BIG SHIPS AND TERMINAL DENSIFICATION

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The throughput capacity of most container terminals is determined by the throughput capacity of their container yards (CY), with the latter expressed by the formula:

Throughput Yard Capacity (TEU/Year) = Static Yard Capacity (TEU) x 1/Dwell Time (day) x 365
And:
Static Yard Capacity (TEU) = Yard Area (ha) x Storage Density (TEU/ha)

Accordingly, increasing static (holding) yard capacity mandates increasing yard area and/or storage density. Many ports in the era of big ships suffer from shortage in developable waterfront area. Hence, to increase their terminal capacity they need to increase the storage density of their CYs – the subject of this paper.

THE HIGH BAY SYSTEM (HBS)

Increasing CY's storage density, or densification, is also the main objective of a highly innovative technology developed by High Bay System (HBS) ; HBS' second objective is increasing CY's waterside productivity. The new system consists of three components:

- An Automatic Storage & Retrieval System (ASRS) based on an 11-high, 50-m rack structure and automated 35-ton stacker cranes serving the waterside operation, or ship handling
- Automated Rail-Mounted Gantry (ARMG) cranes serving the landside operation, or truck handling
- An internal, sub-terrain, rail-based horizontal transport system, connecting the stacker cranes and ARMGs

HBS' primary advantage is an increase in CY's storage density by 300% relative to common, manual Strad and RTG-based systems; its secondary advantage is an increase in waterside productivity, to 200 moves/hour per ship, or a total of 400 moves/hour when serving two ships. My intention in this short paper is to compare HBS with present CY's storage systems in terms of density and productivity, examine its overall applicability, and comment on its prospects to 'revolutionize' the container terminal industry.

CROSS SECTIONS OF COMMON YARD CRANES

No cost data has yet been published by HBS. Likewise, the cost of waterfront land, which HBS intends to save, varies widely by location and situation. Therefore, my comparison of HBS with other CY storage systems is not based on their overall economics, but on their basic design features. Figure 1 shows schematic module configurations (cross sections) of HBS and common yard cranes: Straddle Carriers (SC), Rubber-Tired Gantry (RTG), end-loader Automated Stacking Crane (ASC) and side-loader cantilever Automated Rail-Mounted Gantry (c-ARMG). The term "common" denotes that there is no uniformity in dimensions of yard cranes. The comparison criterion selected here is module density, defined as the number of boxes per module's gross width (box/m). The number of boxes is a function of stacks' height (number of tiers) and width (number of rows). The module's gross width is the sum of the widths required for boxes, spaces between boxes, aisles for

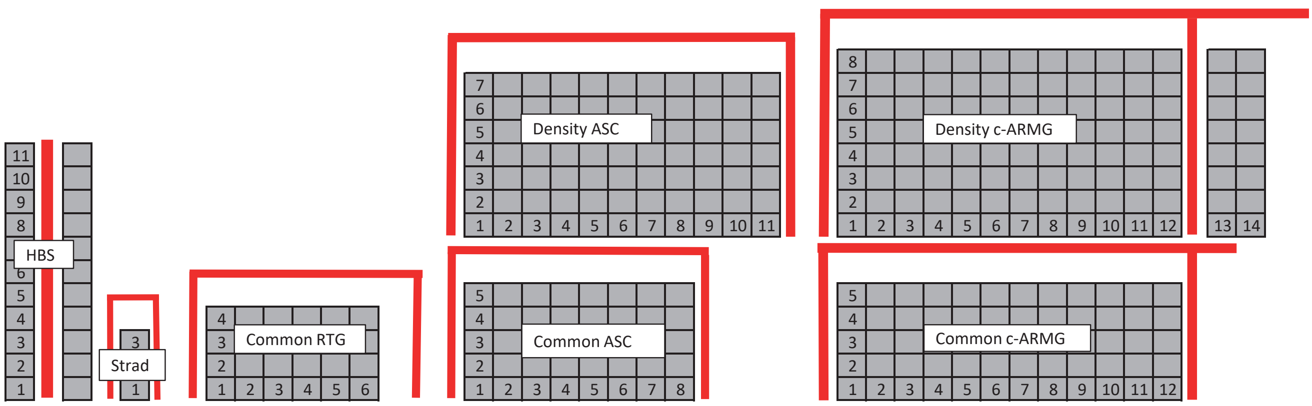

Figure 1: Stack Cross-Section of Yard Cranes

crane legs and between adjacent cranes, and aisles for transport vehicles (in case of side-loaders). Spaces outside stacks, required for ship and truck handling for end-loaders and transport arteries between and around stacks, are not considered here.

HBS VS. COMMON YARD SYSTEMS

The upper section of Table 1 shows my calculation of module density for HBS and other yard cranes. The slot utilization factor reflects a common practice of leaving empty slots in order to minimize re-handling (shuffling, shifting, digging, et cetera). The factor assumed for present yard systems is 75%, meaning that in the case of the popular, 4-high RTGs, the so-called effective stacking height is 3 (4 x 0.75). The rack-based HBS provides direct access to all storage compartments (boxes), or has "perfect" selectivity. Still, full utilization (100%) is impractical since it will result in excessive traveling and long service times of stacker cranes. Likewise, some of the slots are "lost" due to inability to place 2 x 20-ft boxes at a 40-ft slot and the need for special 45-ft slots. Therefore, the slot utilization assumed here for HBS is 85%, resulting in effective height of 9.35 -- more than three time that of RTG. The results of the module density calculation are presented as a percentage increase in HBS' density relative to other yard systems. As seen in Table 1, bottom line, HBS' calculated increase in density is 300%+ relative to Strad and RTG and about 200% relative to Common ASC and c-ARMG -- confirming HBS's densification claim.

The lower section of Table 1 shows HBS' own calculation of relative storage density (%), taken from footnoted papers. HBS' calculation is based on detailed analysis of terminal layouts and operational simulations. There is a high correlation between my and HBS's results for present Common ASC and c-ARMG. This correlation indicates that my admittedly-

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Description	HBS	Strad	RTG	COMMON ASC	COMMON C-ARMG	DENSITY ASC	DENSITY C-ARMG
Rows/Module (box)	2	1	6	8	12	11	14
Stacking Height (box)	11	3	4	5	5	7	8
Boxes/Module-- Gross	22	3	24	40	60	77	112
Slot Utilization Factor	0.85	0.75	0.75	0.75	0.75	0.75	0.75
Effective Stacking Height (box)	9.35	2.25	3.00	3.75	3.75	5.25	6.00
Boxes/Module-- Effective	18.70	2.50	18.00	30.00	45.00	57.75	84.00
BOX GROSS WIDTH (M)	2.90	2.50	2.90	2.90	2.90	2.90	2.90
STACK WIDTH (M)	5.80	2.50	17.40	23.20	34.80	31.90	40.60
RUNWAYS & AISLES WIDTH (M)	3.40	2.10	13.00	6.80	13.00	6.80	13.00
MODULE WIDTH (M)	9.20	4.60	30.40	30.00	47.80	38.70	53.60
MODULE DENSITY (BOX/M)	2.03	0.54	0.59	1.00	0.94	1.49	1.57
HBS DENSITY INCREASE	---	**374%**	**343%**	**203%**	**216%**	**136%**	**130%**

HBS

Description	HBS	SC EUR	BIG MEA RTG	EUR ASC	BIG MEA C-RMG
CY Density (TEU/ha-year)	162,812	45,152	47,375	73,654	67,968
HBS Density Increase	---	**361%**	**344%**	**221%**	**240%**

Table 1: Density of CY Systems

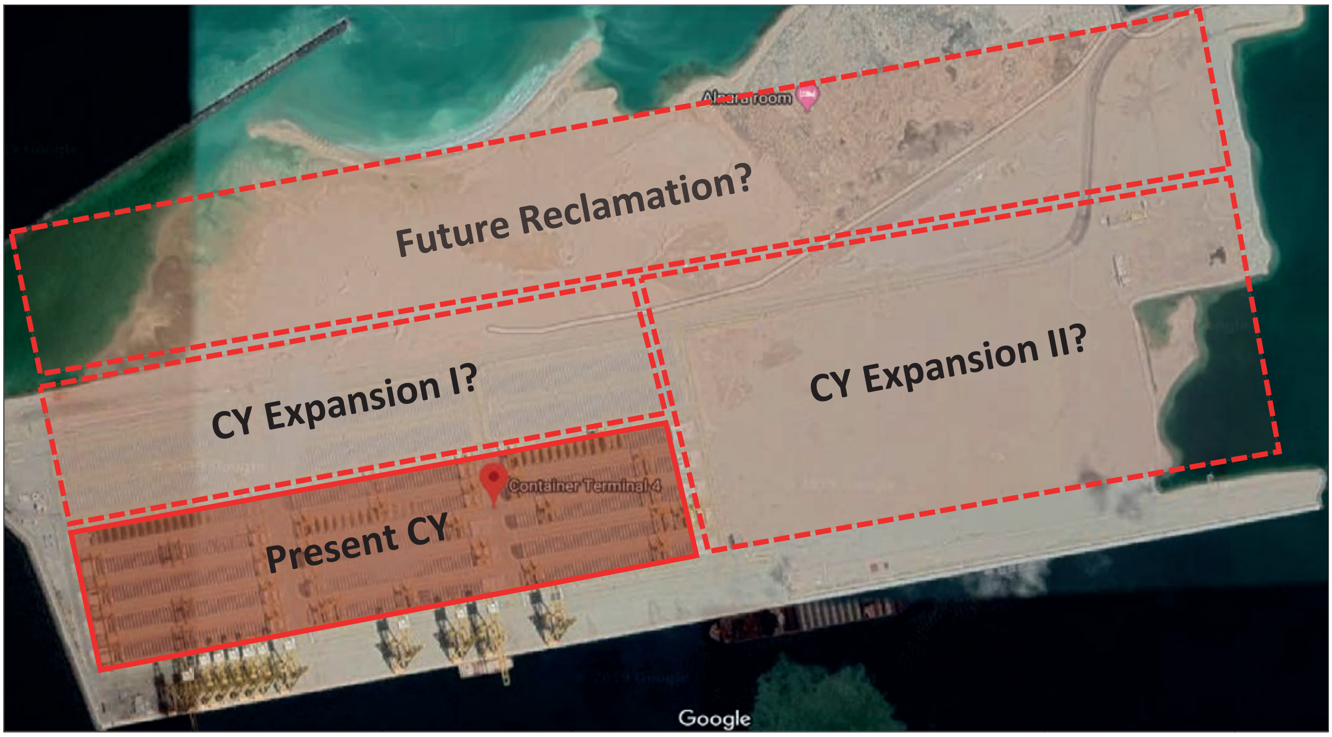

Figure 2: Jebel Ali's Terminal 4

rough method could also be applied to compare HBS with future Density ASC and c-ARMG.

DEVALUATION OF SELECTIVITY

Marine containers are self-stackable. Stacking height is limited by the 192 MT overall weight, equivalent to 6 boxes laden to their maximum weight of about 30 MT. The actual stacks of boxes in ships and CYs can reach much higher since boxes are rarely laden to their maximum weight and some are empty. For example, the stowage plan of Maersk's Triple E, 18,000-TEU, allows 11-high below deck and 10-high above deck. The future MSX24, 24,000-TEU, is based on 12-high below deck and 12-high above deck. The overhead cranes operating in Singapore's Pasir Panjang (PPT1) CY are 10-high. In contrast, present CY stacks served by Common ASCs and c-ARMGs, as shown in Figure 1, are only 5-high. The main reason for not going higher with present CY cranes is the concern of rapid decline in selectivity level and respective increase in re-handling.

A high level of selectivity is not required, however, if much of the boxes are handled or unsorted in "blocks", meaning that the order in which they are stacked and later on retrieved is not important. Block storage of import boxes is possible when a large chunk of them is destined to a single importer, usually a large shipper with large storage yard at his warehouse. Following recent market concentration trends, the number of large shippers is on the rise. For example, in 2018, four US shippers, Walmart, Target, The Home Depot, and Lowe's, collectively imported 2.3 million TEU, accounting for about 10% of the total US import. On some occasions, Walmart alone is reported to bring in 500+ boxes per ship-call.

Block storage is common for rail-bound boxes, with blocks are arranged according to hinterland destination points. Block storage also is common for empty containers, with blocks arranged arranged according to shipping lines, size and type. Stacks of empty boxes can reach 8-high when served by specially-fitted, high-mast lift trucks (empty handler) and can reach 15-high when served by overhead cranes.

Selectivity is less critical for export boxes, since ship's stowage plan is prepared well in advance of ship's call, so boxes can be arranged according to their expected handling sequence. Recent developments in TOS and truck appointment system also allow for "intelligent" CY stowage plan to reduce shuffling. The most important development, however, is "peel-off" operation, a growing trend in USWC ports in which import boxes are unsorted in temporary blocks immediately upon discharge from ship, to be sent after a short stay to nearby, off-dock CYs.

The cost of re-handling in automated CYs is a fraction of that in manual CYs, especially the cost of "house-keeping", a planned re-arrangement of stacks intended to minimize re-handling and shorten crane's service cycle. House-keeping is usually performed during night shifts, when the demand for landside operation is low. In manual CYs, ordering labor for night shifts is highly costly, which is not the case in automated yards. Altogether, the growing trends of block storage, peel-off operation, intelligent stowage planning and low-cost house-keeping suggest that storage selectivity is underway to lose its past importance. The "devaluation of selectivity" is expected to trigger the introduction of denser versions of the present, Common ASCs and c-ARMGs in the near future (5 – 10 years).

HBS VS. DENSITY ASC AND C-ARMG

Figure 1 shows in its lower portion cross sections of Common ASC and c-ARMG, and in its upper portion Density ASC and c-ARMG. In Density ASC, the stack width is increased from 8 to 11, one row wider that DPW's London Gateway, and the height from 5 to 7, similar to Cosco/APMT's Vado Gateway Terminal. In Density c-ARMG the width is increased from 12 to 14, similar to Haifa's Carmel Terminal and the height from 5 to 8. The higher stack height considered for the c-ARMG is because its larger width allows for more opportunities for placing re-handled boxes without resorting to traveling. Another possibility to increase density while not increasing stack height is to increase the width of future ASC and c-ARMG to 12 and 16 respectively.

The proposed increases in height and width of the Density ASC and c-ARMG are modest, but their impact on storage

density is quite dramatic. The rightmost two columns of Table 1 indicate that HBS's impressive density advantage of 300% over manual RTG and 200% over Common ASC and c-ARMG shrinks to a modest 30% over Density ASC and c-ARMG.

To recap, HBS's main claim of a 300% increase in storage density relative to manual Strads and RTGs, as highlighted at the opening of this paper, is factually correct – but irrelevant. Terminals operating conventional Strads and RTGs and seeking to densify their CYs are likely to compare HBS with denser, automated yard systems expected in the near future, where HBS's advantage is probably only around 30%. Likewise, terminals already operating ASCs and c-ARMGs seeking densification are likely to first raise legs of existing cranes and, eventually, consider replacing them with denser versions.

HBS' WATERSIDE PRODUCTIVITY

The discussion thus far only addressed HBS's main component, the 11-high ASRS and its impact on storage density. Let's turn now to HBS' other components: stacker cranes for shipside operation, and internal rail transport system, connecting ARMGs to the ASRS. HBS claims that the unique, 3-component combination can produce waterside productivity of 200 moves/hour per ship, while not hurting landside productivity.

But, achievable by existing yard systems through increasing the number of yard cranes and horizontal transport vehicles and allocating them to serve the waterside. Allocating more cranes to the waterside is relatively simple with side-loaders and parallel arrangement of stacks; with end-loaders it is a bit more complicated, requiring parallel arrangement (Vado), or adding a third crane per block (HHLA/CTB). A Port Technology paper (Nye, May 2014) summarizes a comprehensive simulation study on the performance of ASCs and ARMGs, also demonstrates that 200 moves/hour per ship, or a total of 600 moves/hour for 3 ships, is achievable.

HBS APPLICABILITY

The above analysis of HBS's claimed advantages demonstrated that: (a) HBS has a modest advantage in storage-density relative to future Denser ASCs and c-RMG; and (b) HBS has a limited or no advantage in waterside-productivity. In addition, HBS's complicated system, based on 3-interrelated components, might have problems in coordination and reliability. Hence, I doubt that HBS is going to be a 'disruptive' technology poised to 'revolutionize global port logistics'. HBS would probably be more of a niche technology applicable in special port situations, whereby even a modest increase in storage density is of critical importance.

I also doubt that Jebel Ali's Terminal 4, where the first HBS is planned to be in operation in 2020, would fit the above definition of "special port situation". First, transshipment, which HBS is not designed to handle, consists of about 50% of Jebel Ali's traffic. Second, as illustrated in Figure 2, Terminal 4 appears to have ample expansion area. It also appears that if needed, additional waterfront land can be acquired there via low-cost reclamation.

SHORT AND LONG-TERM SOLUTIONS

CY densification, either by using HBS or denser versions of existing yard systems, can do only so much for CY capacity, and therefore only provide for a short-term solution to the growing problem of shortage in waterfront land. A long-term solution has to focus on the second term in the capacity formula presented the outset of this paper - dwell time. A radical reduction in dwell time mandates rearranging the entire port system: detaching the waterside, ship handling operation from the landside, truck & rail handling operation. My vision of the re-arranged future port system will be the subject of a future, sequel paper.

ABOUT THE AUTHOR

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