Container ship size and the implications on port call workload

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Abstract: As the TEU capacity of container ships has risen, there has been an increase in the workload experienced by container terminals during a ship call. This study quantifies the changes in berth and quay workload resulting from increased ship size and the impact on ship-to-shore service levels of North European terminals. First trends in TEUs per ship metre length since 1975 are presented, then, accounting for changes in the TEU Ratio, this is converted into ship-to-shore moves to calculate a Berth Workload Index. Given the bay configurations of each ship, a Quay Crane Workload Index is then developed to determine the extent to which terminals have met these changes by deploying additional quay cranes or by improving quay crane performance. The study concludes by examining the impact of Maersk's Triple E Class container ship on the workload of a berth and quay crane.

Keywords: TEU ratio; ship size; container terminal; quay crane; terminal capacity; terminal performance; Panama Canal; ship design; Triple E; berth workload; port call.

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1   Introduction

Since the introduction of containerisation to the North American coastal and short-sea trades in the 1950s, and its subsequent adoption for deep-sea trades from the mid-1960s there have been frequent increases in the TEU capacity of ships (see Figure 1). Initially, shipping lines converted general cargo and tanker ships to carry containers on deck, but in the late 1960s the first purpose built cellular non-geared container ships came into service. Over the next 20 years as new ships were delivered their TEU capacity increased but their length, beam and draft remained within the constraints necessary to allow them to transit the Panama Canal. In the late 1980s the industry saw the introduction of the first post-Panamax container ships with APL's C10 Class ships which had a capacity of 4,340 TEU (Smagghe, 1989). Other shipping lines followed and within ten years over 80 post-Panamax ships had been delivered or were on order. Following a period of stability between 1988 and 1996 a major step change in ship size occurred with the introduction of the Maersk K Class ships, with capacities of over 6,000 TEU. A further step change occurred in 2006 with the introduction of the Maersk E Class ships with capacities of 15,000 TEU.

**Figure 1** Growth in ship TEU capacity 1968–2013
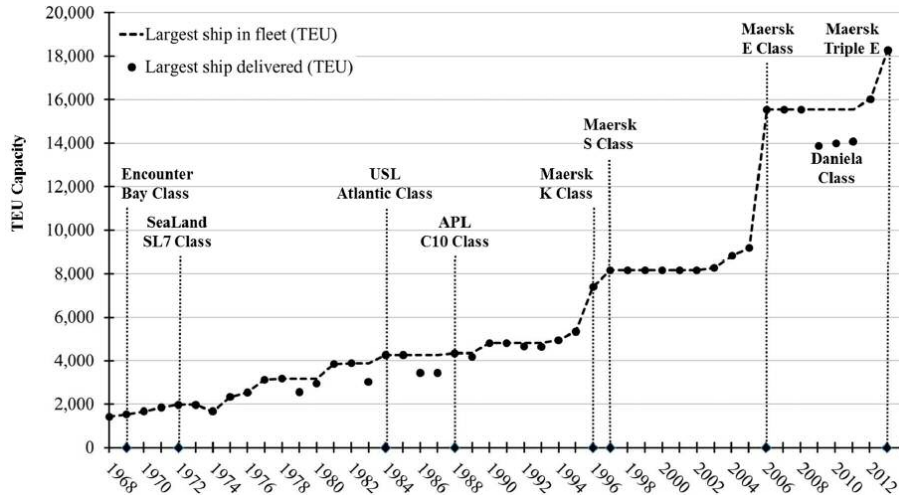
There have been many studies into the operating performance and efficiency of container ports and terminals examining the overall efficiency of capital and infrastructure. These studies have compared variables such as terminal footprint, yard size, quay length and number of quay cranes against total annual throughput volumes (Demirel et al., 2012; Dowd and Leschine, 1990). There is also a growing body of research into the optimisation of resources in terminals with the development of scheduling algorithms to assign berths, schedule quay cranes and to manage the flow of internal transfer equipment using a systems approach (Bichou, 2011; Cheng et al., 2010; Li and Pang, 2011; Stahlbock and Voß, 2008). While published research has acknowledged the increase in container ship size, the extent to which the berth and quay crane workload has increased has not been examined or quantified. This study addresses this issue in two ways. First, by measuring the changing level of ship-to-shore workload through the development of a Berth Workload Index (BWI), the extent of changes in ship-to-shore workload over time is assessed. Then second, an estimate is made of the extent to which the peak workload for quay cranes will have increased between 1975 and 2013. This is measured through the development of a Quay Crane Workload Index (QCWI).

2 Ship dimensions

Until the early 1990s the largest container ships using the Panama Canal were restricted to a beam overall (BOA) of 32.2 metres equivalent to 13 container rows across the beam (Clarkson, 2012) (see Figure 2). Once the beam constraint had been reached further increases in the TEU capacity were only possible by increasing ship length until the maximum length of the Panama Canal locks was reached. This increased the length:beam ratio as naval architects maximising TEU capacity compromised design in terms of water resistance, manoeuvrability and propulsion power, adding to ship construction

and operational costs (Schneekluth and Bertram, 1998). From the mid-1990s post-Panamax container ships became established and ships dimensions were no longer constrained by the Panama Canal. There was a rebalancing of the relationship between TEU capacity and ship dimensions, reducing the length:beam ratio and allowing greater efficiency in construction and operating costs. The impact of this is shown in Figure 3 where the length:beam ratio of post-Panamax ships remains below that of Panamax ships. In 2015, the Panama Canal will be upgraded with a new lock system that will allow ships of 366 m length, 49 m width and 15.2 m draught to pass through the canal system.

Figure 2   Largest ship delivered per year: TEU capacity to BOA and containers across
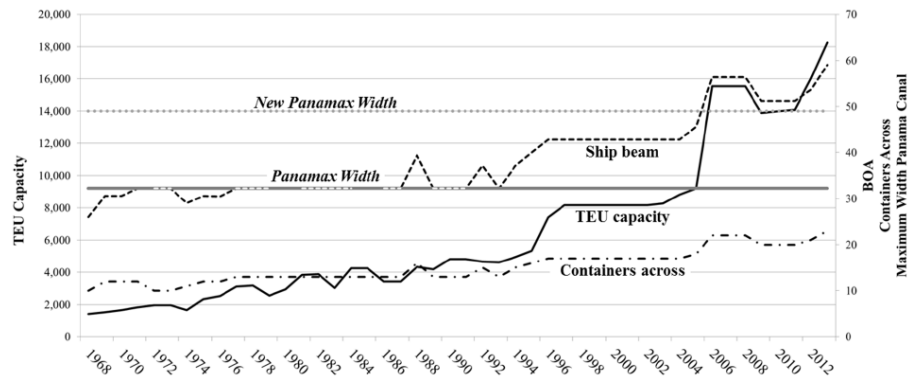
Source: Derived from Clarkson (2012)

Figure 3   Length:beam ratio of largest container ships delivered for each year
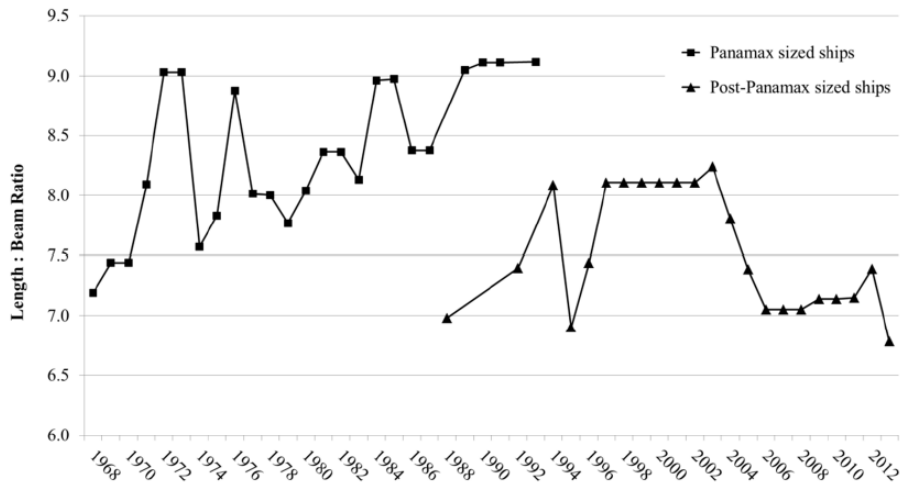
Source: Derived from Clarkson (2012)

The impact of ship dimensions on the workload of terminals can be shown by examining the average number of TEU per metre of ship length. Between 1968 and 1975 container ships, having reached the maximum width of the Panama Canal in 1971, continued to

increase in length rather than width. Thus while ships grew longer and their total TEU capacity increased, the TEU per ship metre length remained constant at about 7 (see Figure 4). From 1976 further increases in ship capacity were achieved through better utilisation of ship space with the length and width of ships remaining unchanged. Between 1976 and 1987, the year prior to the introduction of the C10 Class, the number of TEU per ship metre had increased to 12.7. As a consequence an increase in the number of containers being loaded and unloaded during a port call could no longer be achieved through the use of additional cranes along the length of the ship. Instead improvements in quay crane performance and/or additional ship working time were required. Further improvements were then again required from 1988 to 1994 as the number of TEU per metre of ship length increased to 16.5, before rising to 23.3 in 1996. Finally between 2004 and 2006 the largest increase occurred with the successive introduction of the CMA-CGM Pacific Link, MSC Bruxelles and the Emma Maersk. Over this three year period the TEU capacity of ships increased by 76% from 8,819 TEU to 15,500 TEU and the number of TEU per ship metre length increased by 48%, from 26.4 to 39.1.

Figure 4   TEU per metre of ship length
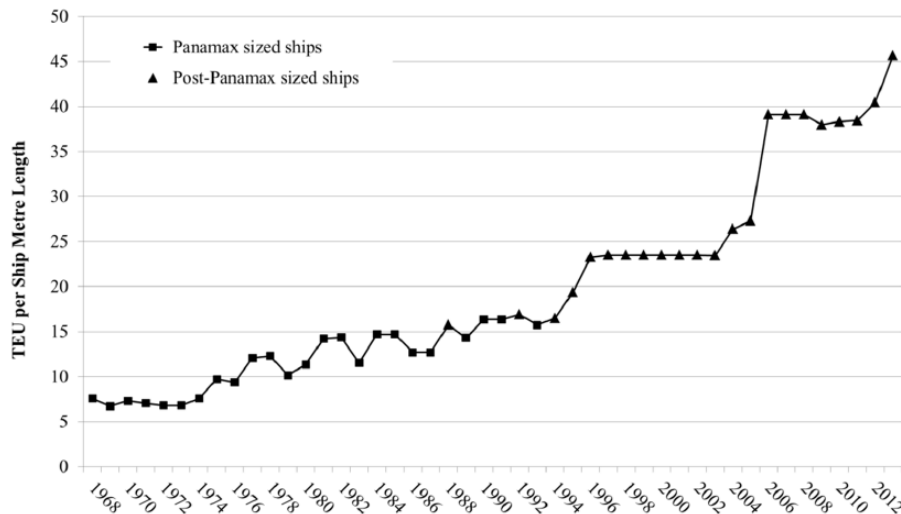
Source: Derived from Clarkson (2012)

For terminal operators the constraints imposed by the Panama Canal dimensions offered three important benefits. Firstly, terminals located within dock basins with sea locks of comparable size to the Panama Canal could receive direct calls by any container ship deployed on trades serving their hinterland. Secondly, it allowed terminals to invest in container cranes with a certainty that the maximum outreach required would equate to 13 containers across, and thirdly, terminal operators benefited from the enforced increase in length:beam ratio. As ships increased in length, the increase in moves required during a port call became spread over a longer length of quay allowing additional cranes to be deployed to perform the increase in workload. While the TEU per ship metre more than doubled in the first 25 years of containerisation from 7.3 to 16.5 between 1970 and 1994, it then doubled again between 1995 and 2006 from 19.4 to 39.1. The introduction of the

E Class ships had the single largest impact on workload concentration increasing the average to 39.1 TEU per ship metre length compared with the previous average of 27.3. The Triple E increased the TEU per ship metre length to 45.7, an increase of 6.6 TEU on the E Class with a year-on-year increase of 5.2 TEU or 13%.

3   Review of the ship-to-shore function

The increase in the physical dimensions of container ships has required container terminals to provide deeper water, longer quays and cranes with greater outreach and height to allow for more containers across and higher stacks on deck. The number of containers that may be unloaded and loaded during a port call, the container exchange, has also risen significantly, increasing from a few hundred containers per call in the mid-1970s (Edmond and Maggs, 1976) to several thousand in the early 2000s (Agerschou, 2004), to in excess of five thousand today (based on research interviews with terminal managers). To assess the impact this has had on berth workload it is necessary to understand port call strategies, time spent in port, impact of ship design and size on quay crane deployment and ship-to-shore operations. This section examines these operations and considers the extent to which terminals have been able to increase the quay crane resources they deploy to service larger container ships.

3.1   Service rotations and port call strategies

Since the 1990s the largest container ships have entered service on the Far East-North Europe trade (McLellan, 1997). This trade has the longest sailing distances and provides the greatest opportunities for economies of scale (Cullinane and Khanna, 1999; Imai et al., 2006; Jansson and Shneerson, 1982). Overtime shipping lines have serviced this trade using a variety of rotation strategies, with pendulum, round-the-world and end-to-end all having been used at one time or another. As ships became too large for the Panama Canal round-the-world services became less attractive and today end-to-end service strategies are favoured (Ducruet and Notteboom, 2012).

On the Far East-North Europe trade services are typically end-to-end rotations of a 70 day sailing period often including one or two hub ports in South East Asia or the Mediterranean. Work at the first port call in the region predominately involves the discharge of imports destined for the local hinterland or inbound transhipment containers connecting with onward feeder services. In contrast work at the last port of call in the region primarily involves the loading of exports from the local hinterland and transhipment containers originating from feeder ports. At port calls in between the first and last ports of call the proportion of containers to be unloaded and loaded will be more balanced and will consist of a smaller percentage of transhipment containers. Regardless of the rotation strategy employed or the number of port calls, on arrival into the region all containers on-board the ship would be destined for North Europe and on departure from the region all containers on-board would be destined for Asia.

Shipping lines in structuring their services and setting port times take account of the sequence of port calls in the region, the planned container exchange volumes, contracted berthing windows, tidal constraints and the container moves per ship working hour each terminal can perform (Edmond and Maggs, 1976). Research has shown that in North Europe there has always been a wide variation in the time spent in port, although tidal

constraints usually require large container ships to arrive and depart a few hours either side of high tide (see Table 1). Port calls are therefore typically based on 12, 24, 36 or 48 hours duration. The varying length of port calls is demonstrated by an examination of Maersk's Far East-North Europe sailing schedules which shows the length of port calls ranging from 13 to 67 hours (Maersk, 2012)[1]. Variation in port call strategies is further demonstrated by the changing number of North European port calls made. For example the number of port calls made by Maersk's E Class ships since they were launched has ranged from two in 2008 (Notteboom and Vernimmen, 2009) to six in 2012 (Maersk, 2012).

Table 1   Port time length

Study	Average port time	Study details
Gilman (1975)	1 or 2 days	Largest container ships at port
Edmond and Maggs (1978)	0.5 to 1.4 days	Ships > 300 TEU at UK ports
Cullinane and Khanna (1999)	10.2 to 13.2 days*	Port calls in Asia and North Europe
Baird (2006)	1 day	4 port calls in North Europe
Notteboom and Vernimmen (2009)	1.17 to 2.06 days	3.93 average in 2005
		3.66 average in 2007

Note: *Based on aggregate of 10.2 to 13.2 days at a total of between 14 and 17 port calls.

No other detailed analysis of container ship time in port exists and reliance on published schedules does not allow analysis of trends over time, as shipping lines implicitly incorporate factors such as contingency into arrival and departure times. However, the limited research that is available and anecdotal observations suggests that although there is a wide variation in the number of port calls and time spent in individual ports, overall the time ships spend in port whilst within the North Europe region has remained relatively constant.

3.2   Port time

Port time is the total time a ship spends between registering as arrived at the port's limits and the moment at which it leaves the port's limits on departure. This includes any time waiting and manoeuvring to/from the berth, completing documentation and ship working time. Ship working time includes productive time when operations are performed (container handling, booming up and down of quay cranes, moving hatch covers and travelling of quay cranes between bays). In addition to handling import, export and transhipment containers the shipping line may also request the terminal to shift containers that are to remain on-board to new locations in the same bay or to restow them to another bay. Remain on-board containers may also be moved for the crane drivers convenience, for example to lower the tier height of stacks close to the quay to provide better sighting and shorter travel distances to slots furthest from the quay. There will also be non-productive time when the ship is not worked; this may be due to shift changes, safety incidences or other disruptions that require work to be suspended.

The total number of moves performed to unload and load a container ship in the region is dependent on the TEU capacity of the ship and the ratio of 20 ft to 40 ft containers carried. The port of Rotterdam whose traffic has been dominated by the Far East-North Europe trade has published detailed throughput volumes dating back to 1970

by both TEU and container units (see Figure 5). This data shows that during the early years of containerisation the proportion of 20 ft and 40 ft containers remained relatively constant. In the 1980s, the ratio slightly reduced reflecting the use of containers for cargo with a greater weight to volume ratio favouring 20 ft containers. From the late 1980s international trade became increasingly dominated by lighter consumer goods and this has been reflected in an increase in the use of larger cubic containers (40 ft and 45 ft), and a rise in the TEU ratio to 1.65 by 2011. In terms of port call workload, this increase in the TEU ratio reduces the number of container units carried and reduces the total moves required to unload and load a ship.

Figure 5   TEU ratio port of Rotterdam 1970–2011
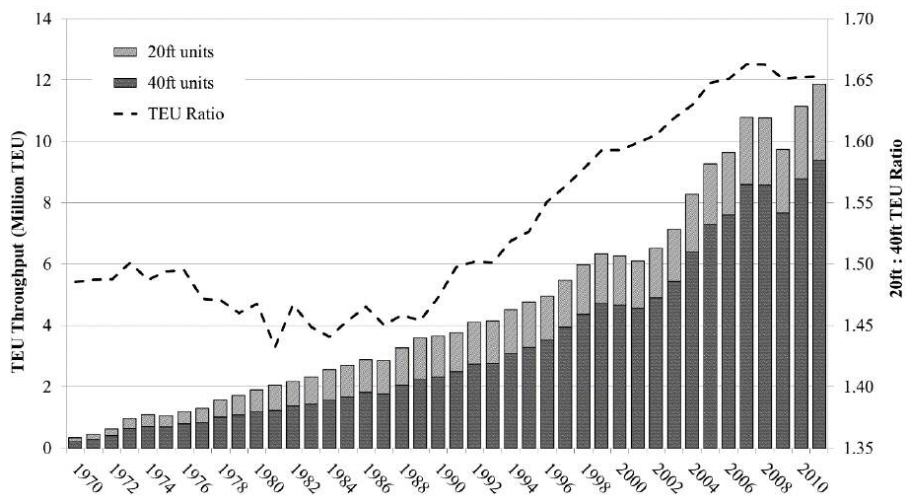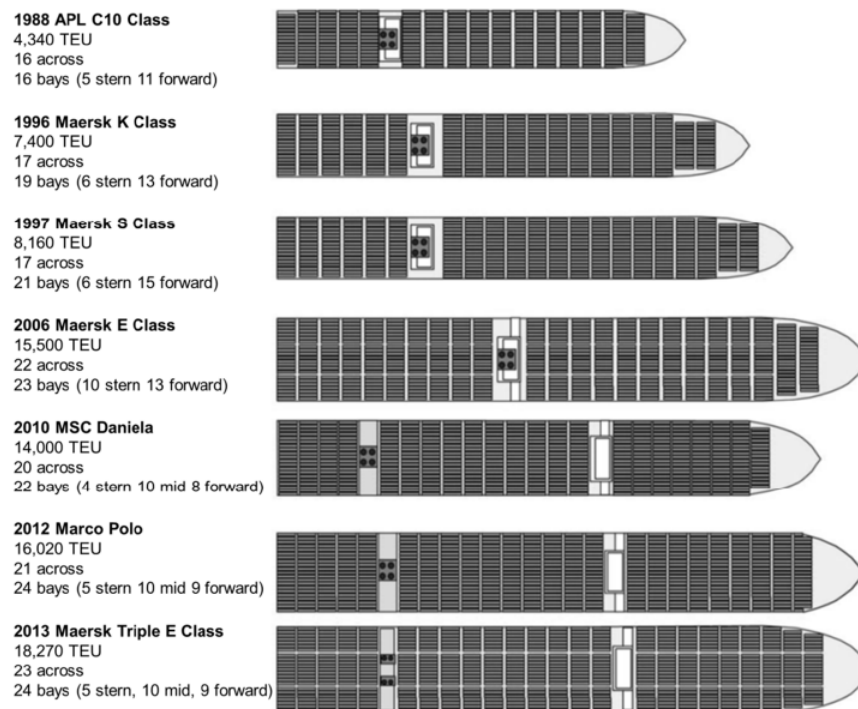

Source: Port of Rotterdam/PIM/CBL

Ship-to-shore operations are further affected by the stowage distribution of containers for each port of call between the bays of the ship. This distribution acts as a constraint on the number of quay cranes a terminal can deploy to work the ship, and is known as the crane split (Bierwirth and Meisel, 2010). Ship stowage is extremely complex having to account for numerous parameters: number and capacity of bays; slots for specific container size types; cargo characteristics (weight, hazardous, reefer or out of gauge); ship stability and safety; port call sequence and port pair combinations; and shipper requests such as door direction, keeping away from heat sources and late arrival at loading port or expedited discharge at destination (Pacino, 2012; Steenken et al., 2001). As the number of port calls within a rotation increases so does the complexity of ship stowage and the more difficult it becomes to distribute containers along a ship to optimise the number of quay cranes that can effectively work the ship (Gilman, 1975). Containers for individual ports calls become more concentrated in a few bays with small pockets of containers for each port located in other bays. This has the effect of limiting the number of quay cranes that can be deployed, leading to poor crane split, and one crane having a disproportionate amount of work extending the time required to work the ship.

3.3 Ship layout and crane deployment

The number of cranes that can be deployed on a ship is not simply determined by the ship's length as location of the bridge and the engine in relation to the bays also constrain the upper limit of quay cranes that can be deployed. As containers have to pass between the legs of a quay crane as they are transferred between the ship and the quay, quay cranes are necessarily wider than the width of a bay block. Consequently when working a bay a quay crane will block access to the bays on either side and prevent them from being worked by other cranes, this is known as the adjacent bay constraint (Murty et al., 2005).

For example, Maersk's E Class ships are 397.71m long and have 23 bays with the bridge and engine housed together giving a bay configuration of thirteen forward bays and ten stern bays (see Figure 6). Applying the adjacent bay constraint it is possible for only seven cranes to simultaneously work the forward section and five the stern, setting a maximum limit of twelve quay cranes for this class of ship. By contrast CMA CGM's 16,020 TEU Marco Polo ship, which is the same length as the E Class ships, has the bridge and engine in separate locations. This results in a bay configuration of nine forward bays, ten mid-ship bays and five stern bays giving an upper limit of thirteen cranes. Therefore the Marco Polo has a ratio of one crane for every 1,232 TEU compared to the E Class which has one crane for every 1,292 TEU. Consequently, although the Marco Polo has a greater TEU capacity its layout offers the ability to deploy more cranes giving rise to a lower average crane workload.

Figure 6 Example bay configurations

1988 APL C10 Class
4,340 TEU
16 across
16 bays (5 stern 11 forward)

1996 Maersk K Class
7,400 TEU
17 across
19 bays (6 stern 13 forward)

1997 Maersk S Class
8,160 TEU
17 across
21 bays (6 stern 15 forward)

2006 Maersk E Class
15,500 TEU
22 across
23 bays (10 stern 13 forward)

2010 MSC Daniela
14,000 TEU
20 across
22 bays (4 stern 10 mid 8 forward)

2012 Marco Polo
16,020 TEU
21 across
24 bays (5 stern 10 mid 9 forward)

2013 Maersk Triple E Class
18,270 TEU
23 across
24 bays (5 stern, 10 mid, 9 forward)

While existing research into optimising crane deployment and scheduling has incorporated the adjacent bay constraint (Meisel and Bierwirth, 2011), it has not considered the impact of ship layout but instead assumes that bays are concurrent. With ultra large container ships adopting separate bridge and engine configurations, there is now an opportunity to re-examine this area. Examination of the bay configuration and maximum number of deployable cranes provides a means to benchmark the potential crane split of ships based on their design and layout. Although the actual number of cranes used to work a ship in practice will be impacted by other operational factors discussed below.

3.4   Ship-to-shore operations

The number of cranes deployed on a ship while at berth will vary over time depending on the crane split and how the terminal adjusts crane deployment along the quay for operational reasons (Meisel, 2009; Schonfeld and Sharafeldien, 1985). For example the coordination of working multiple ships, labour utilisation, contractual commitments to the shipping line, quay crane accessibility and availability, varying crane specifications, tidal changes and traffic management on the quay and in the yard all have to be considered (Hartmann et al., 2011).

Quay crane deployment involves each crane being assigned a work sheet detailing the sequence of each container to be handled and the timing of hatch cover moves, special lifts and travel between bays. The work sequence will be continually monitored and adapted to account for variations in quay crane performance levels and unplanned events such as: inconsistencies between bay plans and actual stowage locations; containers arriving out of sequence at the crane; damaged containers or jammed twist locks; loading of 'hot boxes'; and quay crane stops due to issues such as equipment breakdowns, ship engine fumes obscuring work or breaches of health and safety rules in the work area. The maximum number of quay cranes deployable is a theoretical measure and as such terminal and shipping line managers tend to record the average number of quay cranes deployed over the entire ship working time (total deployed crane hours divided by total ship working time).

The first research into the deployment of quay cranes on container ships was undertaken by Edmond and Maggs (1978) at a time when the largest ships were 3,000 TEU allowing a maximum of seven cranes to be deployed. The study found that the largest container ships were actually worked by a maximum of three cranes and that during the last 10% of the ship working time only one crane would be used. It was concluded that the low number of deployed cranes was due to a number of factors including crane breakdowns, insufficient yard equipment, and terminal operators maximising the use of labour over an entire shift where tidal constraints would have prevented a ship from sailing if work was completed any earlier. Subsequent research by Cullinane and Khanna (1999) examined the average number of quay cranes deployed for different ship sizes. Their study showed that for the largest container ship at the time, the 7,400 TEU Maersk K Class, with a maximum of ten deployable quay cranes, there would be on average five cranes deployed. From interviews conducted with terminal staff they concluded that this did not account for the time towards the end of working a ship when a single crane would be used to complete the ship. When this factor was included the actual average number of quay cranes used to work the K Class was estimated to be 4.4.

Therefore, the average number of quay cranes deployed was less than half the maximum that the ship design allows (42% and 49% respectively).

No more detailed or recent research has been published on this subject and the area is commercially sensitive for terminals and shipping lines – preventing access and publication of this data. However, interview-based research with terminal managers has established that today ships with a bay configuration allowing a maximum of 11 deployable cranes are likely to be serviced by a maximum of seven cranes with an average of 5.5 cranes during the ship working time. For ships capable of accommodating 12 quay cranes a maximum of eight cranes would typically be used with an average of 5.5 cranes during ship working time. The interviews also revealed that attempts to deploy additional cranes had caused operational issues and in particular traffic congestion on the quay, which prevented any gain in performance levels being achieved.

4   Changing terminal workload since 1975

With the lack of published data and findings on the workload of container berths and quay cranes it is necessary to quantify the workload retrospectively before examining changes since 1975. The complexity, volatility and variation in service strategies employed by container shipping lines makes analysis at the individual port call level impossible. However, by calculating the total workload required by the ports within a region the increase in workload across the region can be quantified. Adopting the region as the unit of analysis is appropriate as the aggregate port time in the region has been shown to be constant over time and is independent of the number of port calls made in the region (see Section 3.1). This study uses the North European port region of the Far East-North Europe trades as the range of ports to be assessed. This is justified as the largest ships have been deployed on this trade lane. Also it can be assumed that for Far East trades all containers on-board ships operating on this trade when entering North Europe will be discharged at the ports of call in the region and that all containers on-board on departure from North Europe will have been loaded in the region destined for Asia.

This analysis quantifies the impact of increasing TEU capacity on the peak container exchange volume to be handled by a berth during a single port call between 1975 and 2013. First a BWI is calculated to quantify the impact of increasing container ship size on the amount of work that has to be performed whilst the ship is in port. Then, based on the bay configuration of the largest ships and the number of quay cranes that can be deployed on each ship, a QCWI is presented. Given that the average number of quay cranes to work a ship has remained relatively constant at about 50% of the maximum number of cranes the QCWI provides a good indication of the increase in workload of individual quay cranes. A wide variation in workload between individual quay cranes working the same ship at berth may be experienced due to the crane split causing work to be bunched.

4.1   Berth Workload Index

To calculate the total berth workload for North European port calls first the TEU capacity of each ship is converted into container units – the unit of work performed during ship-to-shore operations. This is achieved by dividing the TEU capacity of the ship by the TEU ratio at the time the ship was built – using the traffic characteristics of the Port of

Rotterdam as the best available representation of the Far East-North Europe trade. Assuming the operational capacity and additional work (restows, shifts and hatch moves) for container ships are proportionate to their container unit capacity a TEU Capacity Index (TCI) and a BWI can be calculated, based on the largest container ship in service. Thus:

$$\text{TCI} = \left(\frac{C_l}{C_b}\right)100 \qquad\qquad (1)$$

where

C_l TEU capacity of largest ship for year

C_b TEU capacity of largest ship for base year (1975)

$$\text{BWI} = \left(\frac{C_l / T_y}{C_b / T_b}\right)100 \qquad\qquad (2)$$

where

C_l TEU capacity of largest ship for year

T_y TEU ratio for year

C_b TEU capacity of largest ship for base year (1975)

T_b TEU ratio for base year (1975).

The TCI measures the growth in container ship size in terms of TEU capacity. By contrast, the BWI measures the growth in container units carried on container ships and indicates the required number of moves to load and unload the ship. Comparing these two indices allows the impact of increasing ship size and changes in the TEU ratio to be examined, see Figure 7. Where the largest ship built in a year had a significantly lower BWI and TCI than the existing industry maximum, for example the Daniela Class, separate data points are included.

During the early years of containerisation the peak workload of berths as measured by the BWI was characterised by a slow but steady rise doubling over a twenty year period. This was followed by a step change with the introduction of the K Class ships in 1996 and the S Class ships in 1997. The BWI rose from 225 to 329 points, representing a 46% increase in peak workload over two years for North European ports serving the S Class ships. It was also at this time that a divergence occurred between the TCI and BWI reflecting the growing proportion of 40 ft containers being shipped on the Far East-North Europe trade route, reducing the number of moves to be performed. By 2006 the BWI had fallen to 10% below that of the TCI.

After 1997 the industry experienced a decade of stability in terms of berth workload until the first E Class, the Emma Maersk, was deployed in 2006. The deployment of the Emma Maersk represented a year-on-year workload increase of 70%, with the BWI reaching 604 points. This required terminals serving the E Class to improve their operational planning and prioritise their resources to achieve the necessary peak workload performance levels required. Between 2006 and 2010 the BWI then remained constant as the E Class remained the largest ships afloat. However, for North European terminals this was a period of substantial change as they geared up for the large number

of new ships with a capacity in excess of 10,000 TEU that were being built. Terminals not only had to prepare their ship-to-shore operations to meet peak workloads on the quay, but also their internal transfer, yard and gate operations so they could cope with multiple calls by these large ships in a week and in some instances simultaneously.

Figure 7   TEU Capacity Index (TCI) and Berth Workload Index (BWI)
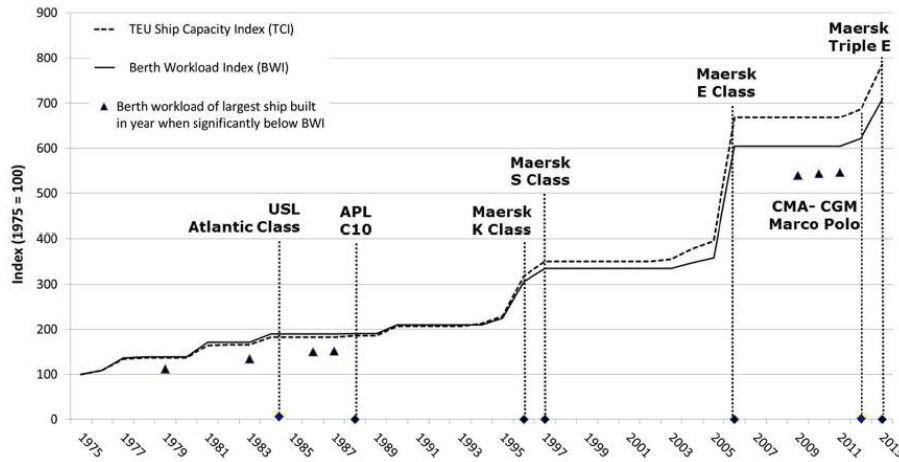
In 2012, the BWI started to rise again with the launch by CMA CGM of the 16,020 TEU Marco Polo and the deployment of the Triple E Class in 2013. The BWI index increased from 604 points in 2011 to 622 points in 2012 and 709 points in 2013, an increase in peak berth workload productivity for terminals of 17% in two years. In contrast, the E Class was significantly longer and wider than previous ships and required a 69% increase in berth productivity.

4.2   *Quay Crane Workload Index*

While the berth provides a measurement of terminal workload the unit of production is more accurately examined at the level of the quay crane. In the early days of containerisation the increase in the TEU capacity of ships was accompanied by an increase in ship length allowing terminals to deploy additional cranes, spreading the work among more cranes. However since 2003, as shown in Section 2, there has been a reduction in the length:beam ratio of the largest container ships built, with the Triple E Class's 6.8 being the lowest recorded length:beam ratio (see Figure 3) of any container ship.

To assess the impact of this change on terminals it is necessary to relate the maximum number of cranes deployable on each ship with the ship's TEU capacity. This requires an assessment of the layout and bay configuration of each ship to determine the maximum number of quay cranes deployable, given the adjacent bay constraint. The QCWI can then be calculated for the period 1975 to 2013 by dividing the total moves for the ship (TEU capacity divided by the TEU ratio) by the maximum number of quay cranes deployable as shown below.

$$QCWI = \frac{\left(\dfrac{C_l / T_y}{Q_l}\right)}{\left(\dfrac{C_b / T_b}{Q_b}\right)} 100 \tag{3}$$

where

C_l TEU capacity of largest ship for year

T_y TEU ratio for year

Q_l maximum number of quay cranes for largest ship for year
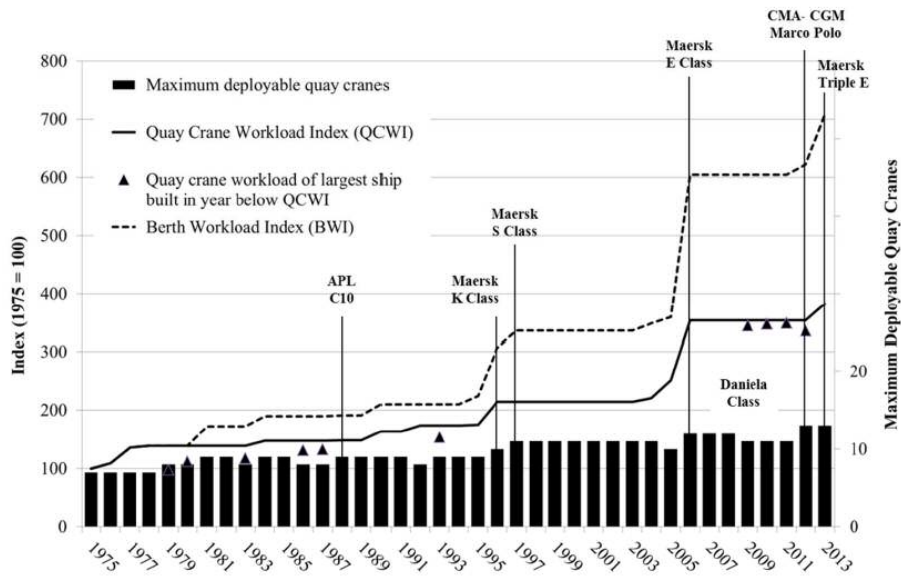
C_b TEU capacity of largest ship for base year (1975)

T_b TEU ratio for base year (1975)

Q_b maximum number of quay cranes deployable for base year (1975).

The QCWI Index measures the average workload of individual quay cranes and shows how increasing ship size has changed the workload of quay cranes, see Figure 8.

Figure 8   Quay Crane Workload Index (QCWI)

Between 1975 and 2013 whilst the berth workload of the largest container ships increased 709% (BWI), the QCWI rose by 382% as the maximum number of quay cranes deployable rose from 7 to 13. This is significant, as it implies that whilst terminal operators have been able to deploy additional cranes they have also had to increase the utilisation and performance of individual quay cranes by nearly fourfold. To achieve this terminals have either increased the proportion of time each quay crane is working whilst

a ship is in port or have increased the number of moves each crane performs per hour – in reality both have been achieved.

Comparing the impact of the Triple E Class with the E Class, it is only 2.3 metres longer and 2.6 metres wider but has an additional capacity of 2,720 TEU and a bay configuration that supports a maximum of 13 deployable quay cranes compared to 12 for the E Class. Whilst it may be possible to deploy one additional quay crane during some of the ship working time the impact on the average number of quay cranes during the ship working period is unlikely to increase. The E Class represented a major increase in both the BWI and QCWI (41% and 69% respectively) requiring terminals serving these ships to overnight achieve a step change in peak operating performance. In contrast the Triple E Class increased the BWI by 14% and the QCWI by 8% demonstrating that the impact of the introduction of the Triple E Class on the peak workload of terminals will be much less than for the E Class.

5   Conclusions

This paper has for the first time measured the impact of increasing ship size on the workload of terminals at the berth and at the individual quay crane level. Through the use of the BWI it has been shown that between 1975 and 2013 the peak workload of berths will have increased by over 700%. Step changes in peak berth workload occurred first in the mid-1990s with the introduction of the K Class and S Class ships (which increased peak berth workload by 49% in two years), second in 2006 with the introduction of the E Class ships which raised the peak workload by 69%, and finally with the deployment of the CMA-CGM Marco Polo in 2012 and the Triple E Class ships in 2013 which will see the workload increase by 17% over two years, a relatively minor increase compared to the E Class.

To assess how terminals have met an increasing workload the paper assessed the layout of container ships and the ability to deploy additional quay cranes. It was shown that operational constraints have limited the maximum number of quay cranes that can be deployed on larger ships, with the maximum increasing from 7 to 13 cranes over the period examined. To support the increase in workload terminal operators have increased the number of quay cranes deployed by 87%, with the average number of cranes used over a ship's working time increasing from less than three in the mid-1970s to just less than six in 2012. Given the increase of over 700% in berth workload compared to the 87% increase in cranes deployed, and the fact that port time has remained constant, it must be assumed terminals have made major improvements in productivity – increasing the proportion of ship working time to total port time, reducing non-productive time while a ship is worked, increasing the quay crane cycles performed per hour and the number of moves performed per quay crane cycle. Although not specifically examined by this study the increase in peak workload at the berth will also be observed at all sub-systems of a terminal, including quay-to-yard transfer, yard and gate operations. Further research is required to understand the impact of increasing peak workloads on these other sub-systems.

The study has made a number of assumptions that warrant further investigation to test their validity, most specifically the relationship between the maximum and average number of quay cranes used and that total port time has remained constant over time. More detailed research is also required into the design and bay configuration of container

ships, most notably to measure the distribution of container slots between bays and to better understand the impact of ship size on quay crane workload concentration. Finally, while existing research into terminal performance has focused on overall operating performance this study has shown the need to consider the peak workload that occurs during a port call. In comparing terminal performance consideration should be given to the trades serviced and the extent to which this requires the provision of additional resources to meet peak ship-to-shore workloads.

With the prominence given to increasing container ship size it is surprising that there have been no previous academic papers published on the impact this has had on container terminal workload and operations. The authors believe that this due to the adoption by researchers in the maritime field of the port as the primary unit of analysis instead of the terminal. Typically, when measuring efficiency and benchmarking container handling performance levels little or no account is given of the size of vessels, container exchange volume or the nature of the trade served by the terminals studied. Often researchers limit their data analysis to published throughput volumes which while readily available at the port level fail to acknowledge that management, operational decisions and performance are dependent on the characteristics of the individual terminal. It is hoped that future research when considering investment decisions and comparative efficiency of container operations will adopt the terminal as the level of analysis and will take account of the size of ships being served.

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Notes

1   Data obtained from Maersk Lines corporate website on 20th October and included 58 port calls occurring from the 2 October 2012 to 11 January 2013, including actual and estimated arrival and departure data.