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Influence of Mega Container Ships on Functioning of Ports: A Study of South Asia Pakistan Terminal

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Abstract

Consequent upon induction of mega container ships, the operational requirements of container terminals have significantly increased stressing on essential alterations in their design, infrastructure, equipment and processes. Our focus is on the effect of mega ship operations on functioning of the recently developed South Asia Pakistan Terminal (SAPT), in Karachi port logistics system with regard to its capacity to manage the movement of import containers. Descriptive analysis method has been used to examine the container terminal processes and evaluate the container management procedures in diverse situations, which differ in function due to call magnitude of mega container vessels. The ship turnaround time, berth occupancy percentage, ship waiting time at anchor, Containers handled at the terminal compared to ship's carrying capacity, berthing constraints and container dwell time have been studied, with an aim to identify weak areas for optimization. The outcomes exhibit that this purpose can be achieved by relocating the containers to a nearby container storage area, better container management by efficient use of terminal resources, and by permitting greater dwell time for outbound containers.

Keywords Container Port, Berth occupancy, Berthing constraint, Ship turnaround time, Mega ships, Dwell time

Introduction

The advent of huge container vessels is a major subject of global discussion in context of port's container management capabilities. Container vessels comprise almost one fourth of the world's merchant marine and are vital for freight carriage across the oceans. A uniqueness of this occurrence is the swift evolution of container vessel's size, compared to other form of ships.

Journal of Business and Management Research
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Volume No:2 Issue No:2(2023)

The container vessels increased in size from about 1,000 TEU (Twenty Foot Equivalent Unit) vessels in 1970 to around 8,500 TEU in 2000, and to nearly 24,000 TEU these days. Hence, the container vessel's capacity has grown massively (almost 1500%) in just 50 years, as shown in Figure 1. Some studies claim the development of even larger capacity container ships in future, though their access will be limited to fewer ports. Swift growth in ship size has led to infrastructure changes in ports, adaption of modern equipment and novel technologies H. E. Haralambides (2019). Ports will thus need to improve their berthing, container handling and container storage processes, to remain viable (Hanson & Nicholls, 2020).

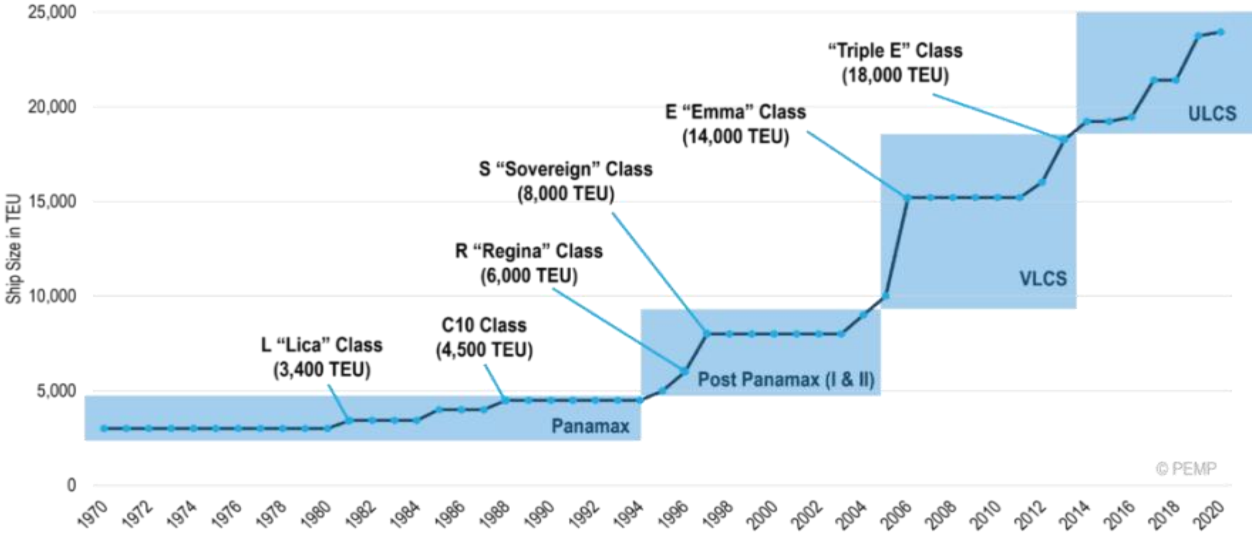

Fig. 1. Evolution of container vessels, 1970-2020.

Source: (Notteboom, Rodrigue, & Forthcoming, 2020).

Literature review

It is noteworthy that the ship size is growing faster than the ports. Increasing disproportion between ships and port size is confining bigger ships to visit smaller and less deeper ports due to limitations. When mega vessels visit a port, they want bigger cranes, greater storage yard and improved inland delivery system (Jeevan, Roso, & Trade, 2019). Problems with huge vessels relate to higher expenses incurred by ports and their service providers, which is much above the comparative growth of vessel dimensions. Thus, it is important to examine such changes with respect to trade-offs about the advantages of huge vessels and their linked costs, besides whole carriage sequence (Tran & Haasis, 2015). These developments also compel shipping lines to wisely select container ports for their liners. The container throughput in countries and top hundred world ports in 2021 is shown below:

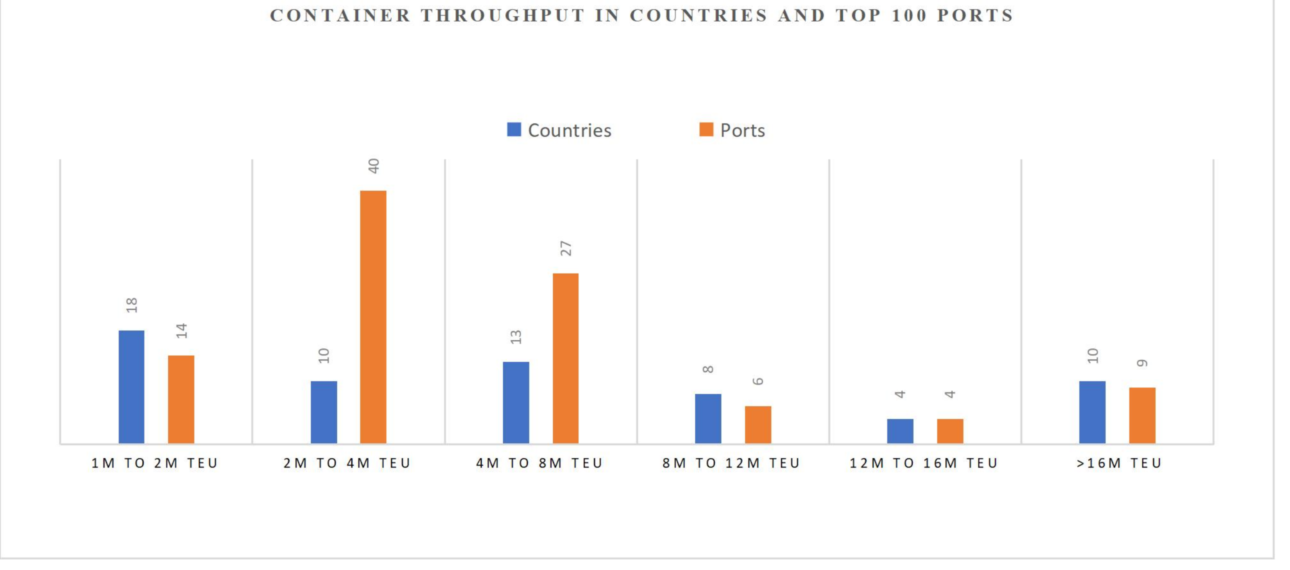

Fig. 2. Container throughput in Countries and Top 100 Ports.
Source: UNCTADStat 2022; Lloyd's List of One Hundred Ports 2021; own elaboration.

As per Brooks and Faust (2018), the gap among growth in call size and productivity broadens when the quantity of containers handled surpasses 4,000 TEUs. Ports achieve best results when vessel size is between 4,000 to 14,000 TEUs (Brooks & Faust, 2018). Study revealed that the most optimal and cost-effective ship size to serve container ports, are between 4,000 to 8,000 TEUs, and especially 5,500 to 6,500 TEUs (Lachner & Boskamp, 2011; Merk, Busquet, & Aronietis, 2015; Sys et al., 2008). Conversely, limited ports can handle ships above 16,000 TEUs capacity (Baik & Practices, 2017). Few researchers believe that the growth in container vessel dimensions is governed by the economies of scale during sea passage, by neglecting the working difficulties and overspendings in seaports. The assessed savings due to attainment of larger economies of scale, among a 14,000 TEU and a 19,000 TEU vessel is $50 per TEU, presuming a volume usage of 85%. Mostly, with the growth of vessel dimensions, from a 2,000 TEU feeder vessel to a 20,000 TEU ultra large vessel, economies of scale continuously decreases (H. E. J. M. E. Haralambides & Logistics, 2019).

Urge for larger container vessels evidently entails profitability challenges, like reducing consignment and increasing productivity, as more time spent in seaports decrease the number of ship visits and reduces the vessel volume per unit of time. Consequently, this creates

Journal of Business and Management Research
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Volume No:2 Issue No:2(2023)

a drive for quicker terminal operations and tackle the applied problems to handle larger ships. This entails the container terminals to always ensure apt productivity, handling processes, effective container management and service quality. Larger vessels have compelled development of crucial infrastructure, and alteration in nautical and land procedures, creating the necessity to improve container terminal management and limit the compulsion for larger investments. Operations research is therefore often utilized by port management, to boost proficiency and throughput by curtailing terminal charges and refining performance indices, which are important for the existing maritime transport (Kaveshgar & Huynh, 2015).

Attractiveness of a container terminal is established by a sequence of several features. Primarily, it is the capacity to accept and attend a mega vessel, reduce its duration of stay in port, and efficient handling of containers. Terminal operators, along with shipping lines and seaport authorities, spend on novel technologies to enhance container management efficiency, at the terminal to help mega container vessels (Salleh, Zulkifli, & Jeevan, 2021).

Descriptive analysis method is often employed in the studies of maritime logistics, primarily for operational assessment of container terminals (Nævestad, Phillips, Størkersen, Laiou, & Yannis, 2019). Many studies about real cases have examined container terminals for their productivity and long-term development plan (Bichou, Gray, & Management, 2004; Davidsson, Henesey, Ramstedt, Törnquist, & Wernstedt, 2005; Steenken, Voß, & Stahlbock, 2004).

Mega container ships face problems of depth and greater charges when visiting ports (Baik & Practices, 2017). In their research Petering, Murty, and Research (2009) suggested to assess the likely need to extend quay or yard area, to accommodate additional containers. The study by Dulebenets, Golias, Mishra, Heaslet, and Theory (2015), revealed that terminal performance could be improved by assessing functioning of the terminal layout.

The paper is arranged in six parts. Part-1 covers the introduction Part-2 contains literature review. Part-3 defines the layout and main mechanisms of SAPT. Part-4 explains a model of container terminal operations. Part-5 describes analysis of the container terminal performance. Part-6 pertains to few deductions and ideas for further research

Layout and main mechanisms of SAPT

With an aim to suggest a technique that maybe appropriate for all maritime container terminals, this study centers on the newly developed SAPT deep sea terminal at Karachi port. The infrastructure was initially developed by Karachi Port Trust (KPT), the port authority at a cost

of USD 350 million and leased to Hutchison port holdings (HPH). As per SAPT masterplan at Figures 3, the total quay length is 1500 meters, each of the four berths being 375 meters long with a depth of 16.5 meters. In Phase 1, two out of four berths; 'SAPT-3 and SAPT-4' were operationalized by HPH in 2016 at an additional cost of USD 600 million www.sapt.com.pk/. Yet, Phase 2 planned for completion in 2020 was delayed due to pandemic. The two other container terminals at Karachi port; Pakistan international container terminal 'PICT' and Karachi international container terminal 'KICT' are constrained to dock
mega container ships due to depth restriction of 12.5 meters.

Fig. 3. SAPT Masterplan
Source: www.sapt.com.pk/

Graphical details of SAPT development plan are shown at Figures 5 and 6.

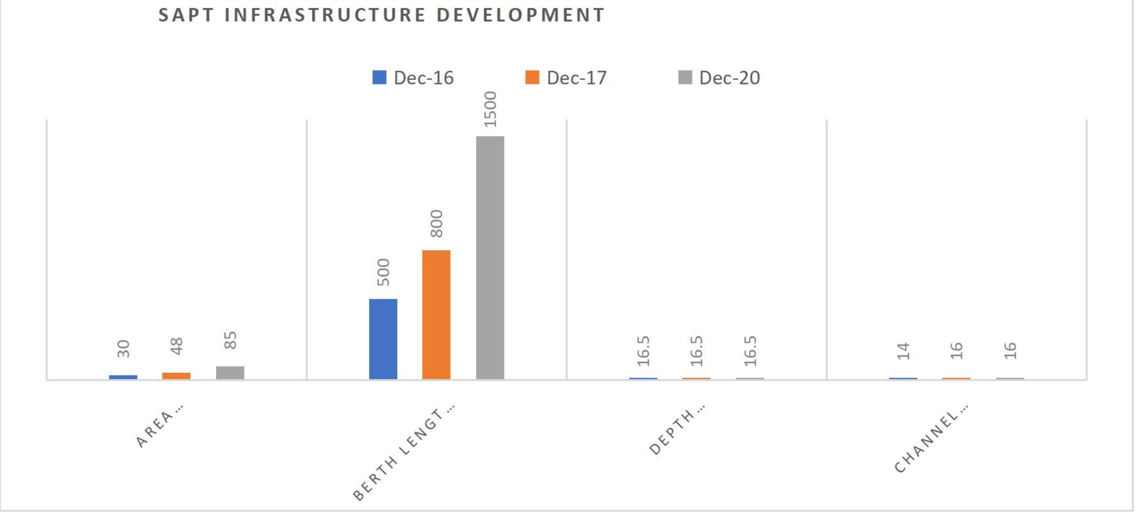

Fig. 4. SAPT Infrastructure Development Plan

Source: www.sapt.com.pk/; own elaboration.

Fig. 5. Layout plan of SAPT harbour

Source: www.kpt.gov.pk

For clearer understanding of container terminal functions and equipment, a typical layout and brief details are shown below:

Journal of Business and Management Research
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Volume No:2 Issue No:2(2023)

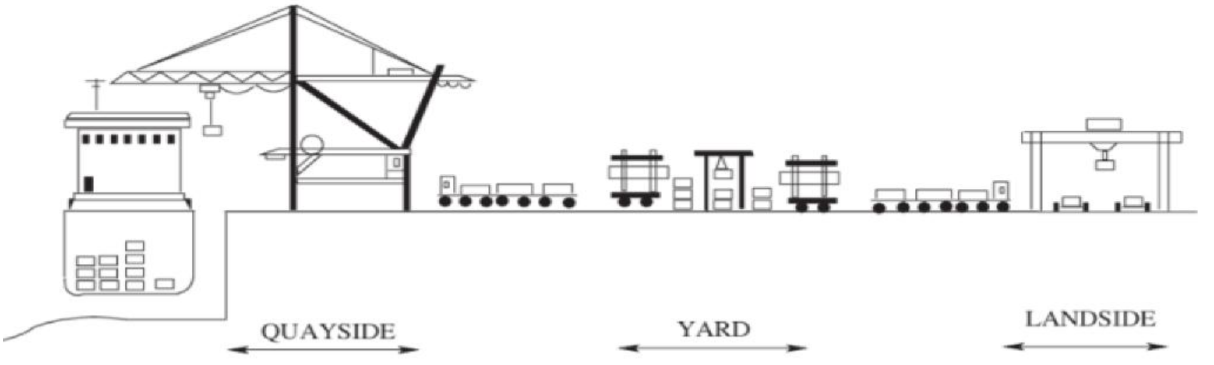

Fig. 6 A typical container terminal, **Source**: Flavia Monaco, 2009

Table 1. Container terminal function and its equipment. **Source**: own elaboration.

Segment 1	Segment 2	Segment 3	Segment 4	Segment 5
Quayside. Key task of the quayside equipment is to load and unload the vessel as quickly as possible to curtail its time at berth	**Quayside yard transport**. Containers are moved from quayside to the container storage yard	**Yard area**. Possibly the core part to operate a container terminal efficiently, with different storage layouts and type of handling equipment	**Landside yard transport.** Distributes the containers to and from other nodes of transport	**Intermodal interface**. Critical interface among the container terminal and rail-road network
Equipment used				
•Quay crane (QC) •Mobile crane (MC)	• Yard truck (YT) • Straddle carrier (SC) • Reach Stacker (RS) • Automatic Guided Vehicle (AGV)	•Rubber tire gantry (RTG) •Rail mounted gantry (RMG) •Straddle carrier (SC) •Reach stacker (RS) •Automated RMG (A-RMG)	• Yard truck (YT) • Straddle carrier (SC) • Reach stacker (RS) • Automatic guided vehicle (AGV)	• Rubber tire gantry (RTG) • Rail mounted gantry (RMG) • Reach stacker (RS)

Nautical access and Infrastructure

With prospects of trade growth in Pakistan, SAPT had been developed to serve mega container vessels of up to 16 meters draft, compared to 12.5 meters at two existing terminals at Karachi port. On the seaside, SAPT has a short approach channel of 4 miles, depth of 16.5 meters and covers an area of 85 hectares. It has adequate berthing facilities and a turning basin of 700 meters for deep draft ships up to 450 meters long, compared to turning basin 410m/ 12.5m of Karachi Port. The terminal has adequate infrastructure, equipment and container storage yard. On landside, SAPT has dedicated entry and exit gates for movement of containers. Yet, port-

Journal of Business and Management Research
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Volume No:2 Issue No:2(2023)

hinterland connectivity has metropolitan congestion challenges that maybe studied independently. The infrastructure development and layout plan are shown at Figures 4 and 5.

Terminal Equipment

The equipment comprises of 16 QCs 25 across, twin lift 65 tons, proficient to manage a single 40-foot or twin 20-foot containers, 52 RTGs (hybrid), 8 reach stackers, 10 empty handlers, 120-yard tractors and 120 chassis. The gross crane rate per hour improved from 29 moves in 2016 to 35 moves in 2018. SAPT has a designed capacity of 3.1 million TEUs per year (www.sapt.com.pk/). The equipment development plan is shown at Figure 6.

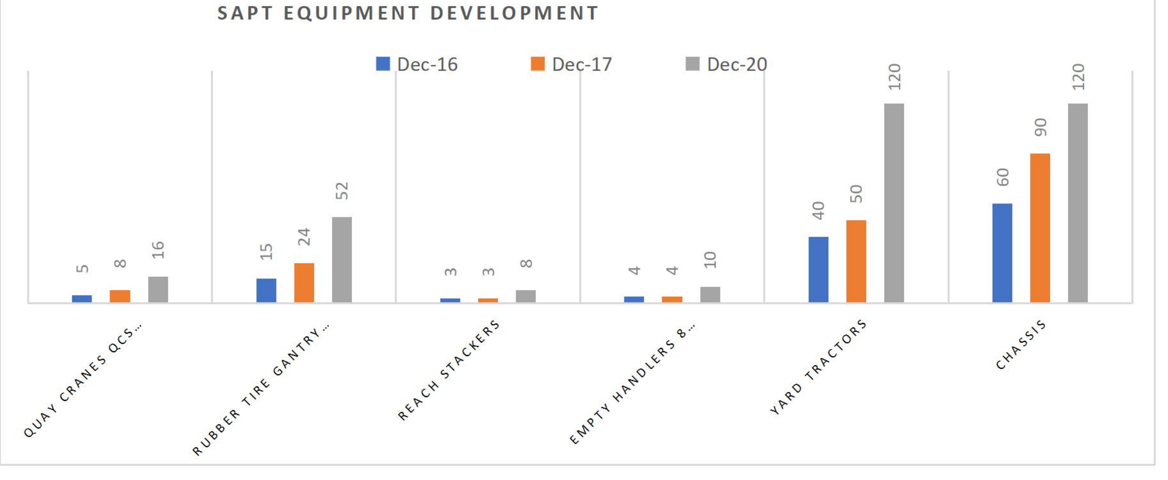

Fig. 7. SAPT Equipment Development Plan

Source: www.sapt.com.pk/; own elaboration.

A six-lane truck passage connects the terminal apron with storage yard designed for 82 blocks to stack containers longitudinally. Each block comprises of 6 rows, and five high tiers as shown in Figures 7 and 8.

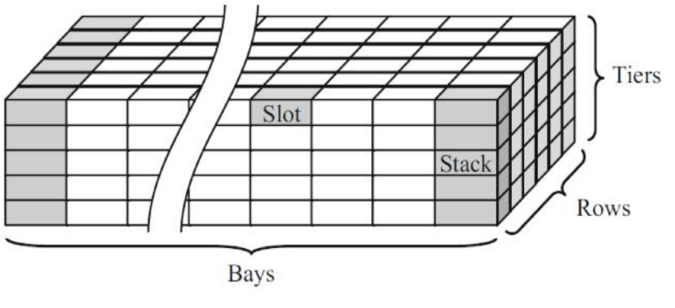

Fig. 8. Container stacking in a block.

Source: (Zhen, Jiang, Lee, Chew, & Systems, 2013).

Fig. 9. Container stacking area at SAPT

Source: www.kpt.gov.pk

Journal of Business and Management Research
ISSN:2958-5074 pISSN:2958-5066
Volume No:2 Issue No:2(2023)

The terminal gates contain 8 Lane 'In' and 6 Lane 'Out' gates, with provision of 2 adjustable lanes. There is a dedicated parking space for 200 trucks, and about 95% trucks exit the terminal within 50 minutes. The railway is designed to operate from its independent yard in the terminal. After disembarkation from the ship, containers are transferred to the stacking area through yard tractors. This procedure avoids the need for instant transfer of containers outside the terminal, and improves container management process at the yard. SAPT gates are shown Figure 9.

Fig. 10. SAPT gates.

Source: https://sapt.com.pk

A model of container terminal operations

With an aim to assess container terminal proficiency, three core factors have been examined signifying the terminal's functional procedures relating to the sea, yard area and land side. Events comprise disembarkation of containers from the vessel, relocation in the storage yard, and embarkation on a truck or freight train to depart the terminal.

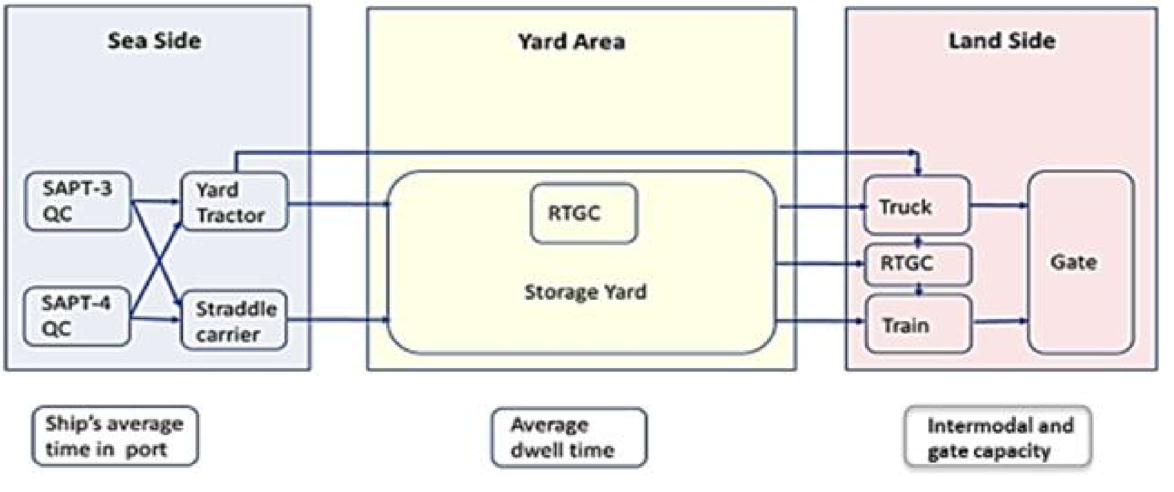

Fig. 11. Hypothetical model of container terminal operations.

Journal of Business and Management Research
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Volume No:2 Issue No:2(2023)

Source: own elaboration.

The model at Figure 10 was applied by describing three key factors that create an overall example; i.e., segments, cushions and equipment. The active segments are the components streaming all over the terminal, which are the vessels and containers. Cushions are all areas of the terminal where segments pause to provide services, like transfer to storage yard and delivery/receipt at the gate, while the terminal equipment helps in container handling and management. For the purpose of this study, vessels have been placed in two categories; that is, large container vessels with 8,000 TEUs and below capacity (designated as LV) and mega container vessels above 8,000 TEUs capacity (designated as MV).

Container terminal operations

Sea side processes begin after the vessel is docked at the allocated wharf. At this stage, specified number of QCs are allocated to disembark containers from the ship (Carlo, Vis, Roodbergen, & Journal, 2015). The handled containers are temporarily placed along the wharf (apron area), from where they are moved to the storage yard or directly transferred to the carriage truck for next destination. A container ship is assisted by three to five QCs, depending upon the ship's length and the spread between holds from where the containers are to be handled. The batch gears handle two containers at a time from the planned berth, and return two containers in output, advancing to their placement in the storage area where yard gantries operate. Standard service frequency of the QC is 30 moves per hour (or 1 move in 2 minutes), though their output may achieve 35-40 moves per hour if required.

After completing the disembarkation operation by QCs, the vessel departs the wharf and is handled by a process taking a usual service period consistently falling between 25 to 30 minutes, asserting the period to be essential for the vessel to leave harbour. The detail of ship's time in port is described below.

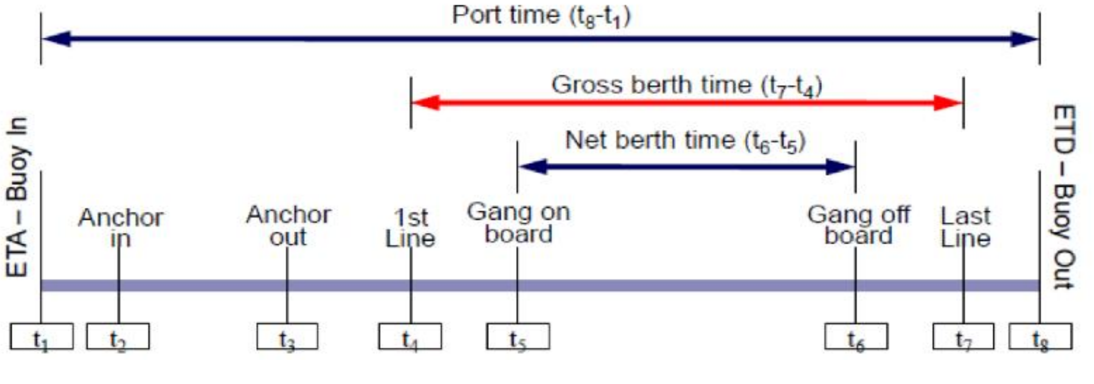

Fig. 12. Ship's time in Port

Journal of Business and Management Research
ISSN:2958-5074 pISSN:2958-5066
Volume No:2 Issue No:2(2023)

Source: UNCTAD

Container management in terminal.

The internal container management process commences when the containers are moved from apron area along wharf to the storage yard. Internal carriage operations link the nautical side, yard area and land side procedures at the terminal (Carlo, Vis, & Roodbergen, 2014). The containers are embarked on yard trucks by QC or reach stacker, and disembarked at storage yard with the help of RTG or reach stacker. Founded on past statistics, RTGs (hybrid one-over-six models), have a standard service frequency of 15 moves per hour for loading/unloading road trucks, 20 moves per hour when stacking containers in the yard, and 30 moves per hour when loading/unloading a rail (Stoilova & Martinov, 2019). Yet, reach stackers have a standard service frequency of 15 moves per hour.

Yard operations at SAPT, are undertaken with the help of 24 RTGs. Containers are relocated from marine side to storage yard with the help of reach stackers and yard trucks. Whereas, RTGs and reach stackers help dispense containers from storage yard to the land side transfer areas dedicated for truck and railway transportation (Ballis & Golias, 2004). On the land side, diverse equipment is used to handle containers, depending on the mode of transport (truck/railway) from port to hinterland. Trucks have a usual service period of 5 minutes per truck from the 6-lane gate, extendable to 8 lanes. Nearly 1,700 trucks would pass the terminal gate per day; each truck carrying 1 or 2 containers. For departure of containers by railway, tractor trailers are used, that carry 7, 20-foot containers in one trip (2 trips per hour) and moves them to the railway yard, which can accommodate up to 2880 TEUs. The embarkation of containers on train inside the terminal is conducted by RTGs and reach stackers. The usual loading period on train is one minute per container. Standard performance of container terminal equipment is summarized at Table 2:

Table 2.

Standard performance of container terminal equipment.

Port Equipment	Moves per hour	Moves per minute
QC	30 moves	1 move in 2 minutes
RTGs (for truck)	15 moves	1 move in 4 minutes
RTGs (for yard stacking)	20 moves	1 move in 3 minutes
RTGs (for train)	30 moves	1 move in 2 minutes

Journal of Business and Management Research
ISSN:2958-5074 pISSN:2958-5066
Volume No:2 Issue No:2(2023)

Reach stacker	15 moves	1 move in 4 minutes
Tractor trailer	2 Trips of 7 TEUs	1 move in 30 minutes

Source: (Stoilova & Martinov, 2019); www.sapt.com.pk

Analysis of the Container Terminal Performance

This study endeavors to assess SAPT's ability to handle huge volumes of containerized cargo from MVs and LVs. The terminal works 362 days a year, and operates 24 hours each day. A 31 days container handling data of SAPT was collected from 5 February to 7 March 2021.

The model was initially ratified by using the standard data defined in Segment 4 above. The study began with Situation-1, based on the 31 days collected data. Five additional situations were assumed and included in the study. For instance, rise in the visit rate of MVs or LVs or both, provided an opportunity to examine the container management ability of SAPT. In situations-2 to 6, an increase in inter-arrival time of LVs and MVs was varied. In situation-2 the time in port of LV was kept constant, while that of MV was increased. In situation-3 and 4 the time in port of LVs was first increased and then kept constant, while the time in port of MVs was increased. In situation-5 and 6 arrival time of both MVs and LVs was increased to assess higher berth occupancy and container management at SAPT.

In situation-1 the berth occupancy rate was calculated as 38.7%, which is quite low, compared to the usual 45% to 55%. In situation-2 to 6, the berth occupancy rate was varied from 50% to 70% in 5% steps. The designed annual capacity of SAPT when fully functional is 3.1 million TEUs. Analysis reveals that productivity can match designed capacity by consistent handling of containers cargo via LVs and MVs, when maintaining berth occupancy rate between 55% to 60%, considering 27 QC moves/hour, as observed from the collected data. Container throughput in various situations, Ship visits frequency and Output of QC, RTG and ship's time in port are shown in Figures 12, 13 and 14.

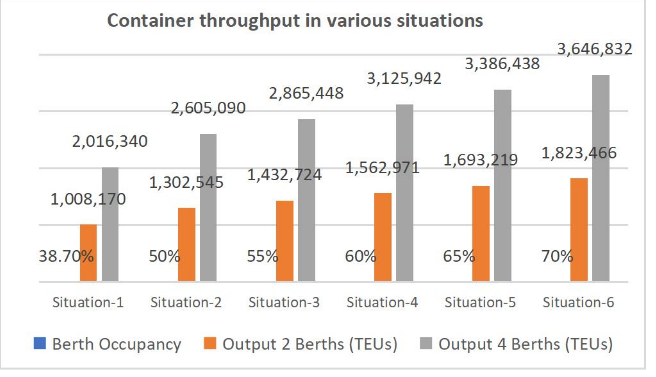

Fig. 13. Container throughput in various situations.

Source: own elaboration.

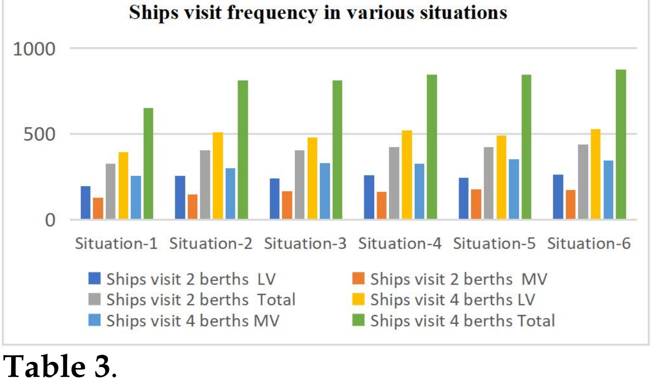

Fig. 14. Ships visit frequency in various situations.

Source: own elaboration.

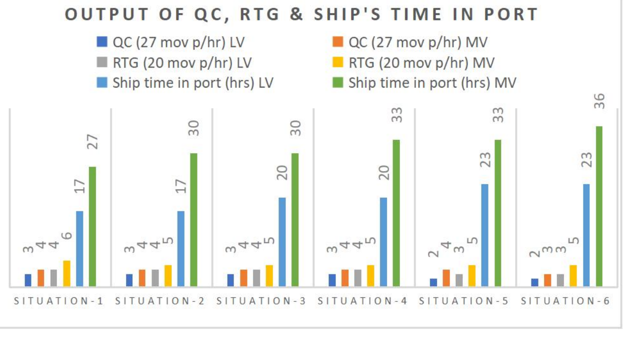

Fig. 15. Output of QC, RTG and ship's time in port.

Source: own elaboration.

Table 3.

Container Terminal output in various situations and berth occupancy rate

Situation	Berth Occupancy	Output 2 x Berth (TEUs)	Output 4 x Berth (TEUs)	QC per ship (27 mov/hr.)		RTG (20 mov/hr.)		Avg ship time in port (hrs.)		Dwell Time 2 x berths (days)	Ships visit (2 x berths)			Ships visit (4 x berths)		
				LV	MV	LV	MV	LV	MV		LV	MV	Total	LV	MV	Total
Situation-1	38.7%	1,008,170	2,016,340	3	4	4	6	17	27	6	197	129	326	394	258	652
Situation-2	50%	1,302,545	2,605,090	3	4	4	5	17	30	7	256	150	406	512	300	812
Situation-3	55%	1,432,724	2,865,448	3	4	4	5	20	30	8	241	165	406	482	330	812

Journal of Business and Management Research
ISSN:2958-5074 pISSN:2958-5066
Volume No:2 Issue No:2(2023)

Situation-4	60%	1,562,971	3,125,942	3	4	4	5	20	33	8	261	163	424	522	326	848
Situation-5	65%	1,693,219	3,386,438	2	4	3	5	23	33	9	246	177	423	492	354	846
Situation-6	70%	1,823,466	3,646,832	2	3	3	5	23	36	10	265	174	439	530	348	878

Source: own elaboration.

As per collected data, 28 container vessels visited SAPT from 5 February to 7 March 2021, of which 17 were LVs while 11 were MVs. Each LV stayed at berth for an average of 17 hours, while MVs occupied the berth for 27 hours. Overall, the LVs handled 40.4% of total TEUs, while MVs moved 59.6% TEUs. As regards the category of containers handled in TEU/FEU (forty-foot equivalent unit) by LVs and MVs, the overall ratio was 25.5% TEUs and 74.5% FEUs. On the average each LV handled 2052 TEUs, while MV handled 4676 TEUs per ship. This ratio also helped identify the average number of TEUs and FEUs handled by LVs and MVs, thus enabling estimation of the crane moves for LVs as 1287 moves and for MVs 2934 moves per vessel. The FEUs were considered as one move while TEUs were counted as single move. With this background, the engagement of QCs was identified as 2 to 4 QCs per ship, considering 27 QC moves per hour. Between 3 to 6 RTGs were required with 20 moves/hour. As per Table 4, the number of ships handled per year in each situation varied for LVs and MVs. The SAPT performance as per collected data was termed as Situation-1.

Five additional scenarios having varying values were considered to evaluate SAPT's performance with 2 operational berths. In Situation-1, 197 LVs and 129 MVs would visit SAPT, whereas in Situation-6, 265 LVs and 174 MVs would visit the port in a year. The berth occupancy in Situation-1 was observed to be 37.8%, which was below the world average ranging between 45-55%, with no waiting time at anchorage (Cheng, Tahar, Ang, & Logistics, 2010). The berth occupancy in Situation-2 to 6 was evaluated from 50% to 70% with 5% difference in each situation. Improved output by QCs from the achieved 27 moves/hour, would reduce ship's time in port, allowing increased ship visits or permit handling of more cargo in the same duration, enhancing berth productivity in both cases.

Journal of Business and Management Research
ISSN:2958-5074 pISSN:2958-5066
Volume No:2 Issue No:2(2023)

Table 4. Movement of QCs and RTGs at SAPT in various situations

Situations	Output 2 x Berths (TEU) LV=40.4%, MV=59.6%	Berth Occupancy	LV (<8000 TEU) time in port	MV (>8000 TEU) time in port	Ships visit 2 berths			Ships visit 4 berths		
					LV	MV	Total	LV	MV	Total
Situation-1	1,008,170 TEU LV 403,268 MV 604,902	38.7%	17 hours 2052 TEU per LV	27 hours 4676 TEU per MV	197	129	326	394	258	652
Situation-2	1,302,545 TEU LV 526,228 MV 776,317	50%	17 hours 2052 TEU per LV	30 hours 5190 TEU per MV	256	150	406	512	300	812
Situation-3	1,432,724 TEU LV 578,820 MV 853,903	55%	20 hours 2420 TEU per LV	30 hours 5190 TEU per MV	241	165	406	482	330	812
Situation-4	1,562,971 TEU LV 631,440 MV 931,531	60%	20 hours 2420 TEU per LV	33 hours 5709 TEU per MV	261	163	424	522	326	848
Situation-5	1,693,219 TEU LV 684,060 MV 1,009,158	65%	23 hours 2776 TEU per LV	33 hours 5709 TEU per MV	246	177	423	492	354	846
Situation-6	1,823,466 TEU LV 736,680 MV 1,086,786	70%	23 hours 2776 TEU per LV	36 hours 6228 TEU per MV	265	174	439	530	348	878

Journal of Business and Management Research
ISSN:2958-5074 pISSN:2958-5066
Volume No:2 Issue No:2(2023)

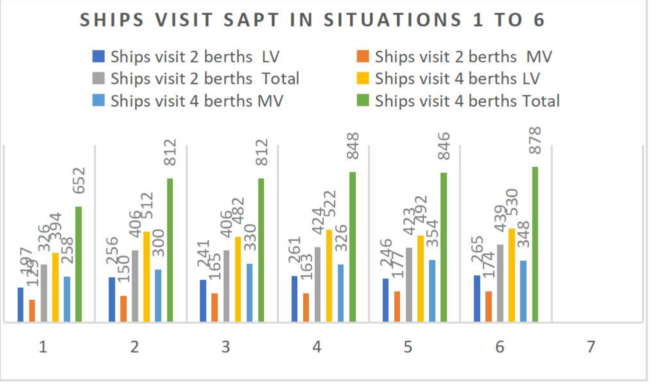

Fig. 16. Ships (MV/LV) visiting SAPT in Situations 1 to 6.

Source: own elaboration.

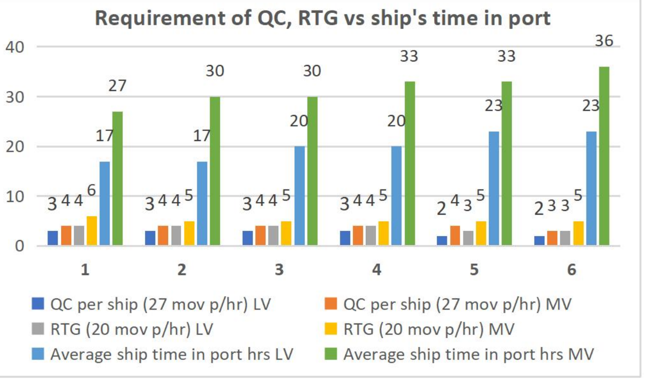

Fig. 17. Requirement of QC, RTG vs Ships time in port.

Source: own elaboration.

As in any analytical study, separate reproduction for every situation were examined to assess the mean values of different performance determinants. The operational aim of SAPT is to set the throughput, considering 362 working days per year, with two operational berths at 1,302,545 TEUs when working with average 3-4 QCs per berth at 50% berth occupancy rate. With similar settings, but 70% berth occupancy rate the throughput is expected to be 1,823,466 TEUs. In the actual Situation-1, projected annual productivity of containers was calculated on the basis of 31 days data, at 38.7% berth occupancy rate. Ships (MV/LV) visits to SAPT with two and four operational berths in all six situations is shown at Figure 15.

Analysis revealed that SAPT handled 25.5% TEUs and 74.5% FEUs. Among them 24% containers were empty, comprising of 16% TEUs and 84% FEUs. Nearly 95% of the empty containers were re-exported. The majority of ships (58%), arrived from Mundra and Jebel Ali, carrying transshipment cargo for Karachi port. Most of the ships (90%) visiting SAPT were designed to carry 5000 to 7000 TEUs, which emerged as the most popular ship size. As per the 31 days data, 11 MVs handled 59.6% containers averaging 4676 TEUs per ship with 27 hours berthing time, while the 17 LVs moved 40.4% cargo at averaging 2052 TEUs per ship with 17 hours at berth. This exhibited MVs to be more effective than LVs as they carried more TEUs per visit, saving time and cost. The QCs averaged 27 moves per hour, which was less than the claimed 30 moves per hour. QCs performed better on MVs compared to LVs. Requirement of QC, RTG vis a vis Ships time in port is shown at Figure 16.

Berth occupancy

It is the proportion of time the berth is engaged by a ship compared to the total time available in that period. High berth occupancy is a symbol of congestion (>70%), and thus decrease of

Journal of Business and Management Research
ISSN:2958-5074 pISSN:2958-5066
Volume No:2 Issue No:2(2023)

services, whereas low berth occupancy indicates underutilization of assets (<50%) (UNCTAD, 2012). Analysis of SAPT data at Table 4 shows the berth occupancy rate as 38.7 %. The port has berthing capacity to handle additional vessels, which has not been availed. Considering 27 moves/hour per QC a berth occupancy of 55-60% will be required to match the designed capacity. One argument could be that no more cargo is needed, because it is beyond the national requirement. Yet a counter argument could be that a country of Pakistan's size, population, potential and economic needs ought to have greater trade. The Government of Pakistan Vision 2025 also emphasizes on increased exports and upgradation of ports. The ongoing China Pakistan Economic Corridor (CPEC) project will not only enhance trade through Pakistani ports, but will also facilitate trade for neighboring landlocked states. Ideal location and infrastructure at Karachi port makes it a natural choice. SAPT can play a key role due to suitable berthing/storage capacity for MVs.

It is essential to indicate that though above average outcomes were associated with the terminal throughput, yet while examining the current situation, a modest usage of terminal assets was detected, specifically in case of QCs and RTGs. Possible hinderances during crane operations are insignificant, due to negligible failure rate and availability of spare equipment.
The containers handled at SAPT-3 and SAPT-4 were calculated from the collected 31 days data of cargo movement for visiting container at appendix A. The ships capacity and TEUs handled are shown at Figure 17. The TEUs and FEUs moved per day were identified. These were projected to worked out per year movement of FEUs and TEUs with the observed ratio, or by multiplying total TEUs by a factor of 62.5. The QC and RTG moves were then calculated considering FEU and TEU as a single move. Thereafter, QC and RTG moves were calculated per day and year.

The usage proportion of SAPT equipment in situation-1 and 6 is shown at Table 5. Outcome reveals that more QC moves were experienced at SAPT-3 as compared to SAPT-4. This showed preference of ships for SAPT-3. Besides, more RTG moves were undertaken for incoming containers as compared to the outgoing containers.

Table 5. Usage proportion of SAPT equipment in Situation-1 and Situations-6

Equipment	Situation-1		Situation-6	
	Crane moves per annum (4 QCs/10 RTGs)	Engaged	Crane moves per annum (4 QCs/10 RTGs)	Engaged

Journal of Business and Management Research
ISSN:2958-5074 pISSN:2958-5066
Volume No:2 Issue No:2(2023)

QC (SAPT-3) 27 moves/hour	338,470	36.5%	611,780	65.6%
QC (SAPT-4) 27 moves/hour	293,944	31.25 %	531,416	56.25%
RTG in, 20 moves/hour	321,456	18.5%	581,420	33.46%
RTG out, 20 moves/hour	298,288	17.2%	539,560	31.04%

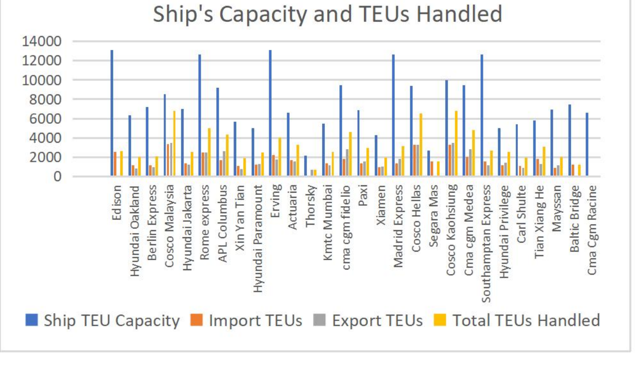

Fig. 18. Ships capacity and TEUs handled.

Source: own elaboration.

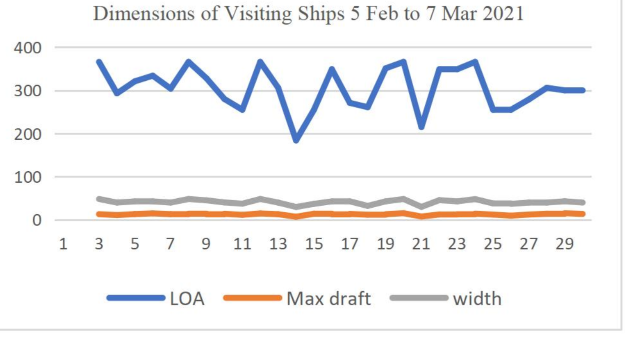

Fig. 19. Dimensions of Visiting Ships 5 Feb to 7 Mar 2021

Source: own elaboration.

In preceding situation, the crane usage was fairly less. The outcomes are befitting for the reason that in each experiment carried out, maximum seven QCs were utilized for two berths, though additional cranes were available. The study assessed the ability of SAPT to manage larger number of import containers through MVs. Hence, founded on the statistics and hypotheses to create model, and examination of differing situations, the likelihood of a probable growth in output and efficiency of the quay was noticed, because no pertinent obstructions had taken place. Yet an instance of idleness that is fairly high, compared to the achievement that the available equipment and assets could have assured.

Ship turnaround time

The turnaround time of both LVs and MVs was assessed. It can be observed from Figure 19 that outcome values of ship turnaround time in all situations appear stable, probably due to fairly efficient quay processes. Though values achieved in the experiments are consistent but could have been higher to align with terminal benchmarks. At SAPT an LV's turnaround time

Journal of Business and Management Research
ISSN:2958-5074 pISSN:2958-5066
Volume No:2 Issue No:2(2023)

was almost 17 hours, while for MV it was nearly 27 hours. The average turnaround time for LV and MV was 20.9 hours, whereas world average as per UNCTAD Stats, 2022 is 19.2 hours. Outcome reveals that, the ship turnaround time does not sizably differ, yet the throughput at SAPT is relatively less.

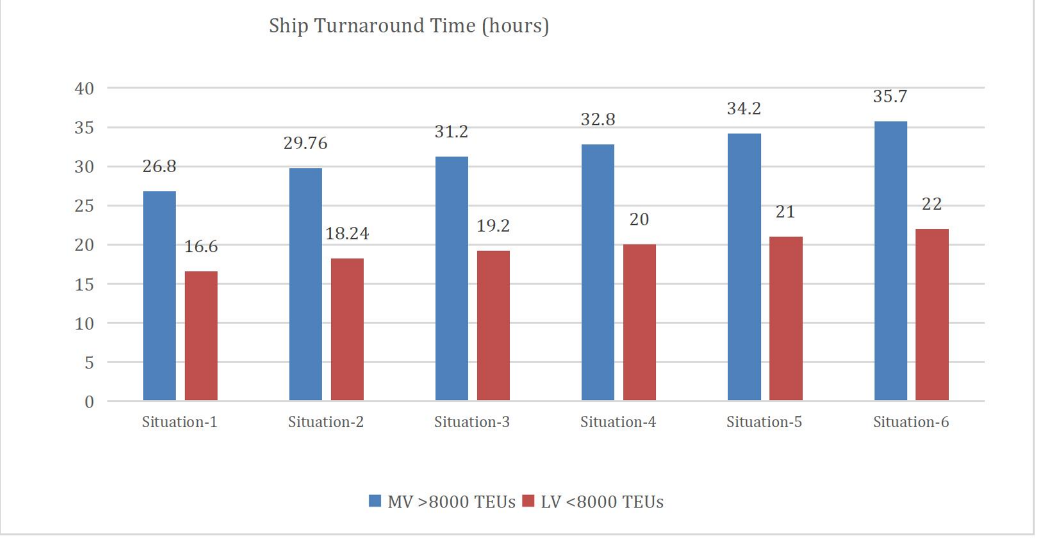

Fig. 20. Ship turnaround time - MV and LV

Source: own elaboration.

Ship Waiting Period Constraint

The average length of 8000 TEUs post Panama II ship is usually 320m, whereas the length of Panama max new ships with carrying capacity up to 14000 TEUs is usually 366m, while the length of VLCC carrying 19,000 plus TEUs is 400m. Physical safety separation among vessels is required to be 10% of ship's length, that is a ship of 320 m length occupies 352 m of berth, while a ship of 366 m length inhabits 403 m berth, and a 400m long ship would reside in 440 m of quay. In case the quay is designed in a traditional straight line, huge vessels require additional waiting period to obtain sufficient space along quayside. Data revealed that four ships had to wait at anchorage prior entering harbour. All four ships were MVs, which revealed SAPT's operational constraints to receive MVs, for which it required additional preparation time.

Table 6

Ship's classification, average waiting time, berth and port time.

Ship classification	Ships visited	Ships waited at	Avg wait time	Avg berth time	Avg port time

Journal of Business and Management Research
ISSN:2958-5074 pISSN:2958-5066
Volume No:2 Issue No:2(2023)

TEU	SAPT	anchor	per ship (hrs.)	(hrs.)	waiting ships (hrs.)
10,001–14,000	5	2	2.5	22.9	25.4
8,001–10,000	6	2	8.8	30.1	38.9
6,001–8,000	8	0	16	NA	NA
4,001–6,000	7	0	18.2	NA	NA
2,001–4,000	2	0	13	NA	NA

Source: kpt.gov.pk, own elaboration.

The average waiting time of ships was identified from 31 days data, which revealed ship's time in port and their waiting time at anchor. Details about ship size classification, average waiting time, berthing time, and port time is shown in Table 6. Examination revealed that MVs (8001-10000 TEU) had to wait at anchor for an average of 2.5 hours; whereas MVs (10001-14000 TEU) waited at anchor for an average 8.8 hours. It was revealed that a constraint did exist to assign suitable berth to MVs. Currently only two out of total four berths were operational. To decrease the waiting period of MVs, a separate berthing plan founded on vessel dimensions and berthing period needs to be prepared. Study shows that MVs need longer berthing period and port time. The average berthing time for ships of 8001-10000 TEU capacity was 30.1 hours and for ships of 10001-14000 TEU capacity berthing time was 22.9 hours. The average port time was 38.9 hours for ships of 8001-10000 TEU capacity and 25.4 hours for ships having 10001-14000 TEU capacity. For LVs, the average berthing time was between 13 to 18.2 hours.

As per Table 7 most ships visiting SAPT were 11 to 12 years old. So, it may be fair to assess that presently the shipping lines operate their middle-aged second tear fleet at SAPT. With the expected growth in trade and Karachi port assuming a hub port role, the shipping pattern is likely to change. Bigger container ships would start visiting SAPT with increased transshipment cargo. Increased trade will build more pressure on SAPT to operate efficiently.

Journal of Business and Management Research
ISSN:2958-5074 pISSN:2958-5066
Volume No:2 Issue No:2(2023)

The challenge of frequent MV visits and handling greater cargo in limited time will require continuous planning, managerial skills, optimal resource allocation and better container management in the terminal.

Table 7

MVs (>8000 TEU) visited SAPT – 5 February to 7 March 2021

Date of Arrival	Ship name	Length (m)	Width (m)	Draft (m)	Ship TEU Capacity	GT	DWT (ton)	Launch year
5.2.2021	Edison	366	48	13.1	13092	142052	141448	2011
9.2.2021	COSCO Malaysia	334	43	14.9	8500	91051	102834	2010
10.2.2021	Rome Express	366	48	14.1	12600	141328	153514	2010
15.2.2021	APL Columbus	328	45	12.9	9200	109712	115017	2014
17.2.2021	Erving	366	48	14.7	13092	142052	141377	2011
22.2.2021	CMA CGM Fidelio	349	43	12.7	9415	107898	113964	2006
26.2.2021	Madrid Express	366	48	14	12600	141328	153514	2010
26.2.2021	COSCO Hellas	351	43	12.1	9469	109149	107482	2006
1.3.2021	COSCO Kaohsiung	349	46	12.4	10000	115776	111414	2008
1.3.2021	CMA CGM Medea	349	43	12.9	9415	107711	113964	2006
3.3.2021	Southampton Expr	366	48	14.2	12600	141328	153514	2011

Journal of Business and Management Research
ISSN:2958-5074 pISSN:2958-5066
Volume No:2 Issue No:2(2023)

Source: www.kpt.gov.pk; own elaboration

Berthing Constraint for MVs

With regard to SAPT infrastructure and visiting ship dimensions, two constraints of SAPT berths have come to light linked to the vessel size it can accommodate. The designed length of each berth is 375 meters, with an intended depth of 16.5 meters. Firstly, only two of the total four berths, namely SAPT-3 and SAPT-4, were fully operational at the time of data collection in February/March 2021, which limited terminal handling capacity. Secondly, SAPT is designed to dock ships up to 400 meters long, with carrying capacity of 19,000 TEUs. Yet, the terminal has so far docked ships of maximum 366 meters length, 49 meters width, and 15.3 meters draft, with carrying capacity of 13,660 TEUs. When a 366m ship is docked then the adjacent berth is able to accommodate a much smaller ship considering that about 10% (37m) of the ship's length will have to be kept as safety separation between ships. So, two MVs were not seen visiting SAPT concurrently.

Containers Handled and Vessel Carrying Capacity

When a vessel, whether LV or MV, arrives at the terminal berth, it is expected to move between 30% to 45% containers of the vessel's total capacity. As per SAPT data, a total of 28 ships moved 39.89% containers of their total carrying capacity. Among them 11 MVs moved 42.86% TEUs, while the 17 LVs moved 36.19% TEUs of their total carrying capacity as per Table 8. Analysis revealed that out of the total containers moved during 31 days, 11 MVs moved

59.58% TEUs whereas 17 LVs moved 40.42% TEUs. In other words, a smaller number of MVs handled about 50% more containers, while nearly 50% greater number of LVs handled less TEUs. Comparison of TEUs moved by MV and LV is shown at Table 8.

Table 8.

Comparison of TEUs moved by MV and LV

	LV (<8000 TEU)	**MV (>8000 TEU)**	**Total**
Vessels visited SAPT	17 vessels	11 vessels	28 vessels
TEU carrying capacity	96,398 TEU	119,983 TEU	216,381 TEU
TEU handled	34,893 TEU	51,432 TEU	86,325 TEU

Journal of Business and Management Research
ISSN:2958-5074 pISSN:2958-5066
Volume No:2 Issue No:2(2023)

TEU handled vs carrying capacity	36.19% TEU	42.86% TEU	39.89% TEU
TEU handled of total	40.42%	59.58%	100%

Container Storage Yard Capacity

The storage yard capacity is a key factor of the container terminal. Although yard capacity is a design function, yet has a deep linkage with managerial skills, ground slots, stacking height, equipment capability, container management efficiency, dwell time and yearly turnover.

It was assessed with data and observation that SAPT will have **13,680** TEU ground slots when fully completed. This means that the completed container yard abreast SAPT-3&4 should be able to accommodate about half, that is **6,840** TEUs. As per Monfort et al. (2011), the area density (ground slots per hectare) for RTG (6; 4+1) (wide; nominal stacking height), the area density (ground slots hectare) is 260 to 300. The operational average stacking height (h) is 2.40. With this ratio, the operational average stacking height (h) for RTG (6; 5+1) of SAPT should be 3.0.

The operational average stacking height is directly proportional to storage capacity. Area density x Operational average stacking height = Static capacity (SC) or 260 x 3 = 780 TEUs per ha; 300 x 3 = 900 TEUs per ha. That is 780 to 900 TEUs per ha. Hence, for 85 ha terminal it is 85 x 780 = 66,300 or 85 x 900 = 76,500, that is total storage capacity of SAPT is between 66,300 and 76,500, average capacity being **71,400** TEUs, and the ground slots being 14,280 TEUs. On the other hand, when the total storage capacity was calculated through available data on SAPT website in conjunction with satellite imagery, and observations during visit, the total storage capacity including railway yard and extra areas was 68,400 TEUs, while the ground slots were 13,680 TEUs. The ground slots calculated for SAPT-3&4 by both methods were 6192 and 7140 TEUs. For the purpose of this study, we will consider the storage capacity of SAPT as 68,400 TEUs and ground slots at SAPT-1&2 as 7,488 TEUs and at SAPT-3&4 as 6,192 TEUs as shown in Figure 20.

Journal of Business and Management Research
ISSN:2958-5074 pISSN:2958-5066
Volume No:2 Issue No:2(2023)

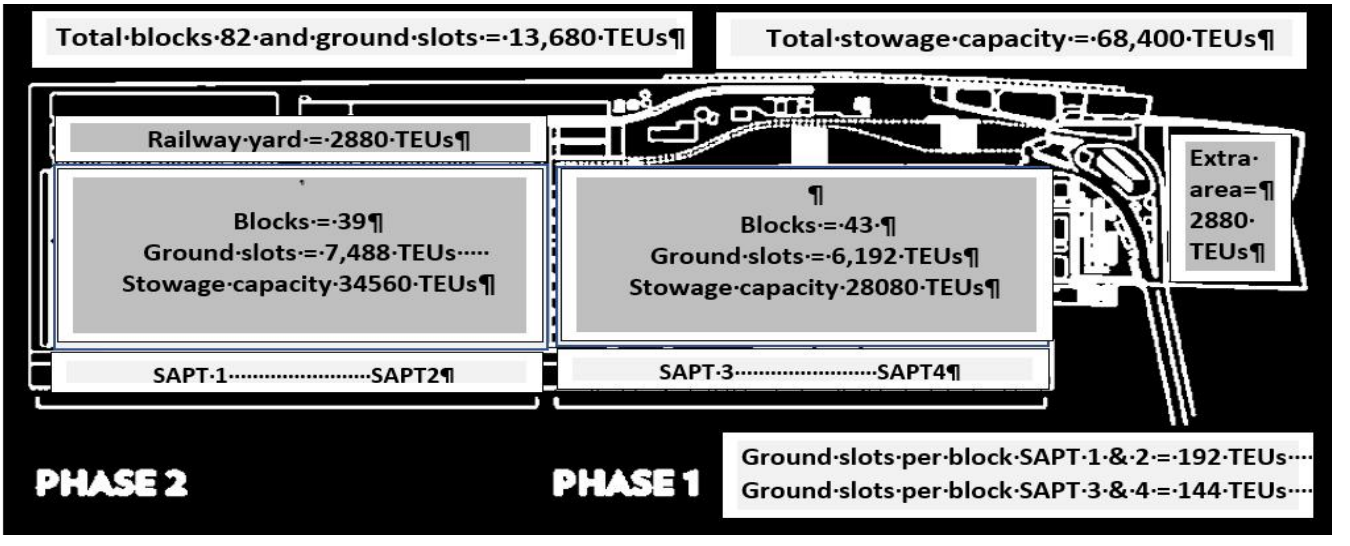

Fig. 21. SAPT layout plan and container storage capacity.

Source: www.kpt.gov.pk; own deliberation

Dwell time

It is an important factor in container terminal operations. It is the time that cargo containers spend within temporary storage facilities in transit, especially at waypoints for intermodal transportation like ports or container storage yards (Rodrigue, Notteboom, & Management, 2009). As per Ministry of Maritime Affairs draft working paper 2020, SAPT has a dwell time of 5-6 days; whereas 6 days dwell time for SAPT has been stated by Liaquat, 2020. On the contrary, during the visit to SAPT in early 2021 it was learnt that the dwell time was 6-7 days, which had improved from 9-11 days in 2018. It is noteworthy that the world average of dwell time is 5-7 days for import containers and 3-5 days for export containers (OECD, 2013), while it is 3-4 days at efficient ports (Dappe & Suarez-Aleman, 2016).

Higher dwell time reduces container terminal capacity. For instance, if dwell time increases from 10 days to 11 days, the terminal storage capacity will reduce by 10% (Kourounioti, Polydoropoulou, & Tsiklidis, 2016; Song, 2012). During visit to Karachi port, it was learnt that main causes of increased dwell time at the container terminals is extensive paperwork, customs clearance process; low-cost storage at ports; container identification issue or poor management. The terminal yard storage capacity in TEUs is related to Dwell Time in days, as shown (Novaes, Scholz-Reiter, Silva, & Rosa, 2012).

Journal of Business and Management Research
ISSN:2958-5074 pISSN:2958-5066
Volume No:2 Issue No:2(2023)

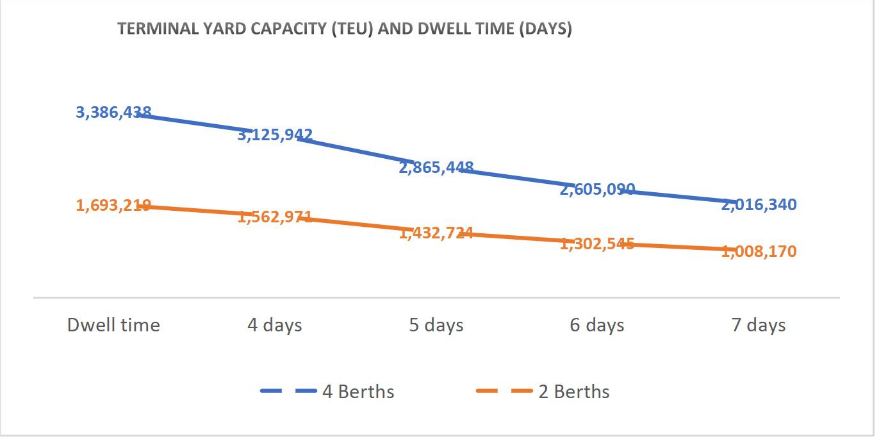

Fig. 22. Terminal Yard Capacity (TEUs) and Dwell Time (days)

Source: own elaboration

Throughput of the container terminal at 50% berth occupancy with two operational berths is anticipated to be 1,302,545 TEUs; while with four berths the output is likely to be 2,605,090 TEUs when dwell time is about 7 days. The relationship between terminal Yard Capacity (TEUs) and Dwell Time (days) is shown at Figure 21.

Containers Handled and Terminal Designed Capacity

The container throughput at SAPT has steadily grown since commissioning in 2016. Yet, the transshipment growth has remained nominal, despite potential. The designed annual handling capacity of SAPT is 3.1 million TEUs when all 4 berths are fully operational, while the annual capacity of its 2 operational berths is about half. With increased call size of ships, the number of TEUs handled have increased. Consequently, the annual throughput of SAPT had grown to 56% of the designed capacity by 2020. Frequent visit by mega vessels exert great pressure on terminal resources and its management as large volume of containers are to be handled in limited time.

Table 9 Containers handled in TEUs at two SAPT berths

Year	TEUs handled	Transshipment		Annual capacity	Throughput vs capacity
		TEUs handled	%		
2016	16,503	80	0.48	1,550,000	1.06%
20	540,1	2,512	0.4	1,550,	34.8%

Journal of Business and Management Research
ISSN:2958-5074 pISSN:2958-5066
Volume No:2 Issue No:2(2023)

17	73		7	000	
2018	527,050	6,319	0.87	1,550,000	34%
2019	930,336	2,561	0.28	1,550,000	60%
2020	870,121	3,797	0.43	1,550,000	56.1%

Source: www.kpt.gov.pk; Ministry of Maritime Affairs Draft paper 2020.

Shipping Traffic at SAPT

The container ship visits at SAPT has matured with time as per Table 3. The ratio of larger ship visits with regard to dimensions, TEU carrying capacity and tonnage has increased and stabilized at about 24 million tons in the recent years. Of late, the largest ship that visited SAPT could carry 13660 TEUs, was 366 meters long, 49 meters wide and had 15.3 meters draft. Since 2017, an average of about 300 ships have visited SAPT per year. Though the number of ship visits per year has slightly declined, the frequency of larger ship visits with respect to GRT (Gross Registered Tonnage) has increased as depicted in Table 10. This growth can be attributed to the increased confidence of shipping lines to operate bigger vessels at SAPT due to adequate logistic facilities and feasible location.

Table 10 SAPT Shipping Traffic.

Year	Vessel	GRT (Gross Registered Tonnage)	Increase in GRT since 2016-17
2016-17	118	5,994,518	-
2017-18	336	21,619,210	27.7%
2018-19	302	24,897,612	24%
2019-20	286	24,705,024	24.2%

Source: www.kpt.gov.pk; Ministry of Maritime Affairs Draft paper 2020.

Journal of Business and Management Research
ISSN:2958-5074 pISSN:2958-5066
Volume No:2 Issue No:2(2023)

Conclusion and Future Research

The influence of huge vessels on effective functioning of the newly operationalized yet partially completed SAPT container terminal at Karachi port was examined. Diverse situations and challenges were analyzed. Only mega vessels had to occasionally wait at anchorage. Berth occupancy remained low (38.7%) despite available infrastructure, equipment and space. Berthing of mega vessels faced constraint due to limited quay length. Ship turnaround time was consistent, yet cargo handled was comparatively less. The yard capacity could be best availed by minimizing dwell time, which was greater than the required value. The outcomes established the approximation by port authority and the terminal operator about its key performance indicators. Capital spending for appropriate infrastructure and proficient QCs enable swift container handling for mega vessels, warranting quicker ship turnaround time. The challenge will further grow with increased trade and completion of the project. Added potential of SAPT could be used for enhanced transshipment and CPEC trade. China-Europe trade accounts for about 70 million TEUs annually. If only 3% share is routed via CPEC through Karachi port, it will increase the throughput from 2.2 to 4.3 million TEUs, for which it has the capacity.

Future research may include the study to develop an additional container storage area for SAPT. Essential improvement in the rail-road connectivity between port and hinterland maybe studied for a greater freight share. Development of inland water way transportation system for movement of containers by barges from port to the hinterland may also be examined.

Journal of Business and Management Research
ISSN:2958-5074 pISSN:2958-5066
Volume No:2 Issue No:2(2023)

Appendix

Table SAPT visiting Ship's TEU Capacity, TEUs Handled, Time in Port and Waiting Time at Anchor – 5 February to 7 March 2021

Date of Arrival	Vessel's Name	Length	Draft	Beam	Ship TEU Capacity	Import TEUs	Export TEUs	Total TEUs Handled	Time in Port (mins)	Waiting Time at Anchor (minutes)
5.2.2021	Edison	366	13.1	48.26	13092	2551	68	2619	1164	216
6/7.2.2021	Hyundai Oakland	293	11	40	6350	1183	846	2029	968	0
8.2.2021	Berlin Express	321	13.3	42.8	7179	1170	946	2116	772	0
9/10.2.2021	COSCO Malaysia	334	14.9	42.8	8500	3318	3452	6770	1620	0
10.2.2021	Hyundai Jakarta	304	13.1	40	6987	1338	1203	2541	1085	0
10/12.2.2021	Rome Express	366	14.1	48.24	12600	2495	2501	4996	1740	88
15/16.2.2021	APL Columbus	328	12.9	45.2	9200	1702	2614	4316	1680	0
16.2.2021	Xin Yan Tian	280	13.9	40.3	5668	1125	757	1882	900	0
16/17.2.2021	Hyundai Paramount	255	11.6	37.43	5023	1211	1298	2509	1172	0
17/18.2.2021	Erving	366	14.7	48.26	13092	2234	1791	4025	1387	0
20/21.2.2021	Actuaria	306	13	40	6589	1705	1562	3267	1560	0
21.2.2021	Thorsky	184	7.2	29.8	2169	0	672	672	781	0
21/22.2.2021	KMTC Mumbai	255	14.1	37	5466	1387	1136	2523	1318	0
22/23.2.2	CMA CGM	349	12.7	42.8	9415	1837	2798	4635	1440	0

Journal of Business and Management Research
ISSN:2958-5074 pISSN:2958-5066
Volume No:2 Issue No:2(2023)

021	Fidelio									
23/24.2.2021	Paxi	271	13.6	42.9	6845	1377	1564	2941	1620	0
24.2.2021	Xiamen	261	11.9	32.3	4253	950	1030	1980	950	0
26.2.2021	Madrid Express	366	14	48	12600	1366	1813	3179	1347	0
26/27.2.2021	COSCO Hellas	351	12.1	43	9469	3281	3266	6547	2700	751
28.2.2021	Segara Mas	215	7.7	30	2700	1550	0	1550	796	0
1/2.3.2021	COSCO Kaohsiung	349	12.4	45.6	10000	3295	3514	6809	1860	0
1/2.3.2021	Cma cgm Medea	349	12.9	42.8	9415	2002	2824	4826	1560	304
3/4.3.2021	Southampton Express	366	14.2	48	12600	1576	1134	2710	1235	0
	Hyundai Privilege	255	12.2	38	5023	1131	1401	2532	1074	0
4/4.3.2021	Carl Schulte	255	9.6	37	5400	1108	864	1972	945	0
5/6.3.2021	Tian Xiang He	279	12.3	40	5800	1802	1269	3071	1310	0
6/7.3.2021	Mayssan	306	14	40	6921	895	1154	2049	980	0
7.3.2021	Baltic Bridge	300	15.3	43	7455	1216	0	1216	600	0
	CMA CGM Racine	300	13.6	40	6570	43	0	43	100	0

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