

Container Terminal Automation

A PEMA Information Paper



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

The paper describes key equipment and technology components of an automated container terminal operation, outlining the various approaches that have already been adopted and those presently under consideration globally.

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

While this paper assesses the full range of robotic equipment developed for container terminal operations, the main focus is on automated stacking cranes (ASCs) as the current prevailing technology.



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INTRODUCTION

DOCUMENT PURPOSE

This Information Paper intends to provide a high level overview of current state-of-the-art container terminal automation worldwide.

The paper describes key equipment and technology components of an automated container terminal operation, outlining the various approaches already adopted and those 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.

Although this paper assesses the full range of robotic equipment developed for container terminal yard operations, the key focus is on Automated Stacking Cranes (ASCs) as the current prevailing technology for robotisation of container yard operations.

DEFINITIONS AND TERMINOLOGY

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

ABOUT THIS DOCUMENT

This document is one of a series of Information Papers developed by the Automation and Control Technologies Committee (ACT) 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, robotics and other advanced technologies to help increase operational efficiency, improve safety and security, and drive environmental conservancy. This, the 2nd edition, updates the first paper published in March 2012.

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1 | EXECUTIVE SUMMARY

Despite a slow start, robotisation of container terminal handling and transport systems is now taking off. More than 1,100 driverless cranes are in operation worldwide today in container yards and are fast becoming a standard product.

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

Automated Guided Vehicles (AGVs) however, have been deployed and proven for horizontal transport at a number of facilities and Automated Shuttle Carrier (AShC) technology is also now being adopted. For instance, automated straddle carrier terminals with driverless straddle carriers, to handle yard storage and horizontal transfer, are in use in Australia.

In the 23 years since the opening of the very first automated facility (ECT Delta, Rotterdam, 1993), some 35 automated terminals have been launched around the world. To illustrate the increasing pace and spread of adoption, since 2012 more than 15 new automated terminals with various levels of automation have been launched around the world.

The main driver for the introduction of automation is to reduce the cost per handled container (cost per move) in the terminal.

Improved reliability, consistency, predictability and safety of operations, plus reduced environmental impact, are also key factors. The deployment of Automated Stacking Cranes (ASCs) additionally results in more economical land use – a factor that is becoming more and more important as coastal port land is typically expensive and in demand for purposes other than container handling.

Critical success factors for the introduction of 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 remain competitive in the future
- 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 using simulation technology
- Introduction of automation is not just a technology implementation project. It is a complete change of most operational processes and practices in the terminal and requires implementation of change management activities with personnel
- Automation deployment requires integration of multiple IT systems. Therefore all vendors in the process need to have the same understanding on how the final solution will work.

2 | BACKGROUND

2.1 CONTAINER TERMINAL AUTOMATION

The development of sensor and navigation technology over the past 25 years has made it possible to physically remove the driver from a container handling machine or transport vehicle. The unmanned container handling machine or vehicle can then be completely controlled by a computer or by using a combination of robotic and remotely operated work phases in sequence. This development follows a similar 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 efficiency and economics. A robotised work sequence is more predictable, without human errors. Remotely operated container handling machines and vehicles also make it possible for one operator to control and supervise a large volume of equipment. In extreme cases, 100% of the work cycle has been robotised and the role of the operator is to supervise and handle exceptional situations.

2.2 HISTORY

The first significant automation with unmanned container handling machines was in Rotterdam, Netherlands at the ECT Delta Terminal in 1993. This installation operates with automated unmanned RMGs (ARMGs) and unmanned Automated Guided Vehicles (AGVs) for horizontal quay-yard container transfers.

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

Today, while there are two automated straddle carrier terminals in operation in Australia, plus some automated RTG operations in use and in planning, automated RMGs, more commonly known as ARMGs continue to dominate the current yard automation landscape.

2.3 EXISTING AND PLANNED INSTALLATIONS

As of mid 2016, there were more than 1,100 ASCs in operation in Asia, Europe, US, Middle East and Australia, handling tens of millions of containers per annum.

Today, yard blocks using ASCs are 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, including 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, unmanned shuttle carriers are used in USA to move containers between the quay cranes and the yard (containing stacking areas managed by ARMGs and Automated Straddle Carriers).

Remote and automated operation of quay cranes are evolving too from a novelty, with first commercial operations in Panama and Rotterdam, to a more standard option as part of major fully-automated operations. In addition technology to enable the automatic handling of twistlocks – one of the biggest hurdles to full automation of vessel handling – is now being introduced.



Lamong Bay Terminal, Indonesia

Location: Surabaya, Indonesia
 Operator: Pelindo III
 Year: 2014/ 2015
 Equipment: 20 ARMGs, H 1 over 5, 9 wide
 Layout: 10 blocks perpendicular to quay, two ARMGs on same rail track



London Gateway, UK

Location: London, UK
 Operator: DP World
 Year: 2013
 Equipment: 40 ARMGs, H 1 over 5, 10 wide
 Layout: 20 blocks perpendicular to quay, two ARMGs on same rail track



Maasvlakte 2 Terminal, The Netherlands

Location: Rotterdam, The Netherlands
 Operator: APM Terminals
 Year: 2015
 Equipment: 48 ARMGs, H 1 over 5, 9 wide
 Layout: 24 blocks perpendicular to quay, two ARMGs on same rail track

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% transshipment cargo.

Since containers are not moved all the way from quay cranes to the gate in a transshipment operation, this affects the optimal selection of the layout. A large transshipment ratio was, for example, one of the factors for selecting quay-parallel layout and cantilever-CARMGs for the Hanjin terminal in South Korea. In this kind of setup all cranes can effectively support both landside and waterside operation, which is not usually possible in a quay-perpendicular ARMG layout. A larger interchange area is required for CARMG-layout compared to an end-loading ARMG arrangement.

On-dock rail is also installed in a number of automated terminals, especially in Europe and the USA where intermodal container traffic is accelerating. This includes the CTA and CTB facilities operated by HHLA in Hamburg, Germany, ECT's Euromax site in Rotterdam, Netherlands and DP World London Gateway terminal, as well as the TraPac and Long Beach Container Terminal (LBCT) facilities in California. The range of containers transported by rail in these facilities can be 30-50% of land-side volume and is increasing. Rail wagons are typically handled with specialised remote-controlled RMGs that span all or most of the rail tracks. Rotating headblocks or trolleys are often used on these cranes. The containers are typically delivered to rail cranes by straddle carriers or tractors. In the case of APM Terminals' Maasvlakte II operation in Rotterdam, rail cranes are fed by the same lift-AGVs used to service quay-yard horizontal transport operations.



3 | CRANE DESIGN AND BASIC TECHNOLOGY

3.1 YARD CRANE DESIGNS

Three types of automated yard cranes and lay-outs exist today:

- End-loaded ARMGs with blocks located perpendicular to the quay
- Side-loaded cantilever CARMGs with blocks laid out parallel to the quay
- Side-loaded automated ARTGs without cantilevers, where the trucks enter the RTG truck lane(s).

The parallel block layout with CARMGs has so far been favoured in Asia, while the perpendicular design with ARMGs has been largely preferred in other areas.

Basic operational differences between the approaches are as follows:

- An end-loaded design separates waterside (WS) and landside (LS) operations enabling the use of automated vehicles on the WS.
- An end-loaded design tends to fix the handling capacity at either end, and provides less flexibility to handle peaks at one side. Exceptions to this are the CTA and CTB terminals in Hamburg, Germany which both have “passing” ARMGs (where a smaller ARMG can pass underneath a larger ARMG in the same stack). However, this design requires more space, having therefore lower capacity of the yard. A side-loading

CARMG design allows capacity to be deployed more flexibly to WS/LS side, increasing peak production.

- An end-loaded design has clearly marked interchange areas, improving the safety of operations.
- In an end-loaded design, there is no traffic inside the yard, reducing lighting requirements, and improving safety.
- A side-loaded design is insensitive to changes in the nature of the cargo flow. If the balance between transshipment and origin-destination (gateway) cargo alters, the yard cranes can be deployed differently. By contrast, an end-loading design is more efficient in facilities with a transshipment ratio below 65%. Beyond that, the landside end typically becomes underutilised.
- In an ARTG design, vehicles enter the RTG truck lanes, typically through dedicated control gates.

A combination of end-loaded and side-loaded designs has been employed in Thamesport, UK and also in Rotterdam World Gateway (RWG) terminal. The following values are typical for land requirements (TEU/ha) in the container yard.

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

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

3.2 ASC DESIGN AND BASIC TECHNOLOGY

Rail-mounted ARMGs run on rail tracks, fixed either to sleepers in a bed of gravel or to a concrete/steel bridge structure supported by pilings. ARTGs run on normal RTG driveways, which is the main benefit of an ARTG solution as the existing yard infrastructure can be used (e.g. brown-field installations). Compensating terrain variations and inclinations, however, require additional effort for an ARTG.

Crane sizing is a trade-off between handling and storage capacity. End-loading ARMGs usually span 8-10 containers wide, while side-loaded CARMGs are generally 10-14 containers wide. ARTG's span is around 7-9 + truck lanes. 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.

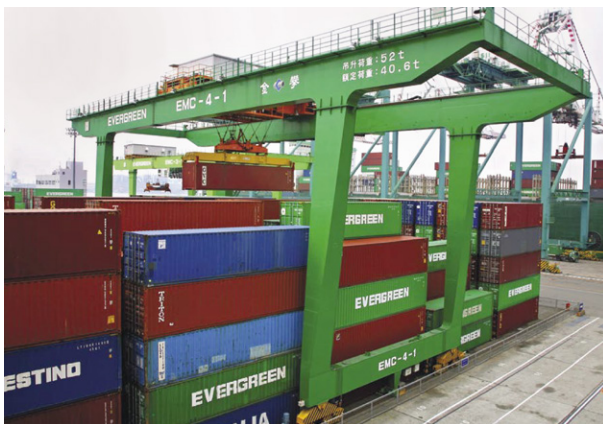


Fig. 1: A typical CARMG design where trucks/ITVs are served under the cantilevers at either side

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:

- 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, dead-lock resolution and evasion moves
- Compensating for changing rail or driveway conditions and inclinations
- Handling crane dynamics and deflection.

For these purposes ASCs are equipped with:

- Sensors based upon laser and/or infrared (IR) technology
- Advanced camera imaging technology
- Navigation sensors (encoders, RF, optical, inertial)
- Powerful process controllers
- Crane management information systems that continuously report the status of the crane.

Sensor systems can be industrial “off-the-shelf” designs or tailor-made for the application. Important systems, such as those for crane positioning in manned operations, are typically made redundant.

Crane movements are performed automatically, based upon work orders received from the Terminal Operating System (TOS). When executing moves from/to a manned vehicle, such as an ITV or an external street truck, a remote operator is often required to perform or supervise the operation when the container is close to the target or is moved over a manned vehicle. For this purpose, the ASCs are equipped with a number of high definition video cameras to provide remote visibility to the operator station.

Fully automated street truck handling (both unloading and loading of the trailers) has already been implemented in some terminals, thereby automating 100% of the work cycle of the ASC. Here the remote operator is only needed for exception handling.

Aside from the fully robotic, driverless ASCs it is also worth noting that today many manually operated rubber tyred gantry cranes (RTGs) are 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). This technical development has also finally enabled the introduction of driverless RTGs.



Fig. 2: A typical ARMG design where containers are moved along the gantry direction and transfer vehicles are served at block ends



Fig. 3: Supervision of operation of the ASC is performed from a remote office

4 | HORIZONTAL TRANSPORT

The horizontal transport system serving fully and semi-automated ASC cranes consists of two separate logistic operations:

- 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.

In addition, Shuttle Carriers (ShC) can also independently handle dedicated storage areas. Also, direct rail transport of containers onto and/or into a container yard is becoming more common, however this is not covered in this paper.

There are important design choices which affect the efficiency and cost structure of a horizontal transport system. They are:

- Synchronized or alternatively, de-coupled operation between horizontal transport system, ASCs and QCs
- Manned or unmanned horizontal transport vehicles.

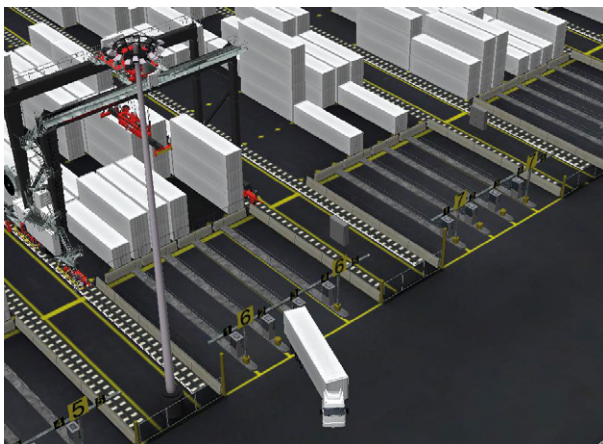


Fig 4: Landside horizontal transport in the end-loading ARMG layout



Fig 5: Waterside horizontal transport with shuttle carriers in the end-loading ARMG layout

4.1 LANDSIDE TRANSPORT

Landside transport, such as external street trucks, will enter the yard via a truck gate, through a check-in area into the terminal zone.

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. Safety arrangements are considered simpler for the so called 'end-loaded' ARMG layouts, since the external trucks only drive to the landside end of the ARMG stacks and the waterside/container yard is completely separated. With side-loading CARMGs, external trucks drive under the cantilevers of the CARMGs and as such it is not possible to separate them from the waterside/container yard. In some terminals, double-cantilevers are used so that Internal Terminal Vehicles (ITVs) and external trucks have separate pathways.

4.2 WATERSIDE TRANSPORT

Waterside transport can be executed using a number of different equipment combinations including traditional tractor/trailer sets or Internal Terminal Vehicles (ITVs), platform-type robotised vehicles (Automated Guided Vehicles – AGVs) or manual/automated straddle-type carriers that lift and move containers from the ground.

Waterside horizontal transport for non-automated gantry cranes was traditionally handled by low cost terminal tractors and trailers. However, these have some disadvantages when used in an ASC environment, for instance:

- The operation of the ASCs has to be synchronised (coupled) with the arrival of terminal tractors. Similar requirement exists with conventional AGVs.
- Having an unmanned crane loading a container while there is a driver in the terminal tractor cabin may create safety problems.



Fig 6: A traditional terminal tractor

ASC cranes have boosted the development of new transport systems that, despite their higher initial investment, may be attractive through their improved productivity and/ or lower usage costs. These new transport systems include AGVs, Shuttle Carriers and self-propelled trailers and platforms.

4.2.1 DE-COUPLED WATERSIDE OPERATION

Waterside operation can be de-coupled by using straddle carriers. Straddle Carriers (SC) were originally developed as a self-contained transport/stacking system for a container port. Using a SC with a gantry crane system for waterside transfer enables the operating cycles of the ASC and QC to be made independent of the horizontal transport (i.e. de-coupled). The ASCs, QCs and SCs all place containers directly on the ground and use the ground interchange areas as “buffer zones” for containers. The advantage of this is higher tolerance for disturbances in the operation and improvement of equipment use.

A lower and lighter “transport” SC has been created for ASC operations. This 1-over-1 SC type – most commonly known as a Shuttle Carrier (ShC) – does not usually stack containers, but transports them between the QCs and ASCs. A disadvantage of ShC is the slightly larger width under the quay crane when compared to terminal tractors.



Fig 7: Elevated rack for “lift” platform vehicle

De-coupling the operation cycles between horizontal transport and ASCs can also be achieved by using 'lifting platform' vehicles. Here special elevated interchange racks are built in ARMG waterside transfer areas. Horizontal transport vehicles and ARMGs are able to independently pick and place containers on the interchange racks, removing the need to synchronize work cycles between the ARMGs and horizontal transport.

Such interchange racks, however, are not practical for de-coupling between horizontal transport and QC cranes (in contrast to ShC), due to the shifting positions of QCs and vessels.

Cassette systems which use cassettes on which containers can be loaded, are also used for de-coupling in a number of terminals, however these are not currently in ASC operation, except for rail interfaces.

4.2.2 UNMANNED HORIZONTAL TRANSPORT

Since the 1990s, ASC terminals, where the waterside transport system is totally robotic, have existed and typically operated by driverless Automated Guided Vehicles (AGVs). As a consequence, Safety risks for drivers have been totally eliminated.

The first AGVs were 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 were coupled – similar to terminal tractors. More recently, a "lift-AGV" (unmanned lifting platform vehicle) has been introduced, which places and picks up container on a special rack, as previously described.

Another unmanned solution is a fully automated Shuttle Carrier (ShC) concept. This vehicle is considered more challenging, since an unmanned shuttle carrier needs to be able to locate the containers and pick them up from ground. However, a fully de-coupled operation is achieved.

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

- Transponders or magnets buried in the ground and antennas in the bottom of the vehicle
- GPS satellite positioning (Real-Time-Kinematic RTK-GPS delivering cm-grade accuracy)
- Local radio-positioning networks and RFID systems
- Laser-based positioning
- Camera-based positioning
- Millimetre-wave-radar positioning.

5 | AUTOMATED QUAY CRANES

5.1 AUTOMATED QUAY CRANES

The influence of yard crane automation concepts is clearly visible in today's modern quay crane designs. Much like ASCs, when automation is introduced into quay crane operation, the cranes can be remotely operated and the driver's cabin is no longer needed. To achieve this, a number of systems are required to execute the tasks normally performed by the driver.

These include:

- Pick-up/set down of containers on platforms, quay and vehicles
- Path control/optimum path
- Controlling the sway and skew
- Crane to crane or crane to ship anti-collision.

As with automated yard cranes, quay cranes for automated terminals are now equipped with:

- Sensors based upon laser and/or infrared (IR) technology
- Advanced camera imaging technology to read container numbers (OCR)
- Crane management information systems that continuously report the status of the crane.

As with yard cranes, certain portions of crane movements are performed automatically, based on work orders received from the TOS. However the operator is generally required to handle part of the cycle over the ship, below the pre-defined height, manually via remote control.

5.2 REMOTE QUAY CRANE OPERATION

With automation most of the crane cycle is handled robotically and the remote crane operator's main task is to supervise the process and take action only when required. Having no driver onboard opens up the possibility for the quay crane to run faster and ramp times and cycle times can become shorter.

Operators located in a control room supervise the crane motion via onboard cameras and the remote control station. This is very useful in instances of taller STS cranes where vision is limited due to the physical distance between the cabin and the target. With access to information provided by the automation system, intelligent guided camera views, including zooming functionality, help to improve the overall operator performance.

Remote crane operation enables human separation from large machines and dangerous and harsh working environments to an ergonomic control room. One remote desk can operate several cranes.

However controlling a crane remotely also has its own growing demands when it comes to safety. The latency times on video signals need to be monitored during operation and emergency stop functionality requires special attention especially when pooling functionality.



Fig 8: Remote controlled quay cranes



Fig 9: Remote control station of quay crane

6 | IDENTIFICATION, LOCATION AND TRAFFIC CONTROL SYSTEMS

6.1 VEHICLE AND CONTAINER IDENTIFICATION SYSTEMS

Optical character recognition (OCR) is used at the QC when loading/unloading containers, at CARMGs and also at the terminal gate to automatically identify a container by its unique reference number. This eliminates 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 or when the container being handled is rejected by the TOS.

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.

The rapid development of “Internet of Things” (IoT) technology will also bring new tracking capabilities to the market, based for example on fifth generation cellular communication technology, new low-power radio technologies and battery-operated tags.

6.2 REAL TIME LOCATING SYSTEMS AND TRAFFIC CONTROL

Once correctly identified containers move into the container yard where their exact location must be maintained. There are multiple means of achieving this task. Most systems, which perform these functions, starting from the exchange or ‘handoff’ point at the land or waterside interface point, use real-time location sensor systems integrated into the ASCs themselves. Waterside transport systems are often equipped with a host of tracking and tracing technology to ensure no unit is ‘lost’ en route to the yard. By knowing the location of each vehicle and being able to communicate work orders to the unit (or 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.

Automated horizontal transport vehicles of course have their own advanced system for the above, which also includes collision avoidance.

7 | TERMINAL OPERATING SYSTEMS

Terminal Operating System (TOS) software controls the logistics of a terminal, including key functions such as vessel planning, container inventory maintenance, job order creation and gate operations. TOS software is provided by several commercial companies and many terminal operators themselves.

In a modern container terminal, some Container Handling Equipment (CHE) may be unmanned and operated by a computer and navigation system while part of them may be manually operated. There is little difference between these modes for TOS itself, however, where there is, it usually occurs where drivers improvise container moves as computers don't. To enable efficient exception handling, the software should be able to handle most common exceptions automatically.

7.1 TOS AND ECS (EQUIPMENT CONTROL SYSTEM)

A group of automated vehicles may share a common software control module at equipment level, often referred to as the "Equipment Control System" (ECS),

handling for example safety features and intra-vehicle coordination. Typically, automated vehicles operating on the same tracks or pathways, such as ASCs, are coordinated by such software. An ECS is defined here as the software that monitors and controls all events and processes at equipment level, either for a single CHE or group of CHE. When it comes to coordinating interactions between different types of automated equipment, an ECS is now an essential part of the terminal software landscape.

Driverless operation also requires some dedicated software to implement all the actions and decisions previously executed by a driver (such as navigation, traffic rules and deadlock resolution). This is another motivation for a layer of additional functionality (ECS) between the CHE on-board control software system (e.g. PLC) and the TOS software.

Figure 10 illustrates the concept of TOS and ECS. Due to the number of system providers and developers, there are of course differences between the functionalities of different TOS software.

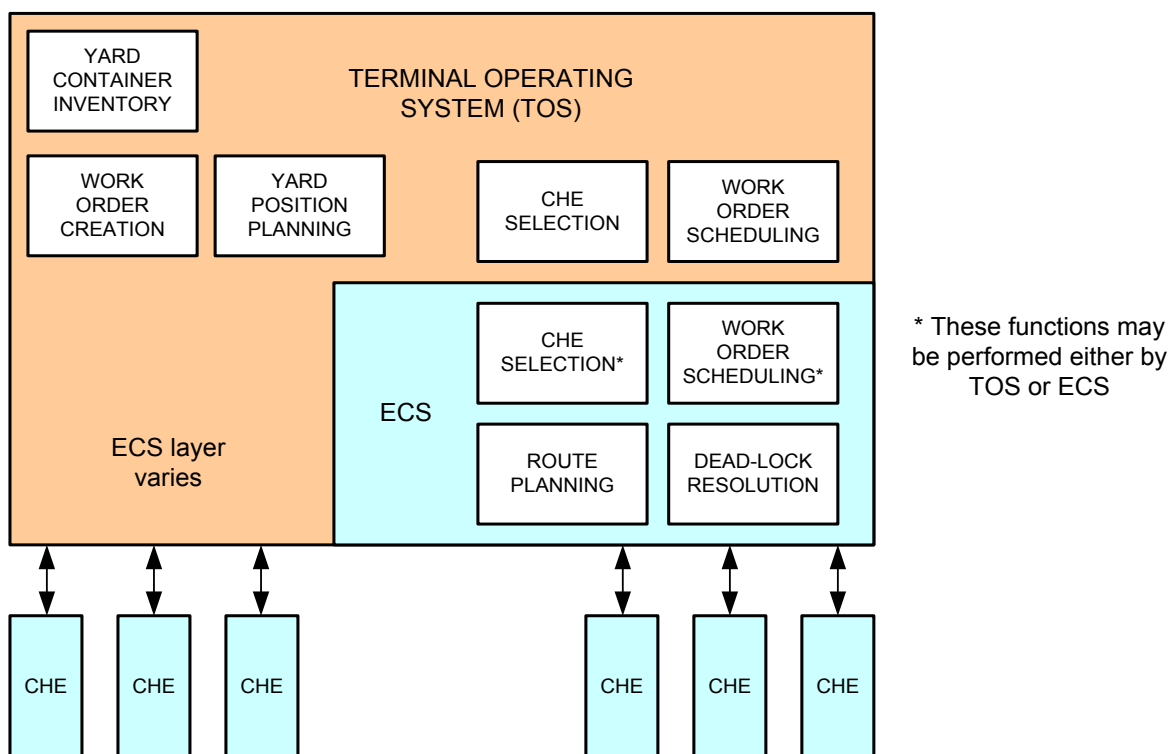


Fig 10: Terminal operating system (TOS) and Equipment Control System (ECS)

Basically, TOS has two main functions from ASC system perspective:

- To maintain a correct container inventory i.e. record all container moves that are reported by the CHE
- To plan container storage locations in the terminal and provide job orders to CHE (or ECS).

Different kinds of optimisation can be performed by TOS and ECS software. The functions typically performed by TOS are:

- Planning the optimal yard positions for containers, especially control of container distribution between blocks (to distribute crane workload)
- Control of transfer points (occupied, free, claimed)
- Creation of the primary transport orders
- Vessel and rail planning
- Gate appointments.

The following functions may be performed by the TOS, but are sometimes implemented by the ECS, (or by the CHE driver when equipment is manned):

- Control of container positions in the blocks (based upon attribute sets and assignment etc.)
- Scheduling the order and dispatching at the time of transport
- Selection of CHE to execute a particular transport order
- CHE sequencing
- Decking for 'shuffle' containers, i.e. 'secondary' container moves.

The communication between the TOS and ASC/ ECS for automated unmanned cranes typically is as follows:

- Submit and confirm work order
- Update crane status and location
- Job concluded (or job interrupted)
- Area status information.

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

- Receiving, validating and confirming the work-order
- Calculating path
- Control of crane movements
- Collision avoidance (containers, vehicles, obstacles, other cranes).

TOS and ECS communicate with each other using dedicated messaging which today is still vendor-specific. PEMA has made an initiative to standardise this communication protocol in order to speed up TOS-ECS integration projects.

7.2 OPTIMISATION AND SIMULATION

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 in TOS. 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 yard capacity, capability of adding extra services to the terminal, patterns and rules in the movement of trucks at gates and inside the terminal, synchronisation of train schedules with ship schedules, and in general the effects of operational changes in the terminal throughput.

Simulation is a simplified version of real life, where the focus is in the areas that are under research, but other parts may be simplified. Simulation usually provides valuable information for comparing different scenarios to each other, but it may not necessarily be used as a reference for real life operational productivity.

Emulation is a special kind of simulation that accepts the same inputs and produces the same outputs as a given system. It 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.

The benefit of emulation is that authentic software can be validated against another authentic software, and ideally only the physical parts of the system (cranes) are replaced as simulators. Therefore testing can be done in remote environments, without actual cranes, and software testing can be executed parallel to equipment manufacturing. Current automated regression testing methods combined with emulation offer a powerful QA environment where repeating testing tasks can be automated.



8 | 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 (while the ultimate goal is to have as few exceptions as possible).

In an automated factory, all materials going into an 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 process. Today's container terminals, however, face 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
- Truck drivers and or operators may not behave as expected, and disrupt the automated process
- Equipment breakdowns.

Automated processes in container terminals will therefore have to cope with disturbances and disruptions that cannot be eliminated. The automated operation will need a manual decision or intervention process which can intervene in uncertain or incorrect operational situations. 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 automation process is put on hold until the exception can be resolved.

Next to performance of equipment, exception handling will have a major impact on the system's overall productivity since the entire operation is relying upon the data flowing with, not after, the actual equipment itself.

The key to exception handling is fast detection and understanding of the situation and a swift intervention to get the process moving again.

9 | MAINTENANCE AND OPERATIONS

An automated terminal typically has higher fixed costs and a lower variable costs 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.

Automated operations substantially reduce wear and tear on equipment such as spreaders compared with manual operations. Consequently, the overall maintenance costs will be lower. With the correct preventative maintenance regime in place, automated terminals today are achieving superior on-demand equipment availability.

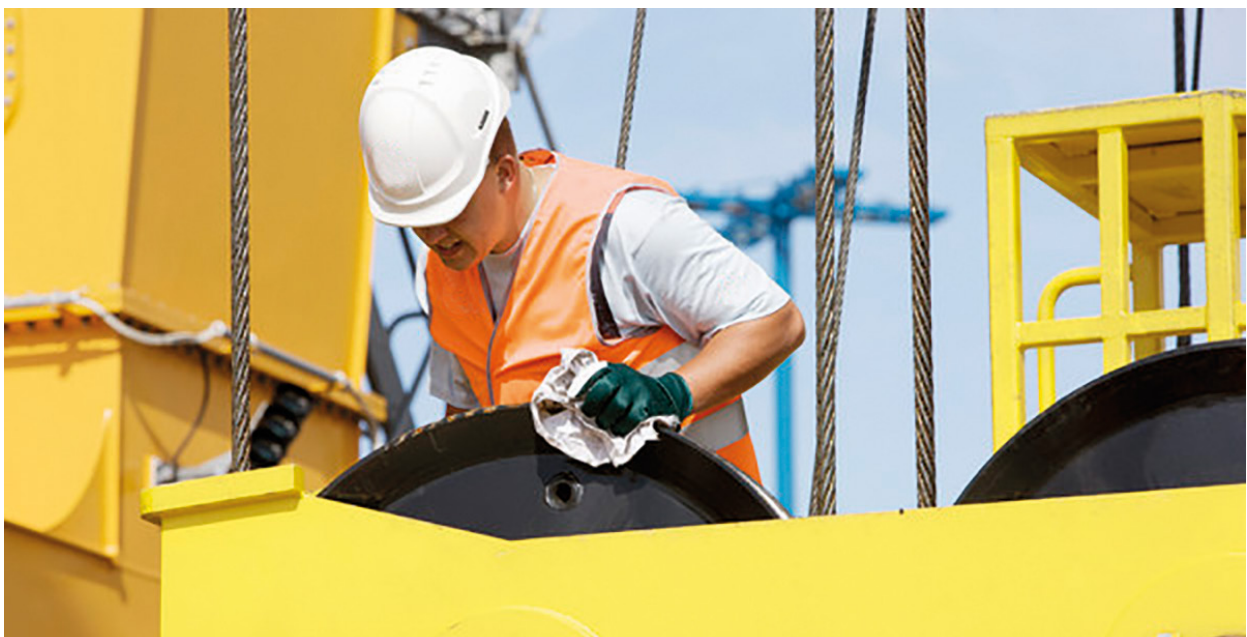
The basic organisation of an automated container terminal operation will be the same regardless of the number of cranes and vehicles used. The main differences compared with manual operations are:

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

Very few automated terminals have delivered their maximum performance within the first years. Maintenance and operations will inherit the task of continuous improvement.

Automated terminals require a shift in focus for both maintenance and operations. To assure high utilisation in an automated terminal key performance data and indicators need to be monitored more closely. It is vitally important that changes in automation efficiencies are detected in a timely manner to ensure counter measures are implemented to stay in high usage mode.

Automated operation typically requires high precision of placing and stacking containers, and high reliability for picking them. This is achieved with sophisticated measurement devices and accurately calibrated systems. This applies to all functional parts of the crane, and therefore has to be the key in all maintenance activities.



10 | BUSINESS DRIVERS AND PROJECT IMPLEMENTATION

10.1 BUSINESS DRIVERS

The main driver for the introduction of automation is often to reduce the cost per handled container in the terminal while ensuring a consistent level of productivity and customer service. The deployment of ASCs also results in better land utilisation, plus a safer, quieter and more environmentally friendly operation.

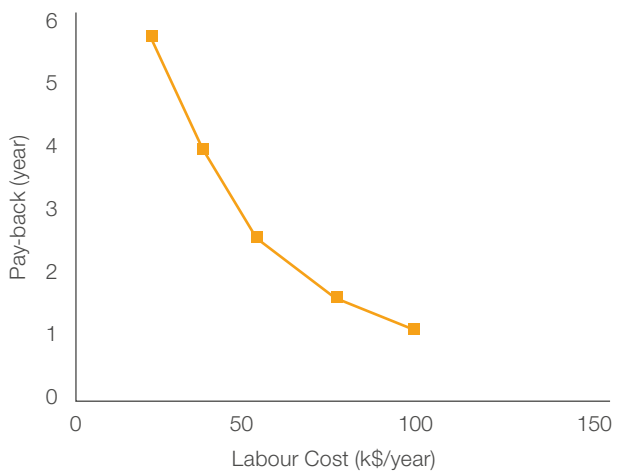
Automation was originally introduced in countries with high labour costs such as Germany and The Netherlands. Today, however, automation is used in a number of countries with varying costs for labour, electricity, land, fuel etc. The design of an automated terminal and the extent of automation of course has to reflect these basic facts.

As is shown in the table below, 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.

A study performed by ABB in cooperation with TBA, comparing electrified manned RTGs and automatic CARMGs, produced the following curve:



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	Belgium	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

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

- A CARMG (Hanjin-type) costs 1,100 k\$/crane more than an electrified RTG
- Two CARMGs 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 automation today is a viable alternative also for terminals handling < 1 MTEU/year.

However, the barrier for introducing 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.

REFERENCES

Vijay Agrawal (2010). Highly productive, dense and automated container handling systems trend. PIANC MMX Congress, Liverpool, UK

Hans Cederqvist (2009). AGVs, ASCs and the fully automated terminal – the future of the industry? – TOC Americas conference, Buenos Aires, Argentina.

Institute of Shipping Economics and Logistics (ISL) (2009). Automation of Container Terminals.

10.2 PROJECT IMPLEMENTATION

The delivery time for equipment for a container terminal yard automation project today can be as fast as 15-24 months.

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 decided by the civil works for the terminal.

Another key factor impacting the project is the construction of the facility itself i.e., the dredging, the construction of the wharf and container yard, the buildings, as well as the low, medium and high voltage electrical systems required to supply power and communications.

Ashebir Jacob (2011). Terminal development at the Ports of Los Angeles & Long Beach. TOC Europe conference, Antwerp, Belgium

Dr Yvo Saanen (2004). An approach for designing robotized marine container terminals.

Dr Yvo Saanen (2006). High density terminals. TOC Americas conference, Acapulco, Mexico.

Source material from ABB, Konecranes and TBA.

APPENDIX 1: TABLE OF EXISTING AND PLANNED INSTALLATIONS

Facility	Location	Country	Operator
Delta Terminal	Rotterdam	Netherlands	Europe Container Terminals (ECT)
Pasir Panjang Terminal (PPT)	Singapore	Singapore	PSA International
London Thamesport	Isle of Grain, Kent	UK	Hutchison Ports UK (HPUK)
Container Terminal Altenwerder (CTA)	Hamburg	Germany	HHLA
Fishermans Island Terminal	Brisbane	Australia	Patrick Stevedoring
Ohi Terminal	Tokyo	Japan	Wan Hai
Evergreen Marine Terminal	Kaohsiung	Taiwan	Evergreen Marine Corporation
Antwerp Gateway	Antwerp	Belgium	DP World
Korea Express Busan Container Terminal (KBCT)	Busan	South Korea	Pusan East Container Terminal Co Ltd (PECT)
Virginia International Gateway (formerly APM Terminals)	Portsmouth, VA	USA	Virginia International Terminals (VIT)
Pusan Newport	Busan	South Korea	Pusan Newport Co Ltd (DP World)
Euromax Terminal	Rotterdam	Netherlands	Europe Container Terminals (ECT)
Tobishima Container Berth	Nagoya	Japan	Tobishima Container Berth Company (TCB)
Hanjin New Port Terminal (Busan Newport Phase 2-1)"	Busan	South Korea	Hanjin Newport Co Ltd (HJNC)
Taipei Port Container Terminal (TPCT)	Taipei	Taiwan	Taipei Port Container Terminal Corp (Evergreen, Yang Ming, Wan Hai)
Container Terminal Burchardkai (CTB)	Hamburg	Germany	HHLA
TTI Algeciras	Algeciras	Spain	Total Terminal International Algeciras (Hanjin)
Hyundai Pusan New Port Terminal (HPNT)	Busan	South Korea	Hyundai Merchant Marine (HMM)

	Start of operations	Yard storage system	Details	Quay-yard transfer system
	1993	ARMG	137 X ARMG	AGV
	1997	OHBC	15 X OHBC	Manned tractor + chassis
	2000	ARMG	18 x ARMG	Manned tractor + chassis
	2002	ARMG	52 x ARMG	AGV
	2002	AutoSC	27 x AutoSC	AutoSC
	2003	CARMG	8 x CARMG	Manned tractor + chassis
	2005	CARMG	6 x CARMG	Manned tractor + chassis
	2007	ARMG	14 x ARMG	Manned ShC
	2007	CARMG	6 x CARMG	Manned tractor + chassis
	2007	ARMG	30 x ARMG	Manned cassette
	2009	CARMG	32 x CARMG	Manned tractor + chassis
	2008	ARMG	58 X ARMG	AGV
	2008	ARTG	12 x ARTG	AGV
	2009	CARMG	41 x CARMG	Manned tractor + chassis
	2010	CARMG	40 x CARMG	Manned tractor + chassis
	2010	ARMG	15 x ARMG	Manned ShC
	2010	ARMG	32 x ARMG	Manned ShC
	2010	CARMG	36 x CARMG	Manned tractor + chassis

Kao Ming Container Terminal	Kaohsiung	Taiwan	Kao Ming Container Terminal Corp (Yang Ming)
Kaohsiung Intercontinental Terminal	Kaohsiung	Taiwan	KMCT – Kao Ming Container Terminal Corp (Evergreen)
Pusan Newport Phase 2-3 (BNCT)	Busan	South Korea	Pusan Newport Co Ltd (DP World)
Barcelona Europe South Terminal – BEST (old Tercat)	Barcelona	Spain	Hutchinson Port Holdings
Khalifa Container Terminal	Abu Dhabi	Abu Dhabi	AD Terminals (Abu Dhabi Port Company)
Brisbane	Brisbane	Australia	DP World
London Gateway Berth 1 and 2	London	UK	DP World
Global Terminals NY/NJ	New York – New Jersey	USA	Global Container Terminals
Sydney International Container Terminals (SICTL)	Port Botany Sidney	Australia	SICT HPH
Xiamen Ocean Gate Container Terminal (XOCT)/ Xiamen YuanHai Container Terminal	Haicang, Xiamen, Fujian	China	Xiamen International Port Co
Trapac	Long Beach	USA	TraPac Inc
Lamong Bay Terminal	Surabaya	Indonesia	Pelindo III
Jebel Ali Container Terminal 3 (T3)	Dubai	Dubai	DP World
Brisbane Container Terminals (BCT)	Brisbane	Australia	HPH
Sydney AutoStrad Terminal	Port Botany Sidney	Australia	Patrick Stevedoring
PSA PPT 3-1a Terminal 5	Singapore	Singapore	Port of Singapore Authority
PSA PPT 3-1b	Singapore	Singapore	Port of Singapore Authority
Manzanillo International Terminal (MIT)	Colon	Panama	SSA
APM Terminals Maasvlakte II	Rotterdam	Netherlands	APM Terminals
Rotterdam World Gateway	Rotterdam	Netherlands	DP World/New World Alliance/CM CGM

Table: Existing installations

2010	CARMG	22 x CARMG	Manned tractor + chassis
2011	CARMG	40 x dual CARMG	Manned tractor + chassis
2012	ARMG	38 x ARMG	
2012	ARMG	48 x ARMG	ShC
2012	ARMG	42 x ARMG	ShC
2014	ARMG	14 x ARMG	ShC
2013	ARMG	40 x ARMG	ShC
2014	ARMG	20 x ARMG	ShC
2014	ARMG	12 x ARMG	ShC
2014	ARMG	16 x ARMG	18 x AGV
2014	ARMG	27 x ARMG	ShC
2014	ARMG	20 x ARMG	Manned tractor + chassis
2014	ARMG	50 x ARMG	
2014	ARMG	12 x ARMG	ShC
2015	AutoSC	44 x AutoSC	AutoSC
2015	CARMG	22x CARMG	Manned tractor + chassis
2015	CARMG	34x CARMG	Manned tractor + chassis
2015	CARMG	6 x CARMG	
2015	ARMG	48 x ARMG	36 x Lift AGVs
2015	ARMG	32 x ARMG	AGV

Facility	Location	Country	Operator
Long Beach Container Terminal (Middle Harbor)	Long Beach	USA	Long Beach Container Terminal Inc
Liverpool2	Liverpool	UK	Peel Ports
Lázaro Cárdenas Terminal 2 (TEC 2)	Lázaro Cárdenas	Mexico	APM Terminals
Terminal Petikemas Semarang (TPKS)	Java	Indonesia	Pelindo III
Tuxpan Port Terminal (TPT)	Veracruz	Mexico	SSA Mexico
PSA PPT 3-2a phase 3+4	Singapore	Singapore	Port of Singapore Authority
London Gateway Berth 3	London	UK	DP World
Victoria International Container Terminal Ltd (VICTL)	Webb Dock, Port of Melbourne	Melbourne, Australia	VICTL/ICTSI
Yangshan Phase 4	Yangshan, Shanghai	China	Shanghai International Port Group (SIPG)
PSA PPT 3-2b	Singapore	Singapore	Port of Singapore Authority
Yangshan Deepwater Port	Shanghai	China	
Container Terminal Burchardkai (CTB)	Hamburg	Germany	HHLA
Jebel Ali Container Terminal 4	Dubai	Dubai	DP World
Vado Ligure	Vado	Italy	APM Terminals
Qingdao Qianwan Container Terminal	Qingdao	China	
Navy base terminal, North Charleston	Port of Charleston	USA	South Carolina Ports (SCPA) owner operator
Tianjing Wuzhou terminal	Tianjin Port	China	
Ports of Auckland	Auckland	New Zealand	
Tuas Terminal	Singapore	Singapore	MPA
DP World Sydney	Sydney	Australia	DP World

Table: Planned installations

	Start of operations	Yard storage system	Details	Quay-yard transfer system
	2016	ARMG	32 x ARMG	Automated
	2016	CARMG	22 x ARMG	
	2016	ARMG	22 x ARMG	
	2016	ARTG	11 x ARTGs	
	2016	CARMG	8 x CARMG	
	2016	CARMG	72x CARMG	Manned tractor + chassis
	2016	ARMG	20 x ARMG	ShC
	2016/ 2017	ARMG	12+8 x ARMG	11 x Auto ShCs
	2017			
	2017	CARMG	58x CARMG	Manned tractor + chassis
	2017	ASC	30 x ASC	
	2017	ARMG	12 x ARMG	
	2018	ARMG	35 x ARMG	
	2018	ARMG	14 x ARMG	Manned tractor + chassis
		ASC	20 x ASC	
	2019			
	2019	AutoSC		
	2020			

APPENDIX 2: TERMINOLOGY

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 gantry crane (either rail mounted or rubber tyred) for container yard handling operations
AShC	Abbreviation for automated shuttle carrier, a driverless 1-over-1 straddle carrier (ShC) for horizontal transport of containers between yard and quay
AutoSC	Abbreviation for automated straddle carrier, a driverless straddle carrier (SC) for transporting and stacking containers in terminals
ARMG	Abbreviation for automated rail mounted gantry crane (RMG)
ARTG	Abbreviation for automated rubber tyred gantry crane (RTG)
CARMG	Abbreviation for side-loading cantilever automated stacking crane, an ARMG 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
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

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This paper revision has been prepared by Kari Rintanen, Konecranes, and Allen Thomas, ABB Port Systems, with contributions from Kalmar, Siemens, Kuenz, ISL Applications, Moffat and Nichol, Navis, TBA, BTG and TMEIC.

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