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CONTAINERSHIP BAY TIME AND CRANE PRODUCTIVITY: ARE THEY ON THE PATH OF CONVERGENCE?

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Abstract

Containerships are getting bigger. Their time at the pier for discharge and load (D&L) is increasing due to larger bays. Bay time depends on gantry crane (crane) productivity (lifts/hour) of D&L. A match of vessel bay time growth and gantry crane output growth keeps containership bay time constant. Thus, are they on the path for convergence?

The paper shows the growth of containership bay time and crane productivity to determine their long-term relationship, using the containership bay time model developed by the authors. The paper quantifies crane productivity and bay time performance, showing their behavior for different vessel classes and long-term trends indicating no convergence. After redefining the crane output, the paper proposes that convergence is possible. The paper also shows that the slow growth of crane productivity encouraged D&L alternatives such as alternate and partial stowing, new D&L technologies (new spreaders, Fastnet) and increases in the number of ports of call to keep D&L time of large vessels efficient.

1. INTRODUCTION

In 1996 the first Post Panamax Regina Maersk of 6,418 TEU (Twenty Foot Equivalent Unit) was introduced. In 2015 the Ultra Large Containership MSC Oscar of 19,224 TEU was launched. The top two containership size categories, Very Large Containership and Ultra Large Containership, are expected to increase in numbers fastest for the next three years, 12.8% and 40.4%, respectively [1]. A series of 20,000 TEU-plus are on order by several shipping lines. The trend of increasing vessel size is to achieve economies of scale at sea, obtain the lowest possible unit cost of container transport and stay competitive.

The increase in containership size is in length, beam, and height. A comparison of containership classes shows that an increase in ship length is not proportional to the increase in ship capacity, and the size of each cargo bay (bay) is much larger. Hence, the number of containers a gantry crane (crane) handles per bay is much larger with an increase in vessel class, i.e., diseconomies of scale in port due to the increase in bay size.

With the present technology, only one crane is working on one bay at any given time. The amount of time it takes to load and discharge (D&L) the largest bay is the basic measuring unit determining bay time for containerships [2]. Crane productivity, defined as lifts/hour (one lift equals one container), of D&Ling the largest bay determines the minimum amount of time it takes to complete it.

The paper's objective is the analysis of D&L time of a containership bay, focusing on the relationship between the two key factors, containership bay size and crane productivity. The results determine minimum bay, berth and port times. After a literature review, the methodology analyzes the relationship between the key variables. The analysis indicates that with the increase in beam size, the vessel's bay size increases. But crane productivity (lifts/hour) is lagging in its growth to match the bay increase in size. The inequality between the two increases the vessels' bay, berth and port times (diseconomies of scale), requiring new D&L technology, multiple ports of call and stowing plans.

2. LITERATURE REVIEW

The literature review is for containership liner service port time and port productivity. The review found little detailed relationship between berth time and crane productivity. Yahalom and Guan [2] indicate that bay time dominates berth time and ultimately port time. Cullinane, et.al. [3] identify port time as a schedule-planning instrument and the consequences of deviating from it. Jordan [4] addresses different D&L technologies to improve crane productivity. Duponcheele [5] discusses a new "double boom" concept of crane to improve productivity. Oliveira Moita and Caprace [6] study the effects of loading conditions and crane assignments on container terminal performance. Cullinane, et.al. [7] indicate that a ship's overall performance should take into account the entire voyage, not only sea time. They also indicate that port time is affected by cargo exchange, crane density, average crane productivity, down time in port, and working schedule. Gilman [8] mentions port time as a handling performance measure. Vulovic [9] is concerned that the port industry does not match large ship needs of minimizing port time. Ducruet, et.al. [10] address the time factor in port performance and efficiency for container vessels, addressing port time in the same way as Moon and Woo [11], who include congestion as a component of port time. Suarez-Aleman, et.al. [12] show that "port time is the combination of … port access time, D&L times, ship waiting time, and time for customs …" Christa, et.al. [13] addresses extended port time, the rationale of using big ships and the need for making up lost port time with higher speed. Tozer [14] discusses port time with respect to differences in vessel size, annual costs and the number of annual voyages. Cullinane, et.al. [15] address the economies of scale of large ships and port productivity improvements on diseconomies of scale in port. McLellan [16] indicates that there are practical limits to ship size that can be imposed on a port, including draft, space, container handling technology, and infrastructure. Brett [17] refers to a Drewry Insight study, indicating that "while overall berth productivity improves with larger vessels, it does not increase in line with vessel sizes." These findings indicate diseconomies of scale in port due to increasing ship size.

The literature review does not address the focus of the study, the link between bay time and crane performance, the key of understanding containership berth, and port times.

3. METHODOLOGY

The objective of terminal operators and shipping lines is to minimize containership berth time, defined as the time between vessel docking and undocking. Berth time is derived from bay time, which is defined in this paper as the amount of time it takes to D&L the largest fully loaded bay of a containership.

There are many bays on a containership. The longer the containership, the more bays. The largest bay stows the largest number of containers. With the present technology, one crane works one bay at a time. Assuming an unlimited number of cranes that can work on all cargo bays at once, the dominating factor of completing the D&L of a vessel is bay time. Bay time is calculated by bay carrying capacity divided by crane productivity.

In reality a crane blocks at least two bays [18]. Therefore, the minimum amount of time to D&L of a containership is two times the time it takes to complete the largest bay. Since most container terminals do not have enough equipment to assign the maximum number of cranes to a containership, it increases the containership time at the berth as well.

Containership bay time (the focus of the paper) is determined by containership bay holding capacity (B_i) and crane productivity (P) (lifts/hour) (Yahalom [2]). Since a bay is D&L'd, bay time is two times the time it takes to only discharge or load a bay, counting every container move as one lift each (Equation 1).

$$B_{it} = \frac{2B_{ic}}{P} \qquad (1)$$

Where:

B_{it} is bay time (in hours).

B_{ic} is the number of containers (20ft and/or 40ft) in a bay, times 2, due to D&L.

P is crane productivity measured in container lifts/hour.

Equation 2, derived from Equation 1, is the percentage change in each of the variables in Equation 1.

$$log\, B_{it} = log\, 2B_{ic} - log\, P \qquad (2)$$

Equation 2 is the foundation for the determination of the relationship between bay time and crane productivity and their implications, as discussed below.

4. BAY SIZE, CRANE PRODUCTIVITY AND BERTH TIME

Bay time is the basic variable and measure determining a containership time at berth and ultimately at the port. It is calculated from bay size and crane productivity.

4.1 Bay Size

Bay size increases with beam size when containerships increase in size. Bay capacity is measured by the number of container slots, 20ft and/or 40ft standard ISO (International Organization for Standardization) containers, below and above deck. One 40ft slot equals two 20ft slots, and one 40ft bay is comprised of two 20ft bays. For example, from the Post Panamax Plus (Regina Maersk) to the Triple E (MSC Oscar), the beam size increased from

141ft to 194ft, respectively; from 241 40ft container slots per bay (15 tiers and 17 rows) to 396 40ft container slots per bay (18 tiers and 23 rows), respectively.

Bay size increase is consistent and predictable with the increase of containership beam. A beam's increase is a multiple of a container width of 8ft [2], which was the trend for decades with each launching of a new containership vessel class. Hence, the number of potential containers stowed in a bay increases accordingly.

4.2 Crane Productivity

Twenty years ago gross crane productivity was 20 to 24 lifts/hour. This productivity includes the time for hatch and crane movements and other disruptions. Net productivity omits the time of these two from the calculations. Today the range is between 33 and 38 lifts/hour [19]. At a range of 20 to 38 lifts/hour the overall advance is 90%. Crane lifts/hour is an established standard used for comparing crane productivity by ports and vessel class.

In general, crane productivity calculation is not constant because there are a number of factors to consider. On board a containership, hoisting and trolleying distances and speeds to D&L depend on containership class and the container location in the bay. The further the distance and the lower the container below deck, the longer it takes to D&L.

4.3 Relationship between Bay Size, Crane Productivity and Bay Time

Equations 1 and 2 are the foundation for determining the relationship between bay size and productivity in order to obtain the bay time. The analysis includes:

1. Required crane productivity to meet a constant bay time
2. Required bay time when crane productivity is a constant

These two are the basis of: identifying the range to leverage investments, motivating new R&D, guiding contract negotiations between shipping lines and ports, improving operations by training, and developing local, regional and national policies.

4.3.1 Constant Bay Time

A liner service operations is a planned service schedule for all the ports of call, including the containership berth time in each port. These times are a part of the contract between the container terminal and the shipping line. Thus, Table 1 identifies the minimum productivity level by vessel class that would assure a bay time of 20 hours.

Table 1: Minimum Crane Productivity (lifts/hour) in 20 hours of Bay Time

Containership class	Number of 40ft containers	Minimum productivity (40ft containers)	Number of 40% to 60% ratio*	Minimum productivity (40% to 60% ratio*)
Panamax	262	13.10	367	18.34
Panamax Max	336	16.80	470	23.52
Post Panamax	396	19.80	554	27.72
Post Panamax Plus	482	24.10	675	33.74
New Panamax	612	30.60	857	42.84
Post New Panamax	756	37.80	1058	52.92
Triple E	792	39.60	1109	55.44

*The ratio of 20ft to 40ft containers is 40% to 60%, respectively.

Table 1 and Figure 1 indicate that the largest bay, with 40ft containers, for a Post Panama containership, requires a minimum of 19.8 lifts/hour to complete D&Ling the largest bay in 20 hours. The aforementioned, when loaded with a mix of 20ft and 40ft containers, 40% and 60% respectively, would require a crane output of a minimum of 27.7 lifts/hour. Obviously, the number of lifts for wider containerships is larger.

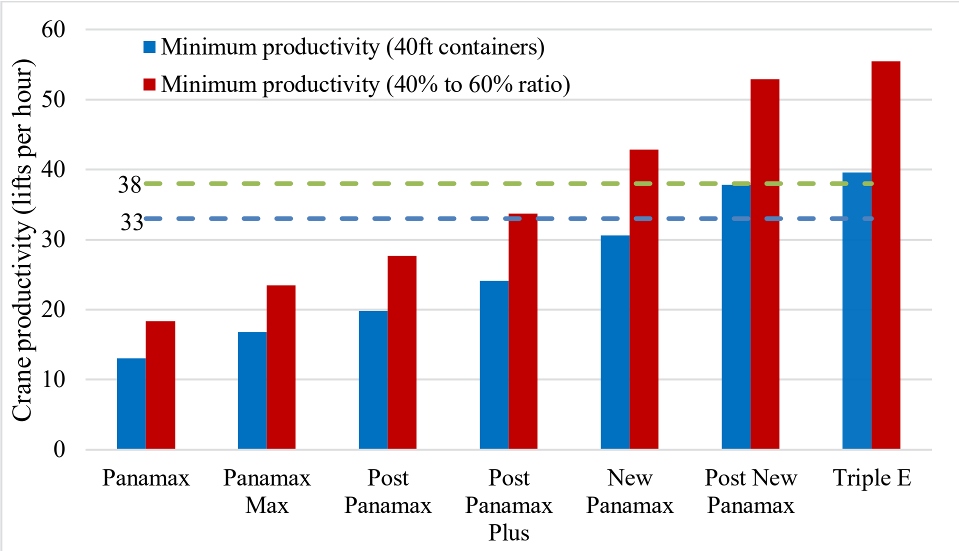

Figure 1: Minimum Crane Productivity (lifts/hour) in 20 Hours of Bay Time.

Assuming that the range of the number of container lifts/hour is 33 to 38, Table 1 and Figure 1 demonstrate that the Post New Panamax vessel class and smaller can complete their largest 40ft container bay in 20 hours. But for a mixed ratio of 40% 20ft and 60% 40ft containers, only the Post Panamax Plus class and smaller can complete the D&L operation in 20 hours. Obviously, other contractual time requirements would lead to other results.

4.3.2 Constant Crane Productivity

Containership bay time depends on crane productivity; at an average of 35 lifts/hour, the minimum bay time of the largest bay of a Post Panamax Plus with 40ft containers is 13.8 hours (Table 2). The same ship with a mix of 40% 20ft and 60% 40ft containers needs a minimum of 19.3 hours. Table 3 illustrates minimum bay time for D&L at different productivity levels, where the D&L with 40 plus lifts/hour is an illustration.

Table 2: Minimum Bay Time (hours) at a Given Crane productivity of 35 lifts/hour

Containership class	Number of 40ft containers	Minimum time at bay (40ft containers)	Number with 40% to 60% ratio*	Minimum time at bay (40% to 60% ratio*)
Panamax	262	7.5	367	10.5
Panamax Max	336	9.6	470	13.4
Post Panamax	396	11.3	554	15.8
Post Panamax Plus	482	13.8	675	19.3
New Panamax	612	17.5	857	24.5
Post New Panamax	756	21.6	1058	30.2
Triple E	792	22.6	1109	31.7

*The ratio of 20ft to 40ft containers is 40% to 60%, respectively.

Ports are under stress to improve productivity due to beam size increases, and liner services need to meet multiport of call schedules. Owners/operators seek to maximize the

D&L in one port at a given amount of time, by modifying container stowing plans that expedite operations at the berth subject to each port's specifications and constraints.

Table 3: Estimated Bay Time (hours) for D&L of the Largest Bay by Containership Size (one bay)

Containership class	Containers for D&L*	Productivity level (P) (lifts/hour)								
		30	35	40	45	50	55	60	70	80
Panamax	367	12.2	10.5	9.2	8.2	7.3	6.7	6.1	5.2	4.6
Panamax Max	470	15.7	13.4	11.8	10.5	9.4	8.6	7.8	6.7	5.9
Post Panamax	554	18.5	15.8	13.9	12.3	11.1	10.1	9.2	7.9	6.9
Post Panamax Plus	675	22.5	19.3	16.9	15.0	13.5	12.3	11.2	9.6	8.4
New Panamax	857	28.6	24.5	21.4	19.0	17.1	15.6	14.3	12.2	10.7
Post New Panamax	1058	35.3	30.2	26.5	23.5	21.2	19.2	17.6	15.1	13.2
Triple E	1109	37.0	31.7	27.7	24.6	22.2	20.2	18.5	15.8	13.9

*The ratio of 20ft to 40ft containers is 40% to 60%, respectively.

4.3.3 Bay size growth, crane productivity growth, and gap analysis

Keeping bay time constant when bay size carrying capacity increases requires that productivity increase (lifts/hour) match the bay size growth (slots per bay) (Equation 3).

$$log\ 2B_{ic} = log\ P \qquad (3)$$

The inequality between the two is due to bay size growing faster than productivity growth, i.e., increasing both the gap between them and the D&L time. Productivity growing faster than bay time growth closes the gap and decreases D&L time.

As noted, crane productivity increased from 20 lifts/hour to 38 lifts/hour, a 90% rise (Table 4 and Figure 3). Due to diversity in crane lifts/hour between ports and lack of records, the study increases every new vessel class launching by an average of three lifts/hour. Column 2 (Table 4) indexes productivity growth where Panamax is the base.

Table 4: Estimated Number of Bay Slots and Productivity Growth (lifts/hour)

Vessel class	Number of 40ft slots per bay	Slots per bay growth (Panamax as base) (1)	Produc-tivity (lifts/ hour)	Productivity growth (20 lift/hour as base) (2)	Gap (1)-(2)	Ratio (1)/(2) (3)	Ratio with one lag (4)	Ratio with two lags (5)
Panamax	131		20					
Panamax Max	168	28%	23	15%	13%	1.88		
Post Panamax	198	51%	26	30%	21%	1.70	0.94	
Post Panamax Plus	241	84%	29	45%	39%	1.87	1.14	0.63
New Panamax	306	134%	32	60%	74%	2.23	1.40	0.85
Post New Panamax	378	189%	35	75%	114%	2.51	1.78	1.12
Triple E	396	202%	38	90%	112%	2.25	2.09	1.48
Next generation	436	233%	41	105%	128%	2.32	1.93	1.80

During a similar time period, the largest bay carrying capacity of the Panamax and the Triple E increased from 131 40ft slots to 396 40ft slots, respectively, i.e., a 202% increase (Table 4 and Figure 3). Column 1 is an index of slot growth where the Panamax is the base.

Productivity and slots per bay growth are fact; their timing and adjusting lag are not clear. The focus is on the trend and magnitude of the gap (Figure 3). The timing and magnitude of the adjusting lag might be off, but their size and persistence are evident and were the cause of action to close the gap by the port and the container shipping industries.

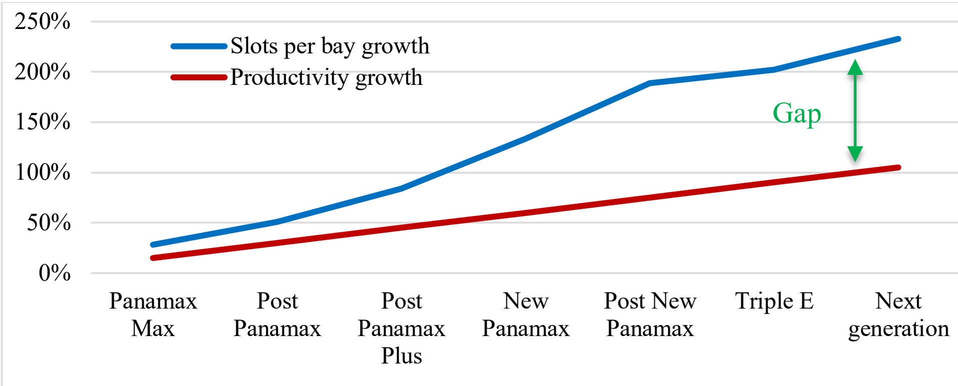

Figure 3: Slots per Bay Growth and Productivity Growth.

Closing the gap between bay capacity growth and productivity growth to stabilize bay time is a port industry's interest and duty (Table 4 "Gap" and Figure 3). For example, the Panamax Max with a 13% growth gap (Table 4, "Gap") caught up with the launch of the Post Panamax. Similarly, the productivity growth gap of the Post Panamax caught up when the Post Panamax Plus was launched. But then there was a setback because the New Panamax was launched (Table 4), and the gap opened again. Catching up to the gap shows that crane productivity improvements had a lag of at least one vessel class; in others, two vessel classes. In the one lag column (Table 4) the ratios are 0.94 and 1.14, nearly an equilibrium. The lag reduced the ratio greatly up to and including the New Panamax with a ratio of 1.40. But the trend in the lagged ratio increases (Table 4), reinforcing the trend and the gap identified above. Some of the gaps close with two or more lags (Table 4).

Converting the lag into time is difficult but it could be estimated at a range of four to seven years, the time it takes to plan and build a new vessel class.

5. CHALLENGES

Containership new builds are expected to increase beam size. The gap between bay capacity and crane productivity (lifts/hour) cannot be closed by increasing the number of lifts/hour alone, due to technical limitations. The gap and its growth forced the stakeholders to look for D&L time-saving solutions, new technologies and operation methods:

New Spreader Technology. The crane operators use spreaders that lift several containers at a time, i.e., two [20], three [21], four [22] and more. This new technology measures the output in moves/hour, not lifts/hour. For example, if all D&L lifts are of two containers or more (2 TEUs, 4 TEUs or 6 TEUs), bay time would be cut substantially.

Fastnet. "Fastnet" [23] addresses the present crane operations itself. It eliminates the present crane's wheel base from blocking two bays. Each bay is assigned a crane, assuming no limit of cranes on the pier. Fastnet closes or doubles the present crane output. Fastnet and the new spreader technology would increase output greatly and are expected to become the standard for the large containerships' operations in the large ports.

Stowing. Stowing planners provide options to reduce vessel stay at berth by stowing containers for the same port in non-adjacent bays to maximize crane use.

The methods identified above when fully implemented with an assigned crane per bay reduce bay time, berth time and ultimately port time.

6. CONCLUSION

Containership bay time increases with vessel beam size and constant crane output. This link inherently causes diseconomies of scale at the port for wide vessels. The focus is on the relationship between the containership beam size, crane productivity (lifts/hour), and bay time. Comparing productivity and output (moves/hour) is key in studying port efficiency/expansion. The paper uses the standardized lifts/hour to measure, compare, quantify and highlight the extent of the problem and its consequences.

The pressure on the owner/operator is reduced by calling multiple ports and by creative stowing plans. The pressure on the ports is to improve productivity and output at the pier.

The paper finds that (1) the diseconomies of scale due to increase in containership beam and productivity (lifts/hour) are substantial and increasing. (2) The gap between the two is adjusting with a lag that does not converge. Hence, external measures to stabilize port performance, whereby output growth matches bay size growth, are needed. Stabilizing this link also requires a large number of cranes. Some short term advances could be by creative stowing and calling multiple ports. In the long-run spreaders with multiple-container lift technology and a Fastnet or similar technology (a large undertaking) are needed. Ultimately combining of these two might eliminate the diseconomies of scale in the port.

The research highlights container terminal operations, long-term terminal needs and the ability to compete. It could also be used for time and planning for bay, berth, stowage, and berth time guarantees during negotiations and for port development and investments.

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