ANALYSIS OF THE IMPACT OF THE USE OF INTEGRATED AUTOMATION SYSTEMS FOR CONTAINER HANDLING IN THE IMPROVED TERMINAL CONTEXT: ARMSVS AND QUAY RAILS.

Schmeing F. D. , Netto J. F.

Universidade de São Paulo – Escola Politécnica – Department of Naval Architecture and Ocean Engineering.
[1]e-mail: felipe.dare@usp.br

ABSTRACT

Containerized cargo trading is a globally growing activity with big players, large amounts of capital, and several risks. These conditions lead to the prioritization of investments in scale gain and operation optimization, leading to changes in vessels and ports towards growth, expansion, and automation. This paper delves into the concept of Improved Container Terminal, an deep-water facility that works as a hub port receiving Ultra Large Container Ships from other Improved Terminals and performs the transshipment for coastal shipping and overland flow. To lower the costs with port operations and maximize throughput, this facility relies on solutions based on innovations in and out of the port industry, such as the High Bay Storage from BOXBAY Terminal. This article is in the sequence of studies started in Scientific Initiation research (Schmeing, 2021). The analysis here presented has focused on the ARMSVs and the Quay Rails.

Keywords. Container terminal, Material-handling equipment, Port Expansion, Automation.

1- INTRODUCTION

As seen in recent decades, international trade continues to grow vastly (UNCTAD, 2021) creating large cargo flows that interconnect producer and consumer centers. Queues at ports, high shipping rates, and enlarging capacity fleets are indications of this expansion in the globalized market.

In particular, containerized freight is a branch with expressive growth and high financial return.

This attractive market draws the attention of key stakeholders. On the water, there are the shipowners vying for customers with low costs and taking on logistical challenges. On land, the ports fight for expansion and to stand out over their regional competitors.

The main strategy to increase profits and survive in this market is to invest in economy of scale when possible. It is shown in the Figure 1, with the evolution of containerships, which are the specialized vessels for container transportation over sea. Its capacity has increased since 1955.

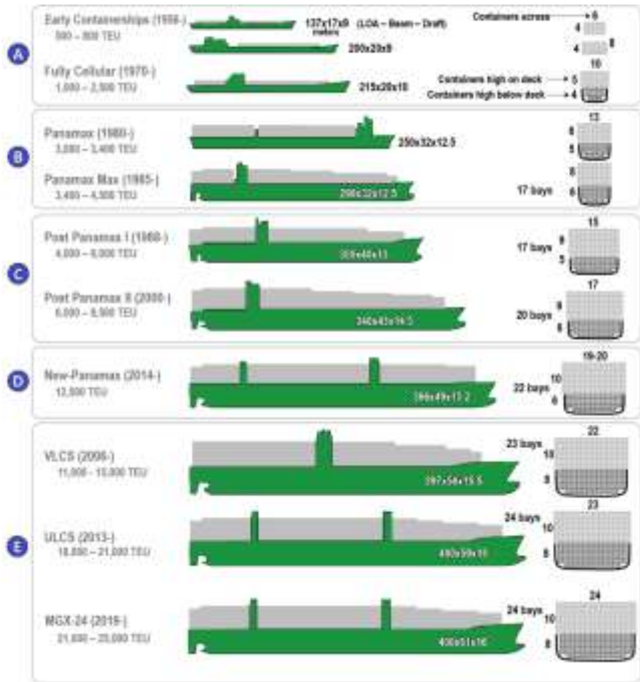

Figure No 1. Growth of container ships
Source: (RODRIGUE, 2021)

Nowadays, the movement of containerized cargo occurs almost absolutely in port terminals dedicated exclusively to this type of merchandise, from where the term "Dedicated Container Terminal" (DCT) comes from. There are several types of DCT models, varying according to the number of units handled, the modes of land transport (road and/or rail) covered, the logistical strategy for storage and transportation, among others.

Today, the most commonly used equipment for loading and unloading cargo from the container ship is the Quay Crane (or Ship-to-Shore Crane, STS). Some problems seen in the use of this equipment, besides its high cost, is the space occupied in the quay, the need to move parallel to the ship, the alignment with the container section, the difficulty in automation, and the vulnerability to weather conditions.

Between the pier and the storage yard, port vehicles are responsible for keeping the flow of containers moving horizontally. The main equipment used for this are Terminal Tractors (TTs), AGVs, and Straddle Carriers (Strad). The use of each vehicle has an impact on the terminal model used and affect the size of the yard and surrounding regions, and even the way cargo stacks are distributed.

In terminals that use passive vehicles, such as TTs or AGVs, the containers make their way into the container yard to the section where RTG/RMG Cranes (or Stacking Cranes) remove them from the vehicles and place them in the stacks.

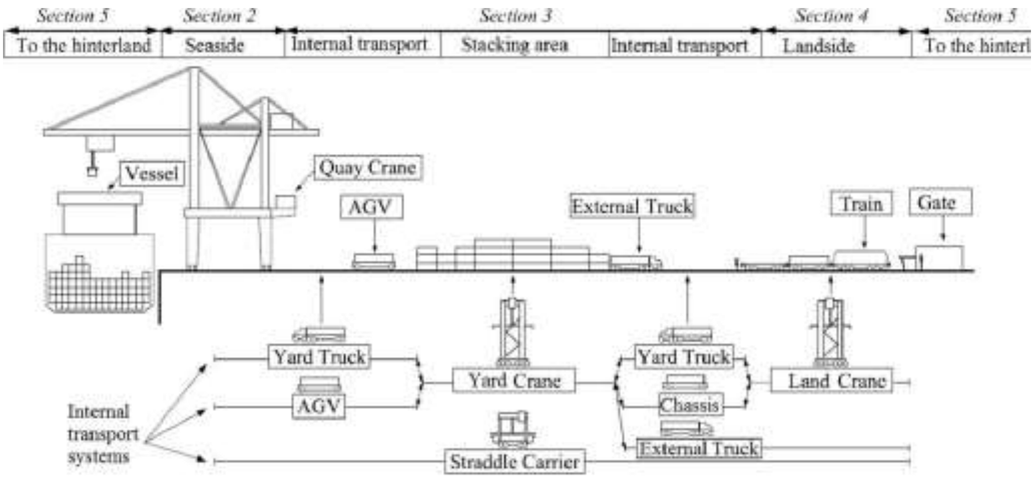

Figure No 2. Traditional DCT
Source: (GHAREHGOZLI, 2014)

Aiming to follow up with the growth of ships and keep up with the competition, ports have been investing hundreds of millions to tens of billions of dollars in increasing the depth and width of berths and access channels, new and larger cargo handling equipment, infrastructure expansion, Land Reclamation works, among others.

One of these GTOs is DP World. Recently, it is modernizing and expanding the Port of Jebel Ali in Dubai, enabling it to receive the world's largest container ships with a capacity of over 23.000 TEUs (Twenty-foot Equivalent Unit).

Part of the project comprises a new port enterprise model: the BOXBAY Terminal (2020). The installation is built to be a test of concept and with the capacity of expand the modular configuration for full operation.

The BOXBAY Terminal was developed by the SMS Group in partnership with DP World and brings as main innovation the use of the High Bay Storage (HBS) system. In this yard configuration, the containers are not stacked, but stored in individual compartments in a structure of up to 11 storage floors that occupies an area equivalent to one third of the area occupied by the stacking sections in a DCT. Cargo handling within the HBS and at the interface with the trucks is done by original machines of the project. The Stacker Crane (STC) stores and unstores the cargo from its compartment, transferring for Strads or the PCS: Pallet Circulation System. (DP World, 2019)

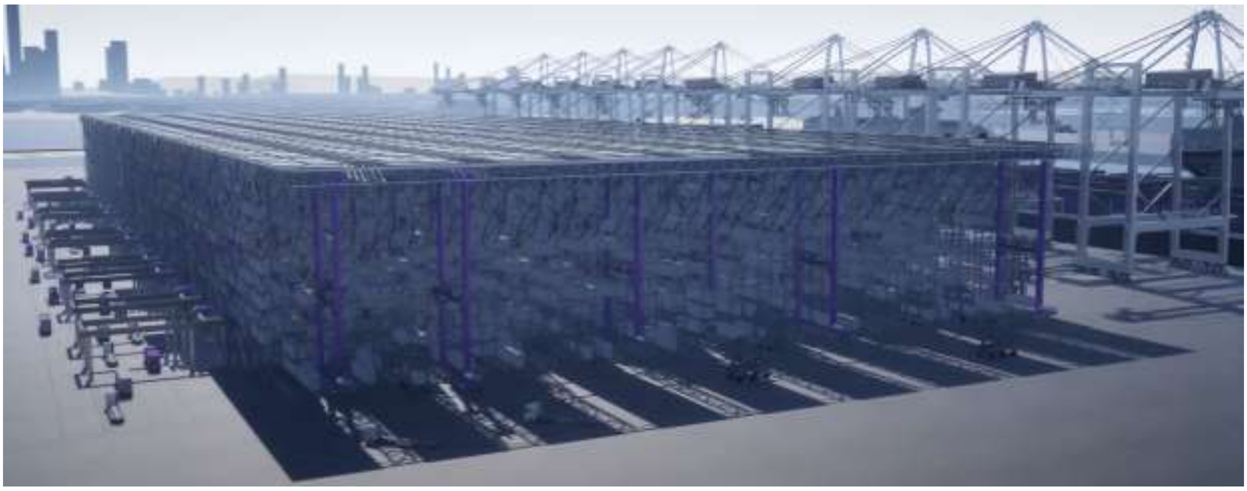

Figure No 3. BOXBAY Terminal
Source: (DP World, 2019)

2- MATERIALS AND METHODS

The Improved Container Terminal (ICT) is an offshore facility dedicated to container handling that bridges the gap between international and domestic routes. Some issues closely covered by this venture are optimizations on the ships, such as the replacement of the superstructure and the use of side locks for access to the basement, and in the port, such as independent power supply with renewable resources from the coast.

With these changes, it is possible to achieve the objectives of increased port productivity, easy coverage of services to ULCSs, reduced energy consumption, low installation and operation capital, and thus lower costs on products to the final consumer. The study of ICT advantages is the main scope of this work.

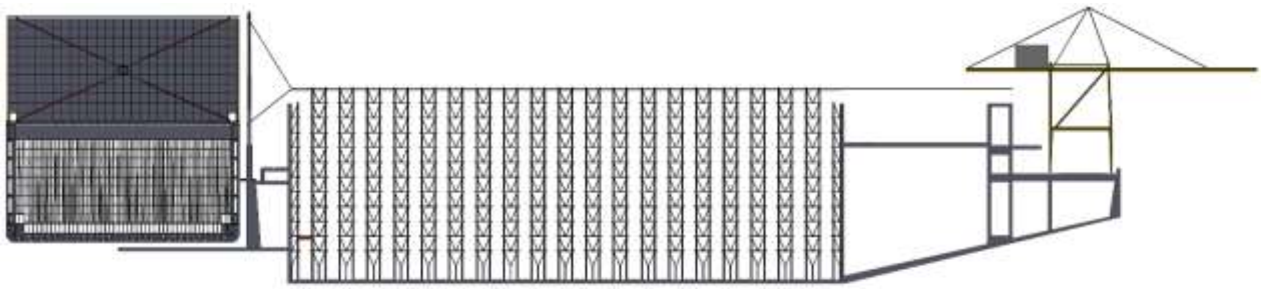

Figure No 4. Improved Terminal
Source: (Schmeing, 2021)

In a little more detail, the use of ARMSVs makes the task of removing the cargo from the ship and transporting it to the storage area be done not with two movements - of the ship-to-shore crane and the port vehicle - but in only one. In relation to the BOXBAY Terminal, there is also the exclusion of the movement performed in the underground of the HBS structure before the reception of the container by the STC, the tower responsible for allocating the cargo in the proper compartment.

The systems integrated into this model of pivot port are:

Quay Rails, which allow the flow of horizontal cargo from the cabotage berths, road, and rail intermodality zone, top of the storage structure going to the ULCSs berth, in which it has movable rails for height adaptation in the access of ARMSVs to the ship;

ARMSVs, which are the vehicles that use the Quay Rail system for cargo movement, replacing port vehicles such as Straddle Carriers, AGVs, TTs, and even Ship-to-Shore Cranes in the (un)loading of ULCSs;

LBS, a structure similar to the HBS, but with container entry at the top and outflow at below, occupying the impolder created with the Empoldering Method of Land Reclamation, see the central zone in Figure 4;

Elevators, responsible for moving cargo vertically and storing it in the LBS compartments, replacing STCs, RSTs, RMG/RTGs;

Indented berth, for more shelter for the ship and increased productivity in loading and unloading, with layout possibilities compatible with the piers and the Quay Rails that minimize time and distance in cargo movement, besides facilitating maritime and land access;

Intermodality and transshipment, with areas covered by the Quay Rails, where the unloading and loading of containers is done by ARMSVs in an agile manner;

Automated management and operations systems, which involve compliance with logistical requirements and constant analysis of the operations' performance.

In this Graduation Work, the methodology focused in the development of ARMSVs and Quay Rails from the vehicles of Traditional DCTs.

3- BIBLIOGRAPHIC REVIEW – PORT VEHICLES

3.1- STRADDLE CARRIER

Straddles Carriers are heavy vehicles, weighing more than 60 tons. The structure of the machine can be divided into the lower module, which performs the horizontal displacement, the vertical metallic columns, the upper module, where the machinery platform and the operator's cabin are located (for non-remote or automated operations), and the hoisting mechanism, containing cables, guides, and a spreader to grab the containers. There are terminals that use Straddle Carriers to just transport the units, handing them off to cranes to do the stowing in higher stacks and without the presence of spacing between them, as seen in Figure 5, in the layout on the right.

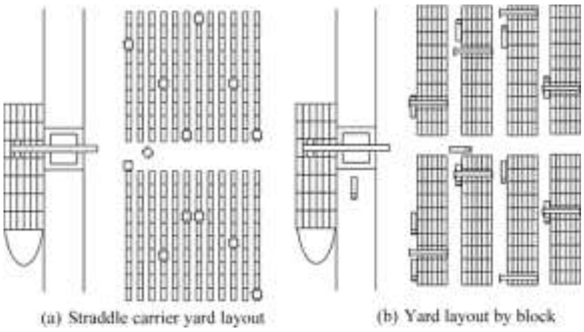

Figure No 5. Comparison between yard layouts
Source: (CARLO, 2014)

Figure No 6. Straddle Carrier storing a container
Source: (CROZEL, 2019)

Other terminal models prefer the total integration of the storage yard so that Straddle Carriers perform all the operations of transport, storage, and subsequent removal from the stack and deposited on the land disposal vehicle (external trucks). For this, the space occupied by the yard needs to be larger due to the lower height of the piles, limited to the height of the Straddle Carriers fleet, and the required spacing between columns, for vehicle access as shown in Figure 6.

The height of the columns reflects in saving space but brings logistical challenges with the larger presence of reshuffling.

3.1- AUTOMATED GUIDED VEHICLE - AGV

The invention of this machine was more recent, compared to the Straddle Carriers, and represented a technological leap by the use of automation in the horizontal movement of containers between the berth and the yard.

The main moving elements of AGVs are related to their main function. Thus, the mechanical control and operations favor accurate positioning of the vehicle, good acceleration and speed, agile maneuverability and steering, and stopping again with precision. (SAANEN, 2016).

Like Straddle Carriers, AGVs need wide flexibility in transporting cargo between the cradle and the storage yard. An important point for operations is the duration demanded of refueling and the frequency of recharges, as it is a time when the machine is unproductive.

For AGV navigation, some terminals use a mesh of transponders on the ground that communicate with the vehicle and indicate its absolute position in the port. This is one of the most reliable ways of guiding the AGV and the central office in the positioning of each transport unit. (KALMAR, 2018).

Figure No 7. AGVs in an automated container terminal
Source: (PORTPICTURES, 2015)

Figure No 8. Lift-AGVs depositing containers
Source: (Konecranes, 2018)

To alleviate the flow of moving or waiting vehicles at the berth and (un)loading points of the yards, it is common to use waiting areas between these two regions, as seen in Figure 7.

The layout has a large effect on port operation and installation and operation costs, covering the number of vehicles required. For example, if a configuration presents a longer distance from the storage yard to the berth, the cycle time of each port vehicle becomes longer (considering the same operation speed). To maintain productivity in relation to the shorter layout, it is necessary to place a larger number of vehicles, keeping the flow at the ends.

3- RESULTS

3.1- IMPROVED CONTAINER TERMINAL - ICT

After the brief literature review, where it was possible to understand the types of horizontal transport port vehicles most used in container terminals, it is now time to apply the acquired knowledge in the formulation of two important pillars of the Improved Terminal concept: ARMSVs and Quay Rails.

To recap, Dedicated Container Terminals (DCTs) have been developed over decades improving their processes and making the movement of containerized cargo cheaper and more efficient.

The concept of the Improved Terminal is a way to optimize the port operations as a whole, changing the need for equipment that limits the operations, simplifying the processes. In other words, based on the proposed improvements in the storage system added to the new technologies of deepwater port construction and the global demand for port and ship expansion, the Improved Terminal concept is built to meet these requirements.

3.2- AUTOMATED RAIL MOUNTED STRADDLE VEHICLE - ARMSV

At the Improved Terminal, the ARMSVs are responsible for the horizontal movement of containers, covering from the berth, with the embarkation and disembarkation of the ship, over the LBS, where it can deposit/receive cargo to/from the Lifts, over also the intermodal area of land disposal vehicles arriving at the transshipment berth for cabotage vessels to be (un)loaded by QCs.

As the name implies, this is an automated vehicle, mounted on rails (the Quay Rails) and operating on the basis of lifting the load, i.e., active mechanism.

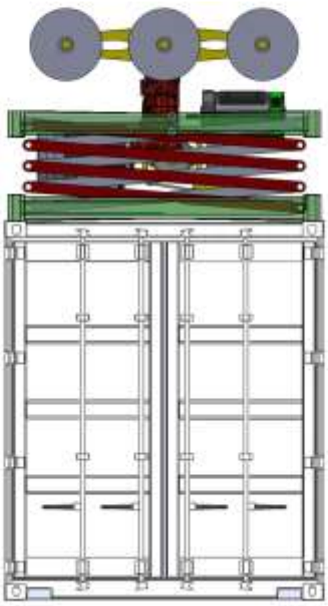

Figure No 9. Sketch of ARMSV hoisting system in compressed position and drive system
Source: Own elaboration

In the choice of mechanical and electronic components, the goal is to minimize weight, cost, and energy consumption. Among the mechanical components, these are divided into 3 systems: hoisting; locking and releasing; and drive.

The Hoist System is responsible for lifting and lowering the load in a controlled manner within established parameters such as maximum operating time, stability, and type of movement according to the length, within the limit of 6 meters of amplitude.

The hoist device can basically be of 4 types: cable with rotary motor; piston with linear servo motor; rack and pinion; and mixed, combining some components of the above. Among these options, the rack-and-pinion was chosen for its smaller footprint and lower weight when compared to the other types, which use drums or hydraulic fluid tanks among other components.

Like AGVs and other port vehicles, ARMSVs also need a navigation system to send position, speed, and direction data to the central office that manages operations in real time. This is important for optimizing terminal throughput and critical when it comes to remote or automated operations, which is the case with the Improved Terminal.

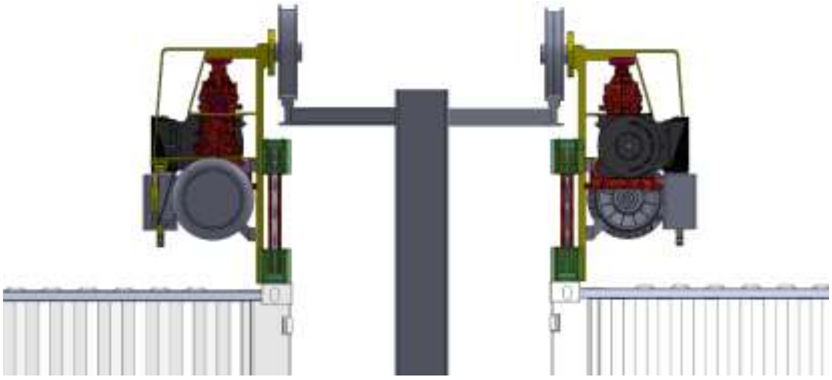

Figure No 10. Sketch of the support of the fixed section of the QRs with ARMSVs
Source: Own elaboration

In the structural aspect, ARMSV is based on the suspended structure of a monorail. The fact that it is suspended is due to the way the cargo is received and deposited from above, using twistlocks.

The ARMSV is responsible for the horizontal load-displacement so that most of the operation is in the plane without slope. The slope is present only in the cradle for ship access, with the rail elevation varying according to the height of the container to be (un)loaded onto the ship. The fixed and mobile parts where the vehicle moves are part of the Quay Rails system.

3.3- QUAY RAILS

The QR constitute the main innovation brought by the construction of an ICT. From it, it becomes attractive: the use of ARMSVs; the Empoldering work for the installation of the LBS as a variant of the HBS and with Elevators instead of STCs; the layout of the container terminal containing one or more indented berths and the intermodality and transshipment zones; in addition, it also facilitates the use of automated management and operations systems to command the operation of the ICT.

Figure No 11. Sketch of the mechanism for regulating the QR interface with the LBS
Source: Own elaboration

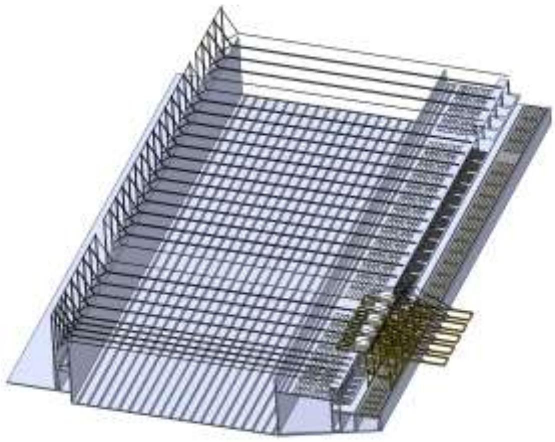

Figure No 12. QR extension in ICT (without LBS)
Source: Own elaboration

The Quay Rail system is divided into sections according to the cargo sections of the ship, see Figure 12 with the modular sectors. In each division, pairs of ARMSVs move along the track, with one end at the cabotage berth and the other at the intercontinental ship berth. In addition, within each section, there is the mobile part and fixed part, as stated.

Quay Rails are structures with an extensive fixed part, supported on the LBS and directly on the concrete at the intermodal yard and the cabotage berth, and a mobile part, at the pier of the ULCSs, with at least two mobile supports on the concrete, one at each end.

4- DISCUSSION

4.1- LOGISTIC COMPARISON

In the Improved Terminal, depending on the procedures performed, the total amount of operations for the displacement of a unit may vary, involving more than one operation of ARMSVs and/or other machines as STSs, Elevators, and internal ship's hold lifting mechanisms.

There are several procedures involving less than 3 operations, presenting a great logistic advantage of the Improved Terminal in relation to the Traditional DCTs and the BOXBAY system, besides the suggested innovations and handling structures cited.

The duration of port processes in a common loading and unloading situation is shown in Table 1. The operations cover the movements from the ship to the inland disposal vehicle including the storage of the cargo.

Table No 1. Duration of processes to move 1 container in each terminal.

Operation	**DCT**	**Duration** [s]		**BOXBAY**	**Duration** [s]		**ICT**	**Duration** [s]	
Standard Case	**Machine**	shorter	longer	**Machine**	shorter	longer	**Machine**	shorter	longer
1	STS	75	100	STS	70	95	ARMSV	90	150
2	AGV	60	120	Straddle	120	220	Elevator	50	70
3	ASC/RMG	75	100	STC	60	75	Elevator	45	65
4	ASC/RMG	75	100	STC	55	70	-		
5	-			Straddle	120	220	-		
	Total	**285**	**420**	**Total**	**425**	**680**	**Total**	**185**	**285**
Extra	Reshuffle	150	200	-	-	-	-	-	-
	Total	**435**	**620**	**Total**	**425**	**680**	**Total**	**185**	**285**

In a Traditional DCT using AGVs, moving a container involves 4 operations: the STS, the AGV, the stacking crane (ASC, RMG, or RTG, usually). The need to move the unit adds 2 operations to each occurrence.

At the BOXBAY Terminal, the number of operations performed on a container can vary between 5, 6, 7, and 8, depending on the path taken and the machines involved.

In the Improved Terminal, it is possible to perform several complete procedures from ship to land disposal vehicle, and vice versa, with 1 or 2 operations. Considering storage, this number stops at 3 or 4. In the case of transshipment to cabotage vessels, the quantity is between 2 and 5 operations.

Traditional DCTs with high investments in port process speed can achieve berth movement rates (Port Moves Per Hour, PMPH) approaching 300 containers moved per hour.

The investments mainly involve using more port vehicles so that there are no delays at the berth. In addition, more cranes need to be reserved for operations on a single ship, which can delay processes on other docked vessels. Large ships can have up to 7 STSs working on cargo handling.

The use of ARMSV not only saves time for the port vehicles but for the STSs as well, which represents a great advance in terms of time and movements.

In each section of a ship, several containers can be moved simultaneously, both above deck and in the hold, following the necessary modifications to the ship's structure.

In the largest modern ULCSs, the distribution of containers follows a similar pattern of 24 bays from bow to stern, 24 rows from side to side, and 20 tiers from hold to top. Future ships with a capacity above 24,000 TEUs will probably have a larger mouth for 26 columns and a longer length for 26 sections or more.

Considering the ship in the first case with 24 sections and 24 columns, there are 572 accessible containers (576 minus 4 by narrowing the bow and decreasing rows), unobstructed and free to be lifted. A port with a high investment and purchase of 1.144 ARMSVs is able to unload all 572 accessible units at a time, in simultaneous operations.

If all 4 macro movements of the ARMSV have a duration of 2 minutes, in 1 hour it would be possible to move 17.160 containers. In other words, a 24.000 TEUS ULCS can be completely unloaded and completely reloaded in 3 hours. It is possible to obtain even higher results, since the indented berth allows the flow of cargo from both sides, so that while a fleet of ARMSVs comes down with cargo on one side, on the other side they already enter the superstructure in your vehicles to receive the cargo. In addition, there is access to the hold, but for logistical and economic reasons with the Quay Rail, it can present challenges if operations occur simultaneously with those above deck.

Another point is that weather effects such as winds can stop operations in Traditional DCTs and in the BOXBAY terminal by the risk of undue cargo swinging and sometimes danger of tipping over or damaging the port vehicle.

4.2- ENERGETIC COMPARISON

Focusing on port vehicles, the energy consumption in each container terminal model was developed based on information from suppliers and estimates based on the power and quantity of the engines used. The modes of operation were also taken into account.

The results obtained were analyzed with similar terminals and showed satisfactory estimates. It is noteworthy that there are terminals with similar amounts of equipment but with considerable differences in handling capacity and annual throughput. This is due to the integration of the machines with the use of management software, automation, logistic strategies, among other resources. There is also a limit to the desynchronization of equipment, especially when this begins to affect the logistics of the port. In terminals with high throughput, the cost of delays can present greater losses than the cost of energy spent to maintain productivity.

At the BOXBAY Terminal, the use of bays annuls the need for cargo reallocation. The minimized expense is considerable since, in this process, the equipment used are cranes with high power demand. Besides this, there is a low demand for flexibility because they are fixed machines, one can consider that the electricity supply is made by the network.

At the Improved Terminal, one of the strategies to increase productivity and reduce energy consumption is to reduce the amount of heavy machinery, giving preference to operation with light vehicles. This also contributes to the stress on the port's energy distribution system.

4.3- FINANCIAL COMPARISON

The analysis of the financial viability of the Improved Terminal's port equipment began by researching the costs of purchasing, maintaining, and operating port vehicles at Traditional DCTs for comparison. After that, estimates were made for the equivalent expenditures for each piece of cargo handling equipment at the BOXBAY Terminal. Finally, the study proceeded to the Improved Terminal, calculating the costs for ARMSVs and the Quay Rails based on existing vehicles and the market value of the inserted components. Estimates were also made for the use of locks and a pumping system at the ULCS berth.

On a larger scale, one of the costs present and of great relevance is with the civil works, which include the execution of Land Reclamation projects, where there are high amounts of investments with raw materials. The filling of the terminal area with sand, stones, and concrete, as shown in more depth in the Scientific Initiation Report (Schmeing 2021), presents a high demand of capital and time for a sufficient result avoiding subsequent problems of settlement and other concerns.

The main portion that causes the growth of CAPEX of BOXBAY in relation to a Tecon is the amount involved in the construction of the High Bay Storage structure, which certainly involves a larger investment than the treatment of the soil in the stacking yards.

The CAPEX reduction is aimed through the economy with area, by using one-third of the space used in a DCT for the same amount of containers stored. The Improved Terminal design contains the HBS costs and advantages from the BOXBAY system, with other added benefits. The ICT concept focuses on reducing the logistical, energy, and financial pressure on large machines and distributes this impact to smaller vehicles.

In the cost calculation of Quay Rails, the foundation and steel tracks are the main portions, since the leveling and soil treatment for the support of ties are less necessary.

As with the energy issue, the quantity of each machine to obtain a productivity of 100 thousand TEUs per day was defined. For the Improved Terminal, this necessarily involved the total unloading of 25.000 TEUs and subsequent reloading of the same quantity.

From this number of vehicles and the cost of acquisition, assembly (if applicable), transportation, and installation, the CAPEX involving port machinery was calculated for the three terminal models: Traditional DCT, in the configuration using AGVs and ASCs or RMGs; BOXBAY, with an equivalent cargo movement between Straddle Carriers and Interface Cranes; and the ICT. The results are shown in Table 2.

In an equivalent way, the OPEX was estimated and is presented in Table 3.

Table No 2. CAPEX of port vehicles and machinery in the 3 terminal models.

DCT	**Qtd**	**Cost**	**Subtotal**	**BOXBAY**	**Qtd**	**Cost**	**Subtotal**	**ICT**	**Qtd**	**Cost**	**Subtotal**
Machine	[un.]	[US$/un.]	[US$/un.]	**Machine**	[un.]	[US$/un.]	[US$/un.]	**Machine**	[un.]	[US$/un.]	[US$/un.]
STS	55	40 M	2,2 B	STS	50	40 M	2 B	STS	15	25 M	375 M
AGV	431	700 K	301,7 M	Straddle	160	1 M	160 M	ARMSV	250	300 K	75 M
ASC/RMG	150	2 M	300 M	STC	160	2,1 M	336 M	Elevator	1136	1,7 M	1,9 B
				TT	252	290 K	73,1 M	TT	70	290 K	20,3 M
				Interface	24	1,6 M	28,4 M	QR	100	1,5 M	150 M
				Pallets	84	400 K	33,6 M	Water Gate	2	34 M	68 M
								Berth Pump	10	15 K	150 K
Total	**636**	**-**	**2,8 B**	**Total**	**703**	**-**	**2,6 B**	**Total**	**1585**	**-**	**2,6 B**

Table No 3. OPEX of port vehicles and machinery in the 3 terminal models.

DCT	**Qtd**	**Cost**	**Subtotal**	**BOXBAY**	**Qtd**	**Cost**	**Subtotal**	**ICT**	**Qtd**	**Cost**	**Subtotal**
Machine	[un.]	[US$/un.]	[US$/un.]	**Machine**	[un.]	[US$/un.]	[US$/un.]	**Machine**	[un.]	[US$/un.]	[US$/un.]
STS	55	440 K	24,2 M	STS	50	400 K	20 M	STS	15	320 K	4,8 M
AGV	431	100 K	43,1 M	Straddle	160	245 K	39,2 M	ARMSV	250	110 K	27,5 M
ASC/RMG	150	350 K	52,5 M	STC	160	310 K	49,6 M	Elevator	1136	70 K	73,8 M
				TT	252	75 K	18,9 M	TT	70	65 K	5,25 M
				Interface	24	290 K	6,96 M	QR	100	30 K	3 M
				Pallets	84	35 K	2,94 M	Water Gate	2	400 K	800 K
								Berth Pump	10	20 K	200 K
Total	**636**	**-**	**119,8 M**	**Total**	**703**	**-**	**137,6 M**	**Total**	**1585**	**-**	**115,4 M**

In the ULCS berth, the STSs were replaced by ARMSVs and the QR system. In the cabotage berths, the STSs are smaller, with a significant reduction in the cost of STS acquisition.

5- CONCLUSIONS

Attending to the growing vessels has been a challenge, even for the main ports of the globe, so that expansion works, improvements in processes and logistical optimization are fundamental for success in this business. In order to cover these three pillars, the concept of the Improved Terminal brings innovations in infrastructure, equipment, and software use, increasing the simultaneous movements in the terminal, reducing distances and duration of operations, and promoting energy, financial, and sustainable benefits.

Thus, from the introduction of the theme in the Scientific Initiation Report and the deepening, in the monograph, of two of the innovations brought by the AT concept - which are the ARMSV and the Quay Rail (QR) system - it was possible to answer the research question for the current level of detail. The conclusion was that, based on the use of ARMSVs and the Quay Rail system, within the context of deepwater port automation and expansion, the investment in an Improved Terminal is advantageous on the logistical, energy, and financial fronts compared to other DCTs and proposals.

The cargo handling capacity allows the reduction of berth time from days to hours. The larger number of machines reduces the demand peaks and generates less stress on the network. The rail vehicles get easier feeding and weight reduction. The installation and power of expansion of the activities need low capital. For more details, see: https://youtu.be/YBhW78rfhKk.

6- BIBLIOGRAPHIC REFERENCES

1. SCHMEING, F. D. Aprimoramento Portuário em Águas Profundas. São Paulo, SP, p. 198, 2021.
2. Shipping during COVID-19. UNCTAD, Geneva, CH, 2021. Available in: <https://bit.ly/3saAw7M>.
3. RODRIGUE, J.-P. Evolution of Containerships. The Geography of Transport Systems, New York, US, 2021. Available in: <https://bit.ly/3yp55aQ>.
4. GHAREHGOZLI, A. H., ROY, D., KOSTER. B. M. De. Sea Container Terminals: New Technologies, OR Models, and Emerging Research Areas. Business, Engineering. 2014.
5. DP World. Introducing boxbay - a new and intelligent high bay storage system. 2019. Available in: <https://youtu.be/K68Kq8s4EaI>.
6. CARLO, H. J.; VIS, I. F. A.; ROODBERGEN, K. J. Transport operations in container terminals. European Journal of Operational Research, v. 231, n. 1, p. 1–13, 2014. ISSN 0377-2217. Available in: <https://bit.ly/3dRt3lH>.
7. CROZEL, J.-L. PortSynergy prépare “un programme colossal” à Marseille-Fos. La Provence, Marseille, Fr, 2019. Available in: <https://bit.ly/3pXBRw3>.
8. SAANEN, Y. AGV VERSUS LIFT AGV VERSUS ALV. PORT TECHNOLOGY, Delft, NL, v. 70, p. 30–35, 2016. Available in: <https://bit.ly/3pQk5KY>.
9. KALMAR. Kalmar FastCharge™ AGV. Kalmar, Helsinki, FI, p. 1, 2018. Available in: <https://bit.ly/3dU0Drc>.
10. PORTPICTURES. AGV Gardens. Rotterdam, NL, 2015. Disponível em: <https://youtu.be/zm_rlLyelQo>.
11. KONECRANES. Lift-AGV 007.png. 2018. Available in: <https://bit.ly/3EZppSJ>.