A photograph of a container terminal crane, showing its tall lattice tower and horizontal boom. The image is overlaid with a semi-transparent red filter. The crane is positioned on the left side of the frame, with its boom extending towards the right. The background shows a clear sky and some distant structures.

Considerations of electric powered horizontal transportation at container terminals

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Summary

Along with the use of hybrid power sources, interest in full electric powered horizontal transportation at port terminals has never been higher. Whether driven by environmental legislation, local pressure groups or pure economics, the need to reduce emissions, noise or over-complicated maintenance is growing. When implementing a quay to stacking area transportation system, there are basically three electric powered alternatives. Which concept provides greater added value completely depends on the characteristics and requirements of the application.

At automated container terminals utilising automated stacking cranes (ASC), the two options are the flatbed automated guided vehicle (AGV) or the shuttle carrier, which can be manually operated or fully automated. As container movement between the quay and the container yard is a potential “bottleneck” in the terminal, the Kalmar FastCharge™ shuttle carrier already offers a major advantage by fully decoupling activities at both ends. Various derivatives of the AGV offer decoupling at the ASC but coupled operations at the ship-to-shore crane (STS) can still limit productivity.

In a straddle carrier terminal, waterside and landside operations are already fully decoupled with a single machine handling both horizontal transportation and stacking. The speed, reach and flexibility of the Kalmar FastCharge straddle carrier allow terminals to use a single type of equipment for all container operations, either manually operated or fully automated.

The majority of all-electric AGVs presently in use utilise lead-acid batteries which, due to the long charging times, require automated battery replacement and charging stations. Newer technology lithium-ion power sources, as used in the Kalmar FastCharge shuttle and straddle carriers, now charge so quickly that the battery stays in the vehicle and replacement is unnecessary.

There is no ‘one-size-fits-all’ solution, which creates the need to be aware of the actual performance, characteristics and parameters of each alternative, to ensure an objective evaluation is achieved. This white paper attempts to provide an objective comparison between the systems in order to help determine which concept is a better fit for a particular terminal.



The Kalmar AutoStrad™ is the ideal solution for medium-sized and large terminals where high equipment flexibility and minimal labor costs are key requirements.

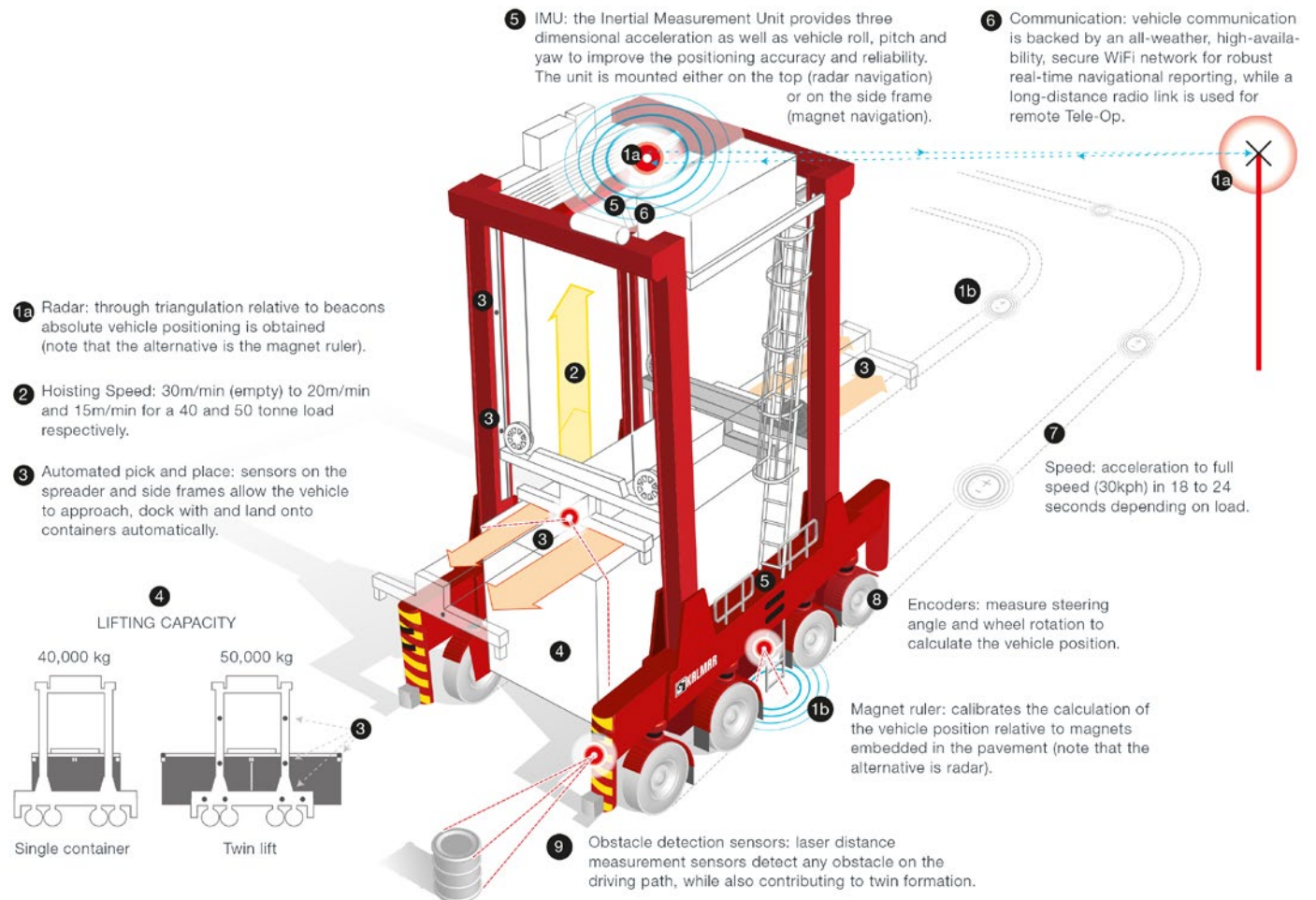
” The berthing time at the terminal quay needs to be as short as possible.

1. INTRODUCTION

In recent decades, container volumes handled worldwide have continuously increased as a result of globalisation, economic growth and geographical distribution of activities. Overseas container transport costs have considerably decreased due to economies of scale by continuously increasing vessel sizes from 4,000 TEU in the early 1990s to 14,500 and above today. Larger container ships place an increasingly heavy demand on terminal infrastructure to handle the increased number of containers moving to and from the quayside.

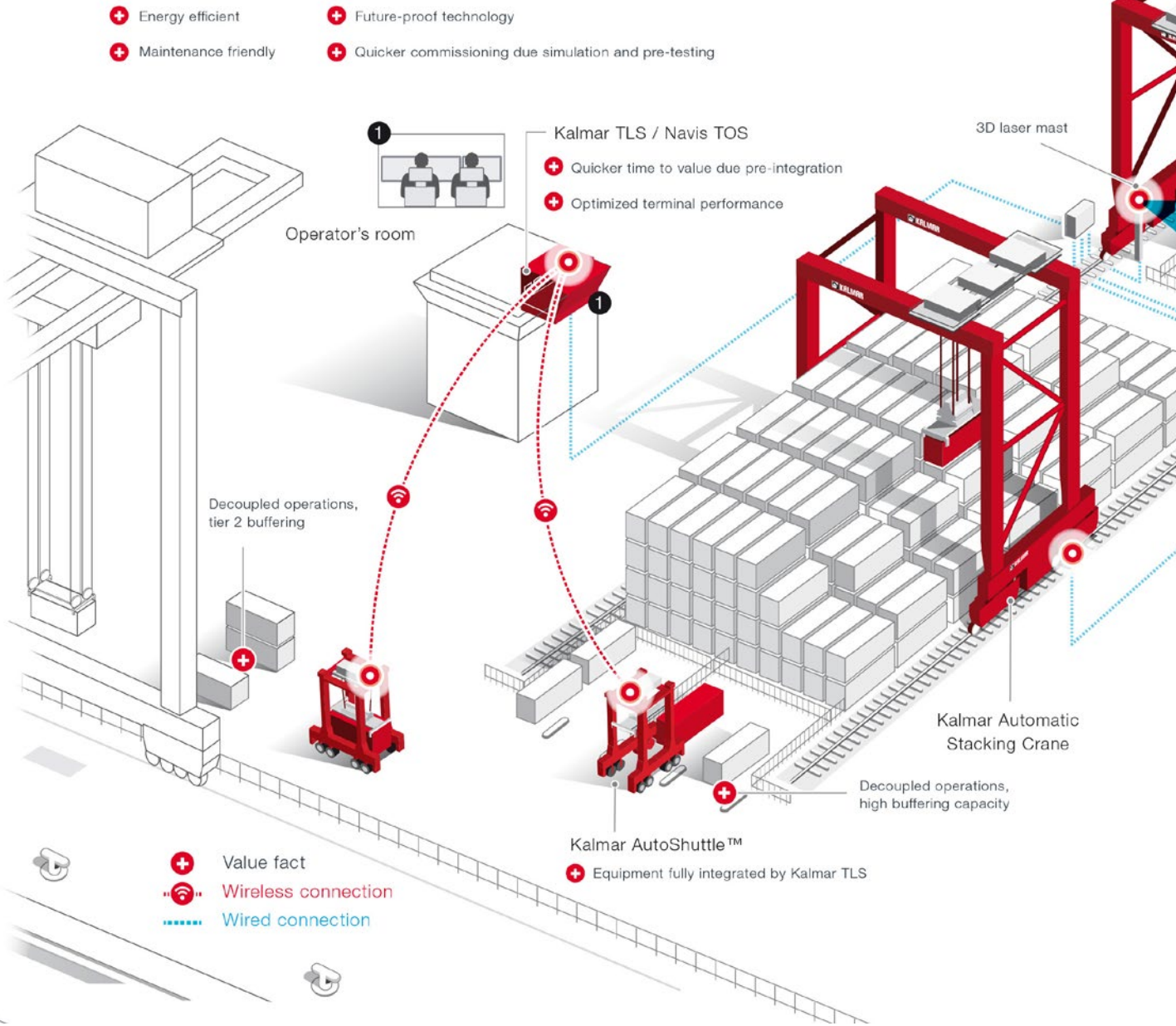
Time is money and as the container ship only really makes money while at sea, the berthing time at the terminal quay needs to be as short as possible. This can only be achieved by fast loading and unloading, which requires close cooperation between the quayside ship-to-shore cranes and the container stacking area. For many years, the straddle carrier and terminal tractors with one or multiple chassis were the default options for horizontal transportation with straddle carriers capable of handling both horizontal transportation and stacking.

Automated straddle carrier



Straddle carriers are capable of handling both horizontal transportation and stacking.

Kalmar ASC System



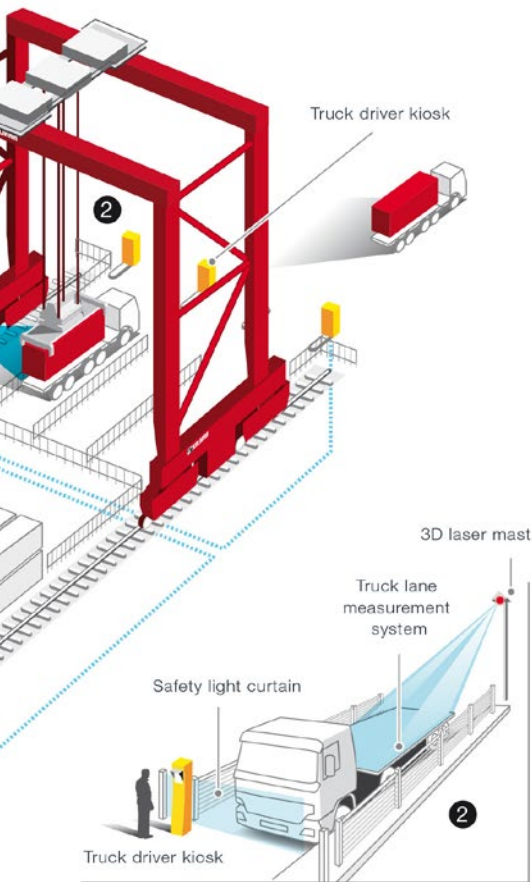
Kalmar's end-to-end ASC System encompasses Kalmar ASC, automated truck handling, (Auto)Shuttles™ and related software solutions.

2. HORIZONTAL TRANSPORTATION

In the early 1990s, the flatbed AGV was the first driverless horizontal transportation system to be introduced into terminals. While many improvements have been made since, the flatbed AGV is basically an automated version of the chassis used for horizontal transportation at that time. Today, the high productivity of STS cranes can be limited by the AGV's need to be present to load and unload containers, and the coupling of the work cycles of the quay and yard cranes.

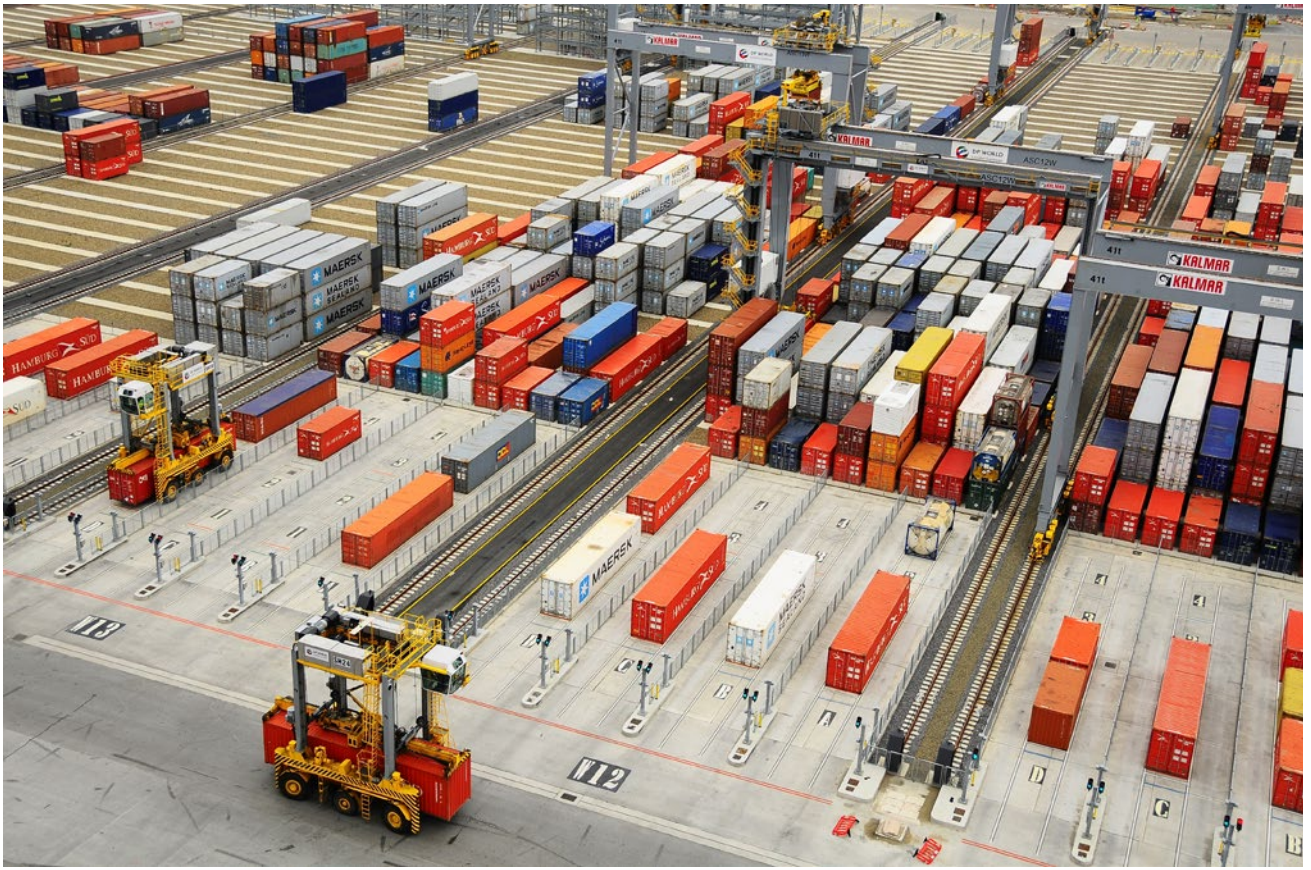
Even with developments like the active lift AGV, operations are still only partially decoupled at the stacking area. As a rough guide, the coupled operation at the STS crane requires a minimum of five AGVs to be deployed for each STS crane. A proposed cassette AGV also promises decoupling at the quay with a portable cassette. However, with no existing commercial installations, how cassette placement will be achieved in the dynamic environment of the STS crane remains unclear.

The ideal decoupling buffer is created by placing the containers on the ground at the STS crane, to be picked up and dropped on the ground at the waterside interchange area. This is where the interest in the shuttle carrier as a form of horizontal transportation originated. By fully decoupling STS and ASC activities, one shuttle carrier can achieve the same productivity as two AGVs. This decoupling adds buffer zones both at the STS and ASC, making exception handling, whether caused by delays in loading or unloading, easier to manage.



Kalmar automated truck handling

- + Less remote control operators (exceptions only)
- + Shorter truck turnaround time
- + Increased safety



Today's modern terminal utilising automatic stacking cranes (ASC) led to the further development of horizontal transportation to remove the potential bottleneck at the quay.

The innovative shuttle carrier concept developed by Kalmar, a smaller 1 over 1 stacking version of the straddle carrier, was first tested at the port of Helsinki in 2003. The Kalmar AutoShuttle™ is able to transport single 20 and 40 foot containers, picked up from the ground, as well as two 20' boxes in twin-lift operation. With the ability to pick up any container rather than only the outermost and to stack containers two high, the AutoShuttle offers more versatility, especially in pooled allocation schemes serving more than one STS crane and dual cycle operations with simultaneous loading and unloading. Whether fully automated or manually operated, the shuttle allows faster fully decoupled container transfer in the terminal.

” Diesel/electric driveline is generally more reliable and requires less maintenance than diesel.

3. HYBRIDS

Today, both AGVs and shuttle carriers offer electric driveline using a diesel engine as the main power source. Diesel/electric driveline has the same advantages as diesel but is generally more reliable and requires less maintenance. The diesel/electric has also seen the introduction of hybrid designs much in the same way as cars, allowing a considerably smaller engine with batteries or super capacitors supplying peak load capacity.

New battery technology allows the engine to be sized for average power, whereas the use of the lower energy storage super capacitors requires a larger engine sized for maximum peak demand. These designs also feature regenerative energy systems to convert braking and spreader lowering energy into electric power that is stored for later use. An automated stop-start system chooses the optimal balance between engine and battery power, which also extends the operational life of engine and generator, as well as maintenance intervals.

Consuming up to 40% less fuel than existing shuttle carriers on the market, Kalmar hybrid shuttle carriers with lithium batteries emit over 50 tons less CO₂ per year than a traditional diesel unit.

” As environmental legislation becomes more stringent, electric driveline with batteries is the only alternative.

4. WHY FULLY ELECTRIC?

While hybrid systems provide excellent economy and reduced emissions, the ultimate target is an emission-free (at least at the point of use) horizontal transport solution. As environmental legislation becomes more stringent for CO₂ and NO_x, especially the latter, electric driveline with batteries is the only alternative. As well as no emissions to the atmosphere, other advantages include less noise, reduced maintenance with a smaller number of vehicle components and up to 50% increased energy efficiency compared to diesel/electric driveline.

5. THE FULLY ELECTRIC AGV

Since the first installation in 2013, the current commercial usage of electric AGVs has been possibly limited by the increased investment cost in the necessary batteries and charging facilities. Using lead-acid battery technology, these AGVs require almost 10 tons of batteries to provide a useful operational working time of eight hours. The actual running time is considerably less. One study quotes a moving ratio of 40% and an operational stoppage or unpowered waiting time of 60%, implying that for 36 minutes of each hour the AGV is non-productive. Recharging requires removal and replacement of the battery, which although fully automated requires the AGV to be driven to the exchange station and remain inactive while the battery is replaced.

As recharging takes at least six hours, at least three battery packs are required for two AGVs. For example, at an all-electric installation in Rotterdam, a total of 87 battery packs were initially supplied for 37 electric lift AGVs with two robotic battery exchange stations. Development of the all-electric AGV required a redesign of the vehicle chassis to accommodate the weight of the batteries and distribute the load uniformly to all four wheels. Newer designs based on fast charge battery technology have been announced, but at the time of writing, details of actual operation and charging methods have not been disclosed.

6. NEW TECHNOLOGY BATTERY

Lithium-ion (Li-ion) battery technology, first proposed in the 1970s, today powers everything from phones and personal computers to electric cars and buses. Li-ion development has been rapid and, unlike its 150 year old lead-acid counterpart, has seen a steady progression in performance and capacity with recent developments providing the advantage of extremely fast charging.

Opportunity charging in public transportation, such as large capacity electric buses, uses the high-charging capability to partly recharge the battery in as little as 15 seconds while passengers are alighting and boarding at bus stops.

Compared to lead-acid, these batteries offer up to 80% weight savings for the same capacity and have a much better low-temperature performance with 80% of full capacity still available at minus 30°C. In addition to the enhanced efficiency and energy-conserving qualities of Li-ion batteries, this technology offers a high level of safety compared to alternative options. Being entirely free of carbon they avoid thermal runaway or overheating, which is a main cause of fires in traditional energy storage systems.

” The higher cost of lithium-ion batteries is partially offset due to the fewer number of vehicles required.

The higher cost of lithium-ion batteries when using a fully decoupled shuttle operation is partially offset due to the fewer number of vehicles required compared to the partially decoupled operation with AGVs. Whether using a battery changing station or fast charge technology, twice as many AGVs are still required to achieve the same moves per hour capability of the shuttle. One manufacturer has announced the use of Li-ion batteries in a terminal trailer concept and promises a run time of 12 hours. However, the battery then has to be charged for 2.5 hours during which time the vehicle is non-productive.

” The Kalmar FastCharge shuttle and straddle carrier offer a truly flexible concept for existing and greenfield terminals.

7. THE ELECTRIC POWERED KALMAR FASTCHARGE™ SHUTTLE AND STRADDLE CARRIER

Freed from the lead-acid six to eight hour charge cycle, the lighter fast charge batteries have allowed Kalmar to replace the diesel engines in shuttle and straddle carriers without a weight penalty, offering tremendous advantages in the practicality of an existing vehicle design.

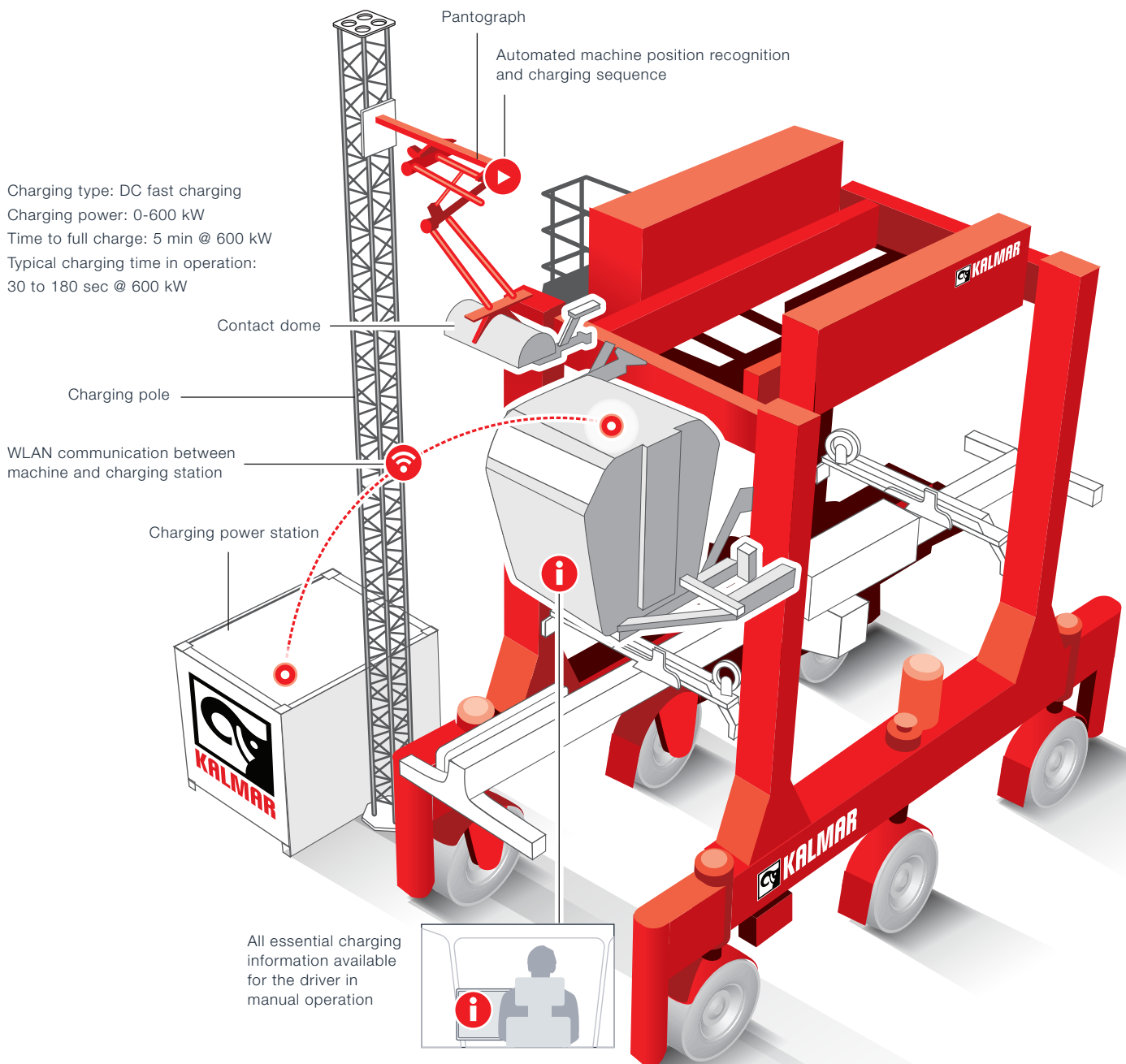
Experience of the batteries already utilised in Kalmar’s hybrid straddle carrier have enabled engineers to optimise battery capacity and onboard charging is supplemented by regenerative systems to store reclaimed braking and spreader lowering energy.

Available in both manually operated and automated versions, the Kalmar FastCharge shuttle and straddle carrier offer a truly flexible concept for existing and greenfield terminals. In hybrid terminals, where ASCs are being partially introduced, they offer the unique opportunity for gradual expansion while retaining fully decoupled container transfers.

When modernising the terminal with automation increasingly taken into use, existing manual shuttles and straddle carriers can be fully automated leading to improved return on original investment and optimised total cost of ownership.

Kalmar FastCharge™ Solution

Charging type: DC fast charging
Charging power: 0-600 kW
Time to full charge: 5 min @ 600 kW
Typical charging time in operation:
30 to 180 sec @ 600 kW



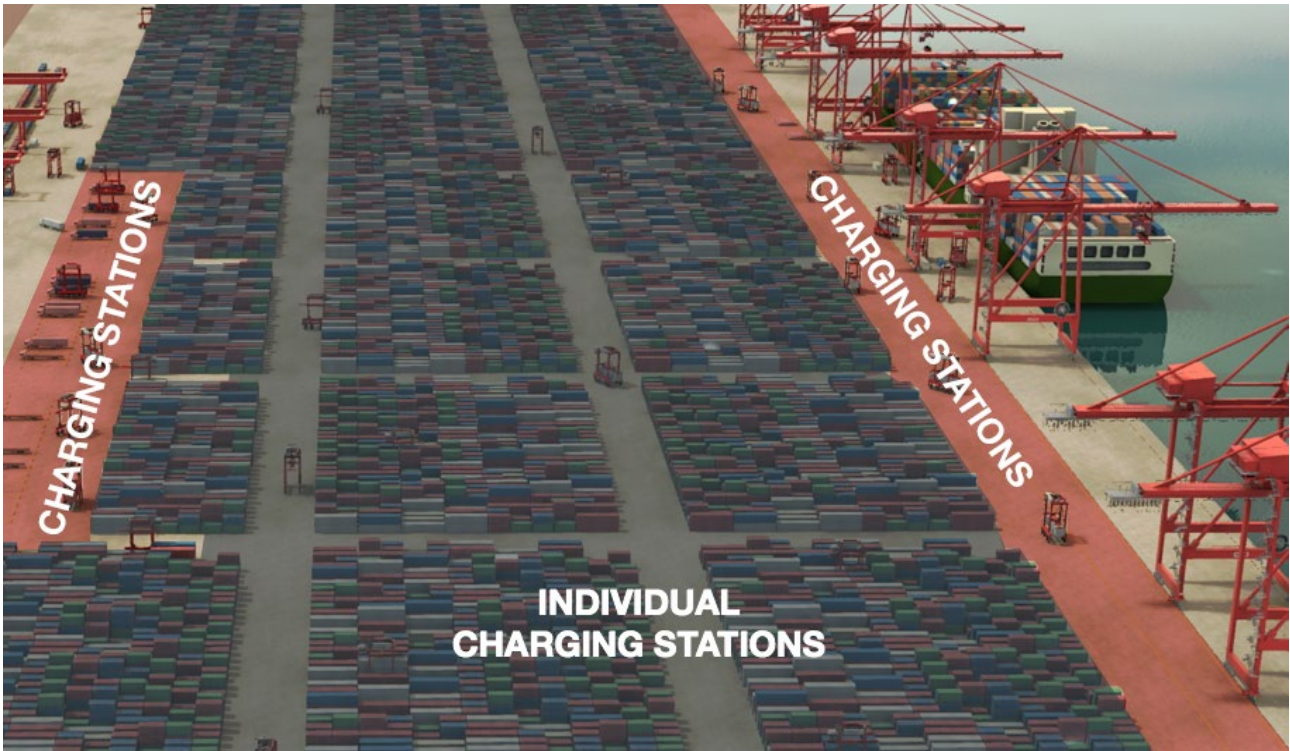


Fast charging stations can be installed along the shuttle working route in order to utilize idle time for charging.

8. FAST CHARGING

Battery charging of the Kalmar FastCharge AutoShuttle is achieved with an inverted pantograph direct current charging system, fully automated in operation and similar to the system in use on electric buses. Location of the current collector on top of the shuttle adds to the safety of the solution and protects it from damage. This is possibly another reason why Li-ion technology is not used in AGVs, as on-board charging would usually be at ground level and very difficult to reliably automate.

Non-contact methods such as inductive charging have also been investigated but are unable to deliver the power required without considerable energy loss. The fast charge battery technology makes it possible to utilise very high charging rates, which by being scalable up to 600 kW allow rapid on-board charging. One pantograph located









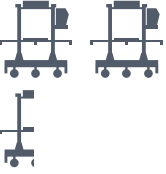
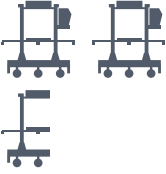

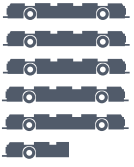


In the straddle carrier terminal there is high flexibility in charging station installation.

on the FastCharge shuttle carrier route can serve several vehicles as charging is very flexible. Since the driving cycles are short, frequent thirty-second charging periods, depending on the shuttle cycle and state of battery charge, do not slow down container transfers and enable the vehicle to be utilised to its maximum effectiveness.

The impact of fast charging to the local power grid, in terms of electricity quality, is minimised with an intelligent charging system control. This more frequent charging avoids the deep discharge, which can shorten the life of any battery. Pantograph charging stations can also be more easily positioned than battery exchange stations, with convenient locations on shuttle routes to eliminate disruption of the shuttle work cycle.

” One pantograph on the working route can serve several vehicles as charging is flexible.

	Terminal A (Europe)	Terminal B (Europe)	Terminal C (Americas)	Terminal D (Europe)
	 x 11	 x 8	 x 8	 x 15
	 x 26	 x 22	 x 27	 x 84
	 Ratio 2.4	 Ratio 2.8	 Ratio 3.4	 Ratio 5.6
<i>Note!</i> On some terminals shuttle carriers are used in land side operations as well.				

Terminal E (Europe)

Terminal F (Americas)



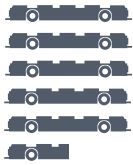
x 11

x 14



x 62

x 72



Ratio

5.6

Ratio

5.1

9. ELECTRIC AGV AND FASTCHARGE AUTOSHUTTLE CONCEPT COMPARISONS

As previously described, in most terminals one FastCharge AutoShuttle is capable of virtually the same productivity as two AGVs. The reduction in vehicle numbers compensates for the higher initial cost of the FastCharge solution with additional savings when the AGV charging stations are taken into account.

The AGV is very dependent on the trouble-free operation of the robotic charging station, which typically dictates a second station to provide a degree of redundancy. Owing to the weight of batteries involved, the battery change/charging station requires very substantial foundations, which may also dictate a less than ideal location with increased travel time for charging. The FastCharge charging station requires considerably less space and several of them can be conveniently located on regularly used routes. Compared to a lead-acid robotic battery exchange and charging station for 30 AGVs, the cost of the FastCharge station for 15 equally productive shuttles is approximately 80% less when building costs are included.

Practicality is another area in which the FastCharge AutoShuttle scores highly by using a tried and trusted vehicle design. Unlike the AGV, where the vehicle was designed around the battery, tried and proven features of the diesel/electric and battery assisted hybrid shuttle carriers were used in the development of the FastCharge model. As well as shortening development time, this allowed Kalmar engineers to concentrate on the new technology aspects and avoid redesign of the whole concept.

Battery lifetime is a serious consideration in the purchase of any electric vehicle. Typically, battery manufacturers quote lifetime in cycles. For lead-acid deep cycle batteries this equates to between 400 and 800 cycles, depending on the degree of discharge. One AGV manufacturer promises 1,200 cycles, with the recommendation that the almost 10 tons of battery per AGV is replaced every 2.5 years. By comparison, fast charge battery manufacturers quote as many as 20,000 cycles, which, with the increased frequency pantograph charging method, conservatively equates to a more than 10-year battery lifetime in the FastCharge solution.

Space, in terms of real estate, is an expensive resource in both new and expanding terminals. The increased manoeuvrability of the AutoShuttle allows for higher productivity and maximum land usage. The layout of an AGV equipped terminal is specifically designed with waiting bays on the apron to ensure a sufficient number of AGVs to maintain STS crane productivity. AutoShuttles do not require such spaces or waiting time and, in addition, the smaller fleet of vehicles required reduces traffic congestion.

10. CONCLUSION

When selecting a horizontal transportation solution for the modern container terminal, the choice to convert to an all-electric solution needs careful consideration. When calculating the total cost of ownership, many new factors need to be taken into account, as well as old criteria, such as the type and number of vehicles, which can take on a new meaning in the green terminal. Improving throughput by decoupling ship-to-shore and yard operations reduces operational compromise and allows each type of equipment to operate at its own optimum speed and best performance.

The new battery technology described, only recently applicable to industrial applications, is under rapid development helped in part by its ready acceptance in public transportation.

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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.