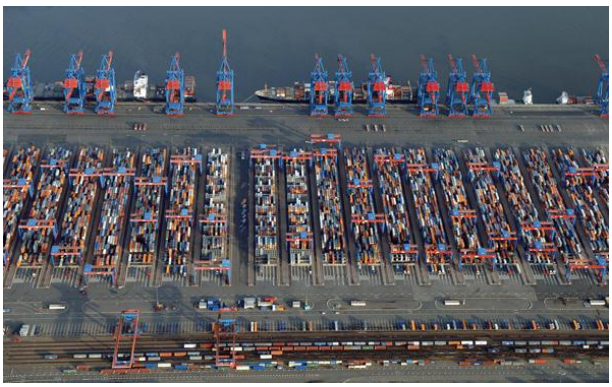
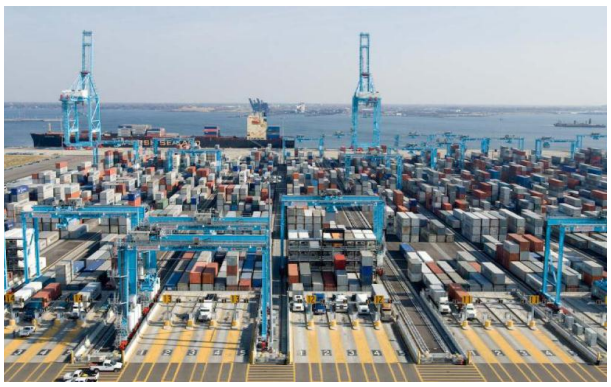
CONTAINER TERMINAL YARD AUTOMATION

A PEMA INFORMATION PAPER





This Information Paper provides a high level overview of adoption trends and the current state of the art in container terminal yard automation worldwide.

The document describes the key equipment and technology components of an automated container terminal yard operation. It outlines the various approaches that have so far been adopted and are presently under consideration around the world. Operational and maintenance issues are reviewed, together with capex and opex benchmarks, plus guidelines on implementation and delivery lead times. Existing and planned installations worldwide are listed, with details of the yard automation and horizontal quay-yard transfer systems deployed.

While the document touches on the full range of robotic equipment that has been developed for container terminal yard operations, the main focus is on automated stacking cranes (ASCs) as the current prevailing technology.

PEMA
PORT EQUIPMENT MANUFACTURERS ASSOCIATION

Secretariat Office:
3 Pretoria Road, London E4 7HA, UK
Tel: +44 20 8279 9403
info@pema.org

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INTRODUCTION

DOCUMENT PURPOSE

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The document describes the key equipment and technology components of an automated container yard operation. It outlines the various approaches that have so far been adopted and are presently under consideration around the world.

Operational and maintenance issues are reviewed, together with capex and opex benchmarks, plus guidelines on implementation and delivery lead times. Existing and planned installations worldwide are listed, with details of the yard automation and horizontal quay-yard transfer system deployed.

While the document touches on the full range of robotic equipment that has so far been developed for container terminal yard operations, the main focus is on automated stacking cranes (ASCs) as the current prevailing technology.

DEFINITIONS AND TERMINOLOGY

There is a broad set of terminology and acronyms used to describe technologies, applications and processes in relation to the unmanned operation of container terminal yards. A lexicon is provided in Appendix 2.

ABOUT THIS DOCUMENT

This document is one of a series of Information Papers developed by the Technology Committee (TC) of the Port Equipment Manufacturers Association (PEMA). The series is designed to inform those involved in port and terminal operations about the design and application of software, hardware, systems, automation and other advanced technologies to help increase operational efficiency, improve safety and security, and drive environmental conservancy.

This document does not constitute professional advice, nor is it an exhaustive summary of the information available on the subject matter to which it refers.

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1 | EXECUTIVE SUMMARY

From an initially slow start, automation in container terminal yard operations has now taken off. More than 500 driverless cranes are in operation worldwide today in container yards and these are fast becoming a standard product.

Horizontal transport between the quayside and the yard storage blocks has not yet reached the same level of automation maturity. In many cases, automated yards are served by manned horizontal transfer vehicles. The challenges that this poses are among the topics discussed in this Information Paper.

However, automated guided vehicles (AGVs) have been deployed and proven for horizontal transport at a number of facilities and new automated shuttle carrier (AShC) technology will be adopted in the near future.

In the 19 years since the opening of the very first automated facility (ECT Delta, Rotterdam, 1993), some 20 automated terminals have been launched around the world. To illustrate the increasing pace and spread of adoption, as of March 2012 more than 10 major new automation projects are being executed around the world, including Asia, Australia, Europe, Middle East and USA.

The main driver for the introduction of automation is to reduce the cost per handled container in the terminal. Improved reliability, predictability and safety of operations, plus reduced environmental impact, are also key factors. The deployment of automated stacking cranes (ASCs) additionally results in better land utilisation. This factor is becoming more and more important since coastal port land is typically expensive and in demand for purposes other than container handling.

Critical success factors for introduction of yard automation in a container terminal may be summarised as:

- Adapt the design to the prevailing conditions (labour costs etc.)
- Take a reasonable step forward – a new terminal needs to be at the edge of technology to stay competitive for many years to come
- Avoid taking big steps requiring additional test activities which can cause delays and cost overruns
- Clearly define the operational conditions such as container and vehicle type limitations due to labour conditions etc.
- Adapt the production schedule to the capacity of the mechanical supplier and the method of delivery of the cranes
- Confirm the design and the number of required vehicles and cranes by utilising simulation technology

2 | BACKGROUND

2.1 CONTAINER TERMINAL AUTOMATION

The development of sensor and navigation technology during the last 20 years has made it possible to physically remove the driver from the container handling machine. The unmanned container handling machine is then completely controlled by a computer or by using a combination of robotic and remotely operated work phases in sequence. The development follows the same pattern seen earlier in warehouse automation, the main difference being that the technology required for outdoor conditions has proven to be vastly more demanding.

The financial drivers of this development are related to both efficiency and economics. A robotised work sequence is more predictable, without human errors. Remotely operated container handling machines also make it possible for one operator to control and supervise a large number of vehicles. In the extreme case, 100% of the work cycle has been robotised and the role of the operator is supervision and to handle exceptional situations.

2.2 HISTORY

The first significant automation with unmanned container handling machines was realised in Rotterdam ECT Delta Terminal 1993. This installation operates with automated unmanned RMGs (ARMGs) and unmanned platform-AGVs.

The next similar installation was HHLA's CTA facility in Hamburg in 2002. Thus, the adoption of unmanned technologies was not rapid in the beginning, but since then development has accelerated.

Today, while there is one live automated straddle carrier yard operation in Australia, plus an automated RTG operation in Japan, automated RMGs, more commonly known as automated stacking cranes (ASCs) have emerged as the norm.

2.3 EXISTING AND PLANNED INSTALLATIONS

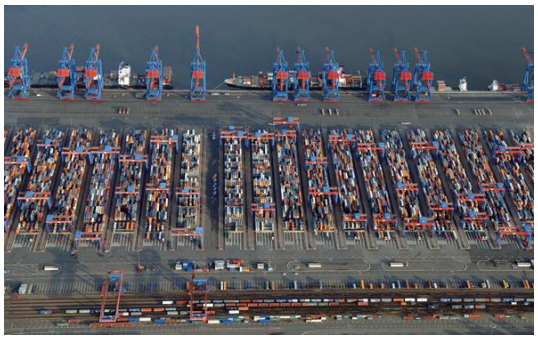
As of early 2012, there were more than 500 automated stacking cranes (ASCs) in operation in Asia, Europe and US, handling >20 million TEU per annum. The global ASC fleet has so far notched up more than 10 million operating hours.

Introduction of ASCs is planned in the Middle East and Australia in the near future and additional projects are under development in the USA.

Today, yard blocks using ASCs are being served by AGVs, road trucks, internal transport vehicles (ITVs), straddle carriers (SCs) and shuttle carriers (ShCs). The choice of equipment deployed to serve the stacks is determined by a number of factors, such as required investments, labour costs, technical capabilities etc.

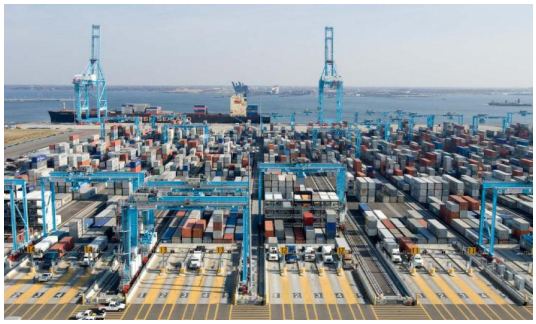
A number of advanced new concepts are presently being studied and simulated around the world. For instance, in addition to AGVs, the first order has recently been announced in the USA for unmanned shuttle carriers to move containers between the quay cranes and ASC blocks.

Remote and automated operation of quay cranes is also under development, with a first pilot installation at Manzanillo International Terminals in Panama. Additionally, technology to enable the automatic handling of twistlocks is now being introduced.



Container Terminal Altenwerder (CTA)

Location:	Hamburg, Germany
Operator:	HHLA
Year:	2002
Equipment:	52 ASCs, H 1over 4/5,10 wide, 74 AGVs, on-dock rail
Layout:	26 blocks perpendicular to quay, 37 TEU long, two ASCs per block which can pass each other (separate rail tracks)



APM Terminals Virginia

Location:	Portsmouth, Virginia, USA
Operator:	Virginia International Terminals Inc (VIT)
Year:	2007
Equipment:	30 ASCs, H over 1/5,8 wide, 20 manned ShCs
Layout:	15 blocks perpendicular to quay, 60 TEU long, two ASCs on same rail track

Hanjin Busan

Location:	Busan, South Korea
Operator:	Hanjin Newport Co
Year:	2008
Equipment:	42 automated ASCs with twin cantilevers, H 1/6,10 wide
Layout:	21 blocks parallel to quay, 52 TEU long

2.4 MODE SPLIT

The operational range of the facilities that have so far adopted container yard automation is wide, ranging from the APMT facility in Virginia, USA with 100% import/export cargo to the TTI Algeciras site in southern Spain, which has around 95% transhipment cargo

Since containers are not moved all the way from the quay cranes to the gate in a transhipment operation, this will affect the optimal selection of the layout. A large transhipment ratio was for example one of the factors for selecting parallel layout and cantilever-ASCs for the Hanjin terminal in South Korea. A larger interchange area is required compared to an end-loading arrangement.

On-dock rail is also installed in a number of automated terminals, especially in Europe. This includes the CTA and CTB facilities operated by HHLA in Hamburg, Germany and ECT's Euromax site in Rotterdam, Netherlands. The range of containers transported by rail in these facilities is 30- 50% and increasing. Rail wagons are typically handled with separate manually operated RMGs and the containers are then transported to ASCs.

3 | LAYOUT, CRANE DESIGN AND BASIC TECHNOLOGY

3.1 LAYOUT

Basically two types of layouts exist today:

- End-loading ASCs (E-ASC) with blocks located perpendicular to the quay, as seen in Algeciras, Antwerp, Hamburg, Rotterdam and Portsmouth/Virginia

- Side-loading cantilever ASCs (C-ASC) with blocks laid out parallel to the quay, as seen in Busan, Kaohsiung and Taipei

The parallel block layout with C-ASCs has so far been favoured in Asia, while the perpendicular design with E-ASC has been largely preferred in Europe.

The basic operational differences between the two layouts are as follows:

- The E-ASC design separates waterside (WS) and landside (LS) operations and thereby enables the use of automated vehicles on the WS

- The end loading E-ASC design more or less fixes the handling capacity at either end, and provides less flexibility to handle peaks at one side. The exceptions to this rule are the CTA and CTB terminals in Hamburg, Germany which both have “passing” ASCs, where a smaller ASC can pass underneath a larger ASC in the same stack. However, this design requires more yard area. The side-loading C-ASC design allows capacity to be deployed more flexibly to either side, increasing peak production.

- The end-loading design has clearly marked interchange areas, as such improving the safety of operations.

- In the end-loading design, there is no traffic inside the yard, reducing lighting requirements, and improving safety.

- The side-loading design is insensitive to changes in the nature of the cargo flow. If the balance between transhipment and origin-destination (gateway) cargo alters, the yard cranes can be deployed differently. By contrast, the end-loading design is more efficient in facilities with a transhipment ratio below 65%. Beyond that, the landside end typically becomes underutilised.

A combination of these two designs has been employed in Thamesport, UK and is presently being planned for a couple of greenfield terminals.

The following values are typical for land requirements (TEU/ha) in the container yard:

Yard equipment type	Horizontal transfer method	TEU/ha
E-ASC (1 over 5)	ShC	1400
C – ASC (1 over 5)	ITV	1350
E-ASC (1 over 5)	AGV	1250
RTG (1 over 5)	ITV	1100
Straddle carrier (1 over 3)	n/a	700

These numbers include access roads and the area between quay and blocks.

3.2 ASC DESIGN AND BASIC TECHNOLOGY

ASCs run on rail tracks, fixed either to sleepers in a bed of gravel or to a concrete/steel bridge structure supported by pilings. Crane sizing is a trade-off between handling and storage capacity. End-loaded ASCs usually span 8-10 containers wide. Side-loaded ASCs are generally 10-12 containers wide. The most common storage height for both designs is usually 5 containers high with one container passing over (1 over 5).

The distance between containers in the block ranges from 350-500 mm.

Since ASCs are not equipped with a cabin, or driver, a number of systems are required to execute the tasks normally performed by the driver. These include:

- Starting/ending a job
- Pick-up/set down of container
- Path control to move from A to B
- Controlling the spreader and container position with cm accuracy
- Avoiding collisions
- Compensating for changing rail conditions
- Handling crane dynamics and deflection

The typical C-ASC design where trucks/ITVs are served under the cantilevers at either side

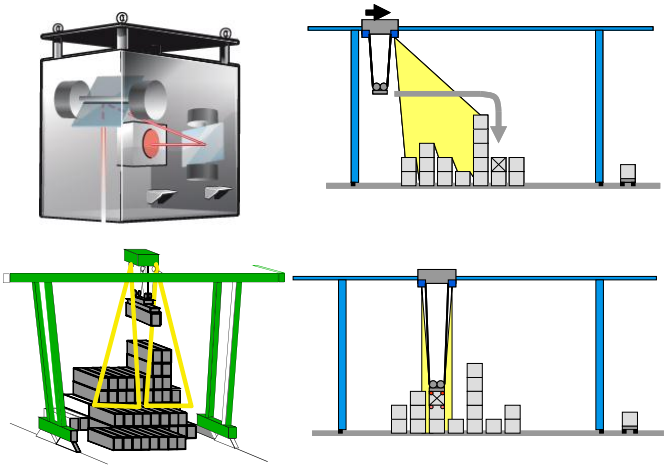
The typical E-ASC design where containers are moved along the gantry direction and transfer vehicles are served at the block ends

For these purposes ASCs are equipped with:

- Sensors based upon laser and/or infrared (IR) technology
- Advanced camera imaging technology
- Powerful process controllers
- Crane management information systems that continuously report the status of the crane

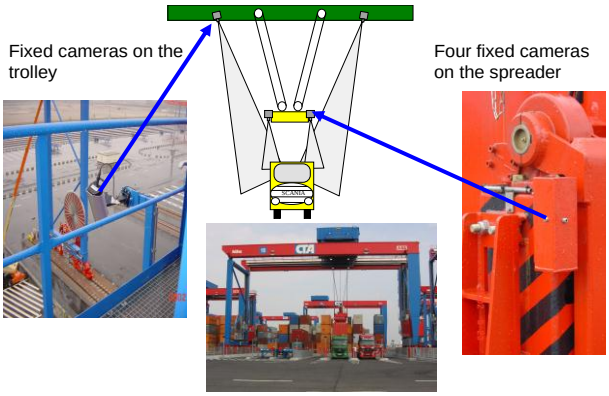
Laser systems can be industrial "off-the-shelf" designs or tailor-made for the application.

A typical laser system for finding the target:



Important systems such as those for crane positioning in manned operations are typically made redundant. All movements are performed automatically, based upon work orders received from the terminal operating system (TOS). This aspect is described in Chapter 8.

When executing moves from/to a manned vehicle such as an ITV or an external street truck, a remote operator performs or supervises the operation when the container is close to the target. For this purpose, every ASC is equipped with TV cameras.



Supervision or operation of the ASC is performed from a remote office:

Aside from the fully robotic, driverless ASCs it is also worth noting that many manually operated rubber tyred gantry cranes (RTGs) are today equipped with various automation systems to assist the driver. These systems include automatic steering, anti-sway, spreader micro-motion, collision avoidance, truck positioning, automatic gantry and trolley positioning, and container position detection systems (PDS).

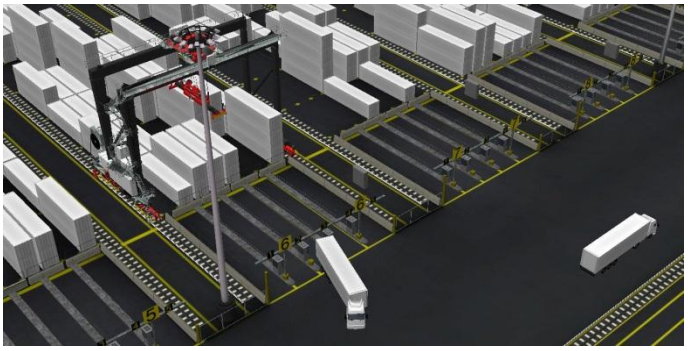
4 | HORIZONTAL TRANSPORT

The horizontal transport system serving ASC container yards consists of two separate logistic loops:

- Landside (LS) transport: moving containers from the terminal truck gate or intermodal railhead to ASCs and vice versa
- Waterside (WS) transport: moving containers from quay cranes (QCs) to ASCs and vice versa

Landside transport is normally handled by external street trucks entering through the gate into the terminal area. Waterside transport is handled by internal terminal vehicles (ITVs), such as terminal tractors/chassis, straddle carriers or AGVs.

Since street trucks entering the terminal are driven by external labour unfamiliar with unmanned cranes, special attention needs to be given to safety in ASC terminals. The safety arrangements are considered simpler for the end-loading ASC layout, since the external trucks only drive to the end of the ASC stacks and the waterside is completely separated. For side-loading ASCs, external trucks drive under the cantilevers of the ASCs and such total separation is not possible. In some terminals, double-cantilevers are used so that the ITVs and the external trucks have separate pathways.



Landside horizontal transport in the end-loading ASC layout

Waterside horizontal transport with shuttle carriers in the end-loading ASC layout

Traditionally, waterside horizontal transport for manually operated yard gantry cranes has been handled by low cost terminal tractors (ITVs). However, these have a number of disadvantages when used in an ASC environment:

- The operation of the ASCs has to be synchronised (coupled) with the arrival of terminal tractors. ASCs cannot place containers directly on ground and move onto the next task, reducing yard productivity.

- Having an unmanned crane loading a container while there is a driver in the terminal tractor cabin may create safety problems.

The advantage of using a straddle carrier for waterside transfer is that the operation cycles of the ASC and QC can be made independent of the horizontal transport system (decoupled). The ASCs, QCs and straddle carriers all place containers directly on the ground and use the interchange areas as “buffer zones” for containers.

The disadvantage of the straddle carrier compared with the terminal tractor is obviously the higher price. Thus a lower and lighter “transport” straddle carrier type has been created for ASC operations. This 1 over 1 straddle carrier type – most commonly known as a shuttle carrier (ShC) – does not stack containers, but only transports them between the QCs and ASCs.

Low profile cassettes on which containers can be loaded are today used in a number of terminals, e.g. in VIT for the transport between the blocks and the on-dock rail. The advantage with the cassette is the de-coupling between vehicle and container resulting in reduced amount of tractors and drivers. The use of cassettes in combination with AGVs is currently being developed and has interesting potential in reducing the number of vehicles required.

1 over 1 “transport” straddle carrier

Since the 1990s, there have been ASC terminals where the waterside transport system is totally robotic, operated by driverless automated guided vehicles (AGVs). Safety risks for drivers have thus been totally eliminated.

Originally, AGVs were all of a “platform”-type design, with containers loaded on top of the AGV platform by another crane (ASC or QC). Using this design, the operation cycles of ASC, QC and AGVs are tied together, or coupled, similar to terminal tractors.

Recently, a "lift-AGV" type of vehicle has been introduced, which is able to place the carried

container on a special rack, and also to pick up containers from such racks. These racks may be placed in the ASC transfer zones, thus de-coupling the operation sequences. However, it is not feasible to use such racks under the QC, since the QCs move while loading/ unloading the ship.

The main technological challenge with all AGVs has been the development of reliable positioning, navigation and perception systems for such unmanned vehicles. Existing and proposed new navigation systems include:

- Transponders buried in the ground and antennas in the bottom of the vehicle
- RTK-GPS satellite positioning
- Local radio-positioning networks
- Laser-based positioning
- Millimeter-wave-radar positioning

More recently, a new concept of fully automated shuttle carrier has also been developed. This concept is considered more challenging, since an unmanned shuttle carrier needs to be able to locate the containers and pick them up. It is estimated that the technology for driverless shuttle carriers will be taken successfully in production before 2015.

Some examples of deployed vehicles are depicted below:

AGVs at Container Terminal Altenwerder, Hamburg

Manned 1 over 1 shuttle carriers in Virginia

Manned terminal tractor in Asia

5 | IDENTIFICATION, LOCATION AND TRAFFIC CONTROL SYSTEMS

5.1 VEHICLE AND CONTAINER IDENTIFICATION SYSTEMS

Optical character recognition (OCR) is used at the QC when loading/unloading containers and also at the terminal gate to automatically identify the container by its unique reference number, eliminating the need for personnel to manually perform this task. Seal status, door direction and container damage can also be checked. Manual intervention is required for exception handling only – when numbers are difficult to interpret.

By equipping a container or a vehicle with a radio frequency identification (RFID) tag, its location can be checked and verified by RFID readers located at strategic spots, e.g. the block transfer zone.

5.2 REAL TIME LOCATING SYSTEMS (RTLS) AND TRAFFIC CONTROL

The most popular real time locating technology is DGPS, which allows the precise location of a vehicle to be pinpointed down to 0.5 m or less. By knowing the location of each vehicle and being able to communicate work orders to the driver, the transport fleet can be used very effectively, minimising travelling distances, empty travelling and waiting time.

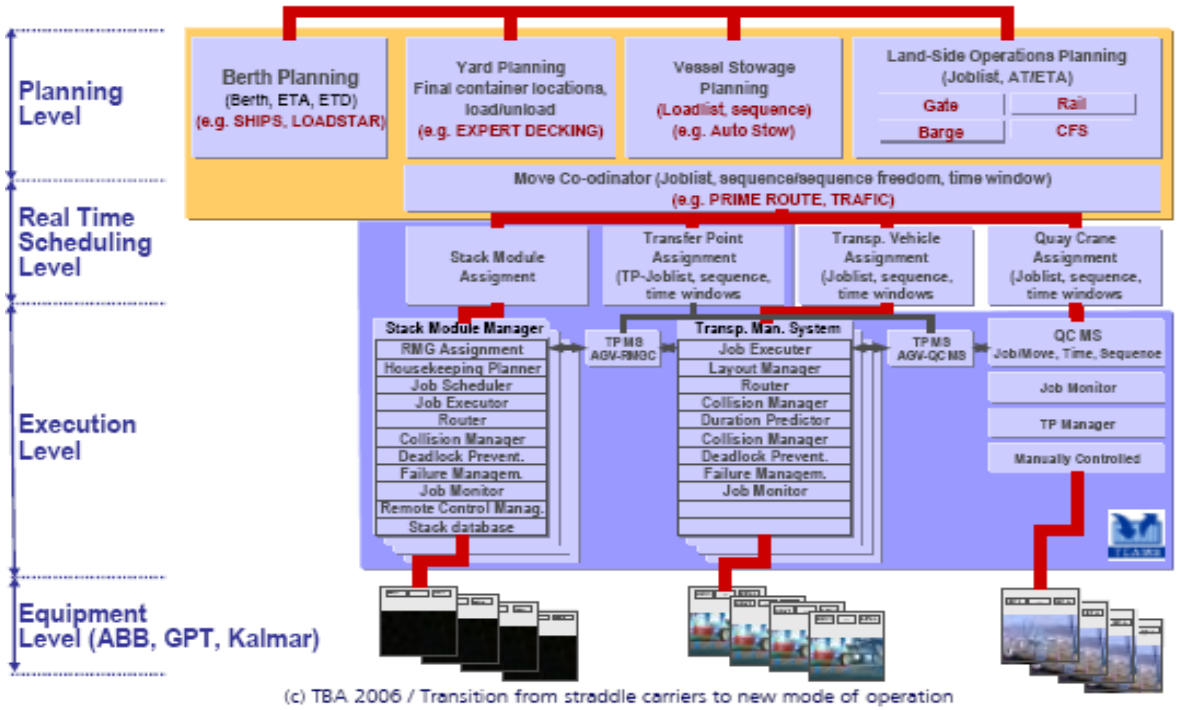
Since the location of the vehicle is known at all times, the risk of the vehicle driver positioning the container at the wrong location is eliminated.

AGVs of course have their own advanced system for the above, which also includes collision avoidance.

6 | TERMINAL OPERATING SYSTEMS

Compared to terminals with manually operated cranes and vehicles, facilities deploying automated handling equipment require a more sophisticated terminal operating system (TOS).

The basic layout can be depicted as follows:



(c) TBA 2006 / Transition from straddle carriers to new mode of operation

The most important additional functionality for the TOS at an automated terminal includes:

- Control of transfer points (occupied, free, claimed)
- Control of container distribution between blocks (to distribute crane workload)
- Control of container positions in the blocks (based upon attribute sets and export/import assignment etc.)
- TOS-ASC communication (submitting work orders, reporting job finished, crane status etc.)
- Submitting work orders for housekeeping and shuffling

For automated (unmanned) cranes the communication between the TOS and ASC typically is as follows:

- Work order submittal and confirmation
- Crane status and location
- Job concluded

Today this is typically managed via access to a shared database between the TOS and ASC.

The following control functions are typically performed at the crane level:

- Receiving, checking and confirming the work-order
- Calculate path
- Control of crane movements
- Collision avoidance (containers, vehicles, obstacles)
- Deadlock prevention

Automated facilities need a more sophisticated approach to equipment control than manned terminals, using a fleet management system (FMS) or terminal logistics system (TLS) to compensate for the loss of local driver intelligence. All decisions that are typically processed by the driver, e.g. route-finding, collision-control, etc. have to be implemented within the central control system. Thus the productivity of the automated system is not only influenced by the hardware, but more and more by the control software.

A useful tool used during the final design stage of the automated terminal is simulation. Simulation is used to verify and validate various operational options, planning solutions and fine tune operational configurations. Simulation can also be used to animate and visualise berth, gate, yard and rail operations.

Simulation is particularly useful when examining the effects of uncertainties in ship arrivals on the yard capacity, the capability of adding an extra services to the terminal, the patterns and rules in the movement of trucks at the gates and inside the terminal, the synchronisation of train schedules with ship schedules, and in general the effects of operational changes in the terminal throughput.

A special kind of simulation, called emulation – a model that accepts the same inputs and produces the same outputs as a given system – will also support the development, testing and optimisation of the strategies within these control systems.

Simulation and lately emulation have been used in almost all the recent automated container terminal projects, such as CTA and CTB in Hamburg, APM Terminal Virginia, Antwerp Gateway, London Gateway, Khalifa Container Terminal and others.

7 | EXCEPTION MANAGEMENT

One of the crucial issues for successful operation of automated container terminals is to have robust procedures and systems in place for managing exceptions.

In an automated factory environment, all materials going into the automation process can be pre-checked and quality-controlled to effectively prevent disturbances and disruptions coming from non-controlled parts being fed into the automated processes.

In today's container terminals, however, there are many potential disturbances and disruptive factors that lie outside the direct control of the terminal operator:

- The quality of arriving containers and/or twist locks cannot be guaranteed
- It may be impossible to automatically identify containers due to illegible ID numbers
- Automated truck identification may suffer from low hit rates for similar reasons
- A truck/chassis appears to be different than expected
- Loading sequence is disrupted – due to vehicle break-down, wrong container weights
- Stowing groups are filled different than planned due to new information

Automated processes in container terminals will therefore have to cope with disturbances and disruptions that cannot be eliminated. The automated process needs a manual decision or intervention. From an automation perspective, any human intervention could be seen as handling of exceptions. This needs to be done as quickly and easily as possible to minimise delay since the process is waiting.

Next to performance of equipment, exception handling will have big impact in the systems overall productivity.

The key to exception handling is a fast detection and understanding of the situation and a swift intervention to get the process moving again. In case of exception handling via remote control stations; it is obvious that exceptions which are easily detected by the operator while having intuitive guiding functions are easily clarified and this will minimise the impact on terminal production.

8 | MAINTENANCE AND OPERATIONS

An automated terminal has a higher fixed cost and a lower variable cost than a manually operated facility. High utilisation is therefore essential for securing the required financial returns. This requires a focus upon preventative maintenance to ensure that equipment is reliably available for service when planned or required.

With the correct preventative maintenance regime in place, automated terminals today are achieving on-demand equipment availability close to or above 99%. Automated operations also substantially reduce wear and tear on equipment such as spreaders compared with manual operations. Consequently, the overall maintenance cost will be lower.

The basic organisation of an automated container terminal operation will be the same regardless of the number of cranes and vehicles used. The main differences compared with manual operations are:

- The lower number of drivers – down to zero for AGVs
- Operations centrally controlled via screens – a more sophisticated control room
- Support for the automatic features – however a lot of this can be done remotely today via VPN-access

9 | CAPEX, OPEX AND PROJECT IMPLEMENTATION

9.1 CAPEX AND OPEX

The main driver for the introduction of automation is to reduce the cost per handled container in the terminal. The deployment of ASCs also results in a better land utilisation – as was shown earlier. This factor is becoming increasingly important since land around ports typically is in demand also for other purposes than container handling.

Automation was originally introduced in countries with high labour costs – Germany and Netherlands. Today, however automation is used in a number of countries with varying costs for labour, electricity, diesel etc.

The design of the automated terminal and the extent of automation of course have to reflect these basic facts.

As is shown in the table going to full automation has a dramatic impact on the productivity per man-year. Similar numbers for manual operations are:

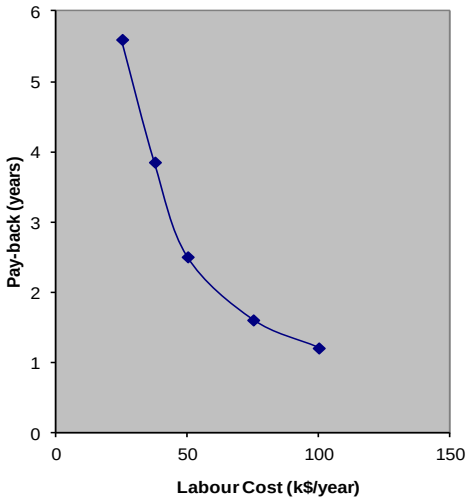
- Straddle carrier operation: 7000 TEU/man year
- RTG operation: 4-5000 TEU/man year

Note that these numbers are based upon technical need – not union manning requirements.

Terminal	Country	Labour cost	Fuel	Electricity	Productivity
		kUSD/manyear	USD/liter diesel	USD/MWh	est'd TEU/manyear for yard operations
CTA/CTB	Germany	100	1.5	75	80,000
Euromax	Netherlands	100	1.5	75	80,000
Antwerp	Begium	100	1.5	75	17,000
Pusan (PNC)	Korea	40	1.2	60	7,000
Pusan (Hanjin)	Korea	40	1.2	60	7,000
Kaohsiung	Taiwan	20	0.8	80	7,000
TPCT	Taiwan	20	0.8	80	7,000
TTI/Algeciras	Spain	100	0.7	100	17,000

Basic numbers

A study performed by ABB in cooperation with TBA comparing electrified manned RTGs and automatic C-ASCs gave as result the following curve:



The curve shows the required pay-back time for the additional investment in crane automation assuming:

- A C-ASC type Hanjin costs 1100 k$/crane more than an electrified RTG
- Two C-ASCs can replace three RTGs due to higher efficiency and speeds
- Minimum manning for both types of cranes based upon the technical need

A large number of similar studies have been made over the years showing that today automation is a viable alternative also for terminals handling < 1 MTEU/year.

However, the barrier towards introducing yard automation typically is the perceived larger risk and investment. As more automated cranes are put into operation it can be expected that this barrier will continue to be reduced.

9.2 PROJECT IMPLEMENTATION

The delivery time for a container terminal yard automation project today is 15-20 months. A summary of projects is shown below:

Project	#	Months	WS
Evergreen/Kaohsiung	6	14	Chassis
TTI/Algeciras	32	16	ShCs
PNC/Busan	31	19	Chassis
CTA/Hamburg	52	22	AGVs
Hanjin/Busan	42	23	Chassis
TPCT/Taipei	20	26	Chassis
APMT/Virginia	30	30	ShCs

The exact time from project launch to full commercial operation depends upon the degree of automation – especially for horizontal transport, where the deployment of AGVs versus manned transport will have a considerable impact – and the time required to integrate these operations and systems. Often the time to commercial operation is also decided by the civil works for the terminal.

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Source material from ABB, Konecranes and TBA.

APPENDIX 1: TABLE OF EXISTING AND PLANNED INSTALLATIONS

EXISTING INSTALLATIONS LISTED BY OPENING DATE (i)

Facility	Location	Country	Operator	Start of operations	Yard storage system	Details	Quay-yard transfer system
Delta Terminal	Rotterdam	Netherlands	Europe Container Terminals (ECT)	1993	ASC	137 x E-ASC	AGV
Pasir Panjang Terminal (PPT)	Singapore	Singapore	PSA International	1997	OHBC	15 x OHBC	Manned tractor + chassis
London Thamesport	Isle of Grain, Kent	UK	Hutchison Ports UK (HPUK)	2000	ASC	18 x C-ASC	Manned tractor + chassis
Container Terminal Altenwerder (CTA)	Hamburg	Germany	HHLA	2002	ASC	52 x E- ASC	AGV
Ohi Terminal	Tokyo	Japan	Wan Hai	2003	ASC	8 x C-ASC	Manned tractor + chassis
Evergreen Marine Terminal	Kaohsiung	Taiwan	Evergreen Marine Corporation	2005	ASC	6 x C-ASC	Manned tractor + chassis
Antwerp Gateway	Antwerp	Belgium	DP World	2007	ASC	14 x E-ASC	Manned ShC
Korea Express Busan Container Terminal (KBCT)	Busan	South Korea	Pusan East Container Terminal Co Ltd (PECT)	2007	ASC	5 x C-ASC	Manned tractor + chassis
APM Terminals Virginia	Portsmouth, VA	USA	Virginia International Terminals (VIT)	2007	ASC	30 x E-ASC	Manned cassette + ShC
Euromax Terminal	Rotterdam	Netherlands	Europe Container Terminals (ECT)	2008	ASC	58 x E-ASC	AGV
Tobishima Container Berth	Nagoya	Japan	Tobishima Container Berth Company (TCB)	2008	Auto RTG	12 x ARTG	AGV
Fishermans Island Terminal	Brisbane	Australia	Patrick Stevedoring	2009	AutoStrad®	23 x AutoStrad®	AutoStrad®
Pusan Newport	Busan	South Korea	Pusan Newport Co Ltd (DP World)	2009	ASC	32 x C-ASC	Manned tractor + chassis

EXISTING INSTALLATIONS LISTED BY OPENING DATE (ii)

Facility	Location	Country	Operator	Start of operations	Yard storage system	Details	Quay-yard transfer system
Hanjin New Port (Busan New Port Phase 2-1)	Busan	South Korea	Hanjin Newport Co Ltd (HJNC)	2009	ASC	41 x C-ASC	Manned tractor + chassis
Taipei Port Container Terminal (TPCT)	Taipei	Taiwan	Taipei Port Container Terminal Corp (Evergreen, Yang Ming, Wan Hai)	2010	ASC	40 x C-ASC	Manned tractor + chassis
Container Terminal Burchardkai (CTB)	Hamburg	Germany	HHLA	2010	ASC	15 x E-ASC	Manned SC
TTI Algeciras	Algeciras	Spain	Total Terminal International Algeciras (Hanjin)	2010	ASC	32 x E-ASC	Manned ShC
Hyundai Pusan New-Port Terminal (HPNT)	Busan	South Korea	Hyundai Merchant Marine (HMM)	2010	ASC	36 x C-ASC	Manned tractor + chassis
Kao Ming Container Terminal	Kaohsiung	Taiwan	Kao Ming Container Terminal Corp (Yang Ming)	2010	ASC	22 x C-ASC	Manned tractor + chassis
Pusan Newport Phase 2-3	Busan	South Korea	Pusan Newport Co Ltd (DP World)	2012	ASC	38 x E-ASC	Manned ShC

Legend		
ASC = automated stacking crane	C-ASC = side-loaded (cantilever) automated stacking crane	E-ASC = end-loaded automated stacking crane
OHBC = overhead bridge crane	SC = straddle carrier	ShC = shuttle carrier (transport straddle carrier)

PLANNED INSTALLATIONS LISTED BY SCHEDULED OPENING DATE

Facility	Location	Country	Operator	Due to open	Yard system	Details	Quay-yard system
Tercat	Barcelona	Spain	Hutchison Port Holdings	2012	E-ASC	36	ShC
Khalifa Container Terminal	Abu Dhabi	Abu Dhabi	AD Terminals (Abu Dhabi Port Company)	2012	E-ASC	30	ShC
Sydney International Container Terminals	Sydney	Australia	Hutchison Port Holdings	2012	E-ASC		
Brisbane Container Terminals	Brisbane	Australia	Hutchison Port Holdings	2012 / 2014	E-ASC	14	ShC
London Gateway	London	UK	DP World	2013	E-ASC	40	ShC
TraPac	Los Angeles	USA	TraPac Inc	2013	E-ASC	20	Auto ShCs
Global Terminal	New Jersey	USA	Global Container Terminals	2013	E-ASC	20	ShC
APM Terminals Maasvlakte II	Rotterdam	Netherlands	APM Terminals	2014	E-ASC	30	AGV
Rotterdam World Gateway	Rotterdam	Netherlands	DP World / New World Alliance / CM CGM	2014	E-ASC	32	AGV
Long Beach Container Terminal	Long Beach	USA	Long Beach Container Terminal Inc	2014	E-ASC	32	Automated
Vado Ligure	Vado	Italy	APM Terminals	2016	E-ASC	26	Manned tractor + chassis
Kaohsiung Intercontinental Terminal (KIT)	Kaohsiung	Taiwan	KMCT - Kao Ming Container Terminal Corp (Evergreen)		E-ASC	40 x dual C-ASC	Manned tractor + chassis
DP World Brisbane	Brisbane	Australia	DP World		E-ASC	14	ShC

Legend		
ASC = automated stacking crane	C-ASC = side-loaded (cantilever) automated stacking crane	E-ASC = end-loaded automated stacking crane
OHBC = overhead bridge crane	SC = straddle carrier	ShC = shuttle carrier (transport straddle carrier)

APPENDIX 2: TERMINOLOGY

AShC	Abbreviation for automated shuttle carrier, a driverless 1-over-1 straddle carrier for horizontal transport of containers between yard and quay
AGV	Abbreviation for automated guided vehicle, a robotic vehicle for horizontal transport of containers between quay and yard
ASC	Abbreviation for automated stacking crane, a driverless rail mounted gantry crane for container yard handling operations
ARMG	Abbreviation for automated rail mounted gantry crane, more commonly known as an ASC (see above)
C-ASC	Abbreviation for side-loading cantilever automated stacking crane, an ASC designed for operation in stacking blocks laid out parallel to the quay
DGPS	Abbreviation for differential global positioning system, a technology for automated identification and tracking
E-ASC	Abbreviation for end-loading automated stacking crane, an ASC designed for operation in blocks laid out perpendicular to the quay
ITV	Abbreviation for internal transport vehicle, a generic term denoting vehicles used for container transport within terminals
OCR	Abbreviation for optical character recognition, a technology for automated identification and tracking
OHBC	Abbreviation for overhead bridge crane
PDS	Abbreviation for position detection system, a system for automatically detecting container and crane location in the yard stacks
QC	Abbreviation for quay crane, also known as ship-to-shore crane, a type of crane for moving containers between ships and terminal berths
RFID	Abbreviation for radio frequency identification, a technology for automated identification and tracking
RTLS	Abbreviation for real time locating system, a solution for determining RFID tag location by triangulation
RMG	Abbreviation for rail mounted gantry crane, a type of container yard handling crane
RTG	Abbreviation for rubber tyred gantry crane, a type of container yard handling crane
ShC	Abbreviation for shuttle carrier, a 1-over-1 straddle carrier designed for horizontal transport of containers between yard and quay
SC	Abbreviation for straddle carrier, a type of equipment for transporting and stacking containers in terminals
TOS	Abbreviation for terminal operating system, specialist software used to plan and manage container terminal operations

ABOUT THE AUTHORS AND PEMA

ABOUT THE AUTHOR

This paper has been prepared by Hans Cederqvist, ABB Crane Systems with contributions from Kari Rintanen, Konecranes, Alois Rechtenwald, Siemens and also ISL Applications, Moffat and Nichol, Navis, TBA and TMEIC.

Hans Cederqvist is responsible for Business Development within ABB Crane Systems and also Vice – Chairman of the Technology Committee within PEMA.

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The Registered Office of the Association is at: p/a EIA, rue d'Arenberg 44, 1000 Brussels, Belgium

The Management and Finance offices of the Association are at: Via Balestra 27, Lugano CH-6900, Switzerland

Administration support is undertaken by the Secretariat at: 3 Pretoria Road, London E4 7HA, United Kingdom.
Tel +44 20 8279 9403
Email info@pema.org

PEMA

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