative multi-purpose terminal concepts for different cargo mixes (chapter 8). These concepts take into account suitable (technological) solutions that are already in use on other terminal types like container terminals or in other sectors. Additionally, they fulfill the requirements for innovative multi-purpose terminals formulated in the previous step. Furthermore, recommendations for the planning process of innovative and future-oriented multi-purpose terminals are formulated (chapter 9). Chapter 10 summarizes all the results presented in this study.

3 Activities for the Design Process of Multi-Purpose Terminals

The following chapter presents activities that are generally required for the design process of port terminals. Topics that generally need to be covered are illustrated in Figure 2. These topics also need to be considered when planning multi-purpose terminals.

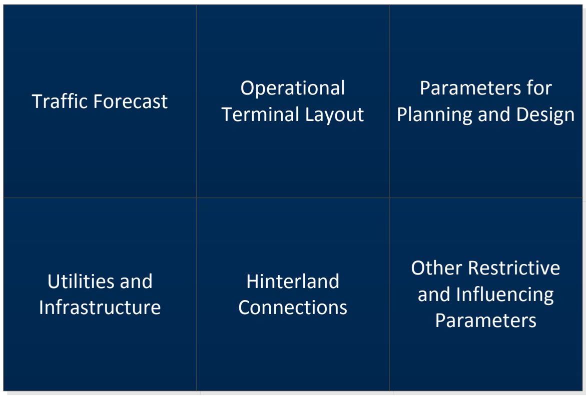

Figure 2: Topics that need to be covered in the design process of port terminals

1. **Preparation of traffic forecast**

   Prior to the layout planning of the multi-purpose terminal, a traffic forecast has to be carried out. Usually, this covers the analysis of potential for the terminal/port over a 30 year time horizon with three different development scenarios. The traffic forecast comprises a vessel forecast indicating

   - Expected vessel type
   - Vessel capacity and size
   - Dwell time

   and a projection of the future cargo potential.

2. **Planning of operational terminal layout**

   The concept terminal layout will be based on the results of the traffic forecast. It will include

   - Cargo mix and flexibility of cargo mix
   - Cluster commodities with regard to their logistical requirements
   - Definition of design vessels per commodity group
   - Identification of cargo handling needs for the terminal
   - Definition of storage types per commodity group, resulting in storage capacities, required auxiliary handling areas and port internal traffic ways
   - Estimation of required berth capacity per commodity group and service type, incl. assessment of resulting berth utilization per commodity and service type and assessment of options for optimized combined berth utilization
   - Identification of berthing needs from auxiliary services and activities (piloting, tug services)

The information obtained will result in the design of operational areas such as container stacking yard, reefer storage area, general cargo area, bulk cargo storage areas including liquid and break bulk, (design of terminal pavement), and areas for high and heavy goods.

For the different commodities and services, necessary cargo handling equipment requirements have to be determined. Administrative and office buildings have to be considered.

3. Determination of parameters for planning and design

As a subsequent step from operational planning and technical analyzes, the functional and technical design parameters have to be defined. These parameters include**:**

- Physical site conditions (subsoil conditions, topography)
- Design loads from operational equipment
- Dimensions and loads from design vessels
- Required depth at berth
- Design working life
- Safety concept and safety factors

4. Design of utilities and infrastructure

The design of a terminal also includes calculations of demand in terms of water supply, sewage, firefighting water, power supply, lighting, and communications including identification of sources as well as elaboration of utility infrastructure general layout.

5. Definition of hinterland connections

In order to ensure cargo flows to and from the terminal during all development phases, the following tasks have to be performed:

- Calculation of resulting traffic originating from the terminal's activities
- Assessment of adequateness of existing hinterland infrastructures
- Discussion of potential road and rail access and/or upgrading options, and
- Definition of interfaces of terminal area with hinterland transportation networks

6. Consideration of other restrictive and influencing parameters

Apart from abovementioned parameters, the following has to be considered:

- Dimensions and depth of navigation channel, harbor basin and turning area
- Terminal limits based on the terminal layout

4 Definition of Functional and Operative Multi-Purpose Terminal Elements

The following chapter presents the current situation regarding multi-purpose terminals worldwide. Firstly, functional areas of multi-purpose terminals are presented. Afterwards, civil engineering and operative elements for maximizing flexibility of terminal usage are described.

4.1 Functional Areas of Multi-Purpose Terminals

In the scope of this study, a terminal is defined as a single man-made facility that may have several berths for the handling of vessels. Port terminals can be constructed for transhipment of special cargo or vessel types or several types of cargo as well as several vessel types. UNCTAD defines a multi-purpose terminal as a “complex of infrastructure, equipment and services which offers a combined and flexible response to the servicing demand of certain types of vessels and cargo”.[1] In such terminals, cargo and vessels within a specified range of properties can be handled efficiently. Properties can be, e.g. the condition (solid, liquid, gaseous) of the cargo, the weight of the cargo, the size of load units, the sensitivity to temperature or humidity. The field of allowed properties can for example include containers and unitized cargo and thus exclude liquid bulk cargo, dry bulk cargo, heavy unitized cargo or rolling cargo. Still, a field of allowed properties means that the terminal cannot only concentrate on handling one cargo but has to provide:

- Non-specialized equipment for ship-to-shore movement as well as for hinterland transhipment, storage and horizontal transport or different types of specialized equipment
- Non-specialized berths or different specialized berths and
- Non-specialized terminal areas or different terminal areas with a specialized function

The flexibility of multi-purpose terminals enables unforeseen transhipment of non-standardized cargo that cannot be handled in specialized terminals. According to the design guide of UNCTAD the following functional areas are common for dimensioning a multi-purpose terminal:[2]

1) Length and specifications of berths suitable for the various types of vessels using the terminal
2) Installation of RoRo berth if needed
3) Covered storage areas, open or closed, for divided cargo and the consolidation and break up of unitized cargo with the necessary equipment for receiving and shipping cargo
4) Open storage areas for containers, including refrigerated containers, roll-on cargo and divided cargo not needing shelter from the weather
5) Work area for the temporary storage and sorting of cargo
6) Reception and delivery area for the reception and delivery of goods awaiting shipment
7) Checkpoint at terminal entrance and exit
8) Park for road vehicles
9) Areas for ancillary services such as offices, workshops and weighbridges and internal roadways
10) Segregated area for dangerous goods

1 UNCTAD (1991), p. 2
2 UNCTAD (1991)

In the upcoming analysis of multi-purpose terminal examples the total area and the built-up area (e.g. offices, storage buildings and all other buildings) will be utilized for description and analyzes. A more detailed determination of the UNCTAD functional areas is not possible without on-site inspections, which have not been carried out in this study.

4.2 Civil Engineering Elements for Maximizing Flexibility of Terminal Usage

4.2.1 Berth Design

For economic reasons, it might be reasonable to opt for a specific berth design for different cargo terminals. For instance, oil and gas handling usually allows a leaner structural design compared to general cargo, containers or dry bulk. Such a strategy would however result in a reduced flexibility of the quay wall usability and thus the entire terminal.

In order to keep flexibility and adaptability to changing requirements high, it is recommended to use a continuous, uniform quay wall design throughout the entire terminal area. This means adapting a uniform bearing capacity, cope level, quay front line, fender and bollard type and spacing, and potentially also the installation of crane rails along the entire quay, if gantry cranes are to be used.

In terms of design, this approach requires the analysis and identification of each significant factor separately for the different types of ships that are expected to berth and the different types of equipment to be used on the quay wall.

4.2.2 Terminal Pavement

Pavement is commonly one of the most expensive parts of a port. The type of pavement should therefore be carefully designed for its requirements. A common approach is to divide the terminal into different areas where different types of equipment operate and to include dedicated concrete runways for equipment with exceptionally high wheel loads (especially RTGs).

Experience however has shown that this approach results in a very rigid terminal layout, with little room for flexibility. For instance, the provision of RTG runways means that the container storage area cannot be rearranged or shifted without major constructional effort and operational constraints.

For a multi-purpose terminal, it is therefore recommended to use the same type of heavy-duty pavement throughout the entire terminal area. This will allow flexible rearrangement of storage areas as required without any major impact on operation. A uniform pavement design also provides benefits in maintenance, as only one type of pavers has to be kept in storage for replacement of damaged areas.

4.2.3 Utility System Design

With the same consideration as for the pavement, the buried services should be designed uniformly for the entire terminal area. Including all required systems in all areas before the commission of the terminal ensures no major reworks are required when storage areas are shifted or rearranged. Connection pits should be included on all areas even if a specific type of service is not required with the current type of usage (such as IT infrastructure in dry bulk storage areas) to allow extending the system at a later stage. When possible, underfloor connection points (power plugs, hydrants, etc.) should be used to minimize obstacles on the surface. The cable ducts and pipes should be laid out with few main (backbone) lines and an extensive capillary system throughout all areas.

Regarding lighting systems, the same consideration applies: Light towers should be high enough to allow efficient lighting of any type of storage area. Increasing the height of towers allows the reduction of their total number, resulting in less obstacles and more flexibility on the terminal area.

4.2.4 Terminal´s Building Design

As for the infrastructure, flexible solutions for buildings and storage facilities are preferable to fixed, rigid systems.

Storage halls, warehouses and workshops could be built using single-point foundations and prefabricated elements for the walls and roofs to allow extension or deconstruction of the structure with relatively little effort and in a short time.

Modular container-based systems should be used for buildings, offices and gates to allow adaption to different usage types. These systems allow to be extended, reduced or even removed in a fast and efficient manner. Interior fittings of the buildings should be included on a standard that allows for different usages, e.g. for storage, documentation and administration, kitchen, first response, etc.

4.3 Operative Elements for Maximizing Flexibility of Terminal Usage

4.3.1 Terminal Equipment

Typical equipment of current multi-purpose terminals is described in the following. Four general groups of equipment can be distinguished based on their main function (although some modern equipment has more than one function, e.g. reach stackers can be used as lifting or horizontal transport equipment): Lifting equipment, equipment for horizontal transport, stacking equipment and mobile conveyor systems (bulk cargo).

4.3.1.1 Lifting Equipment

Quay cranes have the advantage of a larger range compared to a ship’s own cranes, which means that horizontal transport equipment can be directly loaded or cargo can be deposited in a larger radius. Many types of quay cranes are available. The main type for break bulk is a luffing jib crane mounted on rails.

Mobile harbor cranes (Figure 3) are used in many ports around the world for cargo handling. While in most of the major ports they are used only to handle peaks or particularly heavy cargo, they are the major equipment for the entire handling in many small terminals. They are equally suited for use with general break bulk cargos, container handling when equipped with automatic or semi-automatic spreaders, or bulk materials handling when fitted with grab, or heavy-lift and project cargo. Specific equipment steering/operation software as well as a higher operational compatibility of the equipment provides the option to connect and synchronize several of these modern mobile cranes in order to carry out very heavy single project cargo lifts together. The flexible equipment allows the loading and unloading of ships at any berth or even in other port areas. This results in a much higher utilization rate compared to rail-bound or fixed cranes.[3]

[3] Brinkmann (2005)

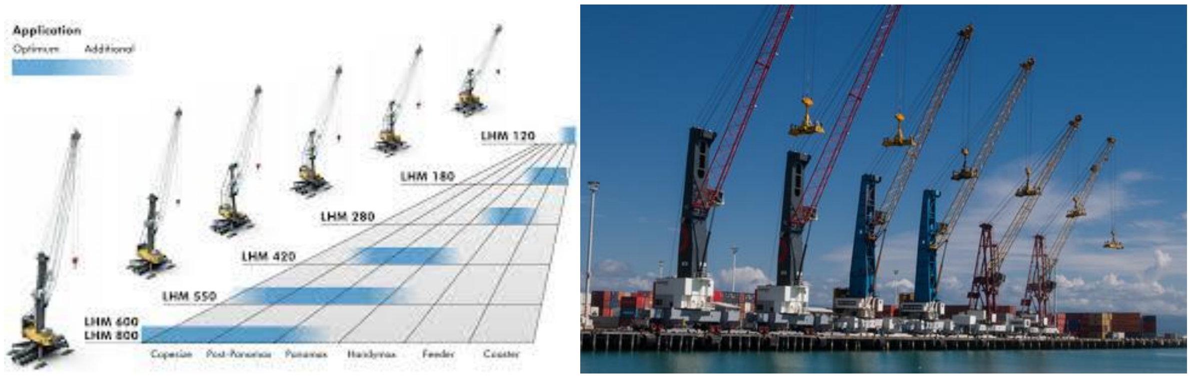

Figure 3: Mobile harbor cranes[4]

Fixed quay cranes exist, but these are rarely installed due to lack of flexibility.[5] If multi-purpose terminals handle a high amount of containers it is also possible that gantry cranes are installed. These do not have the lifting capacity of mobile harbor cranes, but as they are optimized for container handling they can reach a better performance.

4.3.1.2 Equipment for Horizontal Transport

Terminal tractor trucks are used to pull any kind of trailers and semi-trailers for containers, heavy cargo or bulk cargo. They can easily and quickly be connected to the (semi-)trailers to lift and tow them. As quick as they can connect, they also can disconnect from the trailer at the destination point. They feature a smaller turning radius compared to road trucks so that they can maneuver better when approaching the quay or working area. Additionally, they have a smaller one-person-cabin with good panoramic view in all directions.

In some cases road trucks drive onto the terminal and directly to the quay, where the trucks can be loaded or discharged by a crane.

4.3.1.3 (Multi-Purpose) Stacking Equipment

Reach stackers (Figure 4) are vehicles for handling containers or other general cargo. They can operate flexible and are also used for short distance transport. If they are equipped with a spreader, they are able to stack containers as long as they have side access to the stack. Wide variety of other different handling appliances enables the reach stacker to carry out work with almost all types of cargo.

Forklifts are used to handle break bulk and general cargo of various size and weight. Depending on their load handling attachment, they can handle containers up to 9 tiers high and are able to handle two empty containers on top of each other at the same time. Forklifts are also often used for short horizontal transport of break bulk in the terminals.[6] Load handling attachments are available e.g. for loaded containers, empty containers, paper rolls, metal coils, logs, big bags and pallets. All of the abovementioned terminal equipment is used at the multi-purpose terminals described in this report. Additionally, more specialized or single-purpose equipment is used for certain cargo types as soon as sufficient utilization justifies the investment cost.

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[4] Liebherr.com
[5] Brinkmann (2005)
[6] Brinkmann (2005)

Figure 4: Exemplary (multi-purpose) use of reach stackers[7]

4.3.1.4 Mobile Conveyor Systems (Bulk Cargo)

The mobile conveyor system (Figure 5 and Figure 6) is the most efficient system for handling dry bulk cargo on small and medium size terminals. The mobile truck unloaders allow the operator to directly unload trucks easily to eliminate the double handling of material. The fully tracked mobile units are used to take the 'surge' of material from up to 70 t trucks and transfer it to a linked equipment (link conveyors) or auxiliary equipment. The mobility of the units allows them to be utilized in a range of applications:

- Bulk loading/unloading
- Ship loading/unloading
- Barge loading/unloading
- Railcar loading/unloading
- Stockpiling
- Feed crusher/screen

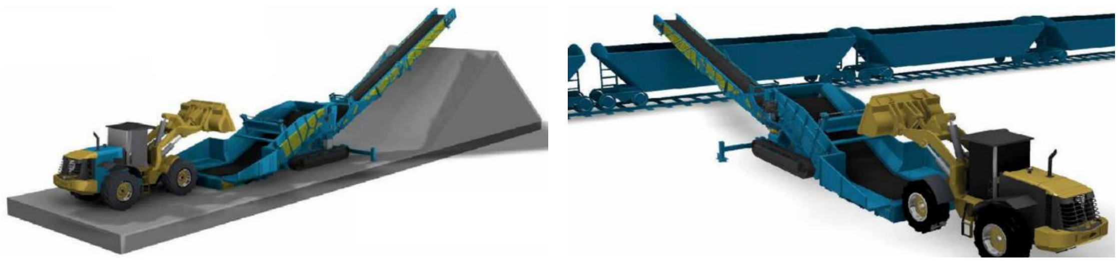

Figure 5: 3D models of mobile conveyor systems (bulk cargo)[8]

7 Sunny.com
8 Telestack (2017)

Figure 6: Exemplary mobile conveyor systems (bulk cargo)[9]

The link conveyor system is designed to reduce the need for truck/wheel loader haulage on site. The range of mobility of the links allow the operator ultimate flexibility to reach all parts of the site with ease.

The standard length of single piece of equipment is 24 m, with piling height ability up to 10 m and capacity of 500-2,000 m^3/h. However, the system cannot eliminate the use of wheel loaders completely. Applications:

- Construction or demolition waste
- Sand, gravel
- Compost
- Topsoil
- Wood waste
- Mulch
- Scrap metal
- Aggregates
- Coal
- Food products

4.3.2 Cloud Computing and Modern Terminal Operating Systems (TOS)

The potential of cloud computing also for certain aspects of TOS system is obvious. First software, storage and data/database as service solution for logistic process management, even ready for multi-purpose terminals, can be found on the market. One sample is the web-based Process Solution Platform (CM3 PSP) from the German IT system provider ‘CheckMobile’, allowing the run of a tailor made process administration/management for complex logistic chains from the cloud. Using SOA architecture, clients can define/program their own required process framework based on a graphical editor and compile/test/run it on the CheckMobile server infrastructure (SaaS mode for on- and offline operation combining fixed and mobile hardware elements on the client side). The system architecture uses an enhanced JBPM OpenSource Engine using extended XML tag language. The backend is a so-called Application Server (jBoss) combined with a Java Rich-Faces Web-Client.

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9 Telestack (2017)

4.3.3 Flexible Storage Area Design

Yard area planned as a ‘chess grid’ (Figure 7) allows organizing the storage of almost all types of cargos while ensuring sufficient segregation and at the same time free access to the cargo. Such flexible grid design can be easily mirrored within the TOS. The yard storage can be optimized by laser scanning (e.g. steel coils, project cargo) and the use of mobile fences (electric system) allows the easy and fast separation of individual activities on the terminal (flexible changes within a couple of minutes, e.g. when changing from container operation to project cargo loading at the same berth).

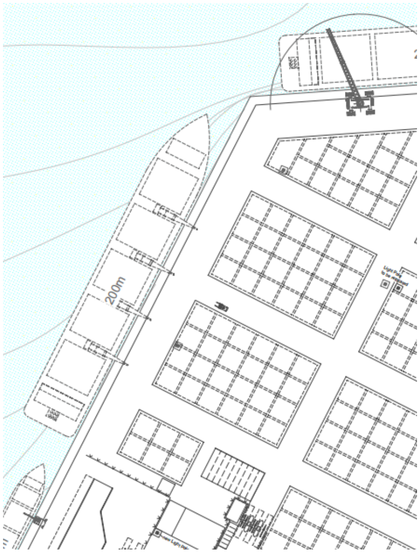

Figure 7: Illustration of the ‘chess grid’[10]

Flexible mobile fencing systems (Figure 8) can be used to ‘connect/dis-connect’ different berths, yard areas and access roads from each other, depending on the given operations circumstances. At the market there are a number of different mobile fencing systems that would satisfy the requirement of maximal segregation of operation, e.g. an automated collapsible fencing system that can be moved into dedicated length within 5 min (remote control steering), a height of 2 m, made of stainless steel/aluminum, 17-19 m/min moving speed, remote control distance of 30 m, double track.

Figure 8: Example for a mobile fencing system[11]

4.3.4 Terminal Automation

Very closely related to the latest generation of TOS systems is the possibility to implement automated terminal operation. Automated port terminals are defined as those using cargo handling

[10] Sellhorn’s own material
[11] juxinmenye.com

equipment that requires almost no human interaction. The development of sensor and navigation technology during the past 20 years has made it possible to physically remove the driver from the cargo handling machine. The unmanned cargo handling machine is then completely controlled by a computer or by using a combination of robotic and remotely operated work phases in sequence. The areas of terminal operations that became common for implementing automation are the following:

- Crane operation/remote steering
- Internal horizontal transport/AGV
- Gate operation
- Inventory activities

For innovative multi-purpose terminals mainly gate automation (paperless administration, automated entrance application and entrance management, camera checks, traffic guidance information) seems to be realistic for the coming years. Wireless access technology is usually used in gate operation, e.g. recognizing via magnetic card and wireless card scanners. Conventional gates are equipped with a checker cabin in which a checker is recording the data of every incoming and outgoing container/cargo including seal check and control of the cargo condition. The checkers have a workstation linked to the terminal host or handheld radio data terminals (EDI). In modern terminals gate procedures are automated or semi-automated. Provided that all data is made available to the terminal operator prior to the truck arrival, there are several applications to support the check procedures in the gate area. Those systems can assist in the following areas:

- Damage claims control and container/cargo condition check
- Identification and validation of container/cargo numbers and vehicle number plate
- Improvement of vehicle and container/cargo dispatch speed and therefore improvement of gate efficiency
- Prevention and detection of any thefts (i.e. containers/cargo units, vehicles)

Two main components of modern gates are the VIS (Visual Information System) and VRS (Visual Recognition System). VIS supports the checker as he can control the container/cargo condition on a monitor from all visible container sides. Only in case that damage might be seen on the monitor, the checker has to inspect the container/cargo by himself if the picture (can be zoomed up to high-resolution pictures) is not clear enough. Up to date there is no automatic damage detection system available on the market. Provided that the container/cargo unit is equipped with an electronic seal or that the seal number is transmitted to the terminal by a reliable source, the checkers may dispatch the trucks more efficiently than on conventional terminals. The VIS consists of a scanning portal with cameras, computer, lighting system and length/height sensor. On a system PC the pictures can be viewed by the checker and the images can be archived.

Data entry to the terminal host may be achieved by a variety of methods, e.g.:

- Manual (via keyboard)
- Semi-automatic (e.g. smart cart, bar code etc.)
- Fully automatic (e.g. transponder)
- Via data link from other systems (e.g. weigh bridge, handheld radio data terminals)
- Via a combination of such methods

VRS, a more advanced technology, means automatic recognition of container/cargo numbers incl. prefix, IMDG labels and truck license plates. The advantage of this system is that the data of the container/cargo and vehicle are automatically linked to the terminal database and that no manual input of the container number is necessary. Data entry to the terminal system can be achieved as described under the VIS system.

5 Multi-Purpose Terminal Examples and Characterization

5.1 Methodology

Several classification criteria systems exist for ports and terminals (e.g. COMCEC (2015)). In this document, the criteria listed in Table 1 will be used to characterize multi-purpose terminals regarding their differences and similarities.

Table 1: Template of key characteristics of multi-purpose terminals

Criteria	
Terminal region	Africa, Australia, Asia, Europe, North America, South America
Terminal development status	Greenfield/new, brownfield/existing
Total terminal area [A]	m²
Built-up area [B]	m²; area covered with buildings like sheds, tanks, offices, etc.
B/A	Percentage of built-up area compared to the total terminal area
Total quay length [C]	m
C/A	Ratio of total quay wall length to total terminal area
Berth information	Including RoRo ramps
Railway information	Track length, special loading tracks, etc.
Crane information	Mobile harbor crane, ship-to-shore crane, portal harbor crane, floating crane
Terminal equipment	E.g. terminal truck, straddle carrier, sprinter carrier, heavy trailers, light trailers
Number of gate lanes (in+out)	#
Terminal throughput per year	t, TEU
Cargo type (commodities)	E.g. container, forest products (timber), metal products, machines, food, RoRo (cars, other vehicles), offshore wind energy farm components, ...
Cargo mix	Share based on tons e.g. 30% container, 20% metal products, 20% forest products, 30% RoRo

From the total terminal area and the built-up area as well as from the total terminal area and the total quay length indicators are calculated. In addition, qualitative information is gathered about the terminals, the ports they are located at, their regional characteristics, the development of the terminals and other information.

Remark:

The abovementioned indicators have been developed to make a comparison of multi-purpose terminals possible and to allow drawing conclusions regarding each terminal's individual efficiency compared to the other multi-purpose terminals analyzed in this report. Such conclusions could however not be drawn. Although the use of the developed indicators allows a comparison of multi-purpose terminals no meaningful conclusions can be drawn because the indicators depend on each terminal's specific cargo mix (see Table 8 in chapter 5.3 on page 30) and the size of the terminals.

Taking the specified criteria as a starting point, the subsequent approach (Figure 9) has been chosen to gather and process data and information on several multi-purpose terminals worldwide as background for the upcoming discussion on optimized multi-purpose terminals:

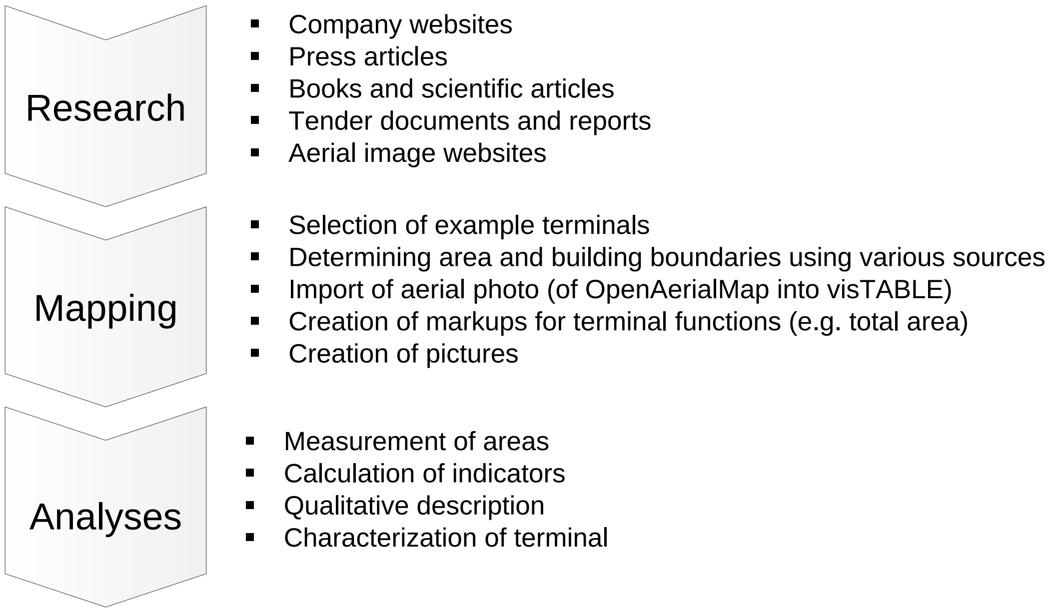

Figure 9: Port terminal characterization approach

Research is done using the Internet and its plenty sources: public websites of terminal companies, international organizations and aerial photo providers as well as various subscription based access meta libraries of general and specialized news media as well as scientific publications. Additionally, conventional library sources are reviewed. In the 'mapping' step, using all available sources, example terminals are selected and information as well as aerial photos[12] are structured and mapped: After importing the aerial photo into the visTABLE[13] software, the total area of the terminal and other areas are drawn using the software based on available information. Using visTABLE, also pictures for this document are prepared. In the last step, visTABLE is used to measure the areas of a terminal as well as the quay length. Using these values, indicators are calculated. Additionally, qualitative properties of a terminal are collected and terminals are characterized in a structured way that enables a comparison with other terminals.

In the following, characteristics of example terminals are described and explained following the approach that has been defined above. The terminals were selected from terminals and terminal projects worldwide where information could be gathered in English. Only terminals that are not specialized to handle one type of vessel or cargo have been reviewed:

1) C. Steinweg (Süd-West Terminal), Hamburg, Germany
2) Rhenus Cuxport, Hamburg, Germany
3) General Cargo Terminal, Chittagong, Bangladesh
4) Baku International Sea Port, Alat, Azerbaijan
5) Port Louis Terminal I and Terminal II, Port Louis, Mauritius
6) Caioporto, Cabinda, Angola

[12] OpenAerialMap (no date)
[13] The software can be used for visualized and interactive layout planning of port terminals.

5.2 Analysis of Existing Multi-Purpose Terminals

5.2.1 C. Steinweg (Süd-West Terminal), Hamburg, Germany

C. Steinweg (Süd-West Terminal) GmbH & Co. KG, owned by the C. Steinweg Group located in Hamburg, Germany is located around 120 km away from the North Sea at the banks of the river Elbe. The city of Hamburg is located on the northern banks of the Elbe whereas the port mainly is located on a natural island. On this island, the port area is scarce and in addition, the expanding urban area of Hamburg reduces the available port area. The terminal is well connected to European countries e.g. by railway and thus can attract transport demand from all over Europe.

The terminal was founded in 1858 and is operated privately.[14] The company leases the land area from the Hamburg Port Authority (HPA). The terminal "has 210,000 m² of operation area, 6 berths, 1,350 m quay length, offers benefits for short sea transports with feeder ships (~ 1,000 TEU, 140 m length, 23 m width), a road and rail connection, 65,000 m² covered storage area, a repair shop and an empty container depot".[15] A part of the terminal area is used by the Hamburg Sugar Terminal mbH for transhipment and storage of sugar. The terminal is one multi-purpose terminal among some other multi-purpose terminals as well as many specialized terminals for containers, liquid and dry bulk in the Port of Hamburg. Some of the bulk terminals in the Port of Hamburg are single customer terminals. Other international ports are close by. This means that C. Steinweg (Süd-West Terminal) is competing with many terminals for cargo but the large hinterland also provides a lot of potential customers.

Currently, the terminal is being extended partly by reclamation of the Steinwerder harbor basin and renting of other areas (see Figure 10). On the additional area, mainly covered storage area is being built. A part of the terminal that was not connected to the main terminal area will become accessible without leaving the terminal premises resulting in a shorter total quay length and increased storage area that will partly be covered. Key characteristics of the C. Steinweg (Süd-West Terminal) are summarized in Table 2.

Before and after the expansion, around 30% of the total terminal area is built-up area (before: 31%, afterwards: 32%). The ratio between quay length and total area is 0.0055 before and 0.0041 after the expansion.

14 C. Steinweg (2017)
15 THB (2016a)

Figure 10: C. Steinweg Südwest Terminal, Hamburg, Germany[16]

[16] © Mapbox © OpenStreetMap contributors; CC BY 4.0; with own mark-ups; On the premises of this terminal, also the Hamburg Sugar Terminal is located, which does transshipment and storage of sugar. The building in the center of the figure and the access road to it do not belong to C. Steinweg Südwest Terminal.

Table 2: Key characteristics of the C. Steinweg (Süd-West Terminal), Hamburg, Germany[17]

Criteria	
Terminal region	Europe, 120 km upstream from North Sea
Terminal development status	Existing since 1858
Total terminal area [A][18]	218,000 m², expansion by 58,000 m² under construction
Built-up area [B][19]	66,000 m², expansion by 21,000 m²
B/A	31%, 32% after expansion
Total quay length [C][20]	1,200 m (1,100 m after expansion)
C/A	0.0055 and 0.0041 after expansion
Berth information	6 ▪ Maximum draft: 11.5 m ▪ Maximum LOA: up to approx. 250 m
Railway information	Various loading tracks of up to 750 m
Crane information	▪ 6 rail mounted and mobile cranes ▪ Maximum lifting weight: 300 t
Terminal equipment	Various forklifts of up to 45 t capacity, reach stackers, tractors and trailers
Number of gate lanes (in+out)	3
Terminal throughput per year [D]	24,000 TEU (≈ 288,000 t)[21] and 280,000 t break bulk (2015)
Area efficiency [D/A][22]	2,61 t/m²
Cargo type (commodities)	▪ Container ▪ Break bulk (e.g. forest products, tubes, steel, iron and metal products, factory sections and machines, food)
Cargo mix (share based on t)	See line 'terminal throughput per year'

5.2.2 Rhenus Cuxport, Cuxhaven, Germany

The Cuxport GmbH terminal, owned by Rhenus SE & Co. KG, created in 1997 is located on the North Sea shore of Germany at the river Elbe estuary. Although the terminal is located close to the city of Cuxhaven expansion areas still exist.[23] The terminal is the largest terminal in the port but also other terminals like a cruise terminal and fishing berths exist. Like the C. Steinweg terminal, access to the European hinterland is well established. The Cuxport GmbH terminal is in competition with other terminals located in close vicinity (also terminals located in the Port of Hamburg).

The terminal is operated privately but leases the land from the regional port authority NPorts. The terminal's main commodities are vehicles, general cargo including containers as well as project cargo related to offshore wind power plant construction in the region. For the handling of components for offshore wind power plants, special berths and heavy pavement terminal areas as

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17 All description text and numbers have been determined as stated in section 5.1. Numbers have been rounded reasonably: values are not exact. Where sources provide numbers, they are stated in footnotes related to the table lines.
18 THB (2016a) states that the terminal has "210,000 m² of operation area".
19 THB (2016a) states that the terminal has "65,000 m² covered storage area".
20 THB (2016a) states that the terminal has "1,350 m quay length".
21 Assumption: 1 TEU ≈ 12 t
22 Area efficiency is determined by type of cargo commodity and provided services.
23 Cuxport (2017)

well as roads have been constructed. The area covered by buildings is 21,000 m² or approximately 3% of the total area (see Figure 11).

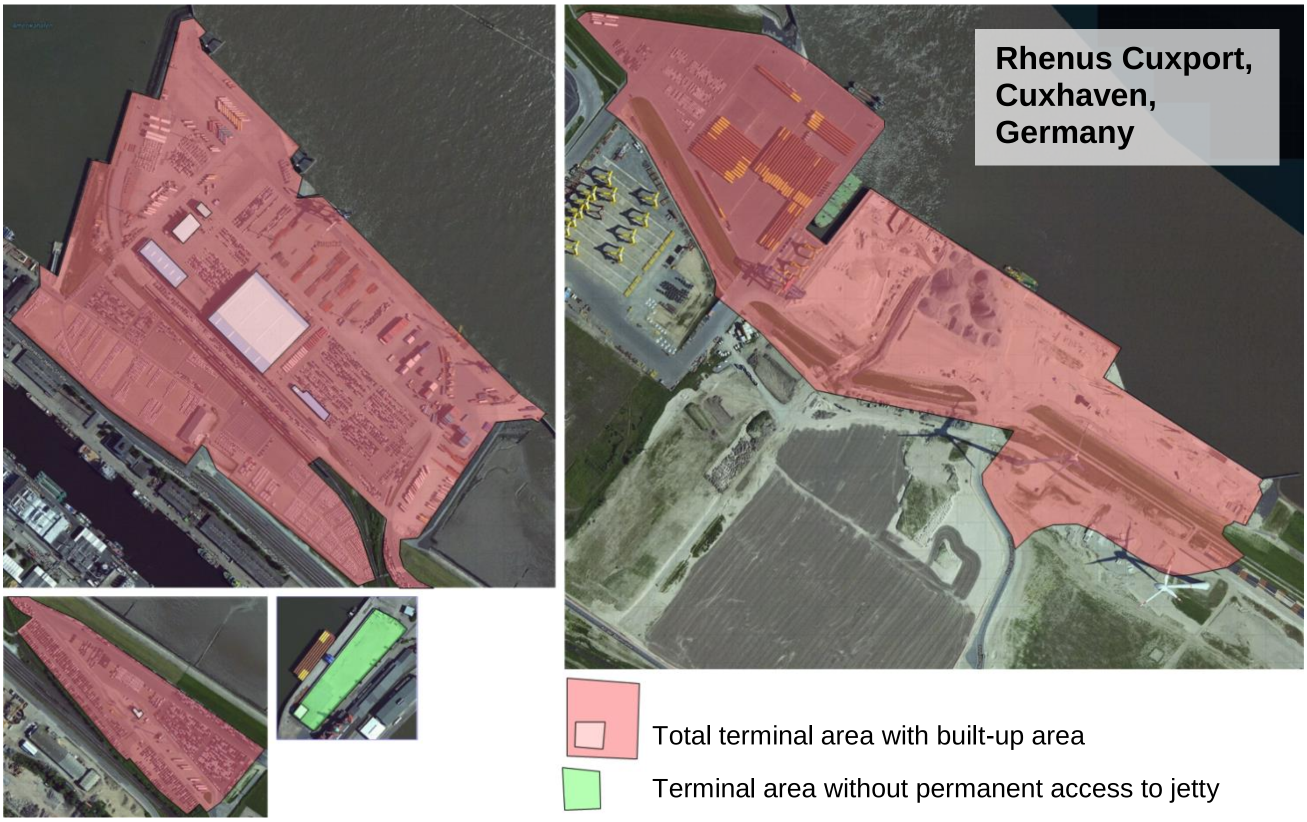


Figure 11: Rhenus Cuxport, Cuxhaven, Germany[24]

The ratio between quay length and total area is 0.002. Key characteristics of Rhenus Cuxport are summarized in Table 3.

[24] © Mapbox © OpenStreetMap contributors; CC BY 4.0; with own mark-ups

Table 3: Key characteristics of Rhenus Cuxport, Cuxhaven, Germany[25]

Criteria	
Terminal region	Europe, North Sea
Terminal development status	Existing since 1997
Total terminal area [A][26]	758,000 m²
Built-up area [B][27]	20,000 m²
B/A	3%
Total quay length [C][28]	1,700 m
C/A	0.002
Berth information	5 ▪ Maximum draft: 15.6 m ▪ Maximum LOA: not specified ▪ 4 RoRo ramps (up to 350 t)
Railway information	Various loading tracks of up to 400 m, four car loading ramps
Crane information	▪ 2 (mobile crane, panamax gantry ship to shore crane) ▪ Maximum lifting weight: 100 t
Terminal equipment	Various forklifts of up to 45 t capacity, reach stackers, tractors and trailers
Number of gate lanes (in+out)	3 lanes in one central gate plus various occasional gates
Terminal throughput per year [D][29]	2.64 million tons (2015)
Area efficiency [D/A][30]	3.48 t/m²
Cargo type (commodities)	▪ RoRo ▪ Container ▪ Cars ▪ Heavy & project cargo (components for offshore wind power plants) ▪ Break bulk (metal products, forest products, …)
Cargo mix (share based on t)	-

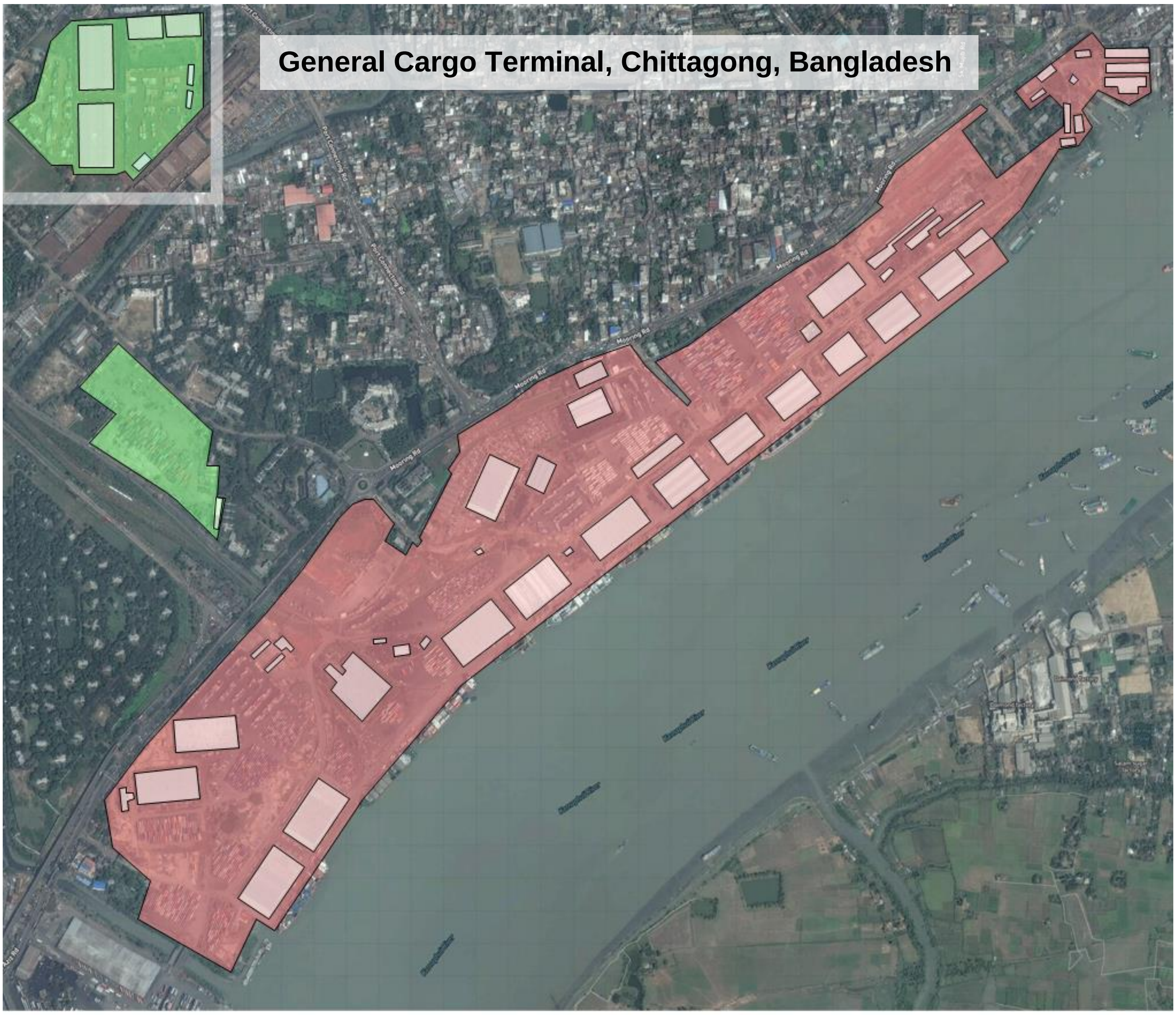
5.2.3 General Cargo Terminal, Chittagong, Bangladesh

The Chittagong General Cargo Terminal is located in the most important port in Bangladesh, about 10 km from the Bay of Bengal at the river Karnaphuli. The city of Chittagong surrounds the port area completely. The first berths where constructed in 1887.[31] Railway connections exist to other regions of Bangladesh and India.

Stevedoring is performed by several private companies in the publicly owned port. A large part of the terminal's business is containers, although there are other dedicated container terminals next to

25 All description text and numbers have been determined as stated in 5.1. Numbers have been rounded reasonably: values are not exact. Where sources provide numbers, they are stated in footnotes related to the table lines. If not specified else, the source for the information in this table is Cuxport (2017).
26 Cuxport (2017) states that the total area is 263,000 m².
27 Cuxport (2017) states that a warehouse of 10,000 m² and 5,500 m² are covered area for cars and trucks
28 Cuxport (2017) states that 1,090 m is the berth length.
29 THB (2016b)
30 Area efficiency is determined by type of cargo commodity and provided services.
31 CPA (2017)

the General Cargo Terminal. Other dedicated terminals also exist e.g. for oil. Currently, another dedicated container terminal is being planned in the vicinity of Chittagong at the shore of the Bay of Bengal. The terminal is shown in the Figure 12.



Total terminal area with built-up area

Total terminal area without direct access to berths (with built-up area)

Figure 12: General Cargo Terminal, Chittagong[32]

Relevant parts of the area were not used at the time when the aerial photo was taken: In the northern part of the terminal, a slipway was located within the terminal premises and in the south part an area was covered by plants. Key characteristics of the General Cargo Terminal of Chittagong are summarized in Table 4.

[32] © Mapbox © OpenStreetMap contributors; CC BY 4.0; with own mark-ups

Table 4: Key characteristics of the General Cargo Terminal, Chittagong, Bangladesh[33]

Criteria	
Terminal region	Asia (10 km upstream from Bay of Bengal)
Terminal development status	Existing since 1887
Total terminal area [A]	1,100,000 m²
B/A	18%
Built-up area [B][34]	200,000 m²
C/A	0.002
Total quay length [C][35]	2,100 m
Berth information[36]	13 ▪ Maximum draft: 9.5 m ▪ Maximum LOA: 190 m ▪ 4 RoRo ramps (up to 350 t)
Railway information	Various loading tracks all over the terminal area
Crane information	▪ 2 mobile harbor cranes ▪ Maximum lifting weight: 84 t
Terminal equipment[37]	45 mobile cranes (10-50 t), 6 forklifts (10-20 t) 91 forklifts (3-5 t), 11 tractors, 5 heavy trailers (25 t), 30 light trailers (6 t)
Number of gate lanes (in+out)[38]	12 (six gates with two lanes each)
Terminal throughput per year [D] [39]	850,000 TEU (≈ 10,200,000 t)[40] and additionally vehicles, other general cargo and break bulk
Area efficiency [D/A][41]	Calculation not possible
Cargo types (commodities)[42]	▪ Container incl. reefer ▪ Timber ▪ Vehicles ▪ Other general cargo
Cargo mix (share based on t)	-

Approximately 18% of the total terminal area is built-up area. The ratio between quay length and total area is 0.002.

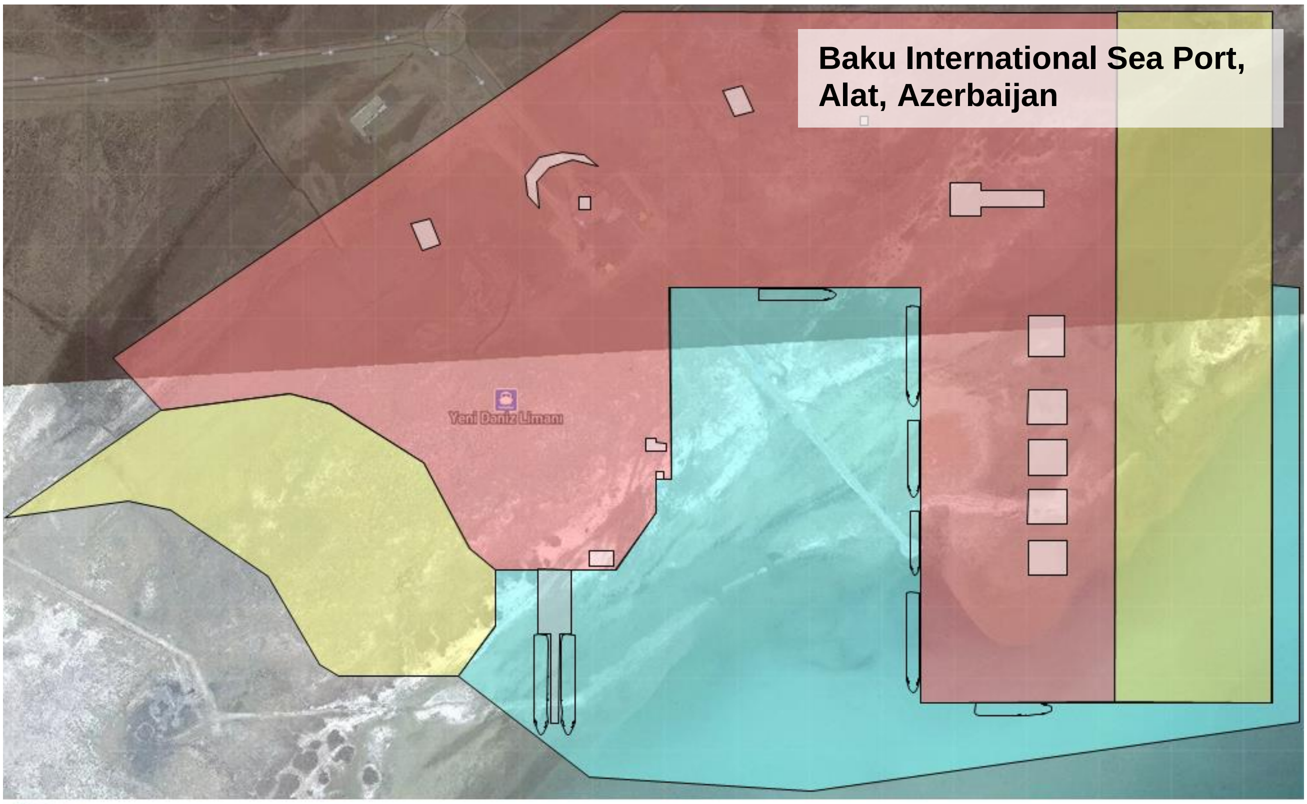
5.2.4 Baku International Sea Port, Alat, Azerbaijan

The port in the city center of Baku - the capital city of Azerbaijan - is currently undergoing a process of change to be used by other than port related businesses and for urban use. Therefore, a new port is built at the coast of the Caspian Sea about 60 km south west of Baku near the city of Alat. The

33 All description text and numbers have been determined as stated in section 5.1. Numbers have been rounded reasonably: values are not exact. Where sources provide numbers, they are stated in footnotes related to the table lines. If not specified else, the source for the information in this table is CPA (2017).
34 CPA (2017) states covered storage space of 118,953 m² in sum.
35 HPC (2015) also states 2,100 m.
36 HPC (2015)
37 According to HPC (2015), the terminal mainly relies on vessel cranes for loading and discharging of vessels
38 HPC (2015), p. 199 and own observation on aerial photos.
39 HPC (2015)
40 Assumption: 1 TEU ≈ 12 t
41 Area efficiency is determined by type of cargo commodity and provided services.
42 Seen from aerials

Caspian Sea can be accessed from the Mediterranean via rivers and canals but the multi-purpose terminal mainly handles cargo of and for other Caspian seaports. Azerbaijan is well connected to the surrounding countries. The antique Silk Road between China and Central Europe crossed this region.

The first RoRo berths where inaugurated in September 2014 and the general cargo berths are currently under construction. The Baku International Sea Trade Port (Closed Joint-Stock Company) is the responsible port authority. The most important businesses are ferries transporting trucks, cars and railway wagons, but also general cargo as well as containers is handled. In the vicinity, other specialized terminals, e.g. for oil, as well as service ports for oil rigs are located. The planned terminal area in phase 1 and 2 are drawn on the aerial photo that does not show any construction work because it was taken before construction works have started (see Figure 13).



Total terminal area (phase 1) with built-up area (left: ferry terminal with 2 berths, right: cargo terminal)

Terminal expansion area (phase 2) (left: ferry terminal with 2 additional berths; right: cargo terminal)

Water surface and vessel berths of cargo terminal phase 1 (grey: RoRo berth)

Figure 13: Baku International Sea Port, Alat, Azerbaijan[43]

Key characteristics of the Baku International Sea Port are summarized in Table 5.

[43] © Mapbox © OpenStreetMap contributors; CC BY 4.0; with own mark-ups

Table 5: Key characteristics of the Baku International Sea Port, Alat, Azerbaijan[44]

Criteria	
Terminal region	Azerbaijan (Caspian Sea)
Terminal development status	Under construction
Total terminal area (phase 1) [A]	900,000 m², expansion in phase 2 by 430,000 m²
Built-up area (phase 1) [B]	200,000 m², no new buildings planned in phase 2
B/A	3% in phase 1, 2% in phase 2
Total quay length (phase 1) [C]	1,640 m, 890 m additional quay wall planned in phase 2
C/A	0.002 in phase 1 and 2
Berth information	8 ▪ Maximum draft: 7.6 m ▪ 2 RoRo ramps, 2 additional RoRo berths in phase 2
Railway information	Various loading tracks all over the terminal area
Crane information	-
Terminal equipment	-
Number of gate lanes (in+out)	-
Terminal throughput per year[45] [D]	40.000 TEU (≈ 480,000 t)[46] and 10 million tons of other cargo
Area efficiency [D/A][47]	11.64 t/m²
Cargo[48]	▪ Container incl. reefer ▪ Timber ▪ Vehicles ▪ Other general cargo
Cargo mix (share based on t)	-

Around 2% of the terminal area are planned to be built-up area. The ratio between quay length and total area is 0.002.

5.2.5 Port Louis Terminal I and Terminal II, Mauritius

Since the 13th century, Mauritius' natural ports where used by pirates, navy, traders and settlers. The first colony was founded by the Dutch in 1638 around the natural port, where Port Louis Harbour is located now. Port Louis became the capital city of Mauritius and the port has been expanded several times. Besides of the multi-purpose terminals Port Louis Terminal I and II - which are described here - the newest terminal (III) is a dedicated container terminal located just outside of the natural harbor. Other dedicated terminals for sugar, fish, oil and cruise business also exist. Port Louis Harbour is the only international port on Mauritius serving approximately 1.3 million inhabitants. All imported and exported goods are handled in Port Louis Harbour, which explains the wide range of commodities transhipped here.

[44] All description text and numbers have been determined as stated in section 5.1. Numbers have been rounded reasonably: values are not exact. Where sources provide numbers, they are stated in footnotes related to the table lines. If not specified else, the source for the information in this table is Republic of Azerbaijan (2010).
[45] azpromo (2017)
[46] Assumption: 1 TEU ≈ 12 t
[47] Area efficiency is determined by type of cargo commodity and provided services.
[48] Ziyadov (2010)

Mauritius Ports Authority[49] provides port infrastructure and facilities; amongst others the Cargo Handling Corporation Limited[50] is responsible for the handling of cargo on Port Louis Terminals I and II. Both terminals are shown on Figure 14.

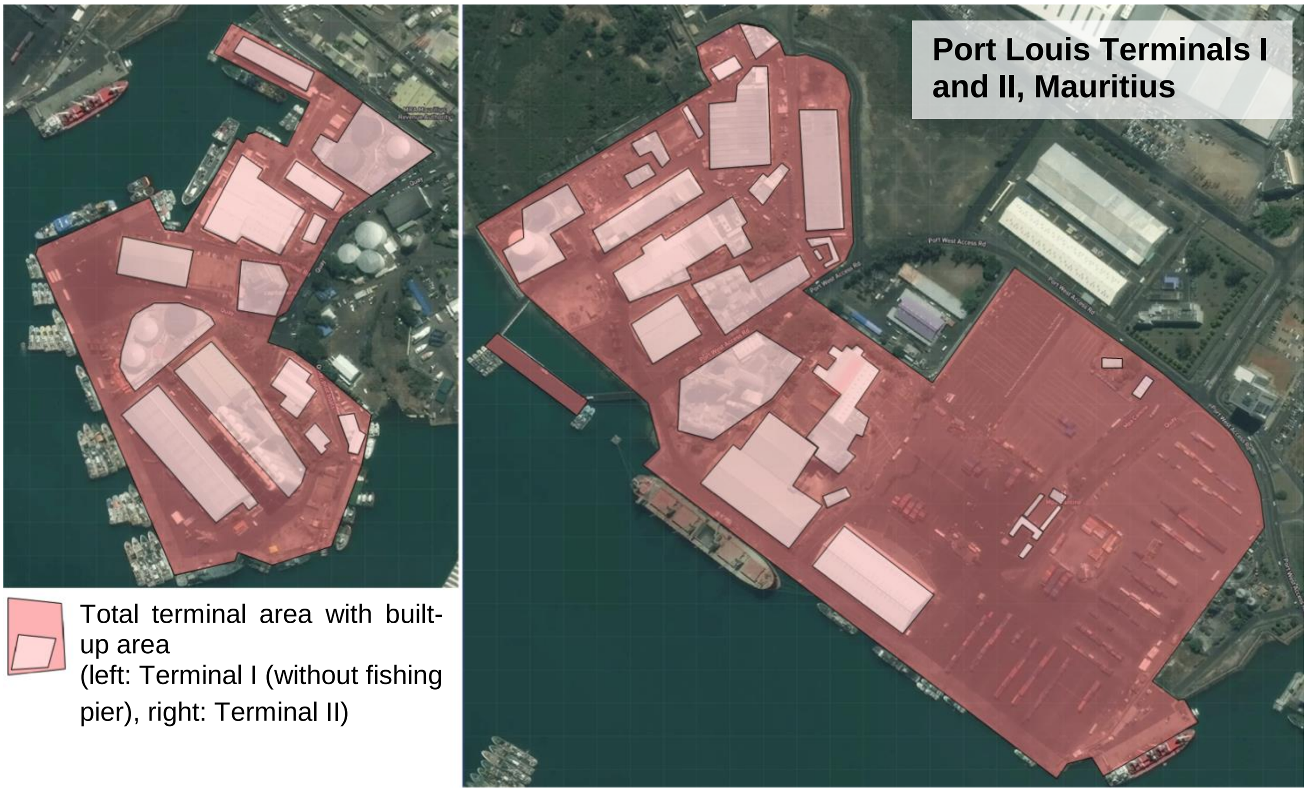


Figure 14: Port Louis Terminals I and II, Mauritius[51]

Among storage sheds and tanks as well as office buildings also industrial processing plants are located in the terminal area: Next to container and break bulk transhipment, many other cargo types are handled on the terminals which make more specialized equipment necessary.

Key characteristics of Port Louis Terminals I and II are summarized in Table 6, also mentioning special cargo equipment.

Table 6: Key characteristics of the Port Louis Terminal I and Terminal II, Mauritius[52]

Criteria	
Terminal region	Africa (island in the Indian Ocean)
Terminal development status	Existing since 16^{th} century
Total terminal area [A]	418,000 m²
Built-up area [B]	115,000 m²
B/A	28%

49 Mauritius Port Authority (2017)
50 Cargo Handling Corporation Limited (2017)
51 © Mapbox © OpenStreetMap contributors; CC BY 4.0; with own mark-ups
52 All description text and numbers have been determined as stated in section 5.1. Numbers have been rounded reasonably: values are not exact. Where sources provide numbers, they are stated in footnotes related to the table lines. If not specified else, the source for the information in this table is Port Guide (2013).

Criteria	
Total quay length [C][53]	1,900 m
C/A	0.005
Berth information	8 ▪ Maximum draft[54]: 11.0 m ▪ Maximum LOA[55]: 198 m
Railway information	None
Crane information	-
Terminal equipment[56]	▪ Wheat/maize: pneumatic ship unloader (200 t/h) + conveyer system ▪ Soy bean meal: crane/hopper/lorry (75 t/h) ▪ Edible oil: pipeline (150-180 t/h) ▪ Molasses: pipeline (250-280 t/h) ▪ Black oil: pipeline (500-800 t/h) ▪ White oil: pipeline (525 t/h) ▪ Coal: crane/hopper/lorry (150 t/gang/h) ▪ Break bulk: (30 t/gang/h) ▪ Bitumen: pipeline (85 t/h) ▪ LPG: pipeline (12 t/h) ▪ Containers and general cargo: reach stackers, forklifts, tractors and trailers
Number of gate lanes (in+out)	-
Terminal throughput per year [D]	No numbers available for Terminals I and II
Area efficiency [D/A][57]	-
Cargo type (commodities)	▪ Black oil, fuel oil, edible oil, white oil, bitumen ▪ LPG ▪ Coal, cement, fertilizers ▪ Maize, wheat, soya-bean meal, molasses ▪ Containers ▪ General cargo
Cargo mix (share based on t)	-

27% of the total terminal area is built-up area. The ratio between quay length and total area is 0.046.

5.2.6 Caioporto, Cabinda, Angola

The currently being constructed port of Caioporto will be located 9 km north of the city of Cabinda in the area of Caio. This area has not been developed so far. This means that the new port is a 'greenfield' project. It is planned that the port shall mainly cater for commercial handling of general and containerized cargo as well as wood and bulk cargo, especially phosphate rock. Moreover, oil

[53] The quay length of Terminal I is 515 m (without fishing pier) and the quay length of Terminal II is 1,001 m. Source: Port Guide (2013)
[54] Port Louis Shipping Company Shipping Agency Ltd. (2017)
[55] Port Louis Shipping Company Shipping Agency Ltd. (2017)
[56] According to Port Louis Shipping Company Shipping Agency Ltd. (2017) ship gear is used at both terminals.
[57] Area efficiency is determined by type of cargo commodity and provided services.

and gas exploration companies expressed their interest to make use of the port for importing heavy pipeline segments and for providing service facilities for their rigs.

The port will have an offshore terminal for the handling of goods and an onshore area to accommodate the administration building, the main gate, a fire station etc. and will be constructed in two phases. Phase 1 is intended to be in operation in 2018, Phase 2 in 2025. To connect the onshore port area to the terminal area, a 2 km long causeway will be constructed.

During Phase 1 the terminal area will be operated as a multi-purpose terminal, while in Phase 2 the first 630 m of the quay will be assigned to pure container handling and the multi-purpose terminal will be shifted to the inner quay of 500 m length. The reclaimed area is designed with a possible extension of quay wall length and terminal area at a later stage. The terminal is visualized in Figure 15.

The terminal area provides storage areas for the commodities to be handled at the port during their dwell time. In addition, several buildings, operating facilities and service buildings related to the individual infrastructures will be constructed on this area. During Phase 1, 3% of the total terminal area is built-up area, while after 2025, 4% will be covered area. The ratio between quay length and total area is 0.0015 before and 0.0020 after the expansion.

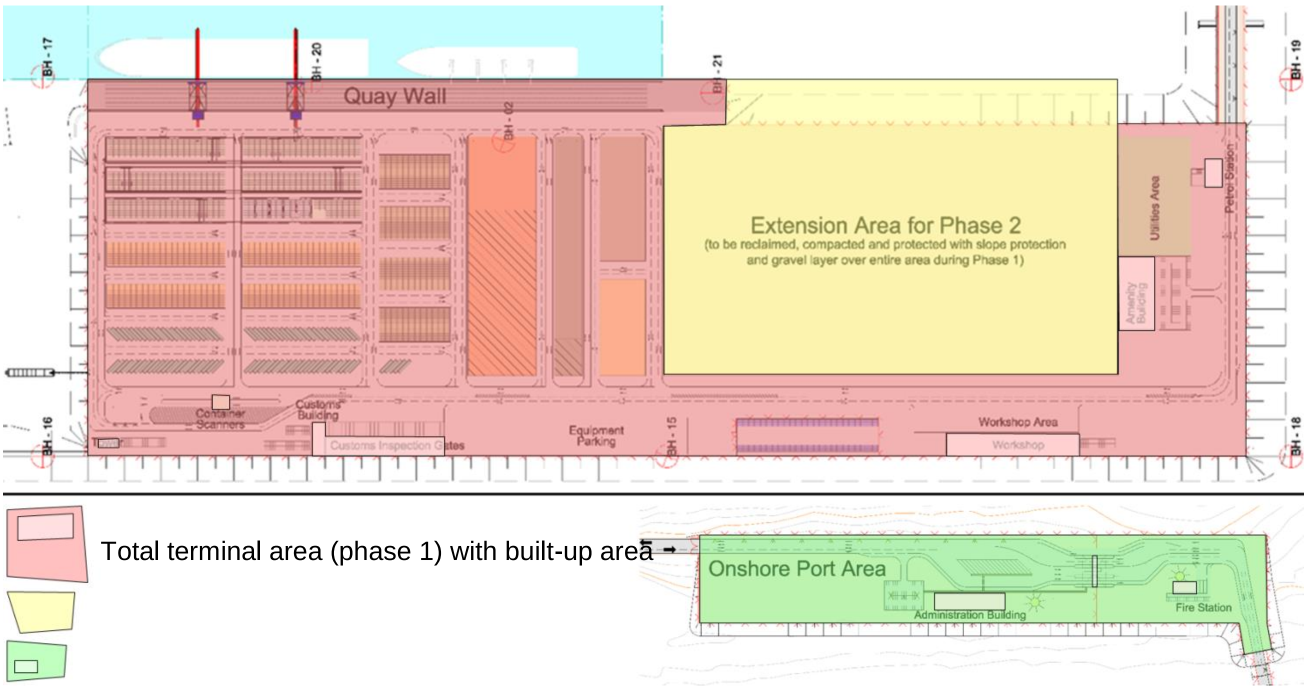


Figure 15: Caioporto Phase 1, Cabinda, Angola[58]

Key characteristics of the Port of Cabinda (Caioporto) are summarized in Table 7.

58 Sellhorn, HPC (2015) with own mark-ups; because an aerial photo only would have pictured the Atlantic Ocean, a drawing was chosen as background.

Table 7: Key characteristics of Caioporto Phase 1, Cabinda, Angola[59]

Criteria	
Terminal region	Africa
Terminal development status	Greenfield, currently under construction
Total terminal area [A][60]	417,000 m² in Phase 1 and 573,000 m² in Phase 2, (on-shore port area of 60,000 m² including gate area)
Built-up area [B][61]	14,700 m² in Phase 1 and 24,200 m² in Phase 2
B/A	3% (4% in Phase 2)
Total quay length [C][62]	630 m (1,130 m after expansion in Phase 2)
C/A	0.0015 (0.0019 in Phase 2)
Berth information	2 (Phase 1) and 4 (Phase 2) ▪ Maximum draft: 12.5 m (Phase 1) to 14,5 m (Phase2) ▪ Maximum LOA: 300 m up to approx. 350 m
Railway information	None
Crane information	▪ Rail mounted STS cranes and mobile harbor cranes (2 of each in Phase 1, up to 4 of each at the end of Phase 2)
Terminal equipment	RTGs, reach stackers, tractors and trailers
Number of gate lanes (in+out)	1 gate (Phase1: 3 lanes in and 2 lanes out; Phase 2: 4 lanes in and out)
Terminal throughput per year [D] (planned Phase 1 capacity)	▪ 200,000 TEU (≈ 2,400,000 t)[63] ▪ 800,000 t phosphate rock ▪ 160,000 t project cargo ▪ 900,000 t general cargo ▪ 60,000 t wood ▪ 6,000 vehicles ▪ 366,000 t ammonia ▪ 1,280,000 t urea
Area efficiency [D/A][64]	▪ 14.32 t/m²
Cargo type (commodities)	▪ Container ▪ Project cargo (oil industry) ▪ Wood ▪ Phosphate rock ▪ General cargo/break bulk ▪ Vehicles ▪ Urea and ammonia
Cargo mix (share based on t)	See line 'terminal throughput'

59 All description text and numbers have been determined as stated in section 5.1. Numbers have been rounded reasonably: values are not exact. Where sources provide numbers, they are stated in footnotes related to the table lines. If not specified else, the source for the information in this table is Sellhorn/HPC (2015).

60 Sellhorn/HPC (2015) states that the terminal has an entire area of 45 ha planned for Phases 1 and 2.

61 Sellhorn/HPC (2015) states that the terminal has "14,700 m² covered storage area" in Phase 1 and replaced or new built storage sheds in Phase 2.

62 Sellhorn/HPC (2015) states that the terminal has "630 m usable length of quay" in Phase 1 and "additional 500 m" in Phase 2

63 Assumption: 1 TEU ≈ 12 t

64 Area efficiency is determined by type of cargo commodity and provided services.

5.3 Conclusion Regarding the Characteristics of Analyzed Multi-Purpose Terminals

Multi-purpose terminals are as diverse as the commodities they handle. The previous sections show that they can be described by using quite abstract indicators and by taking into consideration data on each terminal’s individual layout, annual throughput, and the cargo mix.

However, conclusions like one multi-purpose terminal being more efficient than another multi-purpose terminal can hardly be drawn. Efficiency indicators like e.g. the area efficiency (ratio between annual terminal throughput [t] and the total terminal area [m^2]) depend on each terminal’s specific cargo mix and the size of the terminal:

Although two multi-purpose terminals have the same size, the area efficiency of a multi-purpose terminal with a higher share of dry bulk cargo will most probably be greater than the area efficiency of multi-purpose terminals with a higher share of containerized cargo. The cargo mix however depends on each terminal’s location and customers and can hardly be influenced.

Due to this, a meaningful comparison of different multi-purpose terminals is not possible. There are too many factors influencing multi-purpose terminals so that the ‘multi-purpose-terminal-formula’ has not been found yet. There is no such thing like the right infra- and superstructure for all multi-purpose terminals and there is also not the right layout for all multi-purpose terminals. Instead, the right layout of a multi-purpose terminal depends on the type and volume of cargo that needs to be handled. This becomes clear when comparing all the terminals described in the previous sections as shown in Table 8.

Table 8: Overview of analyzed multi-purpose terminals

Criteria	C. Steinweg (Süd-West Terminal), Hamburg, Germany	Rhenus Cuxport, Cuxhaven, Germany	General Cargo Terminal, Chittagong, Bangladesh	Baku International Sea Port, Alat, Azerbaijan	Port Louis Terminal I and Terminal II, Mauritius	Caioporto Phase 1, Cabinda, Angola
Terminal region	Europe, 80 km upstream from North Sea	Europe, North Sea	Asia (10 km upstream from Bay of Bengal)	Azerbaijan (Caspian Sea)	Africa (island in the Indian Ocean)	Africa
Terminal development status	Existing since 1858	Existing since 1997	Existing since 1887	Under construction	Existing since 16th century	Greenfield currently under construction
Total terminal area [A]	218,000 m², expansion by 58,000 m² under construction	758,000 m²	1,100,000 m²	900,000 m², expansion in phase 2 by 430,000 m²	418,000 m²	417,000 m² in Phase 1 and 573,000 m² in Phase 2
Built-up area [B]	66,000 m², expansion by 21,000 m²	20,000 m²	200,000 m²	200,000 m², no new buildings planned in phase 2	115,000 m²	14,700 m² in Phase 1 and 24,200 m² in Phase 2
B/A	**31%, 32% after expansion**	**3%**	**18%**	**3% in phase 1, 2% in phase 2**	**28%**	**3% (4% in phase 2)**
Total quay length [C]	1,200 m (1,100 m after expansion)	1,700 m	2,100 m	1,640 m, 890 m additional quay wall planned in phase 2	1,900 m	630 m (1,130 m after expansion in Phase 2)
C/A	**0.0055 and 0.0041 after expansion**	**0.002**	**0.002**	**0.002 in phase 1 and 2**	**0.005**	**0.0015 (0.0019 in phase 2)**
Number of berths	6	5	13	8	8	2 (Phase 1) and 4 (Phase 2)
Railway information	Various loading tracks of up to 750 m	Various loading tracks of up to 400 m, four car loading ramps	Various loading tracks all over the terminal area	Various loading tracks all over the terminal area	None	None
Crane information	6 rail mounted and mobile cranes, maximum lifting weight: 300 t	2 (mobile crane, panamax gantry ship to shore crane), maximum lifting weight: 100 t	2 mobile harbor cranes, maximum lifting weight: 84 t	-	-	rail mounted (STS cranes) and mobile harbor cranes (2 of each in Phase 1 up to 4 of each at the end of Phase 2)
Terminal equipment	Various fork lifts of up to 45 t capacity, reach stackers, tractors and trailers	Various fork lifts of up to 45 t capacity, reach stackers, tractors and trailers	45 mobile cranes (10-50 t), 6 forklifts (10-20 t), 91 forklifts (3-5 t), 11 tractors, 5 heavy trailers (25 t), 30 light trailers (6 t)	-	Pneumatic ship unloader + conveyer system, crane/hopper/lorry, pipelines, reach stackers, forklifts, tractors and trailers	RTGs, reach stackers, tractors and trailers
Number of gate lanes (in+out)	3	3 lanes in one central gate plus various occasional gates	12 (six gates with two lanes each)	-	-	1 gate (Phase1: 3 lanes in and 2 lanes out; Phase 2: 4 lanes in and out)
Terminal throughput per year [D] [65]	568,000 t (2015)	2.64 million tons (2015)	850,000 TEU (≈ 10,200,000 t) and additionally vehicles, other general cargo and break bulk	10,480,000 t	No numbers available for Terminals I and II (excluding other terminals).	5,972,000 t
Area Efficiency [D/A][66]	2,61 t/m²	3.48 t/m²	Calculation not possible	11.64 t/m²	-	14.32 t/m²
Cargo type (commodities)	Container, break bulk (e.g. forest products, tubes, steel, iron and metal products, factory sections and machines, food)	RoRo, container, cars, heavy & project cargo (components for offshore wind power plants), break bulk (metal products, forest products, …)	Container incl. reefer, timber, vehicles, other general cargo	Container incl. reefer, timber, vehicles, other general cargo	Black oil, fuel oil, edible oil, white oil, bitumen, LPG, coal, cement, fertilizers, maize, wheat, soya-bean meal, molasses, containers, general cargo	Container, project cargo (oil industry), wood, phosphate rock, general cargo/break bulk, vehicles, urea and ammonia

[65] Assumption: 1 TEU ≈ 12 t
[66] Area efficiency is determined by type of cargo commodity and provided services.

6 Framework Conditions Affecting the Requirements for Future Multi-Purpose Terminals

Terminal operators in general face challenges arising from major global trends like globalization, demographic change, urbanization, sustainability and technological progress. In order to remain competitive, multi-purpose terminals need to adapt to the challenges and need to have characteristics that put them into the position to be able to continuously react to their dynamically changing environment. This means that innovative multi-purpose terminals need to become as flexible as possible.

6.1 Major Global Trends Affecting Seaport Terminals

6.1.1 Globalization

Seaports are the nodes in international maritime transport chains linking waterborne transport and hinterland transport modes. Terminal throughput volumes rely on the fact that not all resources and goods can be compiled with the populations that desire them, and so global transportation services are needed. The throughput of seaports and the handling volumes on individual terminals depend on the international division of labor and how supply chains are managed. Global supply chains and their affiliated freight movements are largely influenced by adjustments in trade and manufacturing specialization as well as production systems, which are a constant source of new challenges for seaports in terms of competition and market share. Changes in production systems lead to changes in the types of products transported (e.g. transport of higher value goods and increasing exchange of semi-fished products or product components of higher value), changes in trade patterns (with increasing transport distances and changes in routes), and changes in logistics organizations.[67]

In the past, the increasing degree of containerization was seen as an enabler for globalization: The pace of globalization over the last sixty years accelerated due to containers. Reasons for the increasing degree of containerization are especially reduced transportation costs per loading unit, a better capacity utilization of vessels and an easier handling of loading units. Furthermore, containers lend themselves to intermodal transportation, meaning that containers can be moved by train, ship, and truck seamlessly. However, the market for containerized transports seems to be saturated. The rate of containerization is stabilized on major maritime routes. Market experts expect that the rate of containerization may only increase for some short sea shipping routes in future. This maturity phase is mainly characterized by a wide diffusion of the container technology around the world and technical improvements that are more and more becoming marginal.[68] Thus, with the container technology as it is cost reductions and efficiency improvements in container handling can just be achieved at a marginal level. Regarding other commodities than containerized cargo, national activities e.g. in the context of the energy transition lead to an increasing amount of heavy and project cargo that needs to be handled in seaports. Examples include components for offshore wind power plants.

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[67] F&L (2008)
[68] Rodrigue, Notteboom (2014)

Requirements for future multi-purpose terminals

Resulting from future economic growth and increasing trade volumes on the one hand and changing production systems on the other hand, the globalization trend places two different requirements on competitive multi-purpose terminals: Firstly, multi-purpose terminals require appropriate capacities regarding infrastructure resources and handling equipment. Secondly, multi-purpose terminals need to react quickly to changing production systems and to be able to handle different types of products. This requires a flexible terminal layout and handling equipment suitable for the handling of different types of products. Terminals need to show a certain degree of flexibility and agility to provide competitive logistics services.

Due to the maturity phase of the container market, there is a high cost pressure regarding maritime transports and cargo handling in seaports. This demands efficient processes in port terminals in general. Multi-purpose terminals are no exception. Due to the fact that they are in most cases not equipped with the most efficient equipment for container handling, efficiency improvements and cost reductions are even more important for multi-purpose terminals. They need to become as efficient and as flexible as possible in order to secure their economic competitiveness. In contrast to container terminals the handling of other loading units than containers does not disturb the day-to-day business of a multi-purpose terminal. Especially in the context of global topics like the energy transition multi-purpose terminals need to prepare for the handling of heavy or project cargo.

6.1.2 Demographic Change

Demographic change affects economies worldwide in a different way depending on a country's fertility, mortality and migration rates. Population growth and decline in different economies, together with an aging population are expected to create different consumer markets. Further, demographic change has an impact on the labor market. The world population grows mainly due to the high fertility and decreasing mortality rate in Africa and in parts of Asia. Industrial countries face the common challenge of an aging population. People get older while at the same time birth rates are not increasing to compensate mortality rates. As a result of demographic change, a decline in the productive and consuming population of the industrialized nations of North America and Europe is expected. At the same time, economic performance is increasing in many Asian countries. Furthermore, in the Asian region, India will become increasingly important both economically and politically. Seaport locations in industrial countries are dependent on experienced workforce requiring suitable working conditions that account for physical limitations, as well as having a need for digital equipment that is accessible and intuitive to use. Furthermore, employees must receive sufficient training to use the emerging new technologies.

Requirements for future multi-purpose terminals

Demographic change and resulting from this an aging workforce demand suitable working conditions for the elderly employees. This means that multi-purpose terminals need to make use of innovative digital solutions that allow employees to stay in their jobs for a longer time. Regarding the fact that there is a lack of specialists in certain regions worldwide, the implementation of innovative technologies may compensate the lack of employees in these regions. This could enable multi-purpose terminals in these regions to continue operations.

6.1.3 Urbanization

Ever since the industrial revolution there has been a trend towards urbanization. Cities grow considerably, especially visible in parts of Asia and Africa dealing with total population increases. Moreover, the ratio between people living in urban areas and people living in rural areas is expected to increase further. Growing cities require sustainable development dealing with competition for resources. Housing and industrial areas are scarce and spatial projects are a prerequisite for the urbanization trend. In this context, port cities need to approach conflicts between port expansion projects and spatial projects. One of the most important challenges for seaports is to manage the port-city interface-waterfront zones in which geography of the port and its city meet.

Requirements for future multi-purpose terminals

Operations of multi-purpose terminals need to be compatible with the requirements of the people living close to port areas. Potential for conflicts are e.g. noise or light emissions and particulate matter emissions resulting from port operations. New technologies and logistical processes can solve conflicts by making the transport flows and port operations safer, more efficient and sustainable, and more seamless. Further, operations of multi-purpose terminals need to be compatible with urban development plans, meaning that terminals need to become more attractive e.g. for tourists that can visit port terminals.

6.1.4 Sustainability

The global trend sustainability is directly linked to the requirements resulting from the rising levels of urbanization worldwide. Sustainability has developed itself into a major goal for the development of economies referring, exemplary, to clean energy production, good jobs provision and economic growth, or building resilient infrastructure networks. Seaports also play an important part in sustainable development of port cities and whole port regions. For instance, environmental issues to be faced imply air pollution, water quality, ballast water, dredging and disposal of dredged materials, solid waste disposal, hazardous substances and land as well as resource use. Air pollution caused by burning fossil fuel and sustainable generation of electricity are in many ports the biggest environmental concerns. Ways to reduce local emissions in seaports from fossil fuels are the use of alternative fuels (e.g. liquefied natural gas, LNG), electrified vehicles and the optimization and automation of processes. In connection with an increasing scarcity of raw materials new strategies are required to enable resource-efficient and sustainable port operations. Circular economy is an important concept in this context. The recycling rate of materials can be increased in order to reduce the need for new raw materials on the one hand and to reduce the amount of waste produced on the other hand.

Requirements for future multi-purpose terminals

A major requirement resulting from the global trend of sustainability is the sustainable operation of multi-purpose terminals, meaning the use of low-emission equipment and the overall reduction of resource-consumption, e.g. by using recycled materials.

6.2 The Megatrend Digitalization

Seaports in general and port terminals (including multi-purpose terminals) in particular are affected by the increasing degree of digitalization, meaning the increasing use of electronic media and mobile applications in everyday business. This results in the dissolution of traditional work structures in favor of virtual (in the sense of location- and time-independent) constellations. Enabled by hard- and software innovation, as well as process and organizational innovations, digitalization is the process of moving to a digital business. It refers to the increase of smart objects connected to the Internet (called cyber-physical systems[69]) creating an Internet of Things. These objects are able to communicate and to make at least very simple decisions. Adding online connectivity to smart objects offers new paradigms in capturing and acting upon a vast amount of data which might be of value for monitoring, controlling and management purposes.

Potential benefits for multi-purpose terminals

Implementing innovative digital solutions could give multi-purpose terminals the opportunity to be able to better tackle the challenges resulting from the trends described in chapter 6.1. Benefits of implementing digital solutions are an increased flexibility (fast adaptation to changing requirements), an increased robustness (insensitivity towards interruptions and errors during operation), an increased efficiency (increased productivity and a more efficient use of resources) and the ability to better handle complexity regarding e.g. the amount of shared information).

On terminal level digitalization offers advantages for the terminal's connection to external transport and information systems. Interfaces connect terminals to Port Community Systems and to other stakeholders' IT platforms. Terminal operations may profit from coordination activities performed externally leading to transparent information on: (1) Cargo arrival and departure times; (2) Cargo type, condition, requirements, origin and destination and (3) Infrastructure condition (traffic congestion, construction works).

From an internal perspective, digitalization offers possibilities to improve the terminal's own cargo handling, storage, monitoring, controlling and management processes. Upcoming operations can profit from available mobile and wireless technology in which humans and machines communicate with each other through advanced sensor, actuator, wireless communication and tracking technology.[70] By using sensors it is possible to collect information about the condition of vehicles, the equipment location or the logistics processes. Advances in speech or image recognition are stimulating improvement of sustainable transport and handling processes. Tasks performed by people have the chance to be assisted by intelligent machines or processes can be further automated. From a technological perspective it is already possible to collect and store a vast amount of data providing digital information on transport processes, vehicle location or infrastructure condition. But the extraction of value from this 'Big Data' (with high volume and high frequency from different data sources) requires considerable analytical effort, terminal investments and business process reengineering. To name but one example, terminal surface area and handled goods could be equipped with tags and sensors that send important information to the terminal control center to better route transports and store cargo on the terminal but also to monitor the status of the transported goods.

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[69] DFKI (2015)
[70] McGrath and Scanaill (2014); Further information is included in Info Box 5 in the Annex.

7 Interim Conclusion

The analysis and characterization of multi-purpose terminals shows that multi-purpose terminals are as diverse as the products they handle. Although a characterization of multi-purpose terminals is possible conclusions regarding each terminal's individual efficiency compared to the other multi-purpose terminals analyzed in this report can hardly be drawn because these indicators depend on each terminal's specific cargo mix and the size of the terminals. There is no such thing like an optimal layout or the right infra- and superstructure for all multi-purpose terminals. Instead, the layout of a multi-purpose terminal depends on the type and volume of cargo that needs to be handled.

Today's multi-purpose terminals face challenges arising from major global trends like globalization, demographic change, urbanization, and sustainability. These challenges demand multi-purpose terminals to become as flexible, reactive, and sustainable as possible. As an example, globalization developments and changes in production systems lead to changing volumes on the one hand and different products on the other hand that need to be handled by multi-purpose terminals.

Demographic change poses a different challenge to multi-purpose terminals: Due to demographic change especially western economies face an aging population and a lack of younger employees. People have to stay longer in the workforce. Terminal operators need to create working conditions that are suitable for elderly people. Further, they have to compensate a potential lack of specialists resulting from the demographic change.

Urbanization and sustainability challenge multi-purpose terminal operators in almost the same way. Both trends lead to a demand for more sustainable terminal operation, meaning less resource consuming and emission or noise pollutant terminal operation.

The megatrend digitalization gives multi-purpose terminals the opportunity to make use of innovative digital solutions to become more flexible, efficient, robust and to be better able to handle the increasing complexity regarding e.g. the different types of cargo that need to be handled or to deal with the huge amount of different customers resulting from changes in production systems and short-term contracts. The implementation of innovative solutions could put multi-purpose terminals into the position to better cope with the challenges arising from major global developments.

8 Innovative Multi-Purpose Terminal Concepts

In the following concepts for innovative multi-purpose terminals are presented. Requirements for innovative multi-purpose terminals are:

- Operation of multi-purpose terminals should be as flexible as possible regarding the handling and storage of different types and volumes of cargo.
- Innovative multi-purpose terminals are characterized by less resource consuming and less emission or noise pollutant terminal operation compared to multi-purpose terminals that are already in operation.
- Equipment is suitable to offset the impacts resulting from demographic change or to support elderly employees in their daily work.

Firstly, (technological) solutions are identified that are potentially suitable for innovative multi-purpose terminals to react to the challenges resulting from major global trends described in the previous sections. Afterwards, innovative multi-purpose terminal concepts are described. Since multi-purpose terminals are as diverse as the cargo handled at these terminals, there is no such thing like one innovative multi-purpose terminal concept only. Depending on what is handled and the annual terminal throughput different innovative multi-purpose terminal concepts are necessary. These concepts take into account the (technological) solutions that are considered to be suitable for innovative multi-purpose terminals.

8.1 (Technological) Solutions that are Potentially Suitable for Innovative Multi-Purpose Terminal Concepts

In the following current (technological) solutions are presented that are potentially suitable for innovative multi-purpose terminals to better cope with the challenges arising from the major global trends described in chapter 6.1. The (technological) solutions have been selected regarding the following focus areas:

1. Traditional tasks of multi-purpose terminals (transport, handling, storage)
2. Digitalization of maritime supply chains and terminals
3. Innovative business concepts for multi-purpose terminals

After identifying the impact of digitalization and technological innovations, requirements for transferability to multi-purpose terminal optimization are tested by discussing the following issues: (1) Development status; (2) Practical application. The final assessment of the development requirements evaluates the concepts with regard to an increase in terminal utilization as well as land efficiency. The development status refers to the state-of-the-art and performance of the technology, its price structure and general capability. The discussion of practical port/marine industry examples and experiences demonstrates the practical application step. The considered solutions, the related global trends, the suitability for innovative multi-purpose terminals and the expected increase in terminal utilization and efficiency are summarized in Table 9.

Table 9: (Technological) solutions potentially suitable for innovative multi-purpose terminals

(Technical) solution	Related global trend	Suitable for innovative multi-purpose terminals	Increase in terminal utilization and efficiency
Focus area 1: Traditional tasks of multi-purpose terminals (transport, handling, storage)			
Alternative powered engines	Sustainability; Urbanization	Full electric engines: Partially, depending on the vehicle type Dual-fuel/hybrid engines: Yes Energy harvesting technology: Not for large terminal equipment but for small devices	Lower greenhouse gas, NO_x and PM and noise emissions
Self-driving vehicles	Demographic change	Yes, under certain conditions	Safer transport processes and reduction of personnel costs
Focus area 2: Digitalization of maritime supply chains and terminals			
Paperless processes	Sustainability, globalization	Yes, transparency leads to more efficient processes and capacity utilization	Reduced check-in and inspection times at terminal gates; reduced port export and import dwell times
Focus area 3: Innovative business concepts for multi-purpose terminal			
3D printing	Globalization, Sustainability	Yes, additional volumes can be generated due to raw materials and 3D printed products and volumes can be secured due to the local industry's demand for 3D printed products	No evidence available (yet) but high revenue per m² anticipated

The (technological) solutions mentioned in Table 9 are described briefly in the subsequent sections.

8.1.1 Alternative Powered Equipment

Alternative powered equipment provides an answer to the challenges arising from trends like sustainability and urbanization.

8.1.1.1 General Description

In order to save fuels and improve air quality in port areas there has been some evidence of the benefits of electric or gas powered terminal equipment. Diesel is the most dominant fuel used for terminal transport equipment. Automation, alternative fuel, and electrification of vehicles are suitable ways to reduce local emissions of port terminals.

The electrification of vehicles already takes place in port terminals worldwide at different scales[71]. Exemplary alternatives to diesel-driven terminal equipment are the following:

- Diesel-driven terminal trucks: E.g. battery-electric terminal trucks are currently being developed;
- Diesel-driven straddle carriers: E.g. hybrid straddle carriers, (automated) electrified shuttle carriers or electrified Automated Guided Vehicles (AGVs) in combination with automated electrified Automated Stacking Cranes (ASC).

[71] Port Technology (2017)

Automation can improve the efficiency of port operation. Exemplary effects can be optimized operation of equipment and optimized fuel consumption or a reduction of human errors and an optimization of terminal processes. Automation does not necessarily mean electrification. Examples for this are diesel-driven AGVs. Battery-electric AGVs have just been developed a few years ago (see Info Box 1).

Info Box 1: Examples of alternative powered vehicles in ports

Horizontal transport equipment producers have included diesel-electric straddle carriers, shuttle carriers, empty container handlers or lift trucks in their product portfolios. For instance, diesel-electric straddle carriers are on order or in use by terminals in the ports of Antwerp (MSC terminal), Auckland (POAL), Durban (TPT), Hamburg (HHLA, Eurogate), Kotka (Steveco), Melbourne (DP World), New Jersey (Maher terminal) or Vado (APMT).

After introduction of the first prototype of a battery-driven AGV in 2009 Gottwald Port Technology GmbH (now Terex Port Solutions) has launched a diesel-electric mobile harbor crane in 2010.[72] The technology uses diesel generators in connection with dynamic brake resistors and short-term energy storage. A pilot project used the new crane technology in a maritime terminal for handling empty and full containers and fruit pallets with a maximum lifting capacity of 100 tons and a hoisting speed of up to 90 m/min. Results showed fuel savings and reduced noise emissions.

If battery charging intervals fit to operation times, even fully electric could be a valuable option. A prototype of a fully electric AGV was tested between 2010 and 2011 in the Port of Hamburg by the HHLA on its Altenwerder terminal. These battery-electric AGVs were introduced into normal operation in 2011. Based on this project the research project 'BESIC' (Battery-Electric Heavy Duty Vehicles in Intelligent Container Terminal Operation) was carried out, aiming at developing a battery management system that allows loading batteries considering North German green power peaks. As a result it was shown how an intelligent charging strategy could achieve significant operating cost savings (for more information please refer to the published results of the research project 'BESIC'). As one of the first terminal operators, in 2016 PSA Singapore invested in fully electric AGVs for its container terminals.

LNG in private but also commercial transport is already successfully used as road fuel in North America, parts of Europe (especially in Italy) and China. In port operation, application of gas powered vehicles is not widespread. One example is provided by the Port of Long Beach. In 2008 heavy-duty compressed natural gas trucks were tested for container movements between the San Pedro Bay ports and nearby freight-consolidation yards. Following up a 'Clean truck programm', the authorities provided subsequent incentives for each LNG or CNG truck purchase.

Besides electricity, Compressed or Liquefied Natural Gas (CNG and LNG) and renewable methane (bio methane) could be alternative energy sources. Advantages over diesel fuels are reduced greenhouse gas emissions; especially producing fewer emissions of sulphur oxide, nitrogen oxide and particulate matters; but also reduced drive noise. In general, cargo transport natural-gas trucks (both LNG and CNG) are available for a wide range of transport operations, including urban and distribution logistics, garbage collection and long-haul trucking operations.[73] Next to using alternative energy sources terminal operators may install energy harvesting systems which enable autonomous operation of self-powered equipment. Energy harvesting is a form of regenerative power supply and

[72] Port Technology (2010)
[73] DENA (2014)

makes use of piezoelectric electromagnetic, electrostatic, thermoelectric or photovoltaic effects to generate power.[74] The concept refers to the generation of (today still) small amounts of electrical energy from sources such as light, temperature, vibrations, or airflows for low-power mobile devices. Major drawback with energy harvesting is the volatile nature of availability.[75]

8.1.1.2 Transferability to Multi-Purpose Terminal Optimization

In the commercial sector with heavy vehicles performing the terminal transport diesel is the preferred power with cost advantages and high performance rates in rough weather conditions outdoors. The distribution of electricity and natural gas or methane as fuel for port terminal equipment has been very low. Picking up first test results from the container terminal industry, multi-purpose terminal equipment equipped with diesel engines tends to remain the preferred technological solution (see Info Box 1). But a promising alternative are dual-fuel/hybrid engines like diesel-electric or (less frequently) diesel-gas, since they are able to meet emission standards and continue to operate with diesel upon need. A switch from diesel to electricity or eventually gas as energy source for terminal equipment seems promising for different terminal types.

When it comes to power supply at present and in the near future energy harvesting techniques remain far away from providing a reliable energy source for heavy-duty vehicles. The amount of power generated with current energy harvesting system designs is small and barely enough to get a laptop running.[76] But with an increase in Internet-enabled devices and a decrease in individual device power consumption, energy harvesting could be the future of power for small devices such as mobile phones of terminal staff or wireless devices connected to the Internet producing light or sound. One of the biggest advantages of energy harvesting technology is the elimination of fix power cables hindering a vehicle’s permanent mobility. Energy harvesting systems designed for mobile equipment would produce energy from light or vibration, although, at present this technology trend is still under consideration.

In summary, alternative powered vehicles in the port industry show the following characteristics:

a) **Development status**: Dual-fuel/hybrid engines like diesel-electric or diesel-gas are fully developed and already in use; energy harvesting systems for heavy-duty vehicles are not available,

b) **Practical application**: Diesel-electric straddle carriers are common practice at container terminals; the Port of Long Beach promotes compressed natural gas trucks.

Multi-purpose terminals can profit from test experiences of hybrid engines of heavy duty terminal equipment in the container industry. Some requirements for transferability of alternative powered vehicles to multi-purpose terminal development are:

1) Reduced costs for the purchase of hybrid heavy transport equipment,
2) Increase of diesel prices,
3) Regulations on terminal equipment emissions,
4) Further reduction of electric or gas engine emissions,

[74] Johnson et al. (2014)
[75] Mitchel (2017)
[76] Mitchel (2017)

5) Advances in battery systems to allow longer operation times of electric–powered vehicles and to reduce size and weight of the carried units,
6) Improvements of storage systems that can store and return energy quickly and allow high cycle rates in rough outdoor operations to work with rapid load changes and associated acceleration and deceleration actions,
7) Optimized battery charging processes in order to fit charging intervals to operation times.

8.1.2 Self-Driving Vehicles

Self-driving vehicles provide an answer to the challenges especially arising from the demographic change, a lack of specialists and a decreasing workforce.

8.1.2.1 General Description

Self-driving vehicles drive in a (semi-)automated way without direct driver input to control the steering, acceleration, and braking. Possible advantages are improved safety, higher driving efficiency and cost savings. Established approaches for supporting techniques in landside transport refer to electronic stability control, adaptive cruise control, or lane centering. To react intelligently, vehicles rely on various artificial sensory devices such as cameras, radar, LiDAR (light detection and ranging), infrared, sonar, or wireless communication.[77] In most cases not only the vehicles but also the given infrastructure is equipped with sensors, actuators and processing power.

Self-driving vehicles do communicate with each other and with the human driver/transport engineer by providing sufficient information about the position, speed and driving direction. Installed on-board vision systems have the ability to detect fixed objects like traffic lights or street signs, and movable objects like vehicles or people. A vision-based collision avoidance system is in place and relies on accurate and reliable positioning information. Positioning data is delivered by vehicle tracking systems (mainly GPS is used in vehicles for tracking and navigation).

In sum, to achieve a vehicle capable of driving itself, four basic interdependent functions are required:[78]

1) Navigation: Route planning using a digital map that includes information on vehicle location, weather, road type etc.; tracking relies on GPS; autonomous vehicles are capable of communicating with each other and usually with the given infrastructure via communication systems such as WLAN.

2) Situational analysis: Monitoring of the environment using visual image recognition techniques; additional positioning data can be obtained using markers embedded in the infrastructure; common sensor technology applied is long-/medium-/short range radar, LiDAR, camera, or ultrasound.

3) Motion planning: Monitoring of the vehicle‘s movements by using sensors that determine a course of motion within a defined period of time avoiding any detected static object; decisions have to be made about adapting speed and direction; indicators such as the peoples‘ hand signals or facial expressions can be analyzed to improve the predictive ability.

[77] Epstein (2015)
[78] DHL Trend Research (2014)

4) Trajectory control: Managing the execution of pre-planned changes in speed and direction; observation and maintenance of driving stability; actions in accelerating or braking and in adjustments to the steering are performed by the autonomous system.

8.1.2.2 Transferability to Multi-Purpose Terminal Optimization

Possibilities for the improvement of transport and handling processes through automated driving of terminal vehicles are still at the very beginning of practical application. AGV installations on container terminals are an exception (see Info Box 2). If non-standardized cargo is handled in a non-repetitive way recommendations are different. Moreover, automated driving of heavy vehicles outside a restricted terminal area is more demanding. Another application field of autonomous driving of heavy vehicles (beyond public transport and the automotive industry) is the agriculture industry. Exemplary, the machine manufacturer Fendt has launched a system that connects two tractors via satellite navigation and radio communication to form one unit. One of the two vehicles is unmanned and performs the same working procedure as the manned vehicle; both tractors turn together at the end of a field, and avoid obstacles and deviations.[79] Again, repetitiveness of operations and a limited surface layout are important requirements.

Terminal vehicle technology profited from one revolutionary technological development outside the port industry: A breakthrough for heavy vehicle transport brought the launch of the so-called ‘autonomous driving kits’. These mobile use devices consist of a visual tracking system (including cameras, LiDAR, radar, other sensors), an on-board computer to process information or communication files and artificial intelligence software, bringing the ‘smartness’ to the vehicle. It is no longer necessary to equip the given infrastructure with sensors and processing power. Although, it showed that some additional traffic signs and some visual road limits helped to speed up the vehicles’ transport speed. Convinced by the advantages of autonomous driving (transport efficiency increased and costs for terminal staff reduced) each terminal truck received an own kit. A driver input is not necessary to control the steering, acceleration, and braking. The autonomous vehicles navigate by using a digital map that stores information on the vehicle location. All trucks communicate with each other via a local wireless network. The environment is constantly monitored using radar, LiDAR and other visual image recognition techniques enriched by positioning data. Main ‘brain’ of the vehicle is an intelligent decision support system that takes over decision on the vehicles’ acceleration, direction, speed and stops. In order to keep the trucks in line and control the driveway the autonomous system also observes and maintains driving stability and is able to adjust acceleration and braking. A terminal traffic manager has the chance to switch on the vehicle’s computer for manual steering. This further supports the vehicle’s intelligence. The terminal traffic center combines all details on each vehicle’s position, speed and driving directions.

Moving to the next level from restricted area to public roads and from shuttle movements to an individual journey, in October 2016 the start-up company Otto completed the first commercial shipment by a driverless truck. The automated Volvo truck drove a 120-mile journey without driver intervention and was equipped with a kit that included cameras, laser-imaging LiDAR, radar and other sensors, as well as artificial intelligence software and an on-board computer.[80] The concept is new as infrastructure preparations are not mandatory anymore and a spatial boundary is no longer

[79] DHL Trend Research (2014)

[80] Forbes (2016b)

required. The smart vehicle acts autonomously making use of attached technology devices, own software and processing power and connectivity to wireless communication networks.

Info Box 2: Examples of self-driving vehicles in ports

> Starting in 1993 ECT's Delta/Sealand Terminal in the Port of Rotterdam was the pioneering terminal for the introduction of Automated Guided Vehicles (AGV) operation from ship-to-shore cranes to the yard and vice versa. The greenfield project HHLA Container Terminal Altenwerder in Hamburg followed in 2002. After several years with application restricted to Europe, AGV technology moved to other destinations. Since 2014 the Long Beach Container Terminal in the USA operates 72 unmanned, fully battery powered AGVs for container transport[81] and there will be 30 fully electric AGVs in operation at the Pasir Panjang Terminal of PSA Singapore.[82]
>
> Showing interest in self-driving vehicles in operation outside a port terminal's boundary, in January 2017 Singapore's Ministry of Transport and PSA International signed agreements with Scania and Toyota for the development of an autonomous truck platooning system to transport containers between container terminals in the Southeast Asian island-state.[83] In a test-project performed by the six truck manufacturers DAF, Daimler, Iveco, MAN, Scania and Volvo six convoys of twelve semi-automated self-driving trucks arrived in the Port of Rotterdam in 2016. The truck platoons involved two or three trucks that autonomously drove in convoy and were connected via wireless communication, with the leading truck determining route and speed.[84]

Overall, self-driving vehicles in the port industry show the following characteristics:

a) **Development status**: Autonomous vehicles are in operation with (amongst others) restrictions on the spatial boundary and the individuality of transport processes; supporting technology improves (cameras, LiDAR, radar, other sensors, software etc.),

b) **Practical application**: AGVs on container terminals are in operation; tests with self-driving trucks and truck platooning are on the way.

Multi-purpose terminals could profit from the introduction of self-driving vehicles. Potential advantages of terminal automation are a reduction of staff costs, an increase in transport safety and efficiency increases. Some requirements for the transfer of self-driving vehicles to multi-purpose terminals are:

1) Advances in sensor, actuator, and tracking technology in order to increase the performance (especially faster speed) and reliability of autonomous systems in harsh environments,

2) Increase in labor costs favoring terminal automation of non-standardized transport and handling services,

3) Decrease of investment costs, e.g. profiting from developments outside the port sector where single or a few vehicles instead of the total fleet are equipped with technical kits (including cameras, LiDAR, radar, other sensors, artificial intelligence software, and an on-board computer), and where infrastructure investments are not mandatory anymore.

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[81] Port Strategy (2015b)
[82] Port Strategy (2016)
[83] Engadget (2017)
[84] The Guardian (2016)

8.1.3 Paperless Processes

Paperless processes provide an answer to the challenges arising from the global trends of sustainability and globalization. On the one hand, cross-border communication is simplified. On the other hand paper consumption and with that consumption of natural resources is reduced.

8.1.3.1 General Description

Paperless processes in maritime supply chains refer to managing physical cargo handling and storage by proceeding of digital information about the transport order, cargo, vehicle, truck driver or customs documents. Port Community Systems (PCS) play a central role in providing an information platform bringing together terminal operators, shipping lines, hinterland operators, customs and other port actors involved. In some bigger seaports a large number of up to several 2,000 to 3,000 thousand transport and handling companies are associated to the different PCS at the port locations. Paperless data exchange in PCS involves order placement for terminal handling via import processing or dangerous goods registration, as well as ship arrival information and notices on ship departure times (see Info Box 3).

Info Box 3: Examples of paperless processes in ports

Paperless gate-in/gate-out: Smart gate-in and gate-out processes have been implemented recently by the introduction of virtual automatic gates, e.g. in the King Abdullah Port in the Kingdom of Saudi Arabia in the Brazilian container terminals Tecon Salvador and Tecon Rio Grande, Port of Virginia's Norfolk International Terminal, or the Port of Charleston.

Paperless import delivery process: APM Terminals Mumbai has become the first Indian container terminal to introduce an online import delivery process.[85]

Paperless cargo management: The Port of Beirut implemented an award winning (Winner of 2015 IAPH IT Gold Award) cargo management system. All port operations are enabled to be processed by using a new software tool enabling the management of vessels and berths, general cargo handling, equipment and warehouses, port services, administrative support, full integration with third party systems, public portal (port community). Main results are 100 percent paperless terminal operations.[86]

Paperless transfer between terminals: In the Port of Rotterdam it is no longer required to have a physical customs document to transfer containers between three participating terminals (APMT, ECT and RWG) that made agreements with the tax and customs administration.[87]

PCS are electronic platforms that connect multiple systems operated by a variety of organizations that make up the seaport community. Services of software providers differ. For instance, the PCS of the Port of Hamburg enables the companies involved in the handling processes to process their orders in a largely automated manner, they exchange messages in real-time via intelligent workflow systems called 'Export Message Platform' and 'Import Message Platform'.[88]

[85] Port Technology (2017b)
[86] Port Strategy (2015a) and Inplan (2015)
[87] Port Technology (2016a)
[88] DAKOSY (2017)

In more detail, the PCS of the Port of Singapore outlines its services as:[89]

1) Information services (general information of the port like infrastructure, ship calls, directory of liners, shipping agents, logistics companies, vessel schedules, or import and export procedures),
2) Document exchange services (e.g. cargo manifest submission, customs declarations for import, export and/or transit-related shipments, berth, channel and pilot application, hazardous cargo Information, haulage instructions)
3) E-commerce services (electronic invoice, e-payment, and credit card payment).

Open issues PCS providers are confronted with are how to integrate services for B2B activities and how to handle new data sources for real-time traffic management.

The extent of information exchange and responsibilities of involved parties differ due to different Terminal Operating Systems (TOS) and Enterprise Resource Planning (ERP) Systems of the participating actors, the actors' willingness to share information, or different levels of benefits for own business processes. On terminal level paperless processes offer the potential to control and manage cargo handling and storage activities more efficiently. For instance, electronic files on the cargo enriched with order details and graphical representations support cargo handling and control at different supply chain stages. Container terminals worldwide are extending their paperless processes from the gate to the quayside. Latest developments were communicated by the Victoria International Container Terminal in Melbourne[90] or the APM Terminals Mumbai[91] which went paperless in 2016.

A paperless import delivery process simplifies and streamlines the import cycle of terminal operations to reduce gate waiting time and congestion, and enables faster container movements into and out of the terminal. Some terminals electronically provide shipping lines with the required export form for export cargo entering the terminal by truck, rail, barge or feeder. Technologies supporting paperless processes are Optical Character Recognition (OCR) at terminal gates or other sensor technologies gathering data on cargo, traffic or infrastructure conditions. OCR gates have been installed to scan the license plate of the truck and the cargo condition before the vehicle gets inside the yard/on the terminal area, and sensor technologies link the gathered information to the TOS/ERP system which will identify and validate the transactions, informing own staff or service providers where to go when with which cargo.

Software enabling paperless processes tends to be applied as stand-alone option on terminal level. But if the TOS/ERP system is linked to certain input data from the PCS or provides output data for the PCS the port's customers and users profit from more integrated logistics processes in the port area.

[89] Redvuce (2014)
[90] IDM (2016)
[91] World Maritime News (2016)

8.1.3.2 Transferability to Multi-Purpose Terminal Optimization

On terminal level, potential exists to digitalize transport and handling processes, whereas, container terminals are again on the forefront of ongoing developments (see Info Box 3). TOS providers or in-house terminal solutions offer software tools that help to automate and optimize managing the movement of cargo through terminals. Electronic declaration of export, transit or import cargo relies on cooperation between terminal operators, cargo owners, carriers and customs authorities. But due to upcoming innovation in data mining technologies potential exists to enrich paperless order information by further data on the cargo and vehicle movement and the traffic situation in order to optimize the logistics processes more holistically. In sum, paperless port processes show the following characteristics:

a) **Development status**: Software components are available; supporting technology is available and its performance increases (OCR technology; tracking technology etc.); reluctant investments and business processes are re-engineered.

b) **Practical application**: Virtual automatic container terminal gates are in operation; full integration with third party systems and PCS enable comprehensive paperless cargo management (import, export, transfer); agreements with public authorities eliminate physical documents.

Multi-purpose terminals might profit from ongoing developments in the container terminal industry by application of developed software tools and established communication processes. Of high value are standardized interfaces between the TOS and (a) the port's community system (if in place), (b) carrier's individual IT systems and (c) other stakeholder's individual IT systems. Some requirements for paperless processes in multi-purpose terminals are:

1) Investment into OCR (or other scanning technology) and/or IT platform approaches integrating terminal processes with the customer's and transport operator's systems to collect relevant transport information from customers/other actors,

2) Message standards of existing systems need to adapt; process re-engineering brings new requirements – The terminal and linked partners have to learn and comply,

3) Standardized data exchange may profit from Internet connectivity (not only company systems but also mobile devices are connected),

4) Willingness to share required information or query of mandatory data (e.g. number plate, truck driver ID, customs clearance, ship arrival time, truck arrival time),

5) Ability to collect data from vehicle and cargo movements via supporting sensor, wireless and tracking technologies (data on cargo arrival and departure times, cargo type, condition, requirements, origin and destination, and infrastructure condition like traffic congestion, construction works),

6) Ability to analyze available data (data analytics) and create value from it (manage transport flows accordingly).

8.1.4 3D Printing

3D printing provides an answer to the challenges arising from globalization and sustainability, meaning that spare parts for e.g. vessels could be produced more flexibly in a decentralized way and that they do not need to be transported over long distances anymore. This increases capacities on board of vessels and improves transport efficiency.

8.1.4.1 General Description

A new technology revolutionizing product manufacturing is 3D printing or so called 'additive manufacturing'. 3D printers add/inject materials like ceramics, plastic, gypsum or metal layer by layer instead of molding or cutting materials to build a three-dimensional solid object. This results in hardly any waste of raw materials. Starting point of the production process is a digital model. Then, a 3D printer uses a certain feed material in powder form to build up the product by, e.g. melting the powdered feed material. At present, the most common methods of additive fabrication are:[92]

1. Stereolithography (SLA) - liquid plastic or artificial resins are hardened by means of an ultraviolet laser beam,
2. Fused Deposition Modeling (FDM) - the object is produced layer by layer from a meltable plastic cord. The plastic is heated in the print head, pressed through fine nozzles and applied layer by layer to a work plate, and
3. Selective Laser Sinterling (SLS) - the starting material is powdered. A laser beam precisely heats the powder and fuses the powder globules together, so that they form a solid three-dimensional object after cooling.

The 3D printing technology makes it possible to create almost any geometric shape using a digital model. Designs may be adapted easily and even after production. Products are lighter than traditional components, but equally stable which make them very attractive for the aviation and health care industry where higher product costs can be outperformed by the other advantages. Due to the modular production process not only small lot batches/lot sizes but also required casting mold can be printed individually. Experts seem to agree that 3D printing promotes local and regional production, and 3D print centers will be established near the sales markets over the next years.[93]

Decentralized production of individualized products is possible in proximity to the customer. The physical transport of produced goods, especially over large distances, can be substituted leading to reduced transport and logistics costs as well as transport time. In summary, key advantages of 3D printing are:[94]

- Higher sustainability and efficiency in production through using the least amount of material and energy in production,
- A lower number of production steps to design, prototype and manufacture highly complex and/or customized products,
- Faster delivery time through on-demand and decentralized production strategies, and
- Lower logistics and production costs (reduced shipping and storage costs, potential elimination of import/export costs through localized production, elimination of new production tools and molds and costly modifications to factories).

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92 AEB (2014)
93 AEB (2014)
94 DHL Trend Research (2016)

Info Box 4: Examples of 3D printing in the marine/port industry

Port of Rotterdam:[95] A pilot project named '3D printing of maritime spare parts' ended in 2016 helping to gain experiences and learn about the current possibilities offered by 3D printing to the maritime and port-related industry. The pilot closed with a consortium of 28 businesses and authorities. Port-related businesses registered with the maritime project, but also businesses from other industrial sectors, such as Fokker (aerospace) and Siemens (software development). The Port of Rotterdam Authority, InnovationQuarter and RDM Makerspace were the initiators of the pilot. As a next step, a '3D FieldLab' for additive manufacturing set up business at RDM Rotterdam in 2016. The FieldLab involves all additive manufacturing players – 3D printing providers, end users, educational and knowledge institutes, testing facilities, certification bodies, software companies and engineers. The aim of this FieldLab is to build up knowledge itself about additive manufacturing and to implement new (certified) applications for the maritime and port-related industry. The FieldLab will also serve as a production and service center. The ambition is for the FieldLab to expand into a fully-fledged digital manufacturing infrastructure within three to five years, with metal and plastic printers, 3D scanning equipment, expertise in production methods and materials and all the necessary software and hardware to design, produce and repair parts and entire products.

Port of Ulsan:[96] South Korea announced a five-year research project starting in 2017 in Ulsan for the development of 3D printed ships and offshore equipment. The Ulsan Metropolitan City is the South Korean industrial hub (headquarters of Hyundai Heavy Industries) and home to a number of heavy industries, including oil refinement and automobile production. The project is going to be financed by the South Korean Ministry of Trade, Industry and Energy with expected costs around $20 million.

AP Möller-Maersk Group:[97] The major shipping line and terminal operating company AP Möller-Maersk Group implemented 3D printers on tankers, to gain insights into the practical use of the technology and obtain feedback from crew. After the end of the experiment it has been decided to install 3D printers on shore rather than on ships.[98]

3D printing is a technology with great potential to reshape production and manufacturing. From its initial main use in prototyping, the technology has rapidly advanced and evolved. It is being increasingly employed in the production process, especially in the automotive and aircraft manufacturing industries.[99] For instance, Airbus has opened a 3D printing facility for titanium components in Varel in Germany in 2016; GE Aviation decided to print a new jet engine fuel nozzle, whereas, instead from 20 different parts the fuel nozzle is produced in a single stage with a 3D printer said to be 25% lighter and five times more durable than the conventional product.[100] In the marine and port sector the uptake of the new technology has been slow (see Info Box 4).

At present, one drawback of 3D printing is the exponential increase in costs relative to the size of the product. This leads to clear benefits for the production of small and valuable parts in a situation where set-up costs for small series are low, e.g. spare parts for maintenance and repair of ships. Printing can take place at the location of the calling port or directly during transit on-board (see Info

95 Port of Rotterdam (2017)
96 Sputnik International (2016)
97 MotorShip (2016a)
98 MotorShip (2016b)
99 MotorShip (2016a)
100 MotorShip (2016a)

Box 4 for on-board test of the AP Möller-Maersk Group). Both printing possibilities may cut not only shipboard inventories but also logistics costs.

8.1.4.2 Transferability to Multi-Purpose Terminal Optimization

The ability of ports to establish large information networks ensuring high speed data access in the port area favors landside printing, especially, because 3D model designs require a vast amount of data exchange. It has been stressed that on shore the use of 3D printers in the maritime sector is expanding, but still, 3D printing is an industry in its infancy and the maritime world is watching developments rather than taking a lead.[101] In summary, 3D printing in the marine/port industry shows the following characteristics:

a) **Development status**: Uptake of the new technology has been slow; the industry is still in its infancy

b) **Practical application**: Remains in a pilot project phase; one rare concrete example is provided by the Port of Rotterdam; a ‘3D FieldLab’ has been established in 2016

Multi-purpose terminals might profit from 3D printing possibilities by providing raw material and final product storage closer to production. However, although a quay wall could be beneficial for 3D print centers, current demand forecasts for 3D printed materials are rather cautious. Thus, current demand forecasts do not provide enough reasons that justify the location of large 3D print centers directly inside a seaport. The expected demand for raw materials is too low yet. Additionally, raw materials required for 3D printing are in most cases transported as containerized cargo. The handling of these containers will most probably not take place at a multi-purpose terminal. Hence, a large 3D print center should better be located inland close to a highway and supplied with the containerized raw materials transhipped via a nearby seaport. Inland areas are less expensive and 3D printing could be more economic. Furthermore, the concept of 3D printing goes in hand with decentralized supply chains. Large 3D printing factories would contradict the idea of a decentralized supply chain. It is unlikely that multi-purpose terminals will rent a large part of the terminal’s surface area to a large 3D printing factory.

Nevertheless, small scale 3D print centers could be an opportunity for multi-purpose terminals looking for new business opportunities and having unused terminal areas. Besides of transport, handling and storage small scale 3D printing could provide additional business opportunities for innovative multi-purpose terminals, but to a limited extent. These small scale 3D print centers would give multi-purpose terminals the basis to store the raw materials required for the 3D printing process as well as the finished 3D printed products. A waterside handling may not necessarily be attributed to these storage activities. Ideally, different producers have the chance to share the same production facilities and storage capacities in the terminal area. Multi-purpose terminal activities might not center only on quayside cargo throughput anymore but on industrial production in close distance to other seaport terminals and on raw material storage activities. Potential markets for 3D printed products are spare parts for vessels that are only rarely needed. Spare parts that are needed frequently can be produced less expensive by the shipbuilding sector itself.[102]

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[101] MotorShip (2016b)

[102] Major players involved in the marine 3D spare part supply chain are described in the Annex.

However, the breakthrough of 3D printing demands that some requirements are fulfilled:

1) Maturation of the 3D printing technology leading to cost reductions, material compatibility and efficiency increases
2) Possibility to use 3D printing for production of larger products with a competitive price structure
3) Possibility to use 3D printing for manufacturing of products from different materials (steel, metal and others)
4) Demand for 3D print products of the local industry (as a start, especially, spare part industry or health care)
5) Demand for 3D print products of the local consumer base (as a start, especially, design products and small batch products)
6) Availability of land space to cluster production facilities and a network of involved players (3D printing providers, end users, educational and knowledge institutes, testing facilities, certification bodies, software companies and engineers)

8.2 Planning and Visualization of Terminal Concepts

After the analysis (chapter 5) and comparison (chapter 5.3) of existing multi-purpose terminals it becomes clear that multi-purpose terminals can be distinguished regarding the terminal area, the overall annual throughput and the cargo types that are handled. In order to provide recommendations that are suitable for a large amount of multi-purpose terminals, different scenarios for multi-purpose terminals are considered:

1. Container and break bulk handling at a small multi-purpose terminal
2. Container, break bulk and dry bulk handling at a medium-sized multi-purpose terminal
3. Container and dry bulk handling at a large multi-purpose terminal

An innovative multi-purpose terminal concept is developed for each of these scenarios.

Remark:

As described in chapter 5.3 a comparison of multi-purpose terminal is possible but not reasonable. An evaluation of each terminal's efficiency compared to other multi-purpose terminals is also not reasonable. No meaningful conclusions regarding e.g. the area efficiency can be drawn (see chapters 8.2.3 to 8.2.5). A comparison of the developed multi-purpose terminal concepts with existing terminals is not carried out in this study.

8.2.1 The Planning Process

8.2.1.1 Traffic projection

For each of the scenarios, a traffic volume for different types of commodities was defined (see tables within the single scenario chapters). These traffic volumes define the basis for the planning and visualization work. Usually, the traffic projection includes a cargo handling volume in tons or units per year as an average as well as in peak times. The choice of a peak factor displays the seasonality of cargo handling but also different distributions of traffic to/from the terminal during a day. A traffic forecast can seasonally fluctuate for different types of commodities; foodstuff, e.g. fruits or grain, usually have a high seasonality but there are also socio-cultural factors, e.g. for some commodities there is a peak time in handling before Christmas or Eid al-Fitr. A traffic forecast may also include some commercial aspects in terms of change of handling commodities during the forecast period.

Based on that basic forecast there is a related vessel traffic forecast (also for different types of commodities a frequency of calls during the year and the peak times as well as the design of those vessels is required, especially with regard to GT, length, draft and beam having strong impact on the adequate design/layout of the terminal) as well as a hinterland transport forecast (usually done for trucks and trains but partly also for inland navigation vessels). A typical traffic projection, based usually on systematic prognoses for a single port, is shown as an example in Table 10.

Table 10: Traffic projection – exemplary results

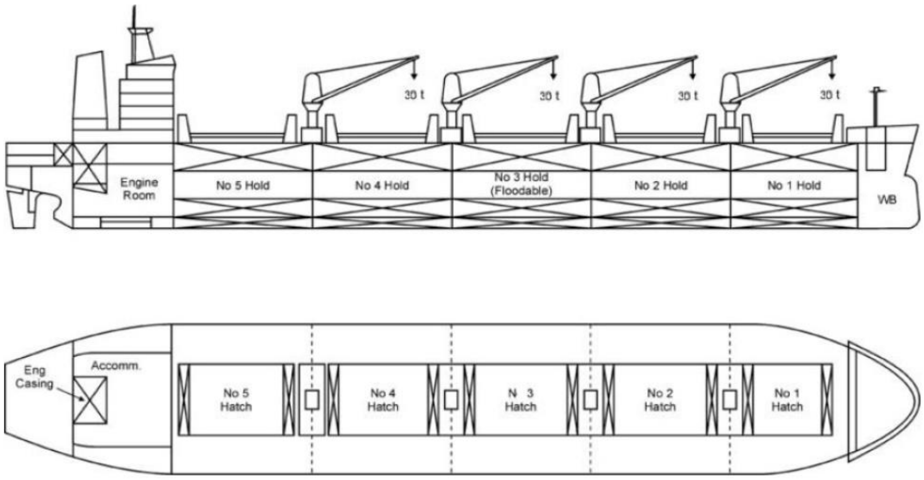
Sample general traffic forecast (multi-purpose) in tons

Tonnes	2013	2014	2015	2016	2017	2018	2019	2020	AGR
Lifestock	104.586	105.916	107.298	108.736	110.232	111.787	113.405	115.087	1,3%
Road Vehicles	123.863	130.040	136.464	143.145	150.093	157.319	164.834	172.649	5,6%
Corn	508.582	521.496	534.928	548.897	563.424	578.533	594.246	610.587	2,6%
Wood	9.668	7.601	5.451	3.215	889	0	0	0	-8,2%
Grain	421.652	436.224	451.378	467.138	483.529	500.576	518.304	536.741	4,3%
Coal	0	0	0	0	0	0	0	0	-
Chemical Fertilizer	114.044	122.193	130.669	139.484	148.651	158.185	168.101	178.413	11,4%
Steel (rebar)	802.000	874.951	920.479	967.828	967.828	967.828	967.828	967.828	2,7%
Cement	21.266	17.729	14.052	10.227	6.249	2.112	0	0	-7,0%
Fruits	0	0	0	0	0	0	0	0	-
Oilfruits	10.428	5.980	1.354	0	0	0	0	0	-4,3%
Vegetable Oil	230.776	242.558	254.811	267.555	280.809	294.592	308.927	323.836	5,5%
Fresh Vegetables (95% Oinions)	7.192	6.622	6.028	5.411	4.769	4.102	3.408	2.686	-8,8%
Maschinery	26.432	27.552	28.717	29.928	31.187	32.497	33.859	35.276	5,4%
Building Materials	125.880	133.229	140.871	148.820	157.087	165.684	174.625	183.924	10,1%
Steel (coils)	452.000	458.082	451.213	444.069	436.640	428.913	420.878	412.520	-1,0%
Paper	1.167	0	0	0	0	0	0	0	-0,9%
Phamazeutical Products	4.930	3.163	1.326	0	0	0	0	0	-4,3%
Rise	0	0	0	0	0	0	0	0	-
Glasproducts	0	0	0	0	0	0	0	0	-
Other Products	23.303	19.873	16.306	12.597	8.739	4.726	553	0	-
Liquid Gas	139.305	142.367	145.553	148.865	152.310	155.893	159.619	163.495	2,1%
Mehl	0	0	0	0	0	0	0	0	0,0%
Sugar	0	0	0	0	0	0	0	0	0,0%
Scrap	350.000	122.000	250.000	300.000	350.000	350.000	350.000	350.000	0,0%
Total	**3.477.073**	**3.377.575**	**3.596.897**	**3.745.915**	**3.852.436**	**3.912.748**	**3.978.587**	**4.053.042**	**2,2%**

Sample vessel forecast (multi-purpose) in numbers

	2013	2014	2015	2016	2017	2018	2019	2020	AGR
Lifestock	105	106	98	99	100	102	103	105	-0,4%
Fruits and Vegetables	24	22	24	22	24	21	17	13	-5,8%
Road Vehicles	190	199	195	204	200	210	220	230	1,2%
Scrap	150	150	150	150	150	150	150	150	0,3%
Steel (coils)	70	70	69	68	67	66	65	63	-1,3%
Long goods general cargo (wood, steel re	203	221	206	216	194	194	194	194	0,4%
Dry Bulk (Grain, Soya, Corn, Wheat, Cher	169	174	172	178	184	177	183	189	2,9%
Building Material	70	74	70	74	79	66	70	74	8,4%
Bagged goods general cargo	33	27	22	16	10	3	0	0	-
Palletise good general Cargo	49	50	51	52	54	56	57	59	2,7%
Project Cargo	132	138	144	150	156	162	169	176	8,9%
Other	100	100	100	100	100	100	100	100	0,4%
	1.294	**1.332**	**1.300**	**1.329**	**1.317**	**1.306**	**1.328**	**1.354**	**1,0%**

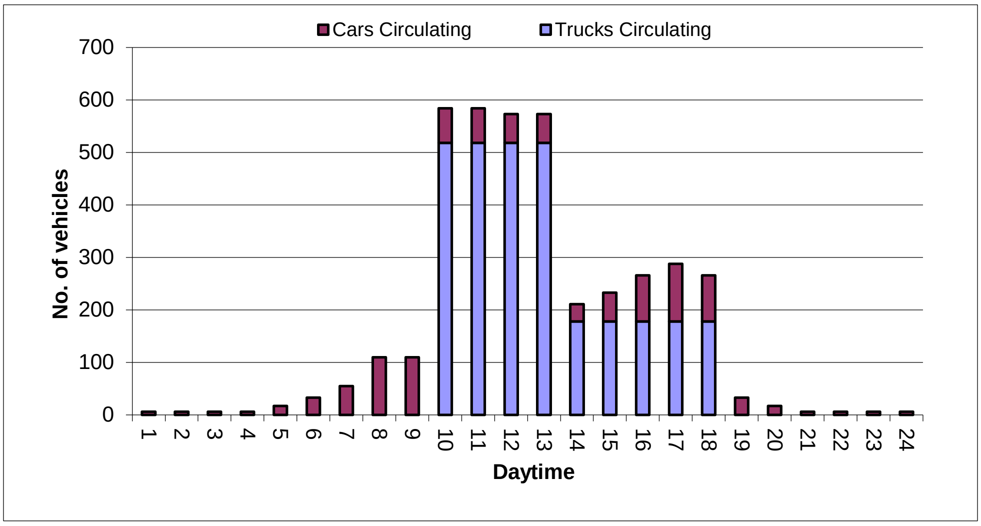
Sample design vessel multi-purpose



Sample annual truck forecast multi-purpose in numbers

	2012	2013	2014	2015	2016	2017	2018	2019	2020	AGR (%)
Trucks with containers	280,414	336,937	347,618	358,627	369,975	381,674	393,737	406,176	419,003	6.2
Trucks with non-containerized cargo	278,784	296,118	303,938	311,597	320,474	325,010	330,431	335,753	342,361	2.9
Total Trucks	**559,198**	**633,055**	**651,556**	**670,224**	**690,449**	**706,684**	**724,168**	**741,929**	**761,364**	**4.5**

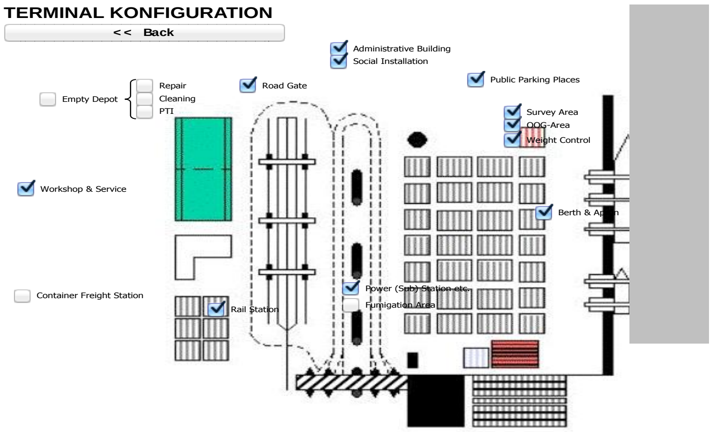
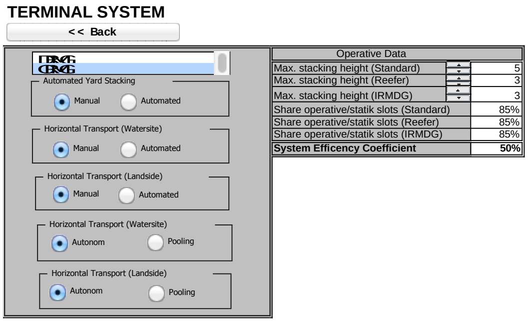
Sample daily truck forecast with hourly distribution in numbers



8.2.1.2 General Operations Planning with Capacity Calculation and Preliminary Terminal Configuration

Using the traffic projection as major input factors the work of terminal planners starts with calculating the required capacity of single terminal elements, as berths, yards, hinterland transport connections, warehouses, etc. based on a chosen preliminary terminal configuration. Usually, this work is carried out by applying computer based operations models that include standard calculations based on fixed planning parameters. These models help understanding the requirements of infra- and superstructure elements of a port terminal in a general way and develop a first preliminary layout/visualization. Exemplary results of the operations planning are visualized in Table 11.

Table 11: Operations planning – exemplary results

Terminal operational planning model – general configuration level	
Terminal operational planning model – specific system element configuration level	

Sample berth capacity calculation (multi-purpose – container handling)

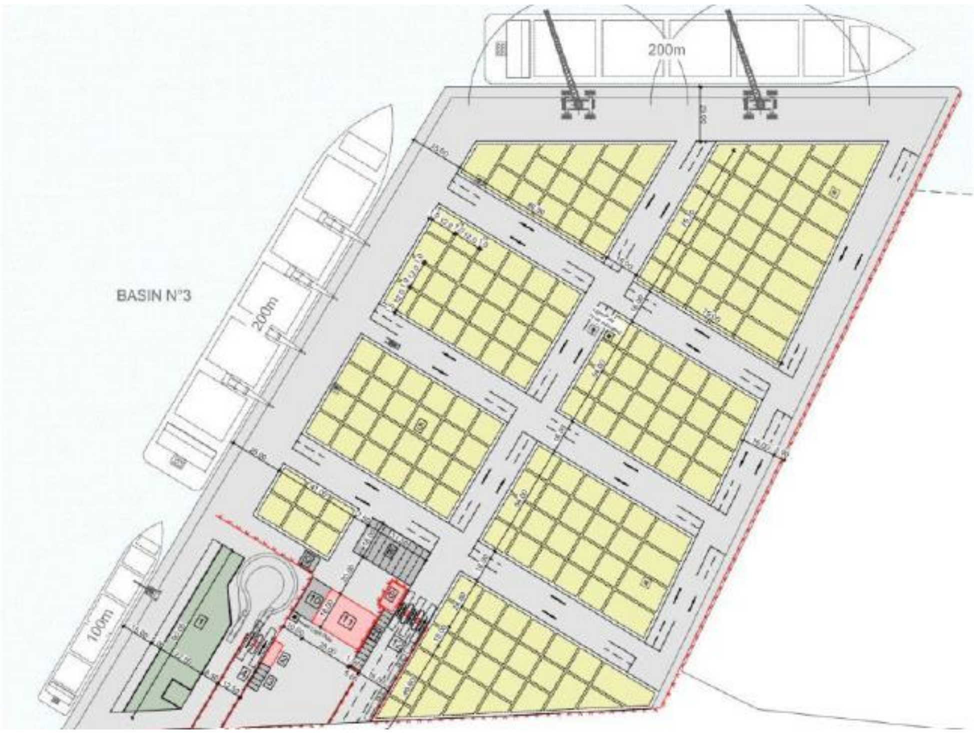
	Unit	
Projected container moves p. annum	boxes	153.171
Applied container factor	factor	1,68
Expected annual TEUs	**TEUs**	**257.327**
Addition. moves for hatch covers ;restsows; shifters etc	moves	2,50%
Total equivalent container moves per annum	moves	157.000
Assumed crane moves per hour	moves	21
Working shifts per day	hrs	2
Working hours per shift	nr.	9,5
Moves per day in shifts	moves	399
Terminal working days per annum	days	362
Assumed annual crane utilization	%	65,00%
Peak demand allowance factor	factor	1,2
Crane availability	%	90,00%
Assumed crane moves p.annum	moves	91.538
Assumed crane moves p.annum in peak times	moves	76.281
Presently deployed SSG:	nr.	4
Available Quay Capacity p.a.:	TEUs	512.610

Sample yard storage capacity calculation (multi-purpose steel coils)

Year	Unit	2012	2013	2014	2015	2020
Steel Coils	Tons	492,529	475,135	469,686	464,019	432,097
Average tons per coil	Tons	15	15	15	15	15
Steel Coils	Nos.	32,835	31,676	31,312	30,935	28,806
Coil per m²	Coils	0.35	0.35	0.35	0.35	0.35
Average stacking height	Coils	1.5	1.5	1.5	1.5	1.5
Operations factor for area usage	factor	1.3	1.3	1.3	1.3	1.3
Assumed operational peak factor	factor	1.5	1.5	1.5	1.5	1.5
Average dwell times	days	**3**	**3**	**3**	**3**	**3**
Storage days per annum	days	364	364	364	364	364
Required Storage Area	**m²**	**11,787**	**11,371**	**11,240**	**11,105**	**10,341**

Sample truck gate capacity calculation

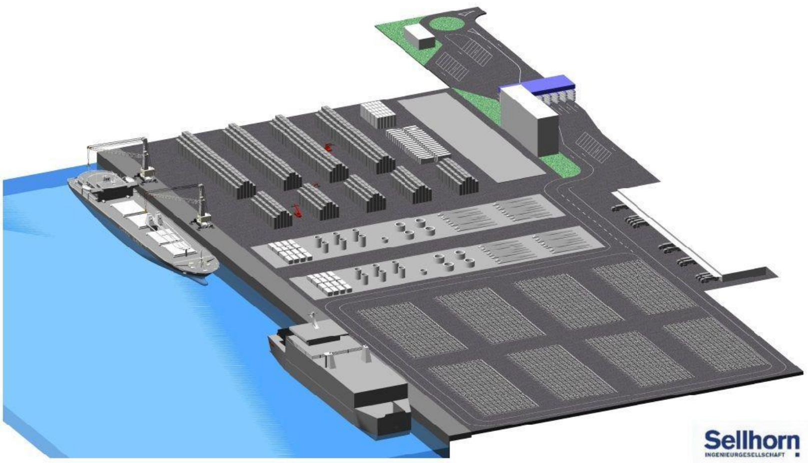
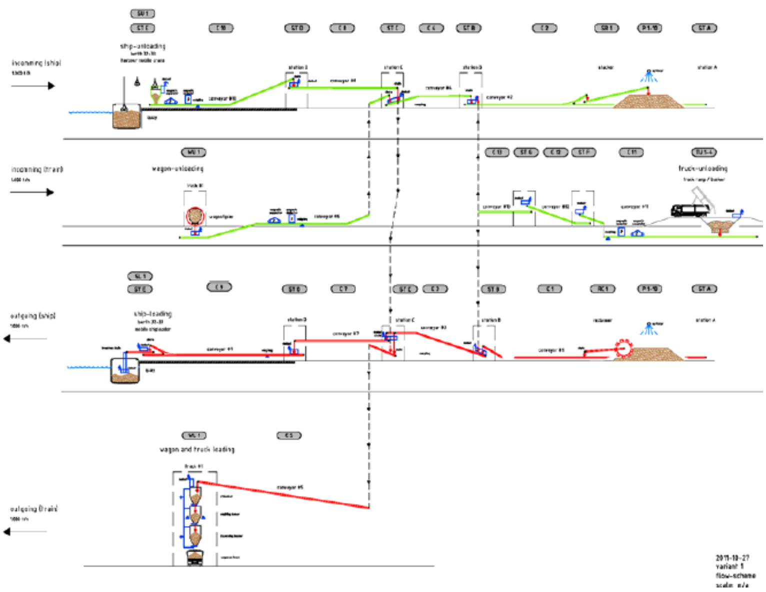
Year	Unit	2012	2013	2014	2015	2020
p.a.-Trucks IN	nr	**105,938**	**112,525**	**115,496**	**118,407**	**130,097**
p.a.-Trucks OUT	**nr**	**105,938**	**112,525**	**115,496**	**118,407**	**130,097**
Annual gate working days	days	364	364	364	364	364
Gate working hours/day	hrs	20	20	20	20	20
Peak factor	factor	1,2	1,2	1,2	1,2	1,2
Max. trucks per "Gate-IN" per hour	nr	15	15	16	16	18
Max. trucks per "Gate-OUT" per hour	nr	15	15	16	16	18
Truck dispatch time: Gate-IN	min	6	6	6	6	6
Truck dispatch time: Gate-OUT	min	6	6	6	6	6
Required Number of Gate Lanes						
"IN-Gate" Lanes	nr	2	2	2	2	2
"Out-Gate" Lanes	nr	2	2	2	2	2
Truck capacity per lane per hour	nr	10	10	10	10	10
Total number of Gate Lanes:	nr	**4**	**4**	**4**	**4**	**4**

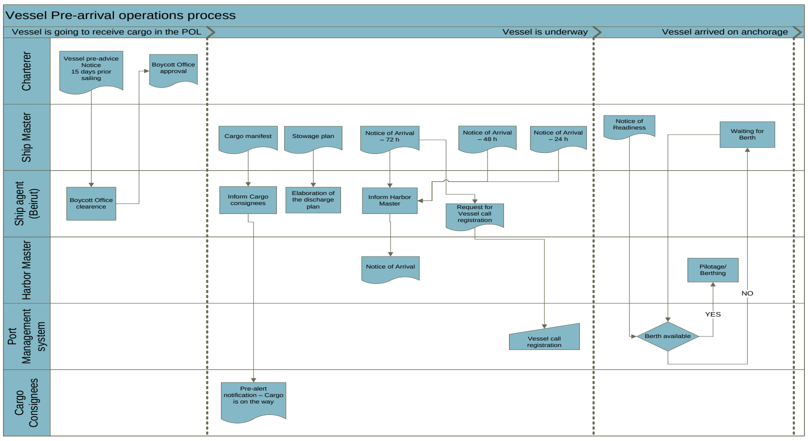
Sample preliminary layout multi-purpose	

8.2.1.3 Detailed Planning

Following the preliminary terminal concept/layout, a more detailed planning of the single terminal elements is usually undertaken in a next step. For large terminal projects, related to high investments, this includes the simulation of operative processes in order to optimize the terminal configuration and to identify bottlenecks and solutions for the various material flow concepts integrated in the multi-purpose terminal based on the given target capacity. Having available an optimized terminal configuration and a related visualization/layout a detailed material flow concept, a detailed definition of each operative process, a detailed specification of key infra- and superstructure elements as well as a detailed specification of the required equipment are elaborated. Exemplary results are illustrated in Table 12.

Table 12: Detailed planning – exemplary results

Sample simulation of operation	
Sample optimized layout/visualization	
Sample material flow schema dry bulk	

<table>
<tr>
<td>Sample process mapping</td>
<td>


</td>
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<tr>
<td>Sample equipment specification</td>
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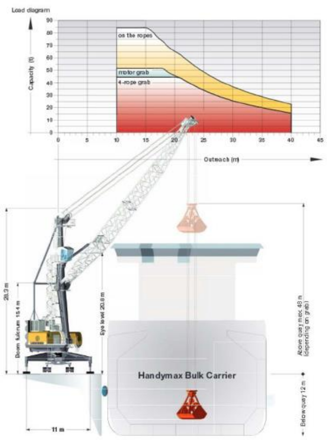
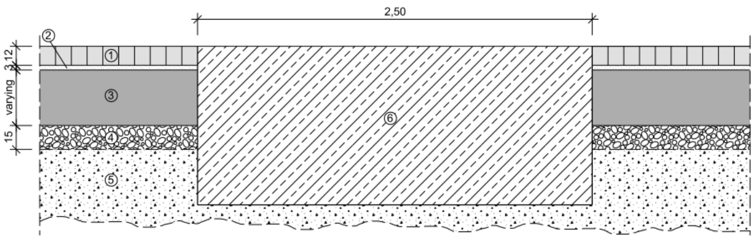
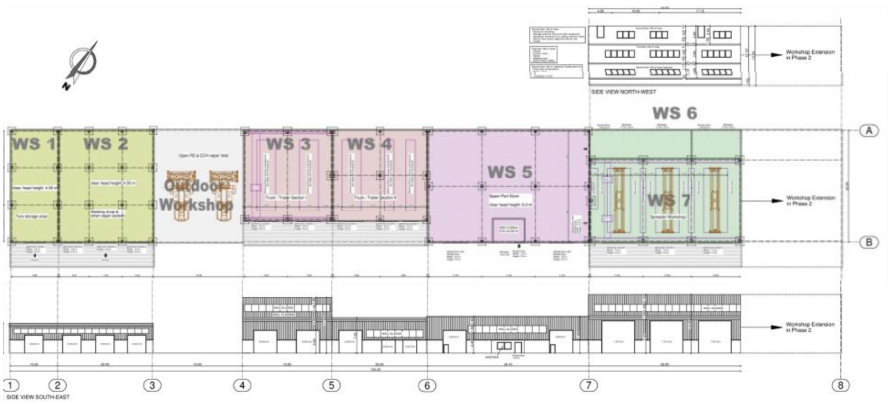


<table>
<tr><td>Min. to max. outreach</td><td>10-40 m</td></tr>
<tr><td>Height of boom fulcrum</td><td>15.4 m</td></tr>
<tr><td>Tower cabin height (eye level)</td><td>20.8 m</td></tr>
<tr><td>Overall height (top of tower)</td><td>28.3 m</td></tr>
<tr><td>Overall length of undercarriage</td><td>16.2 m</td></tr>
<tr><td>Overall width of undercarriage</td><td>5.4 m</td></tr>
</table>
</td>
</tr>
<tr>
<td>Sample infrastructure specification</td>
<td>


Legend:
① Precast Concrete Pavers, C 55/67 accord. to DIN EN 206-1
② Sandbed 0.3/5 mm
③ Base Course
(a) Concrete C25/30, d = 0,35 m
(b) Heavy Duty Macadam (HDM) as defined by UK Highways Agency ‘Specification for Highway Works’ , d = 0,45 m
(c) Dense Bitumen Macadam (DBM) as defined by UK Highways Agency ‘Specification for Highway Works’, d = 0,54 m
(d) Hot Rolled Asphalt (HRA) as defined by UK Highways Agency ‘Specification for Highway Works’ , d = 0,67 m
(e) Crushed Rock Layer with grading 0/32 mm, Ev2 ≥=150 MN/m², reinforced with Geogrid Secugrid® 40/40 Q1 as stabilization layer and Geogrid Combigrid® 60/60 Q1 151 as stabilization and separation layer, d = 0,50 m
④ Sub-base (Optional, only if existing filling material /sub-base is not sufficiently loadbearing and stable): Crushed Rock Layer with grading of 0/32 mm, Ev2 ≥=150 MN/m² . Existing sub-base has to be compacted if required EV2 have not been achieved.
⑤ Sub-grade: Ground Layer / filling, grading of 0/56 mm, Required Ev2 = 45 MN/m²has to be verified. Existing subgrade has to be compacted if required EV2 have not been achieved
⑥ RTG-Beams: Reinforced Concrete (RCC); C 35/45, (Final Design Based on Structural Calculation)
</td>
</tr>
</table>

Sample superstructure specification	

8.2.2 The Planning of the Relevant Scenarios

Using a similar planning approach that is outlined in the previous chapter, the layouts and visualizations of the three innovative multi-purpose terminal scenarios have been elaborated (see following chapters). All principles of terminal planning as set out in chapter 3 of this report have been included. The engineering concept includes a very flexible design with heavy duty pavements at all terminal areas as well as one continuous quay wall able to bear the loads of all kind of heavy duty lifting with mobile cranes as well as a later equipment with specialized port cranes, e.g. STS. This concept provides the basis for a highly flexible operative work approach. The planning also envisages adequate cold-ironing facilities as well as the use of renewable energy sources (photovoltaic installations at the top of the warehouses and office buildings). Conceptual wise, the terminal provides sufficient autonomous power supply systems, also providing enough capacity for the electrification of the main cargo handling equipment as well as for the cold ironing installations working on full load.

It is important to understand that these are exemplary layouts, especially with the location of the different terminal elements. This in-turn means that a final terminal layout of course must be further adjusted with regard to the given specific site conditions, e.g. the locations of the road and rail gates at such a terminal strongly depend on the existing connection to and configuration with the hinterland transport infrastructure. In the presented layouts/visualizations we have included an ideal-typically road/rail gate, rail station, office building, parking places, etc. with location and configuration based on assumptions about the site conditions. However, the location of the terminal elements and their proportion to each other already display a very final optimized configuration based on best practice experiences. In this context it must be further understood that:

1. **Scenario 1** provides the layout of a ‘standard highly flexible handy-size multi-purpose terminal’ that includes all the flexible and sustainable technologies and design approaches that are presented in this study. All elements of the terminal can be used for various purposes (dry bulk, break bulk, RoRo/vehicles, container) and even functions can be easily changed (yard areas can be easily reconfigured and buildings removed or extended if required). The layout/design of the single terminal elements can be easily adapted (in short time and at low cost) to seasonal fluctuations of cargo volumes/composition as well as

towards completely new business opportunities in cargo handling. This terminal configuration includes only limited possibilities for automation, e.g. for the gate.

2. **Scenario 2** already provides a layout for a more ‘specialized’ terminal facility also having reasonable dry bulk handling volumes, especially with regard to the use of specialized cargo handling equipment (RTGs for container handling, fixed areas with stacker/reclaimer for dry bulk handling, etc.) as well as the specific cargo storage units, as silos and warehouses for dry bulk and break bulk. Another relatively fixed element in this configuration is the large rail station already equipped with RMGs for container handling (this defines a relatively fixed terminal layout). However, the terminal provides reasonable flexibility with regard to the storage of larger project cargos as well as RoRo/vehicles. Furthermore, the berth configuration still proves a high operative flexibility for all types of cargo/commodity handling. This terminal configuration includes some possibilities for automation, e.g. for the gate as well as in the container stacking areas (semi-automated RTGs).
3. **Scenario 3** provides a very specialized terminal design that some could name three terminals in one because dedicated areas use highly specialized handling equipment for main cargo commodities (container, dry bulk, general cargo/project cargo). Also the berth area is divided into dedicated areas. The configuration easily can be split into three individual specialized terminals. This terminal configuration includes several possibilities for automation, e.g. for the gate, in the container stacking areas (semi-automated RTGs), for the rails operations as well as for the handling of the large dry bulk volumes (these possibilities can be fully activated when including a physical full segregation of the main commodity operation, especially with dedicated yard/berth areas).

8.2.3 Scenario 1: Container and Break Bulk Handling at a Small Multi-Purpose Terminal

8.2.3.1 Basic Parameters for Scenario 1

Input parameters for scenario 1 are summarized in Table 13. Figure 16 and Figure 17 show the visualization of the innovative multi-purpose terminal concept for this scenario.

Table 13: Key characteristics of the multi-purpose terminal concept of scenario 1

Criteria	
Total terminal area [A]	▪ 220,000 m^2
Built-up area [B]	▪ 23,500 m^2
B/A	▪ 5%
Total quay length [C]	▪ 670 m
C/A	▪ 0.003
Berth information	▪ 2
Railway information	▪ None
Crane information	▪ 2 mobile harbor cranes
Terminal equipment	▪ Reach stackers, front-/top-loader, tractors and trailers
Number of gate lanes (in+out)	▪ 4 lanes in and 4 lanes out
Terminal throughput per year [D]	▪ 720,000 t
Area efficiency [D/A][103]	▪ 4.00 t/m^2
Cargo type (commodities)	▪ Container: 30,000 TEU[104] (≈ 360,000 t) ▪ Break bulk: 300,000 t ▪ Cellulose or paper rolls: 120,000 t ▪ Automobiles: 120,000 t ▪ Project cargo (e.g. components for wind energy power plants): 60,000 t
Cargo mix (share based on t)	▪ 50.00% Container ▪ 41.67% Break bulk ▪ 8.33% Project cargo

[103] Area efficiency is determined by type of cargo commodity and provided services.
[104] Assumption: 1 TEU ≈ 12 t

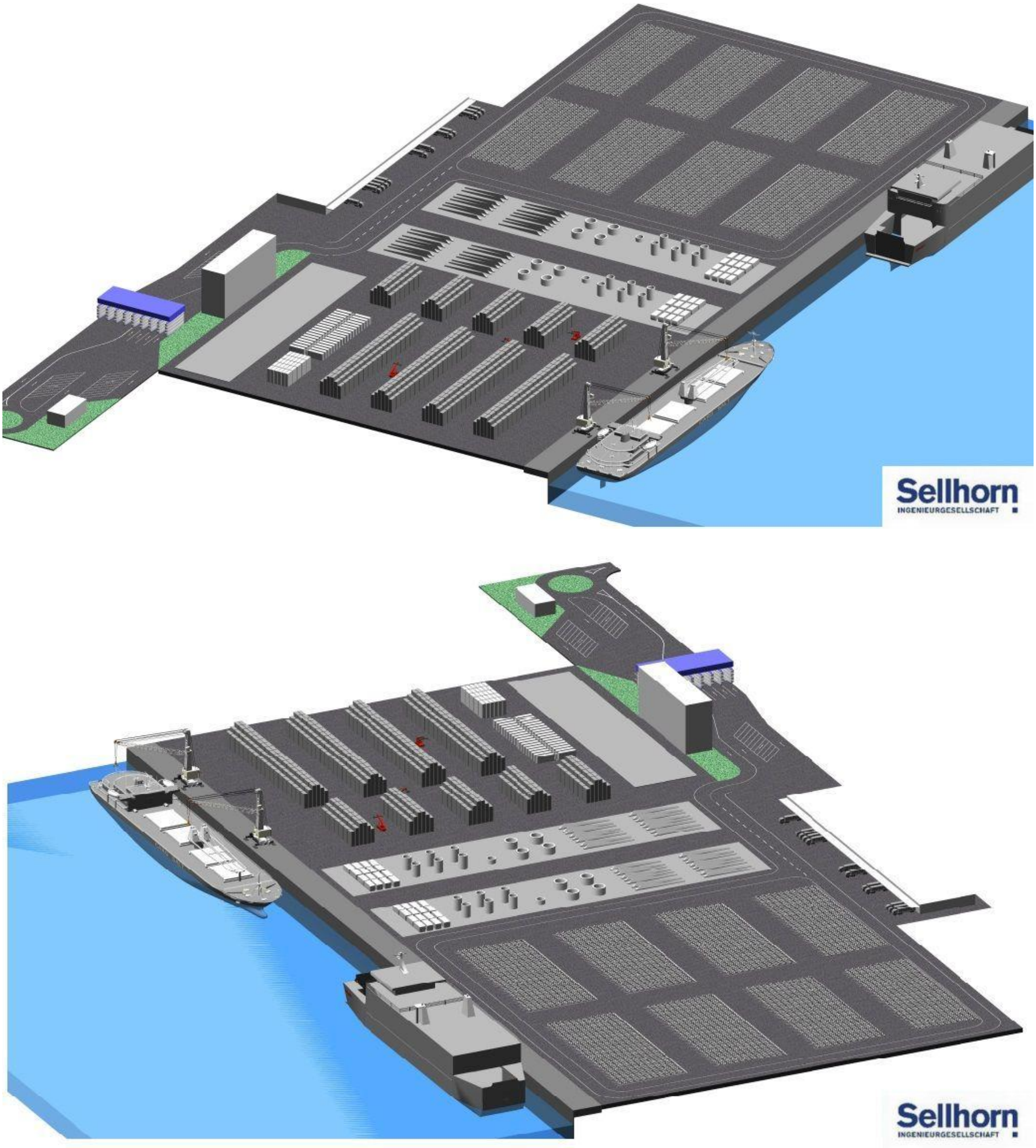


Figure 16: Terminal layout concept of scenario 1 in 3D

8.2.3.2 Functional Description of Scenario 1

Scenario 1 resembles a highly flexible, non-specialized solution for ports with varying commodities and volumes. Cargos are stored in dedicated and mixed areas, which are however only separated by road markings, if at all, meaning that they could easily be adapted to changing requirements. In this example, the port features a storage area for containers handled by reach stackers and trucks/trailers. General cargo is stored in two areas with direct proximity to the quay for timesensitive cargos mostly handled with top-loader. The paper and cellulose is mostly handled in the warehouse complex by front-loaders with specific grabs. Quayside cargo handling is done with mobile harbor cranes and partly as RoRo.

Civil infrastructure on the terminal is kept as broad and flexible as possible (e.g. heavy-duty pavement in all areas able to withstand loads from multiple vehicle types to avoid dedicated concrete runways; uniform arrangement of levels and falls for storm water drainage continuously throughout the terminal, covered storage halls using single-point foundations for flexible extension or removal, etc.). The quayside structures offer a uniform, continuous, non-dedicated berth over the entire length of the terminal in order to allow berthing of different types of vessels of varying size at all locations along the terminal.

The area efficiency of the terminal is low compared to other solutions. This terminal's main advantage is its high flexibility and ability to adapt quickly to changing requirements.

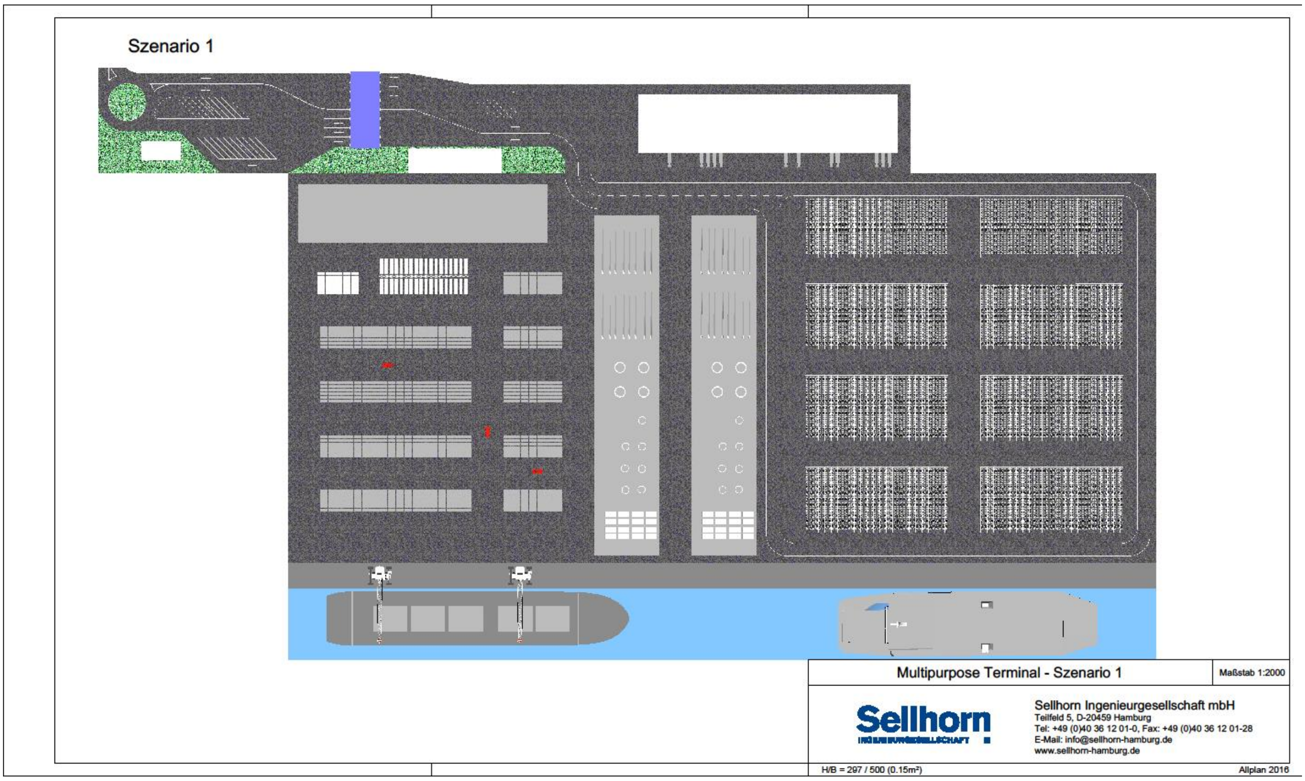


Figure 17: Layout concept of scenario 1 in 2D

8.2.4 Scenario 2: Container, Break Bulk and Dry Bulk Handling at a Medium-Sized Multi-Purpose Terminal

8.2.4.1 Basic Parameters for Scenario 2

Input parameters for scenario 2 are summarized in Table 14. Figure 18 and Figure 19 show the visualization of the innovative multi-purpose terminal concept for this scenario.

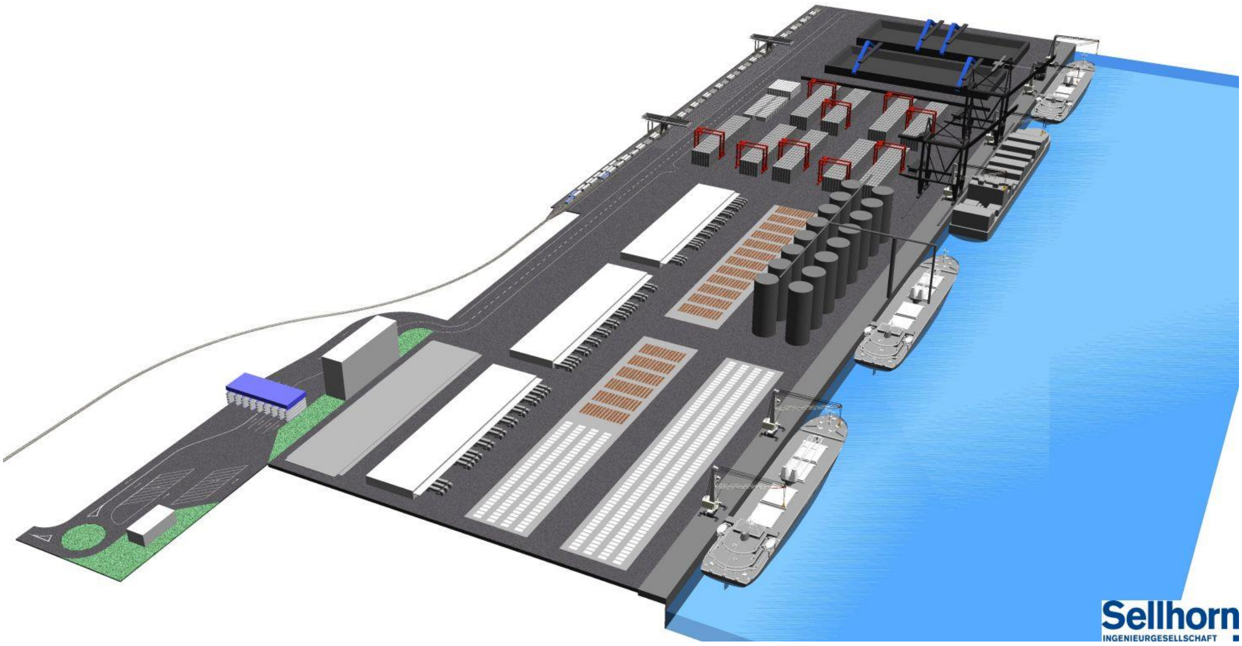
Table 14: Key characteristics of the multi-purpose terminal concept of scenario 2

Criteria	
Total terminal area [A]	▪ 400,000 m^2
Built-up area [B]	▪ 59,000 m^2
B/A	▪ 15%
Total quay length [C]	▪ 1,200 m
C/A	▪ 0.003
Berth information	▪ 4
Railway information	▪ Various loading tracks
Crane information	▪ 8 mobile harbor cranes
Terminal equipment	▪ RTG, tractor and trailers, top-/front-Loader, RMG's for the rail station, stacker/reclaimer for dry bulk
Number of gate lanes (in+out)	▪ 4 lanes in and 4 lanes out
Terminal throughput per year [D]	▪ 4,240,000 t
Area efficiency [D/A][105]	▪ 13.98 t/m^2

Cargo type (commodities)	▪ Container: 270,000 TEU[106] (≈ 3,240,000 t)
	▪ Break bulk: 700,000 t
	  o Steel coils: 280,000 t
	  o Tree trunks: 280,000 t
	  o Cement: 140,000 t
	▪ Dry bulk: 300,000 t (100% corn/grain)

Cargo mix (share based on t)	▪ 76.42% Container ▪ 16.51% Break bulk ▪ 7.08% Dry bulk

[105] Area efficiency is determined by type of cargo commodity and provided services.
[106] Assumption: 1 TEU ≈ 12 t



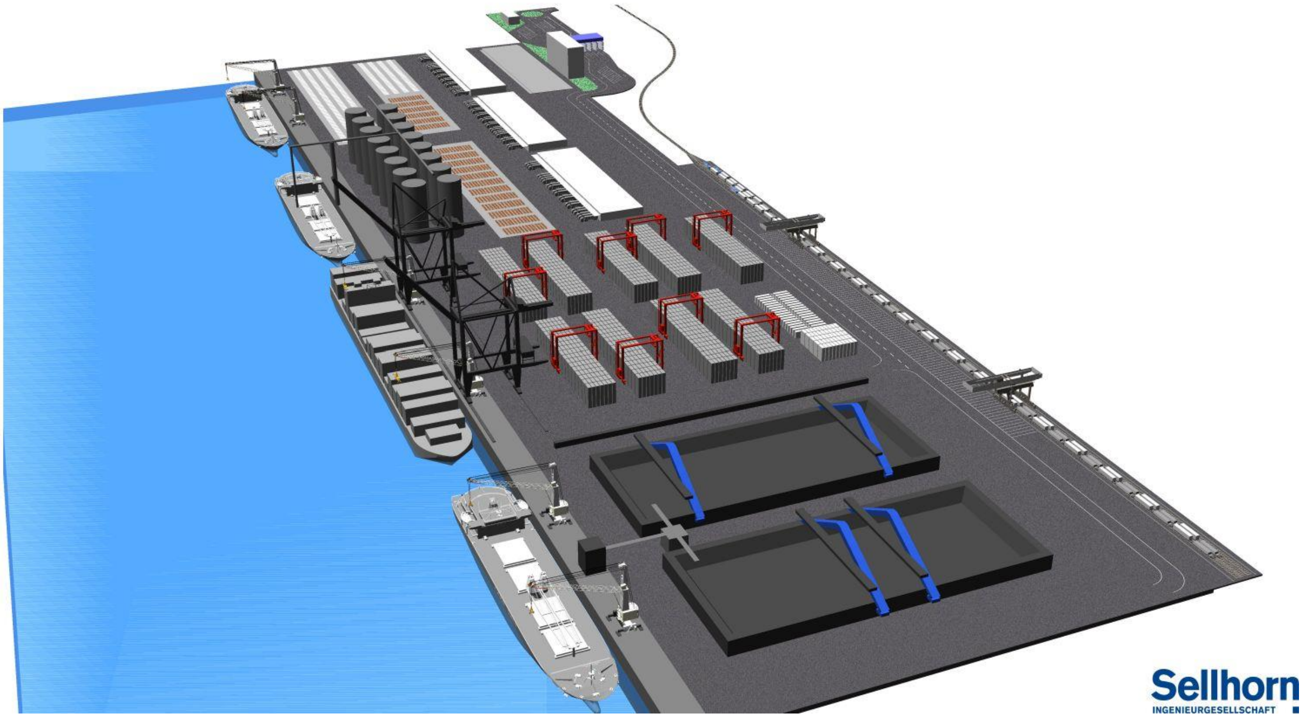


Figure 18: Terminal layout concept of scenario 2 in 3D

8.2.4.2 Functional Description of Scenario 2

Scenario 2 resembles a more specialized layout solution that is common for ports with significant dry bulk handling volumes. Cargos are stored in dedicated areas and are handled by specialized equipment such as RTGs, dry bulk stackers/reclaimers, etc. Steel coils and long wood products are partly handled on the open storage areas, partly in the warehouse complex, depending on the climate/actual weather, the quality of the cargo lots as well as the packing of the cargo units, if any. Handling of some break and dry bulk cargos, such as cement and grain, requires the construction of permanent fixed structures, in this case silos, warehouses, and conveyor belts. For the container yard, the pavement structure and arrangement of levels and falls both are important items to be considered for construction and operation. For some additional flexibility, the same structure and arrangement could also be chosen for other storage areas to allow a future expansion for containers, if required. Due to its size, the rail yard has a strong impact on the general shape and broad layout of the terminal.

Other than the cargo handling equipment, the quayside equipment and berth arrangement are chosen to allow flexible handling of different cargos throughout the entire quay length. Only mobile harbor cranes are used for cargo handling partly equipped with container spreaders, slings, grabbs, etc. (depending on the type of cargo). The dry bulk unloading (assumed to be mostly import) is carried out using fixed hoppers installed over the conveyor belts. In theory, the berth alignment allows all ships to berth at any available position. In reality, the berths will at least partially be allocated to specific types of vessels, while still allowing flexible rearrangement if required. This means that the quayside structure will be constructed as a uniform, continuous berth.

This type of terminal layout arrangement offers an intermediate to high area efficiency while still being reasonably flexible in terms of adaptability to changing requirements and different cargos.

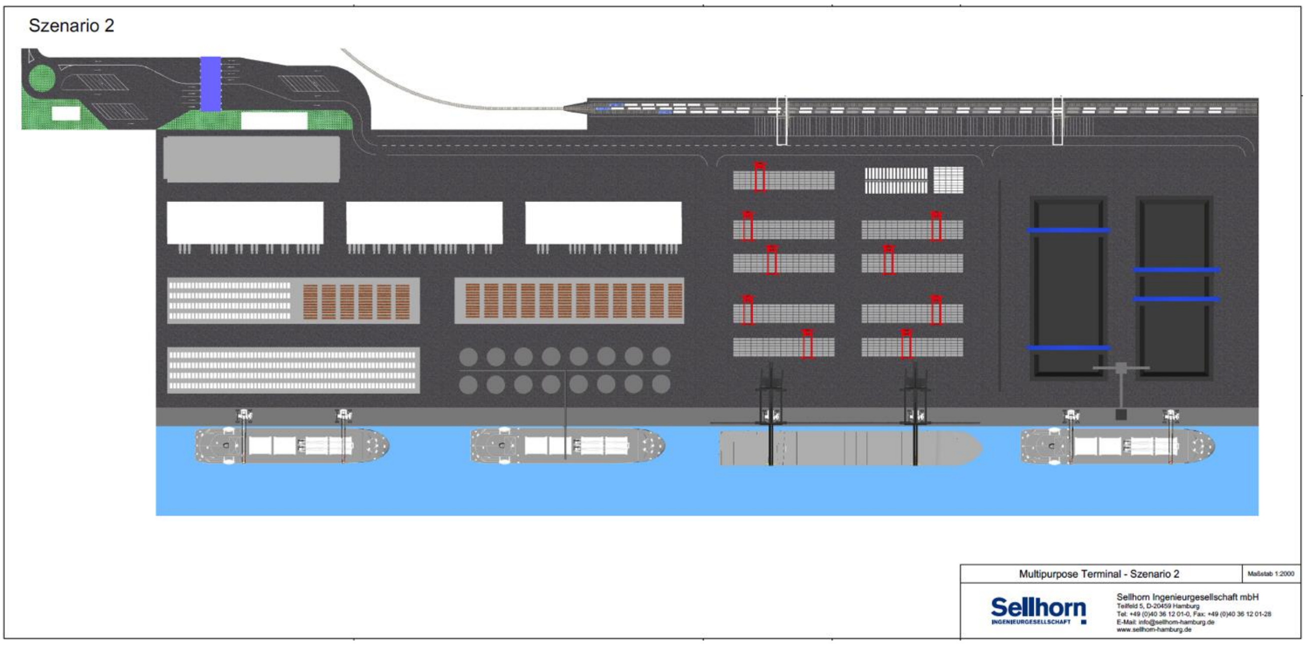


Figure 19: Layout concept of scenario 2 in 2D

8.2.5 Scenario 3: Container and Dry Bulk Handling on a Large Multi-Purpose Terminal

8.2.5.1 Basic Parameters for Scenario 3

Input parameters for scenario 3 are summarized in Table 15. Figure 20 and Figure 21 show the visualization of the innovative multi-purpose terminal concept for this specific scenario.

Table 15: Key characteristics of the multi-purpose terminal concept of scenario 3

Criteria	
Total terminal area [A]	▪ 1,000,000 m^2
Built-up area [B]	▪ 285,000 m^2
B/A	▪ 29%
Total quay length [C]	▪ 3,000 m
C/A	▪ 0.003
Berth information	▪ 10
Railway information	▪ Various loading tracks
Crane information	▪ 12 mobile harbor cranes, 7 gantry cranes
Terminal equipment	▪ RTG, tractor and trailers, top-/front-loader, RMGs for the rail station, stacker/reclaimer for dry bulk
Number of gate lanes (in+out)	▪ 8 lanes in and 8 lanes out
Terminal throughput per year [D]	▪ 25,200,000 t
Area efficiency [D/A][107]	▪ 25.2 t/m^2
Cargo type (commodities)	▪ Container: 850,000 TEU[108] (≈ 10,200,000 t) ▪ Dry bulk: 15,000,000 t (100% zinc/ores/granulate)
Cargo mix (share based on t)	▪ 40.5% Container ▪ 59.5% Dry bulk

[107] Area efficiency is determined by type of cargo commodity and provided services.
[108] Assumption: 1 TEU ≈ 12 t

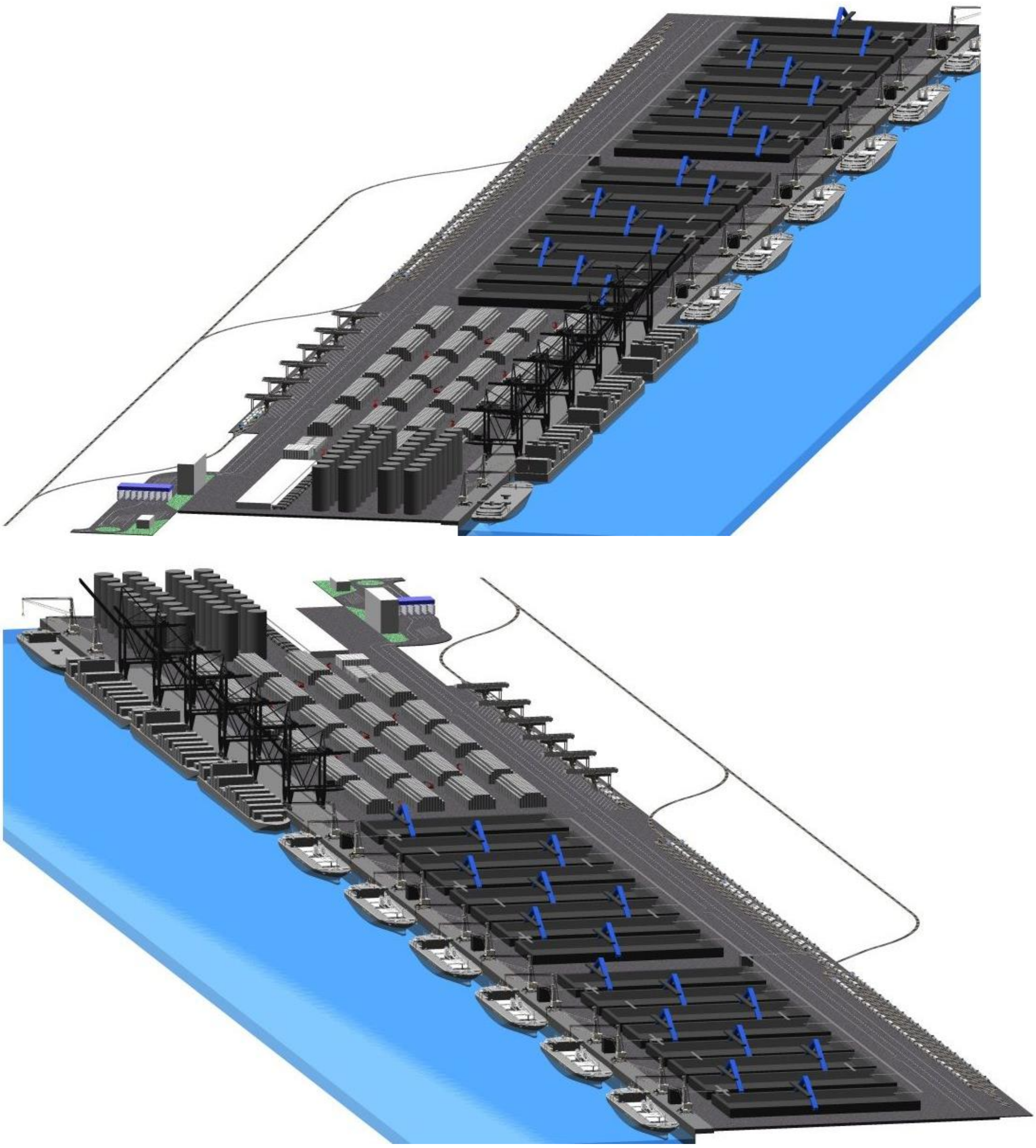


Figure 20: Terminal layout concept of scenario 3 in 3D

8.2.5.2 Functional Description of Scenario 3

Scenario 3 describes a highly specialized terminal layout with very little interdependence between the individual sections. The required civil structures are similar to the ones in scenario 2, with the addition of liquid bulk facilities. All commodities are handled by specialized equipment, e.g. loading arms for liquid bulk, gantry cranes for containers and mobile harbor cranes for dry bulk. The terminal sections could be split into individual terminals specialized to their commodity.

The requirements regarding civil infrastructure vary between each terminal section, as different types of vessels approach them and different types of equipment operate on them. With this consideration in mind, it is recommended to choose pavement type, buried services arrangement and possibly even the design parameters of the quay wall (type, bearing capacity, length, cope level, furniture, etc.) individually for each terminal. This will allow a higher specialization of the infrastructures towards their individual usage requirements and ultimately result in cost savings.

Due to the high specialization grade of this terminal layout, very high area efficiency values can be achieved. Adaptation to changing cargo volumes is possible through the provision of extension areas. However, adaptation to different commodities will require major efforts in rearrangement.

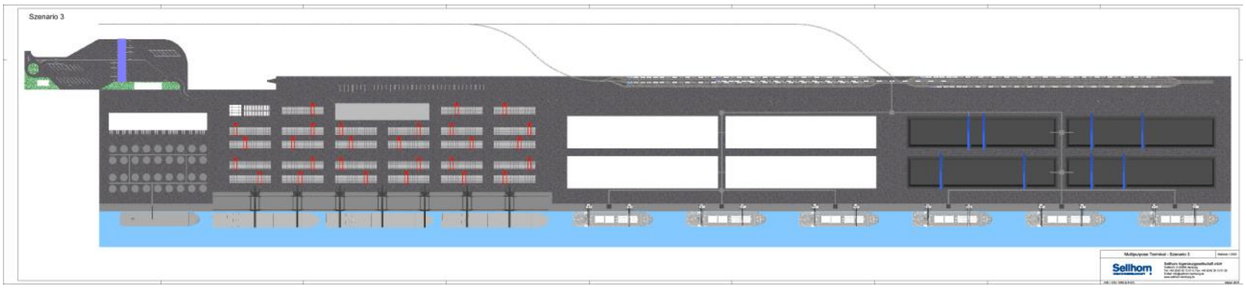


Figure 21: Layout of scenario 3 in 2D

8.3 Cost Indication as Orientation, Benchmarks where Possible

The costs for the construction of multi-purpose terminals are depending on design parameters. Especially the local physical site conditions (subsoil conditions and topography), environmental conditions (water depth, wind, currents, waves, sedimentation, etc.), and design loads (equipment, design vessel) have a major impact on the costs and need to be evaluated for every single case. With regard to greenfield and existing ports' extension, land reclamation can be necessary and availability of reclamation material will also affect the costs. For these reasons, only cost indications can be presented as orientation (benchmarks). They are shown in Table 16.

Table 16: Benchmark costs for construction of multi-purpose terminals

Terminal component	Cost indication
Quay wall	80,000 – 120,000 US$/m
Heavy duty pavement incl. buried service infrastructure	200 US$/m²
Container module (20 feet)	20,000 US$/module
Rail tracks	500 US$/m (non-electric)
Dredging	20 US$/m³ (heavily depending on vessel availability and soil conditions)
Reclamation	25-30 US$/m³ (heavily depending on vessel availability and soil conditions)
Warehouse	600 US$/m²
Office building	1,500 – 2,000 US$/m² (depending on favored standard)

8.4 Assessment of Energy Efficiency and Emission Reduction

There are a variety of approaches to reduce energy consumption and emissions on multi-purpose terminals. For port container terminals, this topic has been intensively investigated but not as deeply for the case of multi-purpose terminals.

In general, electrification of terminal equipment offers the potential to eliminate all emissions on a terminal, e.g. by using renewable energy sources. Thereby, the renewable energy can be generated directly on the terminal area (e.g. by solar cells or windmills) or it can be generated somewhere else and purchased from an energy supplier. Another option to reduce emissions is using alternative energy sources such as LNG or CNG for terminal equipment.

Energy consumption can be divided into cargo-handling-related (terminal equipment) and terminal-related (lighting, buildings etc.) consumption. For typical container terminals, the cargo-handling-related consumption accounts for approximately 80% of the electrical energy consumption and for almost 100% of fossil fuel (diesel) consumption. Therefore, it appears most reasonable to approach energy efficiency and emission reduction especially from the cargo-handling side. For multi-purpose terminals, the numbers might be different but the largest amount of energy is also used for cargo handling. There are basically three starting points for energy efficiency: equipment, operations, and behavior. These starting points and respective reduction measures are described in the following stating the reduction potential based on supplier information and pilot projects. Financial considerations are excluded from the analysis as they depend heavily on fuel and electricity prices in each country. As energy prices vary depending on the location and time and terminals are very different, a detailed financial analysis is not feasible.

8.4.1 On-Shore Power Supply

Innovative terminal concepts include on-shore power supply technology that allows vessels during lay days in the port without using 'on-board' diesel auxiliary engines. Docked ships that are plugged into power from shore eliminate carbon dioxide, sulfur dioxide, nitrogen oxide and particulate emissions that would ordinarily result from burning diesel fuel while in port. The technology also helps to reduce low-frequency noise and vibrations, and allows crews to maintain diesel engines while the ship is berthed. Figure 22 shows an example of an on-shore power supply.

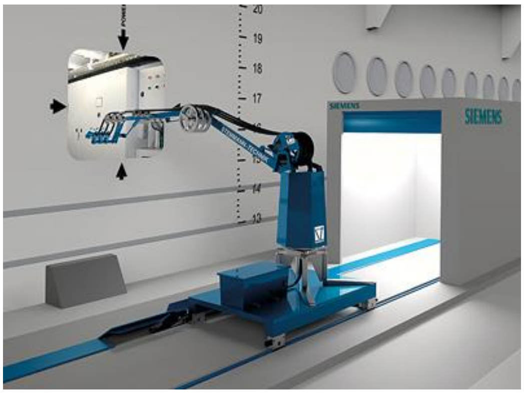


Figure 22: Example of an on-shore power supply[109]

[109] Siemens.com

One of the first European on-shore power supplies for cruise ships is already implemented at the Hamburg Altona cruise terminal.

8.4.2 Hydrogen Fuel Cell

Fuel cells generate electricity through an electrochemical reaction between hydrogen and oxygen, a process that is inherently clean and efficient. Fuel cells can provide the necessary power to refrigerated containers, eliminating harmful emissions from traditional diesel engines. Equally important, fuel cells generate electricity quietly, reducing noise pollution and creating a better environment for dockworkers. The fuel cell industry is already experiencing success in the large stationary power, telecom backup, and forklift markets.

8.4.3 Equipment

Reduction measures for terminal equipment are described for

- Ship-to-shore cranes and mobile harbor cranes,
- Vehicles for horizontal transport, and
- Reach stackers and forklifts

as these types of equipment are the most common on multi-purpose terminals. Potential reduction measures are summarized in Table 17. For terminals with high container throughput volumes also Rubber Tired Gantry Cranes are possible.

Table 17: Assessment of energy efficiency and emission reduction of terminal equipment

Reduction measure	Explanation	Savings	Source
Ship-to-shore cranes and mobile harbour cranes			
Hybrid drive, often in combination with energy recuperation	On-board diesel generator provides electricity for the crane; energy recuperation technology stores the excess energy generated during a cargo-handling cycle and feeds it back during following operations	20-30% fuel 30% CO_2 emissions Less noise	Terex Gottwald, Sennebogen, Liebherr
Purely electric drive, often in combination with energy recuperation	Crane is supplied with electricity from the quayside	100% emissions (locally on the terminal)	
Eco-drive program	Optimized engine settings, automatic stop function etc.	25% fuel 50% NO_x 90% PM 4,5 dB	Sennebogen

Reduction measure	Explanation	Savings	Source
Terminal tractor, AGV and Lift-AGV (Horizontal Transport)			
LNG-powered vehicles		16% CO_2 Almost 100% NO_x and PM Less noise than diesel engine	GreenCranes Pilot Valencia
CNG-powered vehicles	Not feasible due to the following limitations: Large tank needed, problems with engine starts and stops, reduction of engine power which introduced operational limitations when transporting heavy containers		GreenCranes
Battery-operated vehicles		100% emissions (locally on the terminal)	Konecranes, HHLA CTA
Eco-drive program	Optimized engine settings, automatic stop function etc.	Up to 20% fuel reduced operating costs emissions and noise	MAFI
Reach stackers and forklifts			
Dual fuel technology	Upgrading the diesel engine with an additional LNG fuel injector (only small changes required); The LNG comes from an additional tank	Less CO_2, CO, HC, NO_X and PM	GreenCranes Pilot Livorno
Automatic stop function	Automatically activating and deactivating the engine	Up tp 10% fuel	Kalmar
Eco-drive program	Three different driving modes, differentiating between performance and profitability	Up to 20% fuel	Kalmar

8.4.3.1 Operations

Reduction measures focusing on terminal operations aim to avoid unnecessary cargo handling operations and to use the equipment most efficiently. Examples are to minimize re-stacking operations, minimize empty travels and to handle as much cargo as possible at the same time.

8.4.3.2 Behavior

The energy consumption of terminal equipment depends to a certain share on the skills of the equipment operator. Therefore, training the operators how to use the equipment efficiently can reduce fuel consumption by up to 30% (Source: Kalmar).

8.4.3.3 Terminal Related Reduction Measures

Terminal-related reduction measures aim, for example, at the terminal lighting. Installing LED lights or implementing intelligent light management (switching light off if it is not needed) can save up to 50% electricity.

9 Recommendations for Innovative Multi-Purpose Terminal Development – 'Tool-Box'

This chapter aims at combining the steps for a successful design process of multi-purpose terminals with the previously described challenges arising from global trends and technological progress that entail many additional chances and risks regarding the future development of multi-purpose terminals. The result is a so called 'Tool-Box' for the strategic development of innovative and future-oriented multi-purpose terminals. This Tool-Box is illustrated in Figure 23.

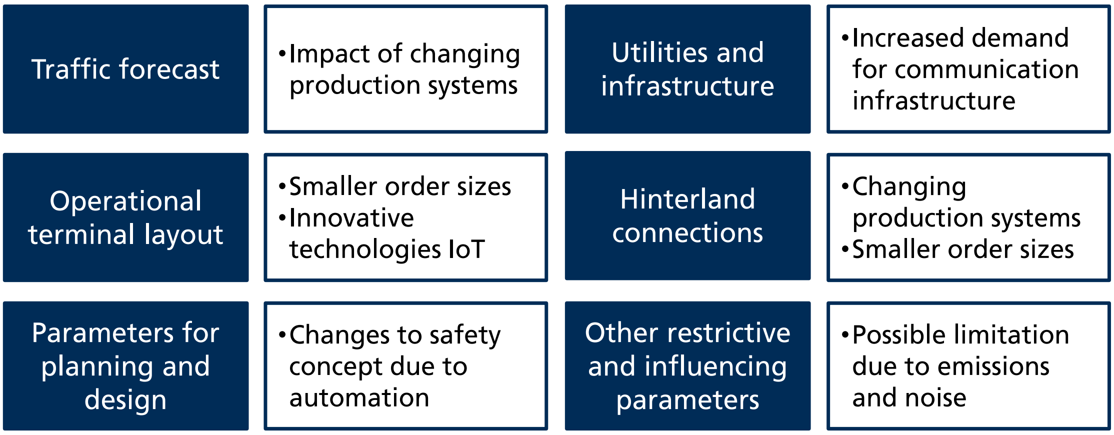


Figure 23: Contents that need to be considered for the development of innovative multi-purpose terminals

As can be derived from the figure above the 'Tool-Box' takes the activities already carried out during the planning process of Multi-Purpose Terminals as a base (chapter 3) and adds contents resulting from the identified major global trends (chapter 6) and technological innovations (chapter 8.1) enabled by the megatrend digitalization.

The following sections aim at adding to the usual terminal planning routines the awareness of possible future challenges and limitations that stem from major global trends such as the environmental protection, a sound port-city relationship that becomes more and more important for terminals being close to housing areas as well as todays and tomorrows available technologies in maritime logistics. The 'Tool-Box' is applicable to all types of port terminals.

Recommendation 1: To take into account global trends when preparing the traffic forecast

For the development of innovative multi-purpose terminals the traffic forecast needs to take into account all major developments that have an impact on global trade flows and affect the volumes that need to be handled at seaports. To get a picture of the market dynamics the transport demand forecast has to take into account different scenarios of economic development but also of the likelihood of

- Changes in logistical patterns such as smaller shipment sizes, changes of transport modes, routes and changes in the shares between import and export cargo or changes in commodities being shipped; and
- New services offered by the terminal, e.g. 3D printed spare parts.

The different scenarios should take into account these possible distortions. In order to be able to cope with such distortions the multi-purpose terminal planning should ensure maximum flexibility of the planned infrastructure and envisaged equipment coping with possible distortions.

Recommendation 2: To take into account flexibility requirements and necessary IT installations when planning the operational terminal layout in order to enable multi-purpose terminals to implement digital innovations

The innovative terminal layout should be based on the results of the scenarios of the traffic forecast ensuring maximum flexibility and modularity of the operational areas, buildings and installations of the terminal. The terminal's individual framework conditions regarding the impact of urbanization and the overall need for sustainable port operations must be taken into account. An option would be that the layout of innovative multi-purpose terminals includes areas for regenerative energy production such as solar panels and wind turbines. In contrast to the contents already described in chapter 3 special focus needs to be on flexibility. Thus, the terminal layout needs to allow a maximum flexibility regarding the commodities that need to be handled and also regarding the storage of these commodities. Steps include:

- Identification of cargo handling needs for the terminal
- Cargo mix and flexibility of cargo mix
- Cluster commodities with regard to their logistical requirements
- Definition of design vessels per commodity group
- Definition of storage types per commodity group, resulting in storage capacities, required auxiliary handling areas and port internal traffic ways
- Estimation of required berth capacity per commodity group and service type, incl. assessment of resulting berth utilization per commodity and service type and assessment of options for optimized combined berth utilization
- Identification of berthing needs from auxiliary services and activities (piloting, tug services)

For the different commodities and services, necessary cargo handling equipment requirements have to be determined. This handling equipment has to be chosen taken into account the necessities arriving from the demand for sustainable port operations. This includes the choice of equipment that features the use of alternative fuels or electric energy instead of diesel engines. Furthermore, equipment can be considered and later purchased that uses energy harvesting technologies.

To put multi-purpose terminals into the position to implement innovative digital solutions the layout needs to include necessary IT installations for Internet of Things (IoT) applications. This means that the planning should include IT buildings, server rooms and LAN and WLAN installations, enabling the terminal to offer possibilities to use digitalization in maritime logistics as a competitive advantage to its customers.

Recommendation 3: To pursue flexibility targets when determining the parameters for the planning and design of innovative multi-purpose terminals

Also for this stage, a maximum approach towards flexibility and modularity should be aimed at. Furthermore, the increased availability of automated equipment requires different safety concepts regarding e.g. terminal areas that cannot be worked on.

Recommendation 4: To include the planning of IT and energy production capacities in the design of utilities and infrastructure

The design of the utilities for water supply, sewage, firefighting water, power supply, and lighting has to include the planning of IT capacities in terms of building space but also in terms of cables, hubs and switches on-site of the terminal. It is rather likely that the market will demand a full coverage of the terminal area with a wireless communication network in order to operate the smart objects being part of the coming Internet of Things logistics operations. Thus, the planning of appropriate IT infrastructure should become a fixed step in planning an innovative multi-purpose terminal. The planning of the infrastructure at the gate should e.g. entail the planning of automated, fast and reliable gate processes for trucks entering the terminal.

It should also not be neglected that the balance towards sustainable operation improves if opportunities to generate renewable energy are deployed on the terminal area. This includes solar panels and wind turbines, which become more reliable and cheaper ever since, while the costs for electric energy produced outside the terminal rises in most regions of the world. The return on investment may consist both of the saved costs for energy and the competitive advantage of sustainable operations.

Recommendation 5: To include urban planning interests and flexibility aspects when defining hinterland connections

Hinterland connections mean on the one hand the hinterland infrastructures outside the terminal and on the other hand the interfaces of the terminal area with hinterland transportation networks. On the one hand the hinterland connections of innovative multi-purpose terminals need to be compatible with urban planning interests. Urbanization can result in increased mobility needs of the population, meaning less available capacity on e.g. the road network linking the terminal to the hinterland. This effect should be included in the forecast and assessment. It may result in requirements for additional road capacity or in a strengthening of other transport modes such as rail. On the other hand, the interfaces should be as flexible as possible, meaning that their access roads should be modular. Depending on the cargo handled the route guidance should be modifiable.

Recommendation 6: To include qualified estimations about restrictions arising from operational conditions

In addition to restrictive issues like the depth and dimensions of the navigation channel, the port basin and the turning area, the terminal planning should also include qualified estimations about restrictions arising from operational conditions. This includes limits to operations in terms of gas and PM emissions caused by terminal operations and limits to operation because of noise if the terminal is close to housing areas.

10 Summary

The study aimed at providing recommendations for the improvement of multi-purpose terminals. The question to be answered was which attributes innovative multi-purpose terminals should have to be able to master the challenges arising from today's major global trends. The work was carried out in two steps: Firstly, the current situation was analyzed regarding the planning of multi-purpose terminals, their characteristics and determining framework conditions. In a second step innovative multi-purpose terminal concepts and a methodology for the planning of innovative multi-purpose terminals (Tool-Box) were developed. The main results of the study are listed below:

Results of step 1: Analysis of current situation regarding the planning of multi-purpose terminals, their characteristics and determining framework conditions

There is no methodology dedicated for the planning of multi-purpose terminals only. The planning process of multi-purpose terminals includes the same steps that are also included in the planning process of other port terminals. These steps are:

1. Preparation of traffic forecast
2. Planning of operational terminal layout
3. Determination of parameters for planning and design
4. Design of utilities and infrastructure
5. Definition of hinterland connections
6. Consideration of other restrictive and influencing parameters

However, due to the specific characteristics of multi-purpose terminals, the individual steps may be more complex compared to the same steps for other port terminals such as container terminals. A multi-purpose terminal is defined as a "complex of infrastructure, equipment and services which offers a combined and flexible response to the servicing demand of certain types of vessels and cargo"[110]. In contrast to other port terminals that are more or less specialized to the handling of one loading unit only, multi-purpose terminals need to handle different loading units and commodities. The huge variety of commodities and loading units makes the planning of these terminals more complex. Multi-purpose terminals have to provide non-specialized equipment for ship-to-shore movement as well as hinterland transhipment, storage and horizontal transport or different types of specialized equipment, non-specialized berths or different specialized berths, and non-specialized terminal areas or different terminal areas with a specialized function.

For the definition of a typical multi-purpose terminal layout concept different multi-purpose terminals have been analyzed and compared to each other in a structured way:

- C. Steinweg (Süd-West Terminal), Hamburg, Germany
- Rhenus Cuxport, Hamburg, Germany
- General Cargo Terminal, Chittagong, Bangladesh
- Baku International Sea Port, Alat, Azerbaijan
- Port Louis Terminal I and Terminal II, Port Louis, Mauritius
- Caioporto, Cabinda, Angola

[110] UNCTAD (1991), p. 2

Although all terminals can be described using indicators like the total terminal area, the annual throughput, the built-up area, the used equipment or the cargo mix, a meaningful comparison of all analyzed multi-purpose terminals is not possible. Multi-purpose terminals are as diverse as the cargo handled on it. There is no such thing like an optimal layout for all multi-purpose terminals. Instead, the layout of a multi-purpose terminal depends on the type and volume of cargo that needs to be handled.

In order to develop recommendations for innovative multi-purpose terminal concepts, parameters needed to be identified that determine the requirements that innovative multi-purpose terminals need to fulfill to remain competitive. Determining framework conditions considered in this study are resulting from the following global trends: (1) Globalization; (2) Demographic change; (3) Urbanization; (4) Sustainability; and (5) Digitalization. Challenges arising from these trends affect the competitiveness of multi-purpose terminals and impose higher standards on multi-purpose terminals. An example for this are changing production systems or an increased customization down to lot size one that have an impact on international trade and with that maritime transport flows. A change in maritime transport flows has a direct impact on the volumes handled in seaports. The global trends of urbanization and sustainability lead to an increasing demand for environmental friendly port operation regarding noise and pollutant emissions or energy consumption. In order to remain competitive innovative multi-purpose terminals need to become more flexible and agile regarding the type, size and amount of cargo handled. Furthermore, a better compatibility with city interests needs to be achieved, meaning that the sustainability of terminal operation needs to be increased.

The megatrend digitalization offers a lot of opportunities. Major benefits from implementing innovative digital solutions are an increasing flexibility (fast adaptation to changing requirements), an increasing robustness (insensitivity towards interruptions and errors during operation), and an increasing efficiency (increased productivity and a more efficient use of resources). Further, implementing innovative digital solutions puts terminal operators into the position to be able to better cope with complexity regarding e.g. the amount of shared information. Nevertheless, the increasing digitalization is a fast evolving trend that may have a negative impact on the competitive position if operators of multi-purpose terminals miss the right moment to participate: On the one hand being an early mover means high risks. On the other hand implementing digital solutions too late may lead to a lack of competitiveness.

Results of step 2: Development of innovative multi-purpose terminal concepts and of a methodology for the planning of innovative multi-purpose terminals

The second step aimed at developing an innovative multi-purpose terminal concept as well as formulating recommendations for the planning of innovative multi-purpose terminals. One of the conclusions from the first step is that digitalization offers huge opportunities for terminal operators to increase their flexibility, robustness and efficiency. Exactly these requirements need to be fulfilled by innovative multi-purpose terminals to remain competitive. Due to this (technological) solutions that are potentially suitable for an implementation at multi-purpose terminals are analyzed. They make use of digital technologies like wireless communication, sensors or actuators and are selected regarding the following focus areas: (1) Traditional tasks of multi-purpose terminals (transport, handling, storage); (2) Digitalization of maritime supply chains and terminals; and (3) Innovative business concepts for multi-purpose terminals. The selected (technological) solutions are listed below:

- Alternative powered equipment,
- Self-driving vehicles,
- Paperless processes, and
- 3D printing.

The mentioned solutions provide answers to the global trends affecting the future development of multi-purpose terminals and are evaluated regarding their suitability for innovative multi-purpose terminals as well as their impact on the necessary increase in terminal utilization and efficiency.

Alternative powered equipment provides an answer to the sustainability requirements concerning multi-purpose terminal operations. Examined technologies are fully electric engines, dual-fuel/hybrid engines and energy harvesting technologies. These technologies are already in operation at other port terminals (especially container terminals) or in other sectors. Dual-fuel/hybrid engines are most suitable for multi-purpose terminals because of the experiences already made in other sectors and on other port terminals. Depending on the vehicle type fully electric engines are partially suitable. The energy harvesting technology is only suitable for small devices. Self-driving vehicles provide an answer to the challenges arising from demographic change. Expected impacts are safer transport processes and a reduction of staff costs and/or the compensation of the lack of specialists in some working areas by automating simple repetitive tasks in other working areas and relocating workers. Nevertheless, automation is only reasonable when the terminal throughput allows an economic automation and when the blocking of complete terminal areas is possible due to safety matters. Expected impacts of paperless processes are reduced check-in and inspection times at terminal gates or reduced port export and import dwell times. The implementation of paperless processes at multi-purpose terminals leads to more efficient and transparent processes and an improved capacity utilization. The last technology, 3D printing, could provide an additional business for multi-purpose terminals, but only to a limited extent. The market is quite small today, because 3D printing is only a future technology so far. Furthermore, 3D print centers do not necessarily require a quay wall but can also be located outside the port area.

Based on the identification of suitable (technological) solutions for multi-purpose terminals innovative multi-purpose terminal concepts are developed. Step 1 came to the result that there is no such thing like one concept for all multi-purpose terminals, but concepts for multi-purpose terminals depend on what needs to be handled. Hence, different innovative multi-purpose terminal concepts for different scenarios are developed:

- Scenario 1: Container and break bulk handling at a small multi-purpose terminal
- Scenario 2: Container, break bulk and dry bulk handling at a medium-sized multi-purpose terminal
- Scenario 3: Container and dry bulk handling at a large multi-purpose terminal

The selected (technological) solutions have little impact on the terminal layout, but on its operation. They may just limit the flexibility of a multi-purpose terminal. As an example, the decision to use Rail Mounted Gantry Cranes (RMGs) blocks a terminal area for other equipment types and for utilization possibilities other than container storage. The use of innovative alternative powered equipment has an impact on the terminal's energy efficiency as well as on local emissions. This is not necessarily true for self-driving vehicles compared to manned vehicles.

In order to realize innovative and future-oriented multi-purpose terminals the conclusions and observations made in this project need to be integrated into the activities for the design process of multi-purpose terminals described in step 1. This includes the following recommendations:

1. To take into account global trends when preparing the traffic forecast
2. To take into account flexibility requirements and necessary IT installations when planning the operational terminal layout in order to enable multi-purpose terminals to implement digital innovations and flexibly react to changing framework conditions
3. To pursue flexibility targets when determining the parameters for the planning and design of innovative multi-purpose terminals
4. To include the planning of IT and energy production capacities in the design of utilities and infrastructure
5. To include urban planning interests and flexibility aspects when defining hinterland connections
6. To include qualified estimations about restrictions arising from operational conditions;

Finally, there is no such thing like an innovative multi-purpose terminal layout. In order to become innovative and future-oriented, multi-purpose terminals should make use of technological innovations enabled by the megatrend digitalization to improve their operational performance. Implementing innovative digital solutions such as automation enables multi-purpose terminals to become more flexible, efficient and sustainable and secures the competitiveness of multi-purpose terminals.

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12 Annex

Info Box 5: Technologies facilitating innovations in port operations

Sensors measure physical, chemical or biological quantities like motion, velocity, position, sound, light, gas or chemicals using different techniques. In other words, they are 'fingers of the Internet', whereas cloud computing provides needed storage, processing, and visualization capabilities. The output signal of sensor processing occurs in diverse forms, e.g. as chemical, electrical, magnetic, mechanical, optical or thermal signal. In consequence, the appropriate sensor technology is referred to as chemical, electrical, mechanical sensors etc.[111]

Actuators are devices that convert an input energy like electric, pneumatic, hydraulic, magnetic energy into mechanical energy. The actuator pushes or pulls. It is a component of a machine that requires a control signal, usually provided by sensor technology, and a source of energy (usually electrical energy). When the information is received, the energy is converted into mechanical motion. Thus, an actuator takes care of moving or controlling a mechanism and goes hand in hand with sensor technology. A hydraulic actuator would use hydraulic power to facilitate mechanical motion. Electric, mechanical, electromechanical, thermal or magnetic actors follow the same concept.

Advanced wireless communication technologies are essential to connect smart objects in an IoT environment. Machine-to-machine communication but also human-to-machine communication requires appropriate network access. Important ways of digital signal transmission are present 3rd/4th generation (3G/4G) and future 5th generation (5G) cellular mobile systems. The communication channels base on the Internet and are dependent on technologies such as Wi-Fi standard integrated into smart devices. In intelligent transport systems, communication technologies enable Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication, which are helpful for vehicle flow and capacity management.

Tracking technologies enable constant visibility of vehicle and people locations in order to better control, oversee and manage resources. Tracking vehicle and people movements by location-aware systems employs various means to obtain position estimates, especially:

- Location-specific mobile technologies like Bluetooth,
- Global Positioning System (GPS) based on satellite technology,
- Active badges applying infrared technology, or
- Wireless local area network (WLAN).

[111] McGrath and Scanaill (2014)

Info Box 6: Major players involved in the marine 3D spare part supply chain

3D printing product manufacturers located either at the multi-purpose terminal or nearby; they hold only small safety stocks at their facilities because order series and batch sizes change quickly,

Ship maintenance and repair companies operating a depot with tools at the multi-purpose terminal; they hold the required certifications and customs releases for quick and safe spare part supply,

LSPs (in some cases also the ship maintenance and repair company) located at the multi-purpose terminal offering specialized storage facilities for different types of raw materials; value added logistics services involve packaging, consolidation, grinding, pre-heating, cooling, or cutting or raw materials; raw materials do arrive as container cargo and are shuttled one to several times a day from the container terminal to the facilities of the LSP,

Importers of 3D printing raw materials located in the port hinterland who have agreements with the LSPs or the ship maintenance and repair company on storage, transport and value added services on the raw materials,

3D printing material suppliers distributed around the globe providing photopolymers (resins, waxes), thermoplastic filaments and pallets, thermoplastic powders, and metal powders (steel, stainless steel, copper, titanium, etc.).