COFASTRANS (Container Vessel Fast Transhipment System)

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ABSTRACT

This paper picks up from earlier research (Beckett Rankine, 2015) and considers a new port layout that will enable faster loading and unloading of containers at the quayside, particularly for the new largest container vessels. The concept is novel and yet practical, using indented berths with innovative ship-to-shore overhead portal cranes. The efficiency of COFASTRANS is built from adaptation of the latest container handling techniques combined with large crane technology from the shipbuilding industry as well as vessel navigation in confined waters, such as seen at the Panama Canal.

Key Words: Container Handling, Mega Ships, Container Terminal, Ship to Shore, Indented Berth

1 INTRODUCTION

1.1 A Revolution of Disruptive Development

New and very much larger container vessels have recently been introduced on the world's main shipping routes to increase efficiency and to bring down costs. This requires faster unloading at ports, but even with new larger cranes the bigger ships cannot be unloaded any quicker because their greater width means having to move faster just to unload at the same speed as before. Ports have simply grown by evolution into much larger versions of the same concept and have now been left behind in the challenge to provide a more efficient, faster and more environmentally friendly link in the supply chain.

Figure 1: COFASTRANS Indented Berth Concept

COFASTRANS, seen in Figure 1, solves this problem by positioning the ship, which is the biggest and most valuable single element in the overall terminal delivery system, at the heart of the central working area, surrounded by port operations with direct access to the shoreside container stacks on both sides of the ship. This compares with the conventional arrangement where vessels are at the periphery and restricted to access over only one side. The indented berth layout opens the way to relieve the quayside congestion that has been building up in recent years, providing twice the area available for landing and loading containers to the ship. The innovative new portal crane (Konecranes 2018, Nevsimal 2018) makes this possible and, with 4 hooks per crane, places up to double the number of lifting spreaders over the ship, with the average trolley travel distance over the vessels halved. This will result in 35-45% reduction in average ship time in port, as well as improved land utilisation, often in environmentally sensitive areas.

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2 WORLDWIDE CONTAINER SHIPPING

2.1 World Trade

Seaborne container trade has increased dramatically since introduction over 50 years ago and until recently the global supply chain has worked well in a mature stability with well-balanced vessel and port dimensions. Apart from the global downturn correction, world container growth has been consistently positive, typically tracking or beating world GDP and related trade growth, as seen in Figure 2.

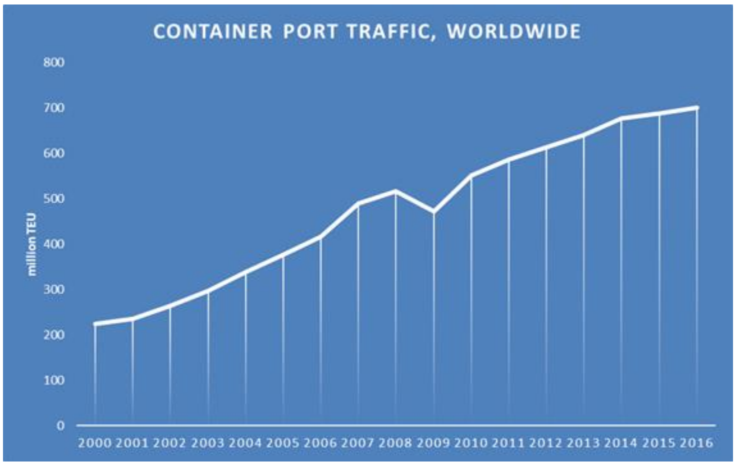

Figure 2: Container Port Traffic (UNCTAD, 2018)

This has meant that ports have consistently been required to invest in additional berthing and land areas and to employ increasingly sophisticated cargo handling equipment to meet demand.

A parallel pattern for ship owners has meant steadily increasing vessel size and the continual search for the fastest possible handling performance in order to keep vessel time in port to a minimum. These larger vessels demand longer berths and bigger ship-to-shore cranes. They have brought inefficiencies that have made some question the benefits of the mega carriers that were intended to improve things.

2.2 Container Supply Chain

The port's role is as a key link in the container supply chain, the ultimate test for which has to be the cost and time taken for the containers' full journey, extending well beyond the port gates. The overall pattern is complex, with regular shipping schedules required for "just-in-time" logistics, empty containers to be returned and a variable mix of 20ft / 40ft containers. Commercial considerations will drive the many options for vessel size and choice of transhipment through major port hubs or direct calls between smaller ports.

As various elements of the supply chain are improved, bottlenecks are created elsewhere, which must be overcome for the full benefits of these improvements to be realised. Recently the shippers have driven the trend for larger ships to make their operations more efficient, and the port operators have had to play catch up to keep their place at the table. But with quayside cargo handling rates not improving as much as shippers would have liked, the benefits to the shipping lines are limited, which in itself has not helped the terminal operators.

2.3 Container Vessels

In the early days of container shipping the vessels evolved from conventional cargo vessels that could sail the oceans and visit ports with few restrictions. Now they have developed into 400 metre long Ultra Large Container Vessels (ULCVs), with a Maersk fleet of 20No. 18,000TEU Triple E class vessels ordered in 2011, only to be followed by further increases to 19,380TEU capacity now being constructed. Other fleets now include vessels of over 20,000TEU eg OOCL Hong Kong with a capacity of 21,413TEU and similar principal dimensions. And even larger vessels can be expected, see Figure 3.

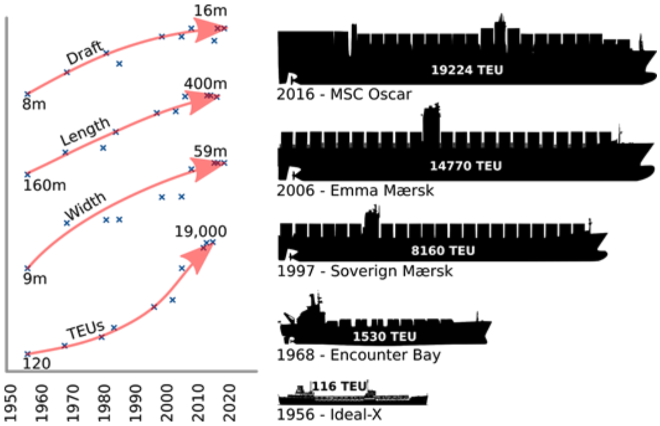

Figure 3: Chart of Vessels vs Year

Cargo handling equipment in ports can also be a restriction to the vessel size, especially on the beam. The largest vessels might be more efficient for the shipping lines, but to meet their profit targets the shipping lines need reduced time in port, which is not possible to achieve with conventional shoreside cranes. If the restriction on vessel beam imposed by conventional port cranes could be lifted, the next generation of vessels could be more efficient with possible benefits of reduced fuel consumption and shallower draughts.

2.4 Container Ports

Other than progressive development, there has been no disruptive innovation in ship-to-shore container handling since the start of containerisation in the 1960's, despite pressure from the large international shipping lines. Since the early days of containers, the recognised approach has been to construct long straight lines of berths. Development has been evolutionary within the framework of the same old layout with a longer line of berths resulting in the larger ports extending for more than 5km over a narrow coastal strip. Such distances can make operations difficult and, impressive as the new cranes are, the longer 60-72m cantilever booms over the ship inevitably need faster equipment just to be on par with the cargo handling speeds attained by the cranes on smaller vessels, never mind the increase in productivity that is sought. The pros and cons of this typical layout are outlined in Table 1.

Arrival of the new mega vessels has been problematic for the ports with a need to invest heavily just to make provision for handling these vessels and avoid loss of trade to competitors. But the sudden deluge of containers from a single ship creates more congestion with peaks and troughs in workload and equipment requirements that are difficult to handle with conventional arrangements.

Advantages	Disadvantages
Flexibility to berth various sizes	Operational inefficiencies
Maximise utilisation of cranes	Environmental and permitting viewpoint

Table 1: Conventional Berths

Looking at the largest 100 container ports (Figure 4) a general growth can be seen globally, albeit more significant in locations strategically important to the global supply train (Figure 5).

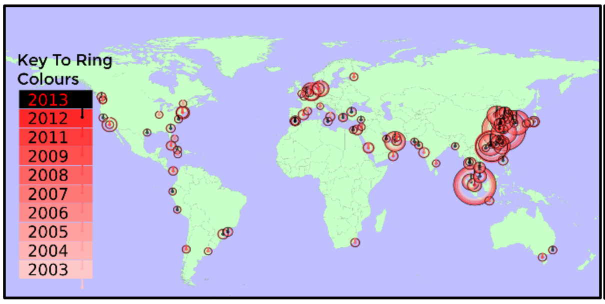

Figure 4: Largest Container Ports

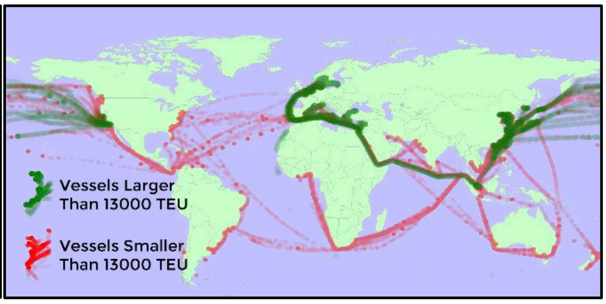

Figure 5: Global Trade Routes

3 ADVANCES IN CONTAINER HANDLING

3.1 Ship-to-Shore Cranes

Successive increases in vessel beam has meant that the ship to shore gantry (SSG) cranes, as seen in Figure 6 have correspondingly longer and higher booms (dimensions in metres). This has required progressive increases in the structures and weight of the cranes and also demands higher trolley speeds to maintain the overall throughput rates. With the present crane technology and berth arrangements, most ports find that 6 or 7 cranes are the maximum that can be operated efficiently on a single ship, with some ports able to deploy 8 or 9 cranes for some time over the largest vessels.

	1970	1995	2002	2013	2018
Outreach	37	54	67	72	72
Backreach	15	20	25	25	
Lift Height +	25	38	41	52	55
Lift Height -	10	14	17	17	

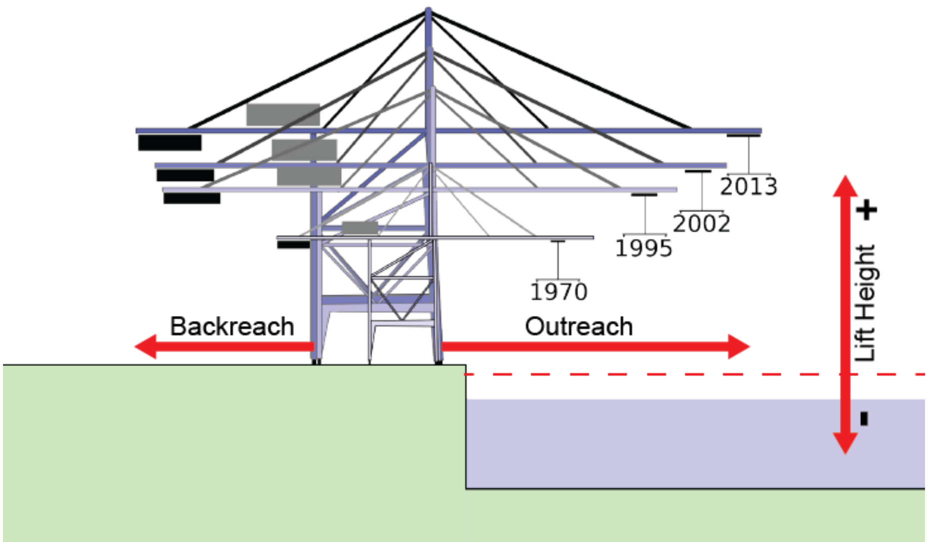

Figure 6: Evolution of Container Cranes

But the original SSG concept is inherently inefficient in two respects: firstly, reaching out to pick up a heavy object using a cantilever means that additional weight has to be placed on the other side to prevent the crane from toppling over, adding to the crane's wheel loads and consequently the need for stronger foundations (see Figure 7 below). Secondly, the further out the crane has to reach the longer it will take to get there, making it slower to handle the bigger ships at a time when the industry is looking to reduce ship time in port.

It has been possible to overcome these problems with larger foundations and greater operating speeds that are now at a practical limit. But as the cranes become ever larger we are facing up to diminishing returns that might not have been widely expected with the advent of the mega ships.

3.2 Quayside Construction

The gauge between crane rails has widened to be generally 30m for modern SSG cranes, the wheel loads have increased with bigger cranes and the dynamic variation in these loads has also increased with the bigger transient loads caused by twin and tandem container lifting.

As can be seen in Figure 7, crane outreach over the vessel (blue) has grown, but this has been linear or at a slightly reducing rate since 1950, following the trend of vessel beam described earlier. And yet leg load (red) is growing at an increasing rate, due to the increase in container loading (twin lifts etc) but also compounded by the cantilever format of the conventional SSG cranes, and associated need for additional counterweights.

This increase in leg load is causing problems for port design engineers in providing adequate and yet efficient foundations for the crane rails, often with construction in poor ground conditions. This is also to be combined with the large retained height of the quayside associated with modern vessel draughts. A reduction in this crane leg load could offer savings on capital cost of civil works.

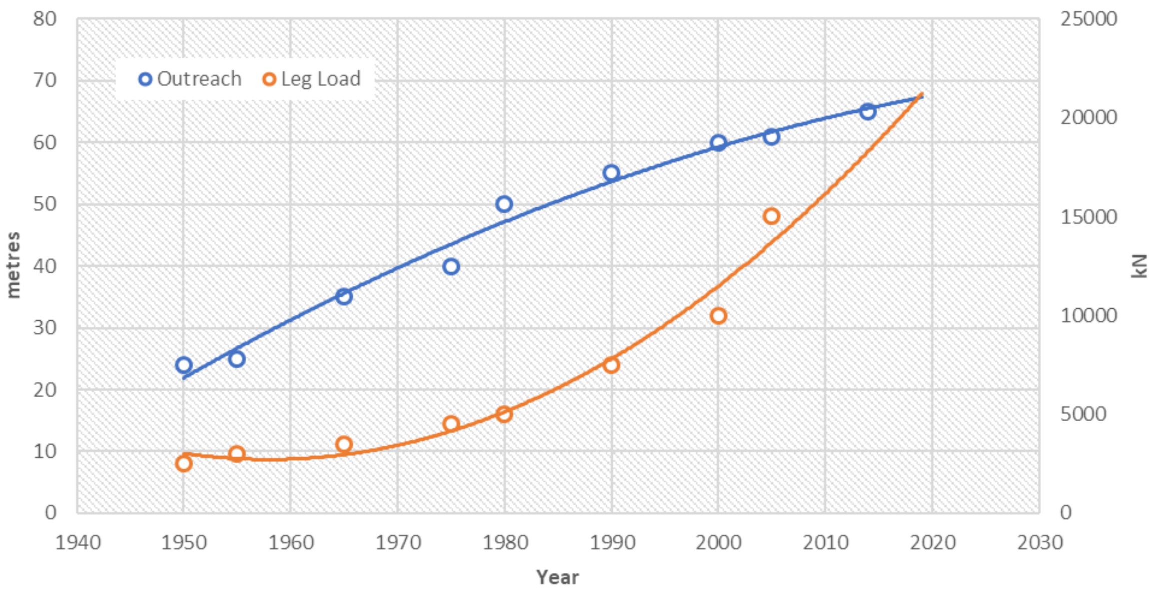

Figure 7: SSG Outreach and Leg Load (data source: de Gijt, 2010)

3.3 New Ideas

Some attempts have been made to change the status quo. A simple indented berth was operated successfully between 2006 and 2008 at the Ceres Paragon (latterly the Amsterdam Container Terminal (ACT)). But as conventional gantry cranes were used from both sides, the interference between cranes inevitably resulted in inefficient utilisation. Further, the berth was never able to demonstrate its full potential because it was accessible only through restricted-tidal locks and close to Rotterdam, which made it a less desirable destination.

Research around this concept continued (Rankine, 1998, 1999, 2000, 2001) exploring various indented berth layouts for the largest ships at that time. Associated work linked this to development of concepts for multi-storey container warehouse systems.

Presumably in response to Maersk's request that a step-change was needed in container handling for the new larger vessels, APM Terminals have spent much time preparing new ideas, including a new concept called Fastnet with narrower cranes intended to enable a greater number of individual cranes to work simultaneously on a vessel. But this was found to be over complicated and has not been adopted.

In 2013, The Maritime and Port Authority of Singapore set a challenge to create a new idea for container handling based broadly on their planned new container port for the 2020's. The winning team focused largely on creating a double height stacking yard on-shore using conventional cantilever ship-to-shore cranes fitted with double-hoist systems to serve both upper and lower levels. It will be interesting to see how this turns out.

Port layouts are still being developed by looking back over the successes of the last 50 years, but the next step cannot be made with normal port layouts and conventional ship-to-shore equipment that have reached full maturity. The basic geometry needs to be re-assessed to create greater efficiency with a view forward to the next 50 years.

4 COFASTRANS - INDENTED BERTHS

4.1 General Description

COFASTRANS is a system for loading and unloading large container ships in international container ports using an innovative portal crane and indented berth, instead of the existing cantilever cranes and long straight line berths. The objective is to substantially improve the efficiency of container transportation in terms of time, cost and environmental impact.

The ship is central to the working area with cargo handled over both sides (as seen in Figure 8), cutting in half any congestion at the quayside. The new portal cranes have been designed so that each crane can line up and address two rows of on-ship containers simultaneously, with each row being serviced by two trolleys. This can double the number of lifting hooks over the ship and reduces the outreach distance by half. Shipping companies have been calling for 250 berth moves per hour (up from about 150 at present) and no current system can get close (Davidson, 2015). COFASTRANS can exceed 250 and also uses less seafront land.

Figure 8: COFASTRANS puts the Vessel at the Heart of the Terminal

With a conventional layout an equivalent port expansion would involve taking a greater length of coastal strip, installing heavier and less efficient cranes and moving containers greater distances between vessel and storage. In contrast COFASTRANS offers port operators a more manageable Mega ship berth arrangement that is equivalent to handling two vessels of half the size using the conventional system. It also removes the in-port vessel width restriction for shipping lines as they seek to further expand their vessel sizes.

Both key elements to COFASTRANS have a tried and tested pedigree from use in other applications and are being used here in an innovative way. The crane has evolved from the latest technology of large shipyard cranes (Nevsimal 2009, 2013, 2017), and the indented berth has evolved from dock and lock entrances. COFASTRANS has been designed to be flexible and versatile so that it can be slotted into existing terminals as well as into plans for new ports. It is compatible and can be used in conjunction with all forms of onshore container handling equipment.

COFASTRANS will offer expansion opportunities for port operators and attract shipping lines to ports that introduce the system because of the significantly reduced vessel time in port.

4.2 New Bespoke Terminal Layouts

COFASTRANS is targeted at the largest international container ports where one or more new berths can augment the existing operation and transform the performance and turnaround time for the largest vessels. New greenfield locations also provide a significant opportunity.

Container ports across the world have very different natural layouts, constraints and requirements, so there are many ways and opportunities for COFASTRANS to be implemented. Each will be different in some way so as to match the operational requirements with the available land and sea conditions.

For this paper, generic information has been distilled and focused on to three arrangements to demonstrate a typical range of layouts that take into account terminal cargo profiles, together with storage and traffic constraints as well as navigational and berthing requirements for the berthing vessels. Clearly any of these layouts will have to be crafted and refined to match commercial and geographical requirements to create an individual bespoke solution that will provide the optimum benefit for any specific terminal, whether it be a single indented berth to enhance an existing heavily invested terminal or a multi indented berth transhipment hub or even an entirely new port. These various types of installation all have the potential to substantially improve efficiency of global container transportation in terms of time, cost and environmental impact on the world's main trading routes.

This concept is all about the introduction of a new layout with a novel crane to enable the change, rather than creating new ways of moving containers around on the ground. There are now many ways of handling containers on-shore and COFASTRANS will work with any of these. Any on-shore container handling equipment and systems that can be applied to a conventional terminal can also be applied to a COFASTRANS layout with correspondingly faster and more efficient results. But it is expected that more development and improvements will be made with increasing use of automation.

4.3 Novel Ship-to-Shore Portal Crane

The concept for the Ship to Shore Portal Crane (SSPC) envisages placing 2 spanning beams with 2 trolleys on each beam over the indented berth to provide 4 independent lifting points per crane (Nevsimal, 2017), as shown in Figure 9, each capable of undertaking a single, twin or tandem lift (i.e. 4 No. TEU or 2 No. 40ft containers side by side). The buffer to buffer length of the cranes will be less than the 53m distance that would allow a maximum of 5 SSPC units to be deployed over a 400m long vessel. However, it is considered more likely that greater efficiency could be achieved by deploying only 3 or 4 SSPC units. In the case of 4 cranes the result will be simultaneous operation of up to 16 spreaders over 8 holds of the vessel. This provides the ability to undertake up to 328 moves /hour on each indented berth assuming only a conservative average of 21 moves per spreader/hour.

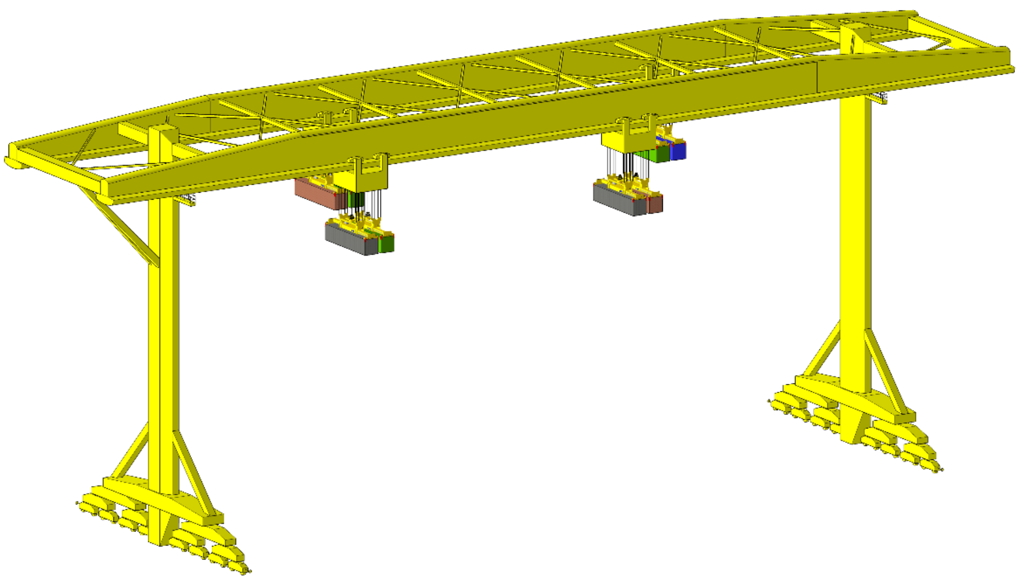

Figure 9: COFASTRANS Ship to Shore Portal Crane

An additional benefit of using a portal crane is that, due to absence of the moment from the eccentric load on the SSG crane, the loads on each runway are significantly reduced and almost equal. Furthermore, the heavily loaded crane rail beams on the jetty superstructure can be located well behind the quay cope line, allowing use of bearing piles only thereby reducing crane beam and runway construction costs.

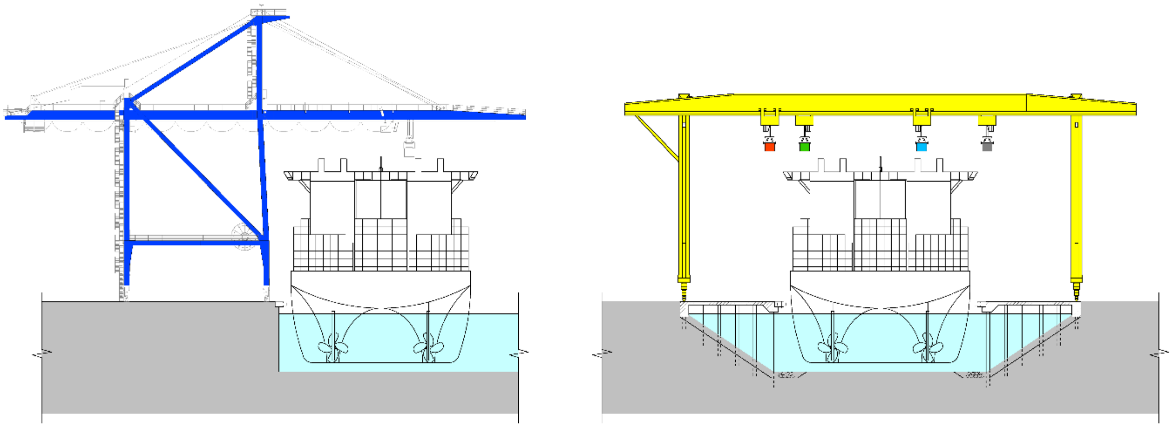

Figure 10: Comparison of SSG and SSPC

The general parameters of the innovative portal crane have been taken as:

- A span between crane rails of 129m, obviating the risk of vessel contact with the crane;
- Two lifting beams set about 30m apart so that each crane works upon 2 non-adjacent vessel holds at once;
- Each lifting beam has 2 trollies operating along it (Trollies will be fitted with proximity switches to ensure that they cannot collide and the hooks can lift eccentrically by a suitable amount to take account of variability of vessel hold spacing);
- With 4 cranes operating, 16 hooks can therefore be used to unload vessels in the indented berth, whereas in standard berths a maximum of 8 hooks can be deployed;
- The cantilevers on each side of the berth will be able to lift containers up to 25m beyond the rail;
- The soffit of the lifting beams needs to be set to clear the largest vessels with the minimum operational draught;
- Trollies will be stored over the quay during berthing;

Operational parameters using twin lift spreaders are taken as:

- Lifting and lowering - Loaded: 90m/min; Unloaded: 180m/min; acceleration: $\pm 0.75 m/sec^2$;
- Trolley transit speed: 125m/min; acceleration: $\pm 0.55 m/sec^2$;
- Gantry travel speed: 30m/min; acceleration $\pm 0.15 m/sec^2$;
- The cranes will be located in advance of the vessel arrival so that unloading operations can commence as soon as the vessel is moored.

It is assumed that the cranes will complete the unloading and loading of each pair of holds before moving to the next adjacent holds and that double cycling is undertaken when possible. With 3 SSPC cranes deployed, the stern-most crane would initially be positioned over the rearmost hold which has been assigned the number 1 and number 3 hold, the crane will complete unloading and loading these then move to holds 2 and 4 and so on. The central crane will start over holds 8 and 10 and the foremost crane over holds 17 and 19. The cranes have sufficient room between them that they can move independently of the others. If dimensions of the funnel and bridge units are the same as the container holds, within the tolerance of the crane boom spacing, then 3 cranes can cover the entire ship each with 3 moves, alternatively 4 cranes can cover it with 2 moves each.

Currently the largest super-post Panamax crane (SPP-SSG) units weigh around 2,500t with an outreach of 72m. It is anticipated that the SSPC crane with lifting hooks spanning 129m would weigh about 20% more than one and cost considerably less than two of these SPP-SSG units.

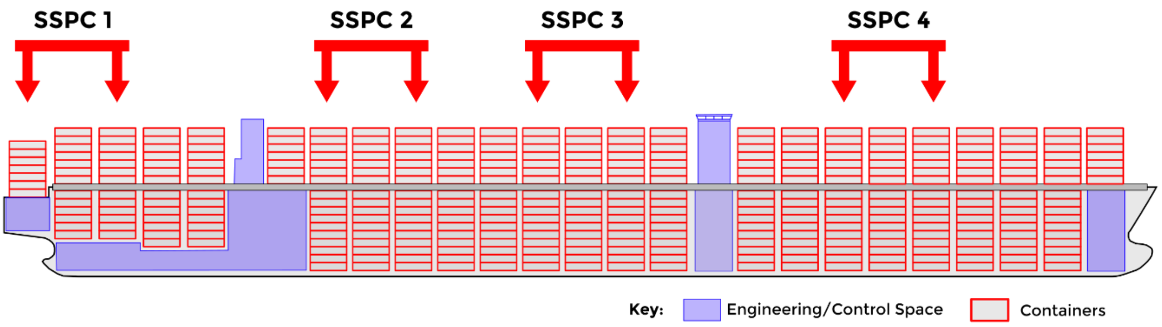

Figure 11: Typical ULVC showing possible SSPC locations

4.4 Intensive Use of Quayside Land

With the ship and indented berth at the heart of the operation, it is important that the berthside container stacks are set up to service the SSPC cranes as efficiently as possible. The concept is that in all cases an envelope is created around the ship that is totally dedicated to transferring containers as quickly as possible between the ship and shore, see Figure12. Clearly when the ship is in the berth, servicing the crane and ship is highest priority with redistribution of containers carried out when possible. When ship handling has been completed and the when the berth is empty the focus would shift to getting everything in place for the next ship.

The berth-side container stacks have to operate with a maximum intensity to service the indented berth. These will be "churning" all the time, moving containers so that their positioning is always being "nudged" and made better for the activities that will be coming up, in accordance with the terminal's operating system and ship loading plans. This would be done even when ship is in, but especially when it is not. This process already happens at modern terminals in existing Automated Stacking Crane (ASC) stacks, but contrasts with the traditional container handling concept of minimising movements within the terminal.

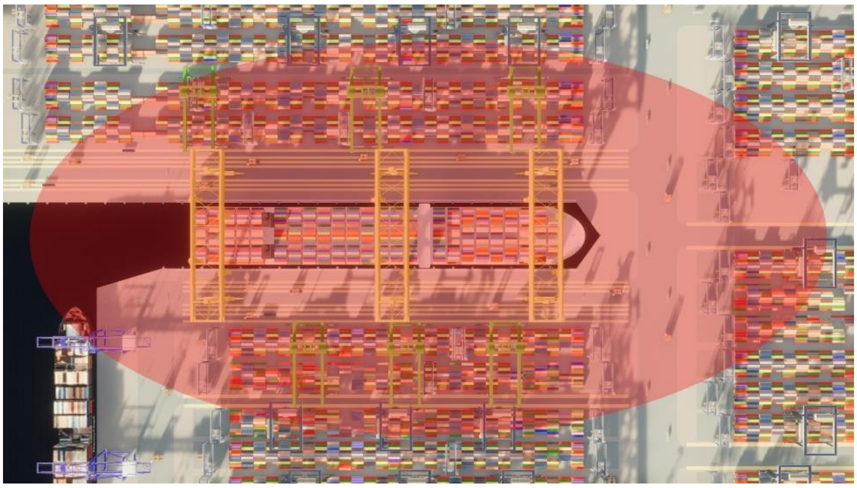

Figure 12: Quayside Zone around an Indented Berth

With COFASTRANS, the ship will always slot into the same position inside the indented berth so shore stack container positions can be pre-determined to suit the vessel length. It is not expected at this stage to transfer directly between vessel and stack because the vessel hold arrangements can differ and are typically more widely spaced than on shore, but means by which this can be achieved are under development. The transfer of containers to and away from the berth will be through ends of the berth-side stacks rather than directly from the ship, thus creating a combined factory style intensive operation encompassing the ship plus shoreside stacks.

It is envisaged that all stacks could be served by ASCs. The intention is that the export containers will be preplaced in the stacks closest to the SSPC crane which will be delivering them to their location on the vessel. The same stacks will also receive all of the import containers from that SSPC crane to reduce the travel distances of the Automated Lift Vehicles (ALVs).

To maximise intensity the berth-side stacks for the “parallel to berth” cases are located in pairs which are also serviced by Automated Rail Mounted Gantry (ARMG) to provide transfer directly to, or close to, the SSG cranes.

4.5 Traffic Circulation and Container Storage

The indented berth layouts have been designed for use with all types of terminal traffic. However there would be some significant differences in the operation for the various types of equipment, as there is at modern present-day terminals. Automation is preferred but manual terminal equipment could also be used. Automated Guided Vehicles (AGVs) or ALVs can be used to transfer containers on the internal roadways.

At this stage ALVs appear to be more efficient with the COFASTRANS concept, taking advantage of the disconnect between the SSPC crane and the pick up or delivery unit.

Traffic circulation at the berth will normally be one-way driving lanes serving the quayside cranes. For most cases a series of circulatory routes will be pre-defined with designated stacks serving each side of each of the cranes in order to minimise potential areas of conflict in road traffic. But there may also be the option to utilise the automated vehicles’ ability to reverse course in some cases.

Transfer of containers to other stacks or feeder vessels would be from the aprons remote from the berth where possible to avoid congestion, especially when this berth is occupied. Typically traffic on a COFASTRANS terminal will have shorter journeys because of the more compact layout compared with elongated conventional terminals, see Figure 13.

Long and narrow conventional terminal
Map data Google, DigitalGlobe

COFASTRANS compact equivalent

Figure 13 Land Use Comparison

4.6 Navigational & Vessel Services

For any indented berth terminal it will be necessary for the largest container vessels to safely and promptly berth in the constrained dock configuration. An initial assessment of requirements was based on information arising from the fendering and configuration of the Panama Canal lock entrances, modelling of the Ceres Paragon (ACT) indented berth and winch arrangements for bringing an aircraft carrier into a dry dock.

Rubber tyred wheel fenders would be located along the length of the dock and a combination of large winches at the head and entrance to the dock and mules on quayside rails will be used to draw the vessel in and assist its departure. To avoid large currents developing as the vessel moves in and out of the dock, the preferred form of quay construction is suspended deck over a revetment slope that will maximise the water area in the cross section. Alternate types of quay wall can be considered depending on the local geotechnical conditions but the width of the indented berth may need to be increased and/or scour protection measures introduced.

Experience from the Ceres Paragon indented berth demonstrated that tugs should be able to control the stern of the vessel within a reasonably sheltered waterway even without a lead-in jetty. However some form of lead-in is preferred to facilitate berthing and the layouts have shown that this can also be beneficial in providing additional near berth container stacking.

For all options:

- Vessels enter the indented berth “bow in” to minimise damage risk to propellers and rudders.
- Bunkering could be undertaken using a small barge moored at the stern of the vessel.
- Provisions can be delivered along a 4m wide 1-way service road immediately adjacent to the quay edge that can also be used as a route for direct delivery of containers to the quayside.

On arrival the incoming vessel will undertake a quarter point berthing with tug assistance against the outer end of the lead-in jetty. Bow lines will then be attached to a hauling system, based on Panama Canal experience as shown in Figure 14, with rails set along the top of the cope line on each side of the indented berth and tugs controlling the stern until the stern lines can be attached to adequately constrain the stern. It is anticipated that the lines will keep the vessel in the centre of the indented berth in a similar way to dry docking but roller fenders on each side will keep the vessel off the cope should conditions keep the vessel alongside. When the vessel is in position additional lines will be deployed to static bollards. The draw in and pull out operations are assumed to be completed within a total of 2 hours.

Because the cranes are already in place and do not need lowering into position, the unloading operation will commence without further delay. The positioning of the vessel during the offloading in the centre of the berth or against the fenders on one side of the dock will depend upon local preference or prevailing conditions.

When the vessel is ready to depart the static lines will be released and the inhaul operation reversed until the bow of the vessel is sufficiently clear of the indented berth entrance that the vessel can safely depart with tug assistance.

Figure 14: Panama Canal Hauling System

4.7 Vessel Improvements

Until now the beam of the vessel has been limited by the outreach of the ship to shore quayside cranes at the destination ports. This has placed a restriction on the vessel designers. The new system decouples the ship from the crane as additional width on an overhead crane is structurally far easier to achieve than on a cantilever, so the berth can be made wide enough even to allow for future larger ships. This gives freedom to naval architects to develop vessels with optimum length / beam / depth to maximise efficiency through the water, improve manoeuvrability or even to adopt wider, shallower profiles for routes with ports that find dredging too costly.

There is much to be done to coordinate the design of the next generation of mega container ships with the indented berth concept to secure even greater benefits for both shippers and port operators.

For example, the SSPC cranes proposed for the indented berth have double lifting beams which will unload alternate holds simultaneously. The efficiency of these cranes will be enhanced if the bridge and funnel structures have the same dimensions as the holds, i.e. if the hold separation is 14.8m then the bridge and funnel upstands should have the same dimension. Also, the position of these elements within the ship should be configured to allow minimum repositioning of the SSPCs during cargo handling. For a full cargo transfer with all holds to be accesed a good configuration would be 4 holds aft, 12 amidships and 8 hold forrard. As the crane height is determined by the highest level of the vessel, a reduction in the height of the bridge and funnel elements would be advantageous.

The position of containers loaded in the holds on arrival is a key driver in efficient handling. This will have to change with the new method of ship handling and compatibility will have to be sought with other terminals on the shipping route that might not yet be operating with indented berths.

5 COFASTRANS - PROOF OF CONCEPT

5.1 Indented Berth Layouts

A COFASTRANS installation might be a completely new all-indented multi-berth terminal or just the addition of a single new indented berth to augment and enhance the ship handling operations for the ULCVs adjacent to an existing terminal, with standard berths handling the smaller feeder vessels using standard SSG cranes. A module could be constructed on reclaimed or redeveloped land to include a single indented berth together with the high-density container storage stacks alongside. Whatever the layout, it is clear that efficient delivery of cargoes to both sides of the vessel has the potential to reduce turnaround times significantly, however this will require a complete re-appraisal of the navigation and landside operations within the terminal.

Many terminal layouts have been considered and reviewed; inevitably some of these have turned out to be more efficient than others. To demonstrate the concept, modular units of the indented berth, complete with the cranes, have been developed along with adjacent container stacking areas either parallel or perpendicular to the berth. Modules have then been assembled into 3 quite different scenarios to represent various contrasting types of terminal operations and these can easily be compared and contrasted with a view to further optimisation at a later stage. Preliminary throughput analysis of all these layouts has just focused on the operation of a single indented berth, because the interactions with the feeder berths and other indented berths would be terminal specific and will have to be assessed on a case by case basis.

It is also recognised that specific local circumstances will have to be used to guide the planning of layouts at particular terminals.

The general parameters have been taken as:

- Width inside indented berth between cope lines of 69m, giving 5m clearance on both sides to the present largest vessels with 59m beam and provide access to vessels with up to 66m width to be accommodated in future (this could be more if needed);
- Roller fenders installed along each side of the indented berth at 30m centres, projecting 500mm beyond cope line;
- Overall length of the indented berth is 490m including a triangular end over last 25m;
- Depending upon the exposure of the site, it is anticipated that, to maintain maximum utilisation, vessels will berth against a 200m long lead-in jetty,
- The portal crane rail gauge can be different but here is taken as 129m;
- It is anticipated that the crane beam support piles will be constructed as a combi or solid wall to retain the filling, with the 30m of suspended deck between the cope and the crane rails formed in order to permit escape of displaced water during the docking procedure;
- For all layouts a deck level of +5mCD has been assumed with high water at +3mCD and low water 0mCD.

It is assumed that vessels entering an indented berth will have been loaded efficiently to minimise the need for repositioning moves. In order to reach the boxes within a hold it is necessary to totally clear the boxes stored on the hatch cover and in an efficient operation all of the boxes on top of a particular hatch cover would be destined for import or transhipment at this terminal. When one hatch has been cleared and the hatch cover removed it is assumed that the columns of boxes will have been loaded so that particular columns hold all boxes for this destination. After one of these columns has been completely unloaded the first of the export boxes can be loaded, and at this stage the double cycling operation for this hold can commence. During double cycling period the unloading and loading will be balanced until the last “import” box is removed after which the single cycling operation will be adopted until the loading operation has been completed for that hold. As each crane is offloading 2 holds simultaneously then the 2 holds should have been unloaded and loaded in such a way that more or less the same number of moves is required for each.

One of the objectives of working the vessel with the SSPC is to completely work the 2 holds under the crane beams until all import containers, both above and below the hatches, are unloaded and the export containers loaded before moving on to the next designated holds.

5.2 Design Vessel

For the purpose of reviewing the effectiveness of the new crane and berth layout the following exemplar ULCV vessel similar to the Marie Maersk shown in Figure 15 has been used with the following assumed parameters:

- Max Capacity 18,270TEU;
- LOA 400 m; LPP. 385m; Beam 59 m;
- Max. Draught 16.5m; Lightest Operational Draught 10.5m; Height above keel 73m;
- Hatch covers are typically 14m x 12.8m.

Figure 15: ULCV

5.3 Conventional Crane Benchmark

On a conventional berth each SPP-SSG occupies a quay length of approximately 30m and, although they can be placed buffer to buffer, a nominal minimum gap of 15m is needed to permit independent adjustment of the crane over the centre of a bay. For a 400m long vessel, the fore-most and aft-most container stacks are spaced by approximately 320m, which means a maximum deployment of 8 SPP-SSG units. However, to allow flexibility it is normal practice for 6 cranes to be deployed on a vessel at major terminals. Each SSG can only put 1 hook over the vessel hold with typically 25, up to a maximum of 35, moves per hour, which, assuming a 6 crane operation might deliver as between 150 and 210 moves/hour of crane operation/berth. Assuming twin lift and an average of 1.6TEU/move, then between 240 and 336TEU/hr/berth may be possible. If we assume 100% exchange for a 19,000TEU vessel, unloading will take a minimum of 2.4 days and loading another 2.4 days. On many of the latest SPP-SSG cranes, tandem-twin lifting (4 TEU) is possible allowing TEU lifting rates to double and, in theory, the time for crane operations to halve. Double cycling, which involves loading and unloading in the same crane cycle, can also increase the handling rate and allowing the move rates to double during these periods.

5.4 Productivity Benchmark

Various handling rates are announced from time to time, for example the ECT Delta Terminal website on 28 October 2014 with 10,557 moves on a single ship with 150 moves per berth per hour of crane operation and on 5 October 2017 APL Tangier Med terminal used 8 Super-post-Panamax cranes on one vessel for 27 hours to perform 7,072 moves (262 moves/hour of crane operation). Inevitably in a competitive marketplace there is a lack of clarity and it is difficult to make direct comparison in performance without a robust benchmark.

JOC research in their 2014 white paper proposed using vessel log data recording the time of arrival and departure, which is referred to as “lines down” and “lines up” (JOC, 2014, 2017). The calculation of moves per hour between these two times is referred to as “unadjusted gross berth productivity” and includes any delays in commencement. Gross moves per hour for a single vessel call is defined as the total container moves (onload, offload and repositioning) divided by the number of hours for which the vessel is at berth. Productivity is defined as the average of the gross moves per hour for each call recorded during the reporting year. The best performing terminals in 2013 achieved an average of 152 gross moves/hour of berth occupancy for vessels larger than 8,000TEU.

In their 2017 paper JOC has sought to extend the port productivity to include berth productivity + waiting time + steam-in (harbour limits, all fast). It reports from 2016 data for the top 30 terminals the average was 1,300 moves in 25 hours which includes 3.6 hours average time waiting before berthing, 1.7 hours for steam-in time/all-fast and 1.0 hour before first container move. With regard to large vessels it records that the average was 2,430 moves which, assuming that these can be completed in the average 15.6 hours with 1 hour before 1st container move, may in 2016 have achieved an average of 146 gross moves/hour for the ULCV vessels excluding the steam in and waiting time.

It is, however, clear that the primary time constraint at the berth lies in the number of crane hooks that can be placed over the vessel and used effectively.

5.5 Layout A - Single Indented Berth

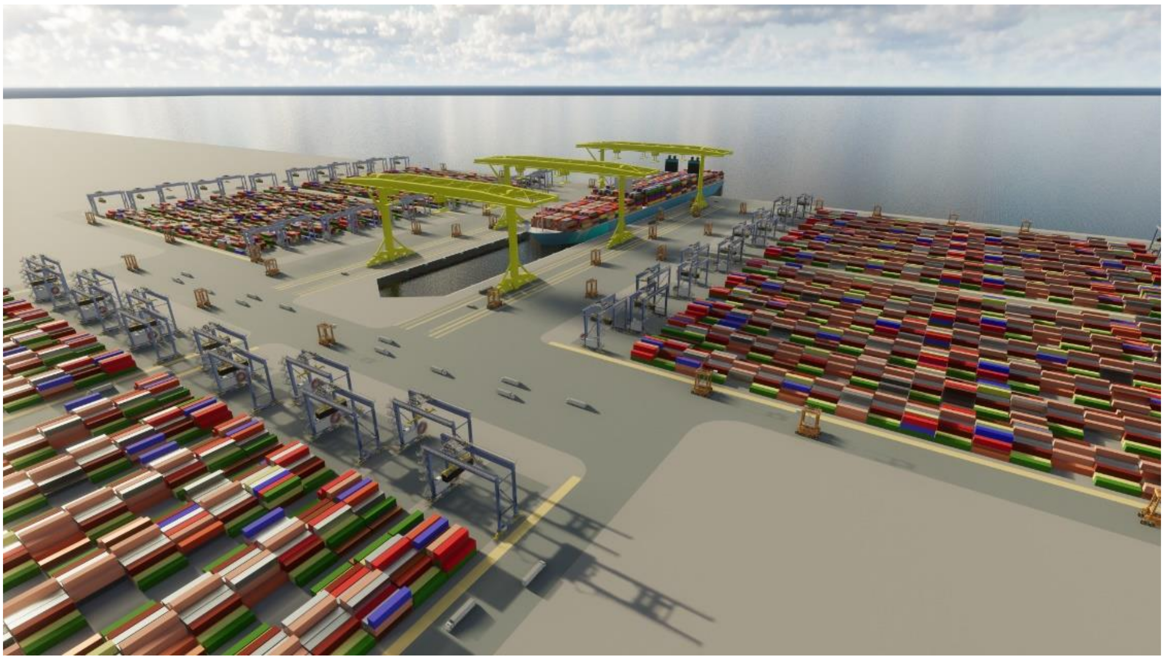

Figure 16: 3D View of Layout A

Here we are presenting the concept in its simplest form. Just one indented berth, as seen in Figure 16, probably installed at a port near to an existing container terminal, but it could be standalone by itself. On each side of the indented berth we have a layout that reflects the best and most modern container terminals, eg London Gateway or Kalifa Port with container stacks set perpendicular to the ship. This could have a high proportion of gate cargo, maybe with some transhipment to nearby terminals via truck transfers. The addition of a single indented berth could transform a terminal forming the first step in a longer-term masterplan development adding additional indented berths as demand increases.

The stacks on each side of the indented berth have a maximum storage capacity of 2,000 TEU per block with the 12 stacks giving a maximum storage of 24,000 TEU for each side. Additional blocks with similar dimensions are provided at the head of the indented berth giving additional storage capacity of 24,000 TEU and a total storage capacity of 72,000TEU for the berth on an overall land area of 72.5Ha.

Each stack has 10 wide by 40 long TEU ground slots (TGS) with the containers stacked 1 over 5 and managed by 2 ASCs working on a 30m rail gauge. Horizontal transport linking these stacks with the berth have been taken as 1 over 1 ALVs. These are 5m wide, so the apron areas on each stack are divided into 4 lanes, each 7m wide, with 4 TGS in each. It is noted that AGVs could also be used and, as these are narrower, 5 lanes could be provided on the aprons.

It is assumed that the arrangement of cargo on the vessel and in the stacks is managed to maximise efficiency of the SSPCs. The container stacks would normally be arranged prior to the arrival of the vessel with the designated export containers in the correct stack for its location on the vessel, and that there are sufficient empty bays to hold the import containers offloaded from the vessel. With 3 SSPCs at the berth, each would have access to 12 aprons and onshore storage capacity of 24,000 TEU/SSPC. In the case of 4 SSPCs, this would be 9 aprons and 18,000 TEU/SSPC.

Two different cargo handling cases have been considered In order to provide an indication of the performance of the Layout. Cargo 1 is an exceptionally large cargo transfer with over 21,000TEU and Cargo 2 is an average cargo transfer of about 4,500TEU (representing the average ULCV 2,430 moves from the JOC 2017 report). Both models assumed twin-lift spreader operation with an allowance of 2% for single TEU lift and SSPC average single cycle time of 140secs and double cycle time of 210secs. A summary is shown in Table 2.

	Cargo 1		*Cargo 2*	
Import	10,459 TEU		2,269 TEU	
Export	10,897 TEU		2,293 TEU	
Double Cycle	62%	62%	0%	0%
Number of SSPCs	3	4	3	4
Crane Operating Time	33 hrs	26 hrs	9.29 hrs	7.42 hrs
Berth Operating Time	35 hrs	27 hrs	11.29 hrs	9.42 hrs
Moves per Crane Operating Hour	327	415	262	328
Moves per Berth Occupancy Hour	299	385	215	258
ALVs required	24	30	24	30

Table 2: Indented Berth Estimated Performance Summary

5.6 Layout B - Indented Berth Pair

This layout, shown in Figure 17 with two indented berths and adjacent conventional berths for feeder vessels, is more complex and looks at maximising the interaction between the ship and the berth side container stacks which are aligned parallel to the berth with aprons at either end. A minimum separation between the indented berths provides adequate space for the required import, transhipment and export stacks.

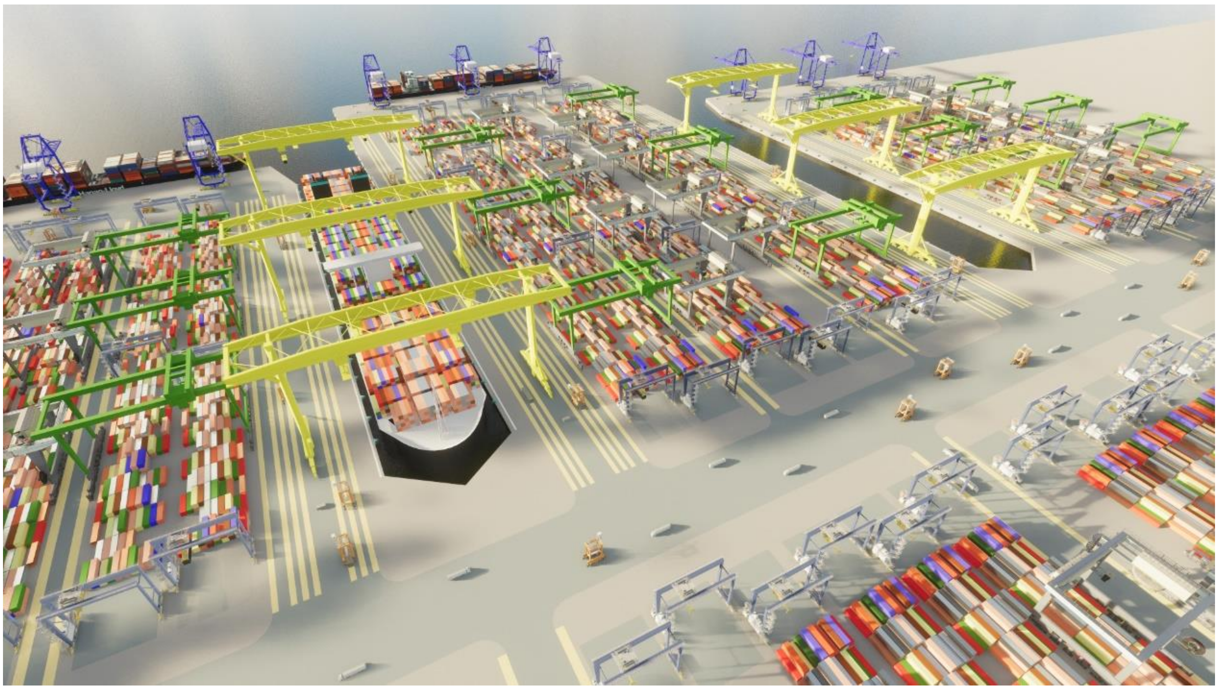

Figure 17: Layout B

The lead in jetty from Layout A has become an extension to one side of the indented berths and feeder vessel berths are provided for post-panamax vessels (7,000TEU with up to 42.5m beam) between the indented berths and for smaller vessels on the other side. All vessels longer than 350m LOA will be accommodated in the indented berths.

In this option the SSPCs spanning the indented berth still have a 129m gauge but, unlike the Layout A, the cantilevers on either side have a lift outreach of 16.6m rather than 25m. This is designed to permit the stacks on either side of the berth to be brought closer to the berth and will provide 3 runway lanes under the cantilevers, giving 6 runway lanes on each side of the berth.

In this case cantilever Rail Mounted Gantry cranes (RMGs) are used over the ASC stacks, working in combination to focus service to the STS cranes. To keep congestion to a minimum up to three different modes of transfer can be enabled. Firstly, the horizontal terminal transport would pick up / deliver from under the cantilever at the stack sides to enable the shortest journeys to the crane pick up zone. Secondly, service can be provided from the ends of the container stacks and the main driving lanes under the cranes. And thirdly in some cases there could be the option of direct transfer provided from RMG to STS crane, thus avoiding the need for some of the horizontal transport units.

This layout would suit a major transhipment terminal with existing terminals close by.

In this example (see Figure 18), the pairs of berthside container stacks served by the ARMG units have a maximum capacity of 5,600 TEU on one side (stacks B8 & B9) and 8,600 TEU on the other (stacks B6 & B7). (This based upon a 1 over 5 arrangement, but consideration could be given to further improvement with a 1 over 6 arrangement on these blocks). As the seaward section of B6 and B7 is primarily for containers on the feeder berth, it is assumed that about 60% of the containers for the indented berth will pass through stacks B6-B9. This means that during the unloading operation import containers will be required to be removed from these stacks and export containers brought in. It will therefore be necessary to provide additional ASCs in these stacks and additional ALVs to move import and export containers between stack B6 to B9 aprons and stack A7 to A12 aprons during the period while the vessel is occupying the indented berth.

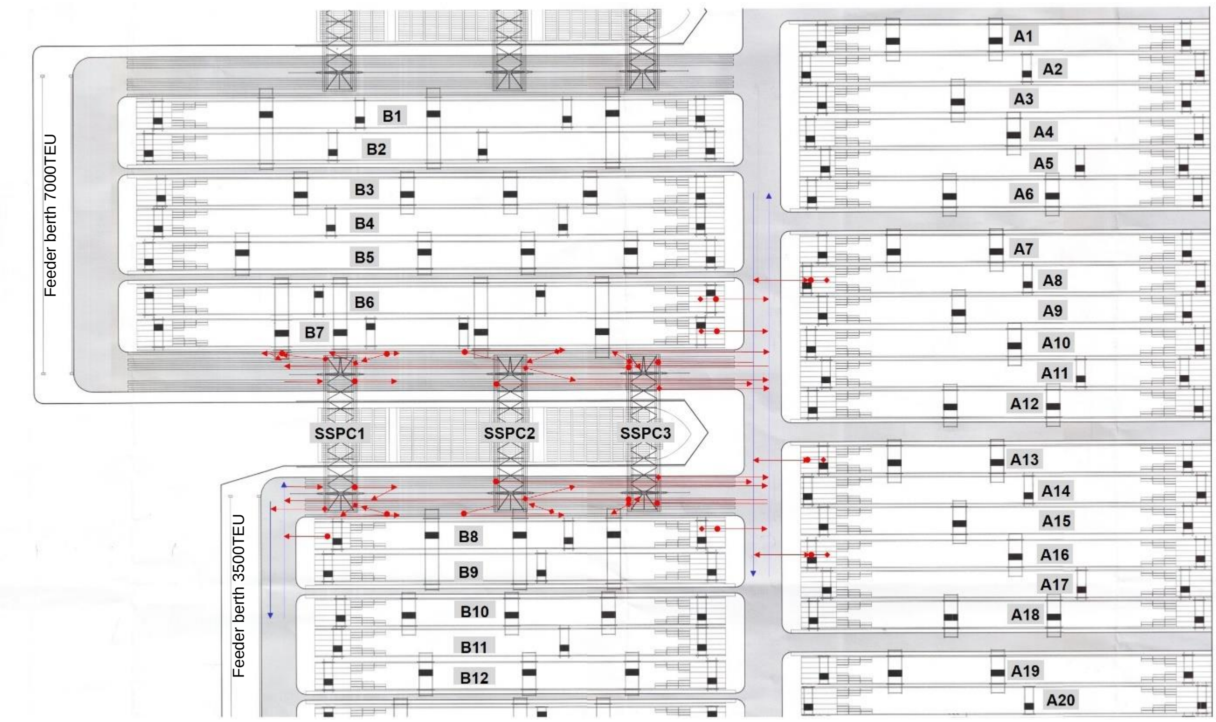

Figure 18: Plan with Indicative Traffic Moves

In order to accommodate the throughput from 3 SSPC cranes this example shows 4 ARMG units over stacks B6 and B7, receiving and delivering containers to/from cranes SSPC 1 and SSPC 2. Only 3 ARMG units will be required over the stacks B8 and B9 to service cranes SSPC1 and SSPC2, because the aprons at the feeder berth end close to SSPC1 can also be used. The SSPC3 crane at the shore end will be serviced from stacks A6 to A18 as for Layout A.

It is envisaged that during single cycle loading or unloading, one ALV will operate between each ARMG and the landing point in the outermost runway lanes of the SSPC1 and SSPC2 units. During double cycling two ALV units could operate a phased circular route, one clockwise and the other counter clockwise, with the 2nd ALV depositing the import containers under the ARMG after the 1st ALV has picked up the export containers from that machine. The 2nd ALV will then move to the 2nd ARMG to collect the next export containers just before the 1st ALV arrives with the import containers collected from the SSPC unit landing point. To separate the routes, the outermost lane will be designated for landing points for export and imports from one ALV and the second lane for the other ALV. A similar circular route is envisaged between the B8 apron and the SSPC1 crane, but may require a 3rd ALV during double cycling. It is assumed that the ARMG cycle times will be close to the shortest cycle times for the SSPC units.

With ship handling performance as Layout A it is estimated that 28 ALVs will be required for 3 SSPCs and 32 ALVs for 4 SSPC.

5.7 Layout C – Multiple Indented Berths

For new very large ports the indented berth pair module can be expanded to provide a highly intensive operation with ship access to both sides of a central core. This would provide a high performance solution for some of the world’s largest container ports of over (say) 20m TEU pa with berths lined up on both sides of a central storage area to facilitate fast transfer between many berths. A central spine road or other form of transfer system would be used to link with the off berth central storage areas.

The layout shown in Figure 19 considers a multi-indented berth terminal with high proportion of transhipment cargo.

Figure 19: 3D View of Layout C

This is likely to be a transhipment hub, but there could be some local import and export with connections to the gate complex central from the main spine road. A modular layout of indented and feeder berths as shown in Layout B is mirrored on each side of this spine roadway. Operation of the berths would be as Layout B, although a stack arrangement similar to Layout A could also be possible.

One feature of this terminal example is that import and export boxes would be taken off or placed upon trucks using an ARMG spanning the central roadway by means of a rotating spreader to help reduce potential congestion. The ARMG will operated along groups of 6 stacks with ASC units from these delivering or removing boxes from the aprons under the cantilevers of the ARMG, then moving away before the ARMG is positioned. Trucks will be loaded/unloaded in runways on either side of the roadway inside the portal legs. Roundabouts will be provided at the cross roads between each group of block stacks to permit the unloaded vehicles to turn. When not required to unload or load vehicles the ARMGs will be used to transfer transhipment containers across the roadway to be adjacent to their allotted berth.

6 COFASTRANS - CONCLUSIONS

6.1 Benefits

Advantages of implementing a COFASTRANS terminal have been outlined above. The resulting benefits will vary from place to place, depending on a multitude of technical, operational and political factors at the designated port location. Here is a summary of the main points:

- Faster turnaround of big ships in port means that fewer ships are needed in the world fleet, resulting in cost and environmental savings.
- A more even traffic distribution can be created during cargo handling with access to both sides of the vessel at the berth, enabling shorter distances to the on-shore container stacks. This results in shorter journeys and fewer horizontal container movers on shore.
- An improved and more compact terminal shape can be created using a mix of indented berths interspersed with conventional berths for smaller vessels. This leads to a more efficient use of coastal land with more cargo throughput achieved in a smaller area.
- Improved safety, especially at the ship / crane interface with the crane leg set back from the quay edge, thus eliminating the risk of ship / crane contact.
- Eliminates the “beam bottleneck”, with options for developing even wider vessels.
- The berthed vessel would be better protected and likely to be less susceptible to motions from wind and hydrodynamic activity such as swell.
- Quayside construction is more efficient with only one crane rail within the structure and smaller loads per spreader.
- Cranes can operate at slower speeds with resulting improved maintenance profile and fatigue life.

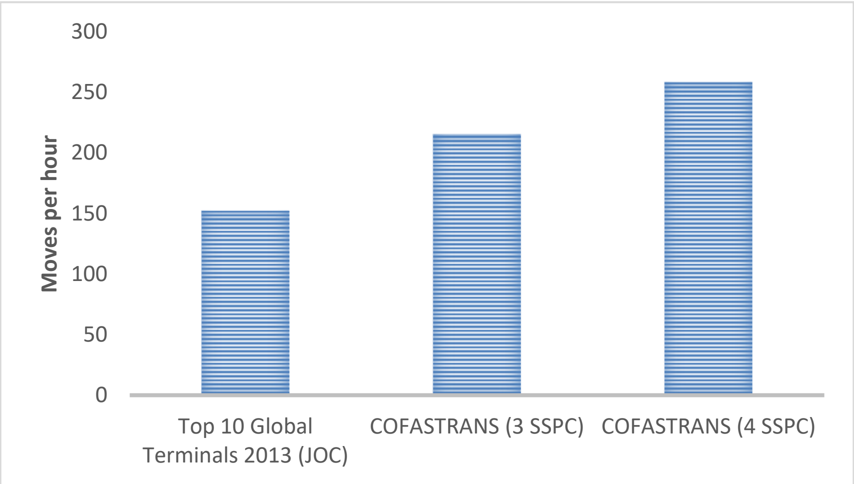

Figure 20: Port Productivity (Refer Section 5.4)

6.2 Challenges

While the benefits are clear, it is recognised that implementation of a COFASTRANS terminal is a major disruptive step. It is not easy to introduce change in a well established industry. The challenges that will be faced will be different across the world, here are some general points:

- This is a significant change in philosophy and will need foresight and confidence to take it to development.
- There is a large initial investment to create the first berth (which can be minimised by selecting the right location).
- Cargo loadplans for vessels will have to be worked out to be compatible with traditional terminal requirements as well.
- Owners of existing terminals that have recently invested heavily and suppliers of conventional equipment will have vested interest in maintaining the status quo.

- Navigation into indented berths may be new for a container vessel crew and will have to be optimised.
- A future proof width to the indented berth will have to be selected before construction.
- The available number of cranes on the berth will be fixed rather than the flexibility of transferring conventional cranes along a straight line berth.

6.3 Opportunities

Implementation of the COFASTRANS system can open up many different opportunities to port operators, shipping lines and wider users of the global container supply chain. Here are some aspects that could be explored further to provide further benefits at various locations:

- An all indented layout could be developed with vessels slotted into known positions.
- By aligning vessels precisely more automated methods for cargo handling can be developed.
- The system would be even more efficient when ships have been built to suit the indented berths.
- The system is a potential game changer in hub / direct call debate because of more efficient and faster loading and unloading of the largest ships.
- This will benefit the increasing number of ports that are in places where growth has become restricted either because of environmental sensitivity of the coastal strip or constraining urban development surrounding the port.
- The system is well suited to further development of double cycling operations.
- Ports with shallow draught restrictions could benefit from wider shallower vessels rather than over dredging.

6.4 Summary

While the concept is novel, it is practical and builds on previous work with adaptations from the latest container handling techniques combined with large crane technology from the shipbuilding industry. There will be challenges to overcome during implementation and making changes to the well-developed container handling industry. But the potential benefits are large, albeit complex to quantify because every port has different geography, historic facilities and customer needs. The COFASTRANS container handling solution addresses the challenge laid down a couple of years ago by the shipping lines on their unexpected introduction of the much larger vessels. A “step-change” was called for with an increase to 250 container moves per crane operation hour at each berth (up from about 150 / 160 at present). While various ideas have been proposed none have so far come close to achieving this aspiration. However COFASTRANS can exceed 300 berth moves per crane operation hour and, by using a more efficient layout, it can occupy a smaller amount of port land.

With more Mega container vessels coming into operation the time is now right for an in-depth discussion on the fundamentals of port layouts for these vessels, as shippers consider placing more orders and port operators seek to gain an advantage over their neighbouring competitors. The COFASTRANS terminal has now been enabled by the introduction of a new patented crane design that will substantially increase efficiency and performance.

Website online at: www.COFASTRANS.com

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