Maintenance of automated terminals.

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EXECUTIVE SUMMARY.

This white paper examines the maintenance of container handling equipment at automated terminals, with the aim of providing a basic understanding of the factors that need to be taken into account when planning a terminal automation deployment.

Converting to automated operations requires a major change in practices and attitudes, not only for the terminal's maintenance team but also for operations and IT. Most significantly, the focus of maintenance moves from reactive ad hoc repairs to a targeted preventive maintenance program. At automated terminals, IT is no longer a separate department but a critical function that needs to integrate seamlessly with operations and maintenance.

Automated terminals require a new calibre of technical knowledge at all levels of the organisation. Even traditional technical roles will need to have some understanding of the entire automation system. The maintenance of the infrastructure surrounding the actual automation systems also requires specialist expertise and resources.

Automated equipment introduces significant requirements for terminal layout and design. These factors need to be addressed already at the design stage so that routine maintenance can be carried out without disruption to ongoing operations.

This white paper also discusses how maintenance needs will evolve over time, from the start-up phase and extending over the lifespan of the equipment. Finally, we look at actual case data that provides a real-world window into the value gains that operators can realistically expect from pre-emptive maintenance of automated equipment.

Introduction.

When converting a manual container terminal to automation, the first thing that comes to mind is installing automated equipment and building the infrastructure needed to run it. However, to ensure the terminal is running optimally, the services and maintenance of an automated terminal also needs proper attention. This focus must begin in the planning phase, continue through the deployment and start-up periods, and extend into maintenance planning and optimisation over the lifetime of the terminal.

Manual container handling equipment will work even if the machines are not in perfect condition, because human operators can work around the deficiencies of each piece of equipment or deal with exceptions in operational processes. By contrast, automated equipment always needs to operate faultlessly to ensure it does not become a constraint on the performance of the terminal.

In a manual terminal, replacing or repairing an individual component or machine typically has a minor impact on the performance of the terminal as a whole. In an automated terminal, the situation is very different. In the worst-case scenario, the breakdown of a single piece of equipment can lead to shutting down part of the terminal for 15 to 30 minutes to remove the machine from the yard.

In automated terminals, the workload of the maintenance team changes markedly, as aspects of human error are eliminated. Dealing with typical manned equipment events such as collisions and accidents, or having to react to ad hoc repairs on equipment is reduced dramatically, bringing cost savings in the long term. Automated equipment can also provide continuous updates on its status, and can send alerts when any faults are detected. However, a consistently implemented inspection and preventive maintenance programme becomes an absolute necessity.

Converting to automation requires a major change in practices and attitudes not only for the terminal's maintenance team, but also for operations and IT. In a manual terminal, these are traditionally separate departments. With automation, IT becomes a critical function that needs to integrate seamlessly with operations and maintenance. This represents a new way of thinking for container terminals, and is often overlooked in the planning phase.

> In automated terminals, a consistently implemented inspection and preventive maintenance programme becomes an absolute necessity.

Maintenance of automated equipment.

A key characteristic of an automated terminal is that decisions are based on data gathered from container handling equipment. The automated machines are monitored 24/7 by equipment control systems, and large amounts of captured data can be analysed in order to detect subtle changes in equipment performance. These identified trends can then be used for scheduling preventive maintenance before actual component breakdowns occur.

Sensitive automated equipment requires a targeted, routine preventive maintenance program to ensure proper operation and provide maximum in-service lifespan. As a result of a routine preventive maintenance program, the need for unscheduled corrective maintenance decreases, since machine failures can often be spotted beforehand due to 24/7 tracking of the machines. Additionally, the number of ad hoc repairs is reduced. In an automated terminal, there are fewer repairs due to collisions, incorrectly handled equipment or human error.

EYES ON THE GROUND

The standard maintenance intervals are the same for both automated and manned equipment. However, for automated terminals pre-planned short-term maintenance checks become increasingly important since there are no drivers to report on the condition of the machines.

Automated container handling equipment incorporates a large number of optical and other sensors. These need to be checked manually at regular intervals. Furthermore, simple visual inspection of the equipment and correct reporting for future use becomes essential.

In automated terminals, monitoring of operation and the condition of the fleet is no longer a 'nice to have' option, but a crucial necessity. Without advanced monitoring tools and remote diagnostics, there is no way to manage the operative fleet actively. Furthermore, not every maintenance condition will be reported by automatic diagnostics. Trained operators are needed to analyse fleet performance and condition to proactively identify any potential maintenance issues and take needed actions to avoid unnecessary interruption in the operation. This analytical work is an expert role beyond the scope of the traditional maintenance technician. In an automated terminal, operational and maintenance staff needs to be familiar with various IT systems, a fact that must be addressed in training.

In automated terminals, the system collects and measures key equipment performance and availability metrics that have been typically collated manually for decades. These statistics are of great relevance for terminals looking to understand and then optimise their fleet performance and usage.

> "Planning the operations and maintenance of an automated terminal is a complex task that requires continuous optimisation.

Maintenance planning in an automated environment.

Planning the operations and maintenance of an automated terminal is a complex task that requires continuous optimisation of multiple variables. A structured approach to maintenance ensures greater equipment availability, which in turn increases overall equipment efficiency.

Knowledgeable automation providers can be of great assistance when optimising equipment maintenance. This helps terminals reap the most significant benefit of automated terminals, namely constant and predictable throughput around the clock, every day of the year.

Terminal layout considerations.

HORIZONTAL TRANSPORTATION EQUIPMENT.

In automated terminals, maintenance needs to be taken into account at every level, including the physical design and layout of the site. The most obvious requirement is that areas in which people need to interface with the automated equipment must be carefully defined and strictly separated from automated areas. This has several implications for the maintenance of the equipment.

Automated straddle carriers / shuttle carriers and automated guided vehicles (AGVs) can be driven outside the automated environment for maintenance. For these types of equipment, separate "airlock" areas must be built at the perimeter of the automated area for short-term maintenance and refueling. To ensure maximum equipment uptime, these check-up areas should be located closer to the container area than the actual maintenance workshops to which the machines can be driven for more extensive service or repairs. This factor needs to be designed into the automated terminal layout from the beginning.

In automated terminals, good maintenance planning and predictive service typically ensure extremely high fleet reliability. However, the unlikely event of machine stoppage must also be taken into account.

A typical strategy for handling serious exceptions is to segment the automated container yard into several zones that can be isolated from each other with light curtains or other safety solutions. In the event of a machine breakdown, these zones can be sequentially closed off from automatic operations and then reactivated after the machine is removed from the yard. This enables the rest of the terminal to continue operating uninterrupted.

An alternate method is to define a software-based safe zone around the faulty machine, so that other automated equipment can move around it. At the end of the shift, operation in the yard is then temporarily halted for the removal of the parked machine.

ASCs.

Unlike rubber tyred-based container handling equipment, automatic stacking cranes (ASCs) cannot be moved outside the container block. This means that for maintenance, the ASC needs to be driven to the maintenance area at either end of the stack to isolate it from the automated environment.

ASCs generally operate in pairs, so when servicing one of the cranes on the block, the complete block can be served by the other ASC.

The stack layout should include sufficiently large maintenance zones in the exchange areas at both ends of the block. The maintenance zones must be large enough that the crane at that end of the block can be taken out of operation for servicing while still allowing the other crane to continue serving the entire block on both the landside and waterside. When this requirement is overlooked, it could mean that the entire landside or waterside operation needs to be stopped when the ASC is serviced.

A typical layout for a maintenance area is 4 TEU long, so the ASC that requires maintenance can be placed at the end of the block. With a four-lane interchange layout, two of the lanes will remain open so the horizontal transportation can still feed the ASC crane that is in operation.

The maintenance planner needs to consider several factors when deciding the most efficient way to service the cranes. The basic principle of an ASC stack is to keep containers moving 24/7 without interruption. This is not possible unless the cranes are serviced at the required intervals, but with careful layout design the block can still be kept operating at half capacity during crane service. Additionally, access corridors must be designed into the layout so that maintenance staff can safely enter the service areas without having to pass through the automated zone.

Automation infrastructure maintenance.

Safety is a key consideration at any automated facility, and safety systems as well as access control solutions must also be maintained consistently throughout the terminal. In addition to the actual automated container handling equipment, an automated terminal has a significant amount of other infrastructure that needs maintenance, from sensors, safety curtains, gates and fencing to wireless networks, LAN, servers and cooling systems. This requires a new skillset for infrastructure maintenance, as staff will need to be competent in maintaining many highly specialized subsystems including PLCs, sensors and lasers.

Calibration.

In an automated terminal, electronic sensors replace the human senses as the principal method of monitoring equipment performance and container movements. The precision of automated equipment depends on the precision of its sensoring and measurement systems, as the human eye and manual judgment are not used to compensate for out-of-tolerance systems. To ensure optimum performance, sensors and measuring systems must be calibrated at regular intervals. Specialist equipment and expertise will also be required for the calibration of wheel alignment tools, turntables, and the lasers used for automated truck handling and spreader positioning.

Infrastructure maintenance.

ASC terminals also require regular measurement and maintenance of the crane rails. Terminals are often built on landfill areas, which can cause changes in rail geometry as the surface of the yard settles over the years. Regular rail inspections are part of the preventive maintenance program, as crane rails that are out of tolerance will affect the movement accuracy of the entire crane. This is different from manual terminals, where such slight discrepancies are easily overcome or even go unnoticed by crane operators.

Software maintenance and support.

Complex automated systems have a direct impact on the terminal's operational efficiency, so the importance of a strong software maintenance and support program increases. Like equipment, software needs 24/7 support to ensure the availability and performance of the system. A typical way to handle software maintenance and support is to sign a long-term Maintenance and Support (M&S) contract with the software supplier.

SOFTWARE MAINTENANCE.

With an M&S contract, the customer can receive access to a customer portal where they can open, update and monitor technical support issues; access a knowledge base on their system; suggest new product features; download patches, tools and drivers; and get hot fixes, maintenance releases and upgrades for their software.

SOFTWARE SUPPORT.

24/7 support is a necessity for software in automated terminals. A small problem in the system can close the whole terminal for hours if the right support is not available 24/7.

Support is divided in 3 levels.

LEVEL 1

Problem definition.
The goal is to clearly identify, validate the legitimacy and concisely define the problem. The end goal is to document and understand the factual problem, plus the related background data in an organised manner so that the Level 2 investigation may proceed without interruption.

LEVEL 2

Problem analysis and determination.
The goal is to determine the singular root cause of the problem so that it may be corrected at this level or at Level 3. An intimate knowledge of how the system is designed and intended to operate is required at this level. All product documentation including user manuals, functional requirements documents, technical specifications, entity relationship diagrams need to be accessible for analysis.

LEVEL 3

Problem resolution.
The goal is to determine the location of the offending code or subsystem and apply a patch, permanent fix or replacement component. Access to the software code, firmware or hardware circuitry and the software/hardware tools to modify the inherent function of the system will be required.

The primary responsibility of software support is to diagnose, isolate and resolve reported technical errors and questions that are related to software products and provide quality solutions as promptly and accurately as possible. An online customer support portal can be a centralised source for support, offering efficient case reporting and tracking options.

TYPES OF CASES.

The support process focuses on cases, which are issues or items of concern brought up by key users. Cases include the following basic types:

- Errors
- Enhancements
- Questions
- Other (e.g. additional license requests, documentation/training requests etc.).

At the highest level, there are two basic kinds of cases: critical and non-critical cases.

Critical cases are errors in software that prevent the terminal from performing mission critical functions. Critical cases need an immediate response and resolution from the supplier, and will be dealt with as extremely high priority.

In some cases, a short-term resolution to a critical case may be provided in terms of a workable manual or system workaround. A system workaround is often considered a short-term resolution to critical cases, because the first order of business is to get the system up and running as quickly as possible.

Critical cases are divided into four categories, depending on their impact:

Priority 1:	Priority 2:	Priority 3:	Priority 4:
CRITICAL IMPACT	**SERIOUS IMPACT**	**SIGNIFICANT IMPACT**	**LOW IMPACT**
• Production system totally inoperable or crashes frequently • Critical impact on business operations • No workaround.	• Production system is operational but frequent malfunction in essential system component • Only short term workaround exists.	• Production system is operational but occasionally mishandles transactions or data • Workaround exists but is inconvenient.	• Production system is operational but not functioning in accordance with documentation • Redundant output, misspelled text or other cosmetic defect • Reasonable workaround exists.

Prioritising is needed to ensure the right allocation of efforts from the user and service provider points of view.

Start-up phase.

> ”In the start-up phase, external experts can serve as “co-pilots”.

The most demanding phase in automation deployment is the ramp-up to production. Terminals typically require support in handling the full range of start-up activities. Operators often experience a sense of urgency in getting the system running, even if all the in-house competence is not yet in place. This is when the risks of unplanned downtime are at their maximum.

Before starting up commercial operations, at least the following functions must be in place:

- Maintenance processes
- Competencies for managing the automated system
- Inventory strategy
- Health and safety plans
- Environmental plans
- IT administration

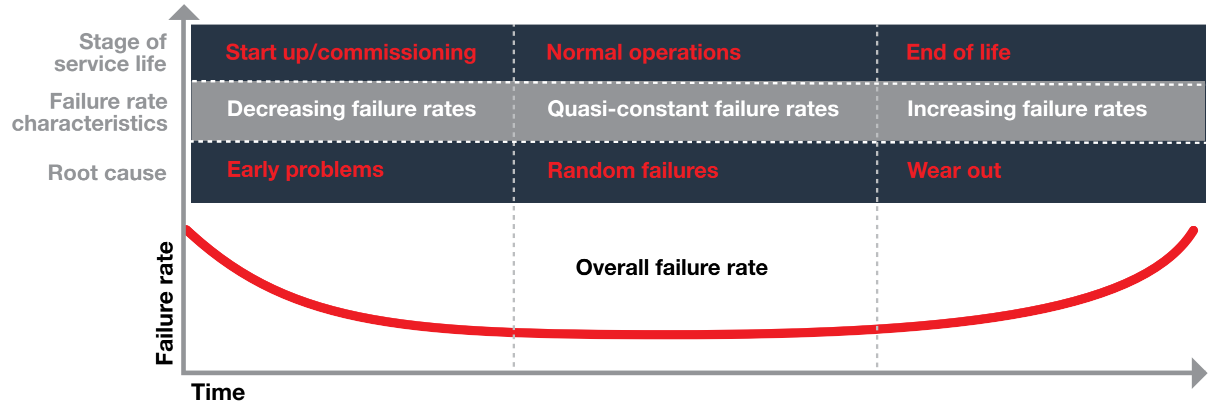
In the critical start-up phase, a trusted service provider can step in to support the terminal in getting the right processes and resources ready. Tasks range from defining maintenance concepts, transferring master task lists to the maintenance programme, creating job plans and defining basic principles in the Computerised Maintenance Management System (CMMS), to setting up processes for third-party warranties, damage management, and procurement. Workshop facilities need to be set up, Health, Safety and Environmental plans must be implemented for maintenance activities, and job descriptions need to be defined. Furthermore, new job competences need to be established through skill mapping within the organisation and/or recruiting new resources for maintenance activities.

In the start-up phase, expertise within the organisation typically needs to be brought up to speed with training and external support. Automated terminals call for a new calibre of technical knowledge at all levels of the organisation. Even traditional technical roles will require some understanding of the entire automation system, which is a factor easily overlooked in terminal automation deployments.

In the start-up phase, external experts can serve as "co-pilots", supporting terminals through an education and knowledge transfer period while the operators develop their skills and build up experience. Maintenance operations also need to be up and running from the beginning. The start-up phase is the ideal time to establish the routines that ensure optimum performance in the long run.

UNDERSTANDING THE OPTIMISATION CURVE.

During the start-up phase, terminals need to have realistic expectations regarding the evolution of maintenance requirements over time.A common assumption with automated equipment is that failure rates will start at zero from equipment deployment and then gradually increase over the lifespan of the machine. In reality, failure rates always follow a "bathtub" curve:



Failure rates begin at some non-zero level on start-up, decrease as the equipment and system are optimised, and then gradually rise again as the equipment nears the end of its planned lifetime.

This phenomenon is also seen in manual terminals, but it is particularly relevant to automated terminals due to the significantly larger number of complex systems that need to be interfaced and integrated. Automation system performance depends on many factors beyond the reliability of the actual equipment, including the IT infrastructure, software applications, server capacity, wireless connectivity and other variables. Any of these can cause technical issues that need to be smoothed out as the entire system is optimised.

Similarly, terminals need to accept that meeting specific key performance indicators such as Mean Moves Between Failure (MMBF) is a gradual process. It will take some time for MMBF to reach its target level, as the automation system is optimised and fine-tuned. However, once the target level is reached, MMBF and other similar metrics can be expected to remain steady and even gradually improve over the lifetime of the automation solution.

Operating an automated terminal system.

Optimisation services that support the terminal's TOS (Terminal Operating System) and Equipment Control System (ECS) can provide terminal operators with insight on how to review performance, analyse data, and fine-tune the use of the systems that support their automated equipment. This allows the terminal to optimise cycle times and maintain maximum operational performance.

When implementing TOS and ECS for an automated terminal, there are some special factors that need to be considered. For example, experience has shown that an on-going testing strategy is essential when seeking to continuously improve the performance of systems, equipment and people at the terminal.

EXCEPTION HANDLING.

Another key factor is the importance of exception handling. Terminals cannot just focus on the 'happy day scenario' of the container flows, but need to ensure that they can handle the situations when something does not work as expected. In an automated terminal, there are no manual workarounds, so this needs to be the focal point of services, testing and training. The highest productivity in an automated container terminal is achieved if exception handling has been efficiently arranged with the correct skillsets.

Paradoxically, as terminal automation develops in sophistication, the need for operator intervention decreases, but the average complexity of the exceptions that cannot be handled automatically increases. This means that operators need to be better trained and have a more complete understanding of the automation system as a whole. Emulation-based exception handling training can help operators practice a wide range of scenarios, and helps ensure that operators can handle the demanding task of managing an automated container terminal.

> ” During the start-up phase, terminals need to have realistic expectations regarding the evolution of maintenance requirements over time.

TESTING.

Automated testing is also gaining ground in terminal software, especially in connection with version upgrades and new features. With automated regression testing, terminals can have thousands of different test cases ready when the new software release is delivered, and can test these scenarios with the latest software over and over again. Sophisticated automated testing saves resources and enables releases to be thoroughly tested prior to deploying them in the production environment.

OPTIMISATION AND CONTINUOUS IMPROVEMENT.

Terminals must also accept that when deploying automation and new software, productivity cannot be maximised at the start. Instead, it must be improved incrementally by fine-tuning the system setup, operational parameters and settings, and prioritising key actions over less important tasks. The operational and maintenance procedures must also be optimised. Productivity is the result of optimal cooperation between equipment, systems and people, and all three require constant focus. Optimisation services enable improvement of cycle times, operational work processes and optimisation of terminal performance through information provided by TOS, TLS and PLC software.

Case study.

QUANTIFYING THE VALUE OF MAINTENANCE SERVICES AT AUTOMATED TERMINALS.

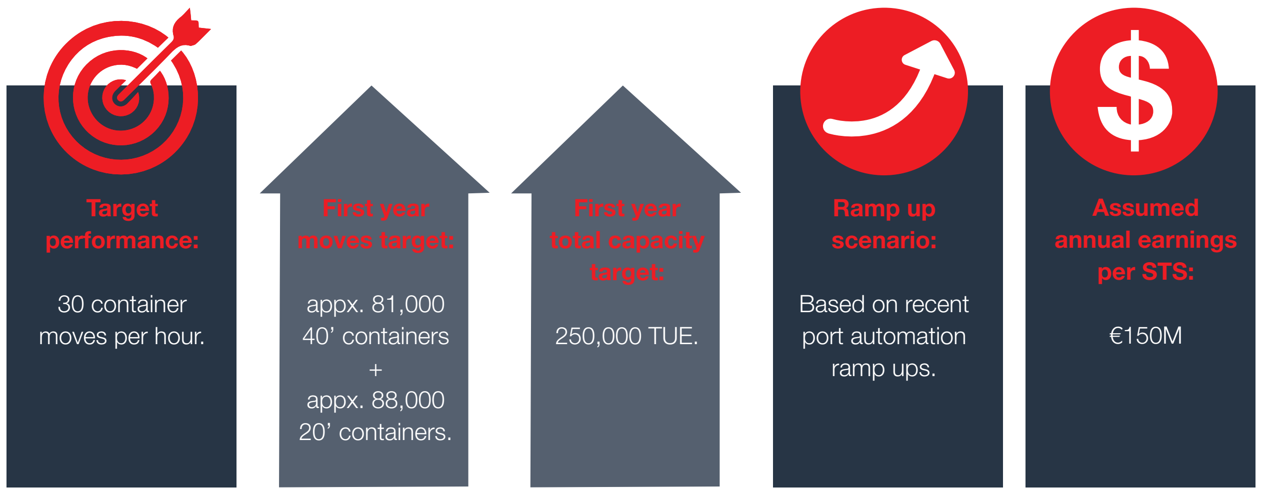
The return on investment, productivity gains, impact on safety and improved revenue potential of an automation deployment are always heavily dependent on the specific circumstances of each terminal, in addition to the business goals and operating model of the terminal operator. However, careful quantitative analysis of various scenarios can provide a clear understanding of the potential of added value that maintenance services can bring to automated terminals.

In the autumn of 2016, Kalmar conducted a detailed business case analysis for a medium-sized container terminal during its start-up phase. The terminal is currently undertaking a greenfield deployment that encompasses automated yard cranes and horizontal transport as well as process automation.

The calculations compared maintenance services supplied in-house by the terminal operator with a flexibly priced service contract delivered by an external partner. The main benefits of the flexible service concept – in which the service fee is aligned with terminal throughput – were identified as, firstly, shortening the time to value of the automation deployment and, secondly, enabling the terminal to gain additional value throughout the lifetime of the solution.

A container terminal's revenue is largely determined by the moves per hour of the ship-to-shore (STS) cranes. Between 20 and 25 moves per crane per ship operating hour is normal for a traditional container terminal with conventional single lift quayside cranes. An industry benchmark of some 115,000 TEU per annum is set for planning purposes, but this tends to reflect more on the systems operating around the crane rather than the crane itself.

The business case evaluation was based on a ten-year period beginning from the start-up of the automated solution. The core assumptions were as follows:



Based on data from the customer's current operations and realistic assumptions on the delivery of the maintenance service contract, the study identified notable savings and potential revenue increases for the customer during the first year of operation, as well as significant savings during a 10 year service contract:

Shorten time to reach full throughput potential (30 moves/hr) from 12 to 10 months.

Higher customer revenue per month starting from the second month of operation.

€450k savings and €1.4M revenue potential increase during first year of operation.

Almost €2M cash flow improvement for the terminal.

Maintenance cost savings of €9M (appx. 16%) over a 10-year service contract.

Longer-term revenue potential increases were difficult to calculate due to the extensive set of assumptions required. However, the potential for added value of flexibly priced maintenance services is clearly evident for both securing optimal terminal throughput and minimising operating expenses.

An automated terminal requires special attention during the ramp-up phase, and maintenance services can shorten the time to optimal utilisation. Additionally, smart data-driven maintenance enables the terminal to have a clear view of its equipment performance and reliability metrics. During the following years, services help minimise the costs of handling the maintenance process. Maintenance pricing can even be connected to specific indicators such as terminal throughput, so maintenance costs are based on actual terminal performance.

AUTHORS

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Vice President, Intelligent Service Solutions, is a service professional who has worked in the service business in several industries over the last 15 years. Before Arto joined Kalmar, in 2012, Arto had a global responsibility for service contracts at Wärtsilä. At Kalmar Arto has worked on the development of the Kalmar Care and is currently heading the Intelligent Service Solutions business line, focusing on terminal and automation services.

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Vice President, Project Delivery at Kalmar, entered the transportation equipment industry at the Valmet Tampere Works in 1984, working in R&D. He worked with the Kalmar straddle carrier product line from 1991, creating the Kalmar AutoStradTM system and introducing shuttle carrier horizontal transportation to ASC terminals in the early 2000s. Currently he is running the Kalmar megaproject delivery function at the company's Automation and Projects Division.

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ABOUT THE COMPANY
Kalmar, part of Cargotec, offers the widest range of cargo handling solutions and services to ports, terminals, distribution centres and to heavy industry. Kalmar is the industry forerunner in terminal automation and in energy efficient container handling, with one in four container movements around the globe being handled by a Kalmar solution. Through its extensive product portfolio, global service network and ability to enable a seamless integration of different terminal processes, Kalmar improves the efficiency of every move.

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