Containership Bay Time and Crane Productivity: Are They on the Path of Convergence?

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Abstract

Containerships are becoming bigger and bigger. Their time at the pier for discharge and load (D&L) of containers are increasing due to their larger bays. A key factor in reducing bay time is the gantry crane productivity (lifts per hour) of D&L. That is, a match between containership bay time growth and gantry crane output growth will keep containership bay time a constant. Thus, are they on the path for convergence?

The paper addresses the relationship between containership bay time growth and gantry crane productivity growth to determine the long-term relationship between the two, using the containership bay time factor model developed by the authors. The paper quantifies the relationship between crane productivity and bay time, indicating no convergence. However, after redefining the gantry crane output, the paper proposes convergence is possible. After the introduction, the paper develops a model that captures these two issues and addresses their behavior for different containership classes. The model tests the relationship between the two variables to determine long-term trends. The paper demonstrates that the slow growth of gantry crane productivity is the foundation for seeking other D&L alternatives in order to keep D&L time of large containerships efficient. The alternatives addressed include: alternate and partial stowing of bays, new D&L technologies (new spreaders and Fastnet), increase in the number of ports of call, etc. The paper concludes by identifying the need for new D&L technologies and provides a method for showing the technologies' contribution to convergence.

Keywords: Containership bay time, gantry crane productivity, stowing plan, beam size, port time, berth time.

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 (VLCS, 10,000 – 13,300 TEUs) and Ultra Large Containership (ULCS, 13,300 – 19,000 TEUs), are expected to have the highest annual growth for the next three years, 12.8% and 40.4%, respectively, among all the containership size categories [1]. A series of 20,000-plus ULCS's are on order by several shipping lines.

The trend of increasing containership 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 simultaneously in three dimensions: length, beam, and height.

A comparison between two classes of containerships reveals two critical factors: increase in ship length is not proportional to the increase in ship capacity, and the size of each cargo bay (from here on called – bay) is much larger. Consequently, the number of containers a gantry crane needs to handle per bay is much larger with an increase in containership class. This highlights the diseconomies of scale in port due to the increase in containership bay size.

Since, with the present technology, there can be only one crane 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 per hour, of D&Ling the largest bay determines the minimum amount of time it takes to complete it.

The objective of the paper is the analysis of D&L time of a containership bay focusing exclusively on the relationship between the two dominating factors, containership bay size and gantry crane productivity. The results determine minimum bay time, berth time and ultimately port time. After a literature review, the methodology analyzes the critical relationship between the two key variables. The discussion that follows indicates the obvious: that with the increase in containership beam size, the vessel's bay size increases. But the gantry crane productivity, measured in lifts per hour, is lagging in its growth to match the bay increase in size. The growth inequality between bay size and crane productivity ultimately increases the containership bay time, berth time and therefore port time, i.e., diseconomies of scale. This gap has significant industry implications for the development of new D&L technology, using multiple ports of call and changing stowing plans which are discussed in the paper.

2. LITERATURE REVIEW

The literature review findings on the port time of a containership liner service and port productivity are discussed below. The literature review does not address in detail the relationship between berth time and gantry 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 discharge and load technologies to improve quay crane productivity. Duponcheele [5] discusses a new "double boom" concept of gantry crane to improve productivity. Oliveira Moita and Caprace [6] study the effects of loading conditions and quay crane assignments on container terminal performance, finding that good planning and management of container terminal operations reduce waiting time. 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, finding that port location (country and region) is important in port performance and efficiency. They also indicate that "three composite indices about logistics performance, port infrastructure quality, and global connectedness did not play a statistically significant role on time efficiency." They address 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 several components, such as port access time, loading and unloading times, ship waiting time, and time for customs and other administrative procedures." Christa, et.al. [13] write about 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 containership 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. … This means that the number of gantry cranes deployed cannot be increased in direct proportion to increased ship sizes. … as vessels become larger, the crane trolley has to move further for each move, slowing productivity." This last finding indicates diseconomies of scale in port due to increasing ship size. In short, there is a consensus by many that the port became a critical point of diseconomies of scale to the economies of scale of a large containership.

The literature review addresses issues associated with berth time and crane productivity, but it does not address the relationship between bay time and gantry crane performance. Equating bay time and crane output per time (lifts per hour) is at the core of understanding a containership berth time and ultimately port time. This is the focus of this study.

3. METHODOLOGY

The objective of terminal operators and shipping lines is to minimize containership berth time, which is defined as the time between vessel docking (berthing) and undocking (un-berthing). 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 that a container terminal has an unlimited number of cranes that can work on all cargo bays simultaneously, the dominating factor of completing the D&L of a containership is bay time. Bay time is determined 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 complete 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. The focus of the paper is on bay time.

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

$$\mathrm{B}_{it} = \frac{2\mathrm{B}_{ic}}{\mathrm{P}} \tag{1}$$

Where:

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

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

P is gantry crane productivity measured in container lifts per hour.

Equation 2, derived from Equation 1, is the percentage change in each of variables in Equation 1. Bay size and crane productivity are continually changing with the increase in containership beam size and the improvements in crane technology.

$$log\, \mathrm{B}_{it} = log\, 2\mathrm{B}_{ic} - log\, \mathrm{P} \tag{2}$$

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 gantry crane productivity.

4.1 Bay Size

Bay size increases with beam size when containerships increases 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 is equal to two 20ft slots and one 40ft bay is comprised of two 20ft bays. For example, from the Post Panamax Plus vessel class (Regina Maersk) to the Triple E vessel class (MSC's Oscar), the beam size increased from 141ft to 194ft, respectively. This growth also accounts for an increase from 241 40ft container slots per bay (15 container tiers below and above deck and 17 container rows) to 396 40ft container slots per bay (18 tiers below and above deck and 23 container rows), respectively. The developments of the Triple E class preceded by the New Panamax and the Post New Panamax vessel classes with 306 and 378 container slots per bay, respectively.

Bay size increase is consistent and predictable with the increase of containerships beam. It follows a formula where the increase of beam size is equal to the width of a container. A beam's increase is incremental, always a multiple of a container width of 8ft [2]. Thus, the number of potential containers stowed in a bay increases accordingly. These incremental increase has been the trend for decades with each launching of a new containership vessel class. Even though containerships' growth might slow down, the growth is expected to continue.

4.2 Crane Productivity

Twenty years ago gantry crane productivity ranged from 20 to 24 lifts an hour. There is a distinction between gross productivity and net productivity. Gross productivity includes the time for hatch movement, gantry crane movement and other disruptions. Net productivity excludes the time of these two from the calculations. Today the range is between 33 and 38 lifts per hour [19]. Assuming a range of 20 to 38 lifts per hour, there is an overall improvement of 90%. Gantry crane lifts per hour are used in the study because it is a well-defined basic standard concept used the same way across the board in the industry. Furthermore, since it is a standardized measure it can be used for various comparisons and as a base for an index for the comparison of crane productivity by ports or by vessel class.

In general, crane productivity determination is challenging because there are a number of factors that come into play. However, on board a containership the different hoisting and trolleying distances and speeds to D&L depend on containership class and container location in the bay. Obviously, the further the distance and the lower the container below deck, the longer it takes to D&L. Thus, the timing of gantry crane D&L per container is not a constant. The analysis focus on different productivity levels and their impact on bay time.

4.3 Relationship between Bay Size, Crane Productivity and Bay Time

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

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, motivate new R&D, guide contract negotiations between shipping lines and ports, improve operations by training, and develop local, regional and national policies and others.

4.3.1 Constant Bay Time

A common practice the liner service is planning the service schedule for all the ports of call including the containership duration at berth in each port. The plan includes a fixed or a maximum amount of time at berth for D&L in each port. These amounts are identified in the contract between the container terminal and the shipping line. For example, Table 1 identifies the minimum productivity level by vessel class that would assure a bay time of 20 hours.

Table 1 and Figure 1 indicates that the largest bay, with 40ft containers, for a Post Panama containership requires a minimum of 19.8 lifts per hour to complete D&Ling the largest bay in 20 hours. The same vessel when the bay is 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 per hour (one lift equals one container). Obviously, the number of lifts for wider containerships is larger. The next generations of containership classes are expected to have larger beams, i.e., larger bays.

Table 1: Minimum Crane Productivity (lifts per 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.

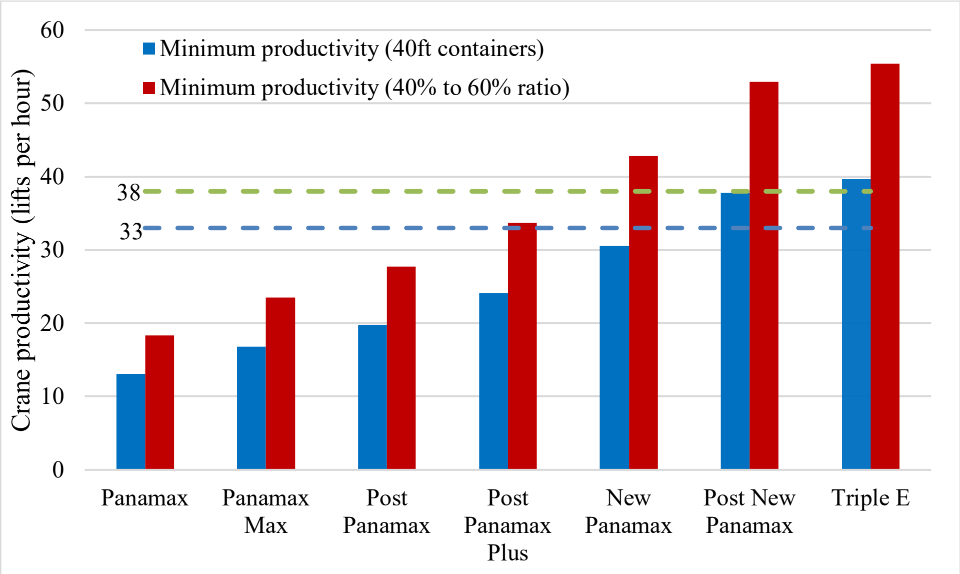


Figure 1: Minimum Crane Productivity (lifts per hour) in 20 Hours of Bay Time.

Assuming that the range of the number of container lifts per hour is 33 to 38, Table 1 and Figure 1 demonstrate that the Post New Panamax containership class and smaller containerships classes can complete their largest 40ft container bay in 20 hours. But when the container sizes are mixed at a 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 gantry crane productivity. For example, assuming average crane productivity of 35 lifts per hour, the minimum bay time of the largest bay of a containership class is reported in Table 2. Table 2 indicate that for a crane to complete the D&L of the largest bay of a Post Panamax Plus vessel with 40ft containers, a minimum of 13.8 hours is required. The same ship with a bay mix of 40% 20ft and 60% 40ft containers and the same conditions requires a minimum of 19.3 hours to complete the D&L

of the largest bay.

Table 2: Minimum Bay Time (hours) at a Given Gantry Crane Output of 35 Lifts per Hour

Containership class	Number of 40ft containers	Minimum time at bay (40ft containers)	Number of 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.

Table 3 provides estimates of minimum bay time for D&L at different productivity levels. However, given that with the present time the productivity level range is 33 to 38 lifts per hour, the estimated time to complete D&L with 40 lifts per hour and beyond is not attainable.

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 per 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.

Since containership beam size has been increasing and it is expected to continue, and since the containership liner service provider must meet the containership multiport of call schedule, the ports are under pressure to improve productivity. While putting pressure on the ports, the shipowners/operators seek internal solutions to overcome the productivity difficulties at the port in order to achieve their target of maximizing D&L in one port at an acceptable amount of time. The containership operators through their stowing planners, modify container stowing plans in order to expedite operations at the berth taking into consideration each port's specifications and constraints and the time it takes to overcome those limitations. In a worst case scenario, some ports might lose a shipping line contract for the lack of or slowness of accommodation. Table 3 could be used to identify bay time given various productivity improvements measured in <u>moves</u> per hour, <u>not</u> lifts per hour (see below).

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

Keeping bay time constant at the time when bay size carrying capacity increases requires that the productivity increase (lifts per hour) match the bay size growth (slots per bay) as specified in Equation 3, i.e., their ratio equals one.

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

The inequality between the two could be due to bay size growth increasing faster than productivity growth, which indicates an increase in the gap between them and an increase in the time to D&L. The alternative of productivity growth increasing faster than bay time growth will result in closing the gap between them and a decrease in the time it takes to D&L.

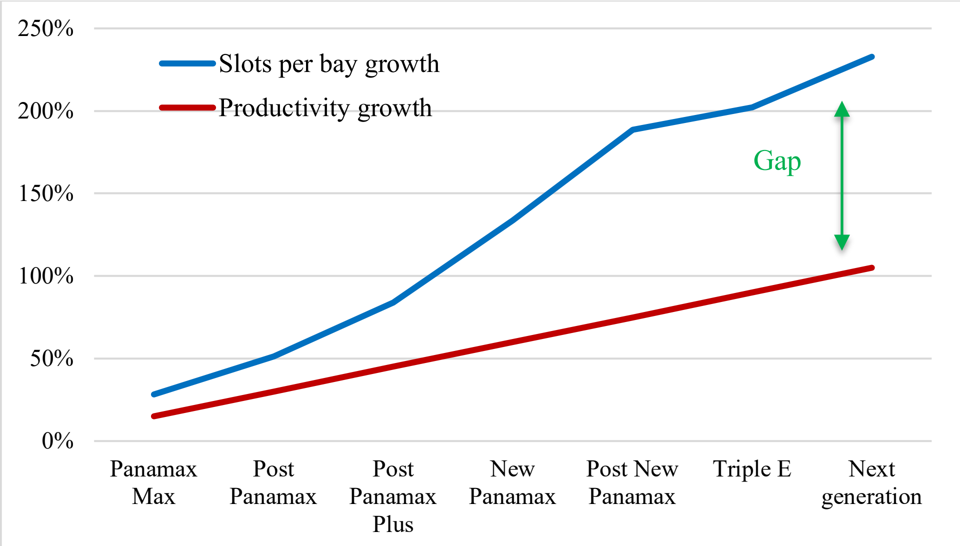
As indicated before, assuming that crane productivity in many ports increased from about 20 lifts an hour, at the time the Panamax vessel class was launched, to about 38 lifts an hour presently, when the Triple E calls ports. This is about a 90% increase (Table 4 and Figure 3). Since the increase of crane lifts per hour differs from port to port and their improvements are not documented with respect to vessel size increase, the study assumes a neutral increase of an average of three lifts per hour with every new vessel class launching. Obviously, better documentation would have provided more accurate results associated with new vessel size.

Table 4: Estimated Number of Bay Slots and Productivity Growth

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

The productivity growth column (Table 4) is an index of productivity growth (lifts per hour), where the Panamax is the base.

During a similar time period, a comparison between the largest bay carrying capacity of the Panamax vessel class and the Triple E vessel class increased from 131 40ft slots to 396 40ft slots, respectively. Thus, the bay carrying capacity increased by an estimated 202% (Table 4 and Figure 3). The next generation of containerships largest bay with 24 rows and about 436 40ft container slots would have a carrying capacity estimated increase of 233% compared to the Panamax class (Table 4). The slots per bay growth column is an index of slot growth where the Panamax is the base.



Note: Only the vessel class axis is synchronized with slots per bay growth

Figure 3: Slots per Bay Growth and Productivity Growth.

Productivity growth and slot per bay growth are an industry fact. But what is less clear is their timing and their adjusting lag. Therefore, the focus is on the trend and the general magnitude of the gap (Figure 3). Even though both the timing of the adjustment of the lag and to some degree the magnitude of the figures might be off when compared to each other, their size and their persistent growing gap are evident and were the cause of taking action to close the gap by the port industry and to some degree by the container shipping industry.

Closing the gap between estimated bay capacity growth and productivity growth to stabilize bay time is an important port industry's interest and responsibility (Table 4 – Gap column and Figure 3). For example, one can demonstrate that the Panamax Max with a 13% growth gap (container slot productivity growth minus crane productivity growth) caught up with the launch of the Post Panamax vessel. Similarly, the productivity growth gap of the Post Panamax vessel class finally caught up when the Post Panamax Plus containership was launched. But as soon as this happened there was a setback because a new containership class was launched, the New Panamax, (Table 4), after which the gap opened up again. Catching up to a gap leads to the conclusion that crane productivity improvements had an estimated lag of at least one containership class; in others it took two containership classes. For example, in the estimated ratio with one lag column in Table 4, we note a ratio of 0.94 (28%/30%) and 1.14 (51%/45%). These figures nearly demonstrate an equilibrium. The lag reduced the ratio substantially up to and including the New Panamax class with a ratio of 1.40. But the trend in the lagged ratio is increasing (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. Furthermore, it could also be argued that the lagged trend demonstrates that the number of lifts will not catch up to beam size growth. The estimated gap between the two is substantial and it requires a major effort by all stakeholders to close or reduce the gap, including other means, because lifts per hour alone will not be enough.

5. CHALLENGES

The containership industry is expected to keep increasing beam size in the next generation(s) of containerships. The solution to the challenges of the diseconomies of scale at the port of the present and future containerships size is primarily from the container port berth side. The size of the gap between bay capacity and crane productivity (lifts per hour) cannot be closed by increasing the number of lifts per hour per crane. There is a limit to the number of lifts per hour per crane. The large gap between the two has been known in the industry for some time, especially for the large containerships (VLCS and ULCS). Thus, the gap and its growth forced each, the port industry and the containership owner and operators, to look for D&L time-saving solutions of new technologies and operation methods.

There are a few major technologies and operation methods used to reduce bay time and berth time:

- ***New Spreader Technology***. The gantry crane operators use new spreaders that lift simultaneously a number of containers at one time, i.e., two [20], three [21], four [22] and more. This new technology measures the output in TEU or in moves per hour, not lifts per 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. The larger the number of containers lifted simultaneously, the shorter the bay time. With this technology a lift could count, for example, 4 TEUs when using a quarto spreader. Container terminals prefer to provide the crane output data in TEUs or containers moved per hour because it is good for business. It could also blur the number of containers moved because a 40ft container could be counted as 2 TEUs instead of one container. This technology highlights the importance of the measures such as “TEUs per lift”, “containers per lift” or “moves per lift”. For example, a crane output could register: an average of 1.8 TEUs per lift, 4 TEUs per lift, 120 TEUs per hour, 60 TEUs per hour, etc. This spreader technology increased crane output. Indirectly this new measure of “TEU per lift,” for example, is an important addition to the statistical information generated in the container terminal. Because a figure such as “2.5 TEUs per lift” measures crane or spreader efficiency and it highlights the system dependency on the sophisticated new technology to improve crane output. This measure when compared to “lifts per hour” shows the dependency on alternative technologies. This measure could identify which alternative dominates by crane, port and vessel class.
- ***Fastnet***. A new technology in its infancy is the “Fastnet.”[23] Fastnet is designed to address the present gantry crane operations itself. Fastnet eliminates the present gantry crane’s wheel base from blocking two bays. This means that each bay can be assigned a crane, assuming that there is no limit of cranes on the pier. This technology can close to double the present crane output. Without Fastnet a gantry crane blocks at least two bays [2]; therefore the minimum berth time is two times the bay time when a crane is operating two adjacent bays. Furthermore, Fastnet together with the new spreader technology (as described above) would increase output substantially. As the gap between bay time and productivity increases, this technology or a similar one is expected to become the standard for the large containerships operations in the large ports.

- ***Stowing***. On board a containership performance improvements can be via stowing. Knowing the container terminal's constraints, the stowing planner can design workable alternatives to minimize containership stay at berth. Since many container terminals have a limited number of cranes and since a containership calls multiple ports, the stowing planner stows containers for the same port in non-adjacent bays at a distance away from each other, if possible. Sometimes the bay is also purposely less than full. The stowing plan is designed to keep up with the contractual schedules of the liner service by minimizing bay time given each port history of crane productivity (lifts per hour) and output per hour (TEUs or moves per hour). These last two measures are monitored regularly by the stowing planners in order to minimize port time for the next voyage. Stowing planning practices change with the circumstances and might concentrate on optimal D&L if the first two technical alternatives above are fully operational.

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

6. CONCLUSION

Containership bay time increases with containership beam size and constant gantry crane output. This link inherently causes diseconomies of scale at the port for wider containerships. The paper reviewed the relationship between the containership beam size, crane productivity (lifts per hour), and bay time. To determine this relationship the paper uses the lifts per crane as a standardized measure of comparison and for quantifying this relationship. This important measure highlights the extent of the problem and the pressure it imposes on the container port and on the containership owner and operator. The pressure on the owner operator is somewhat reduced by resorting to the inefficient call of a large number of ports and by using creative stowing plans for each port. The pressure on the ports is to improve productivity and output at the berth. Improved port performance in the long run is the key for a port to stay in business and be competitive.

The paper finds that the diseconomies of scale associated with increase in containership beam size measured by productivity (lifts per hour) are substantial and increasing. The paper also finds that the gap between the two is adjusting with a lag but the gap reached a level of non-convergence. Therefore, there is a need for external measures to stabilize port performance whereby output growth matches bay size growth. Stabilizing this relationship also requires a large number of gantry cranes. Some improvements in the short term could be offset by stowing planners taking into consideration the limitations of each container port along the multiple ports of call of the liner service. These limitations could include a larger number of gantry cranes assigned per vessel. The stowing plan might also require stowing containers in non-adjacent bays and/or avoiding a high concentration of cargo for the same port in one bay. Creative stowing planning could provide some of the reduced bay time benefits at the cost of multiple ports of call and their inefficiencies.

The paper also find that in the long run the large containerships, especially the VLCS and ULCS, need for technology improvements is in two distinct areas: increase use of spreaders that can D&L multiple containers in every lift and install a Fastnet or similar technology. Spreaders that handle multiple containers are a relatively inexpensive method added to existing equipment. Many ports utilize the technology already. The Fastnet technology is a large undertaking with significant implications for terminal performance and a large investment. The ultimate combining of these two technologies might even eliminate the diseconomies of scale in the port due to the increase in containership beam size.

The paper finds that a comparison (ratio) between productivity (lifts per hour) and output (TEUs or moves per hour) is instrumental in determining port efficiency improvement over time. This captures the improvements from two aspects where the first is the foundation for the improvements.

In addition, the improvement of container terminal performance also requires container terminals to have a sufficient number of cranes, large yards, and equipment to move containers around, trained individuals, and more. These issues are beyond the scope of this paper.

This research highlights container terminal operations, indicating the long-term objectives for container terminal needs and the ability to stay or be competitive. It could also be used for bay time planning, berth time planning, stowage planning, and berth time guarantees during negotiations. The findings could also be used for berth planning, prioritizing berth and port development and investments. Furthermore, the evaluation method could also be used in determining containership development and its impact on berth time.

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