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Container Ship Round Trip Performance Analysis - A Case of Study Between East South America and Europe

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Abstract

In recent years, the shipping of containers has grown worldwide, as well as the size container vessels, following the globalization process. According to UNCTAD Statistics (2019), the global container shipping throughput increased from 45 Million TEUs handled in 1996 to 150 Million TEUs handled in 2018. Although, the seaport operational performance measurement is still restrictive to data providers and conservative on refining KPIs from different operational perspectives. The purpose of this article is to develop an analytical process approach of operational indicators of container throughputs and handling performance, deployed by a shipping line service at an Eastern South America and European round trip voyage. The math model applied in this paper pursues key features and metrics that influence the container liner services scheduling. Accordingly, the methodology framework was designed to explore critical berth productivity factors and to correlate capacity efficiency variables. Furthermore, this research explored process benchmarking analysis on berth productivity from terminals and vessel operators' perspectives. It was clarified by KPIs analog to the line service attendance, such as the aggregated quay cranes handling a throughput of 600,722 TEUs in 2018 in contrast to vessel shipping throughput of 525,840 TEUs for the same period. Also, this research played attention to the optimization of port calls and data standardization.

1. Introduction

The Maritime Transportation is an important gateway for the global container trading of goods, among overseas countries and continents. At the end-to-end logistics journey, large-scale transportation is important to minimize the unit freight cost for costumers. Also, the efficiency of the container transshipment is essential to keep up the economic benefits of multimodality at logistics nodes, such as in port terminals and inland terminals. Understanding the global container fleet organization, the container vessel operation is known as the Liner Shipping Service. According to the United Nations Conference on Trade and Development (UNCTAD), the connectivity of a port in the global container shipping network is an important competitive factor for terminals, as the Liner Shipping Connectivity Index is a proxy for accessibility to the Maritime Freight Transport Systems. To clarify the understanding of the nature and scale of shipping and port industry metric concerns, key analytical tools are characterized on Performance Indicators (KPIs), that guide decision making on impacts assessment, on best choice target KPIs comparison, and drives sustainable development goals. (UNCTAD, 2019).

Concerning the Maritime Transport Performance Measurement, the bottom-up selection approach and aggregation of KPIs are highly engaged in data providers and linked to policymakers, authorities, and business agreements. According to the UNCTAD (2018; 2019) Statistics publication until June 2018, around 62.1 % of the world deep-sea container fleet market share on deployed capacity was operated by seven larger maritime shipping companies and has increased to 82,3% until February 2019. Those cited liner companies are respectively, MAERSK, Mediterranean Shipping Company (MSC), CMA-CMG, COSCO Shipping, Happag-Lloyd, Ocean Network Express, and Evergreen.

In contrast to the high competitiveness of the liner services business environment, over 2018 and 2019 considerable ongoing vertical integration at container shipping and port operational performance reinforced alliances and joint ventures between terminal operators and liner companies, urging dedicated berths to liner services operations, (UNCTAD 2018 & 2019). Besides that, the maritime sector is highly based on economic indicators and statistical analysis, such as independent maritime researches and consulting that records global logistic industry data, providing information reports and advisory guidelines. According to Drewry Statistics (2017), the average container handling throughput per quay crane (TEUs/QC) and the average container handling throughput per meter of quay (TEUs/m) recorded in 2016 was respectively: 127,167 TEUs/QC and 1,154 TEUs/m of around the world; 110,307 TEUS /QC and 849 TEUs /m in Latin America; and Asia recorded the best metrics performance of 162,000 TEUs/QC and 1,627 TEUS/m.

The improvement of container ports and terminals' productivity is a systematic challenge of port management. To enhance port competitiveness, technological improvements in operation efficiency had been designed to attend Shipping Line Services requirements (Rodrigue and Notteboom, 2010). Based on an existing example of liner services operation, to perform a factual case of study in this paper, it was selected a robust Shipping Line that attends East South America linking to Europe, abbreviated as ESAm - EU Line Service; as shown by Figure 1; SAEC1 – Aliança Line Service Route.

According to the Brazilian National Agency of Waterway Transportation (ANTAQ, 2020) on the annual 2018 statistics of port terminals throughputs, the referred line service registered a total of 228 calls at Brazilian Ports. Meanwhile, the ESAm-EU voyage round trip was scheduled to call twice in some ports; one call at Southbound and another in Northbound directions, as following: 2 calls at Port of Santos - Santos Brazil S/A Terminal; 2 calls at Port of Paranaguá - TCP. But only one call per round trip at Port of Itapoá TECON; one call at Port of Buenos Aires - Rio de La Plata Terminal (TRP); and one call at Port of Montevideo - Katoen Natie TCP.

Figure 1: Aliança Line Service Route (SAEC1) operated by eight same class Post-Panamax vessels within up to 9814 TEUs of Nominal Capacity, calling weekly at 14 ports in 56 days round trip on average, on Northbound and Southbound directions.

According to IAPH (ITPCO, 2019), as a port is a crucial node in the supply chain, it should connect and deliver clear visibility of cargo and vessel data to stakeholders. Beyond the efforts on Sustainable Port Programs, the Port Call Optimization is an emerging trend on safe operational management, improving data sharing quality, nautical communication, and terminal efficiency. Moreover, such as developing the “Just in Time Arrival” (JIT) of ships, with more accurate steaming, hinterland connectivity, and facilitate emission reduction (GIA, 2020).

1.1. Literature review

To find out critical factors and research trends on port economics and maritime logistics studies, focusing on Container Terminal (CT) berth productivity concerning liner shipping schedule, it was accomplished by different process approaches, assessing business and operational planning research methods and metrics.

According to Bichou (2009), the process approaches to measure the performance of business development and plans, is synthesized in two different methodological groups based on expert judgment and perception surveys, compared to engineering approaches and process benchmarking toolkits. Towards, a more sophisticated methodology on data analysis techniques used in port studies, requires more appropriate definitions over input and output variables choice and co-related factors, as technical inefficiencies comprehension rely upon parametric and non-parametric frontier analysis deviation.

As published by Pallis et al. (2011), concerning the Terminal Efficiency theme, the most cited methodology on the frontier assessment approach on performance measurement was based on Data Envelopment Analysis (DEA) and Stochastic Frontier Models (SFM). Accordingly, Shi and Li (2016) identified from literature reviewing that a considerable number of publications on maritime transport, ports efficiency, and performance assessment were analyzed also adopting the DEA, SFM, and Total Factor of Productivity (TFP) techniques. Generally, in concerns of Critical Factor for Berth Productivity in Container Terminals, Lu and Wang (2018) reinforced that the Data Envelopment Analysis method was to date regularly adopted to evaluate efficiency at Container Terminal. Analytically to this study, the main factors that influence berth productivity were characterized as dependent and independent variables. Intended to investigate the relation between productivity indicator upon the quayside capability of mega-hub container terminals in China and South Korea, K. and Dwarakish (2018) attempted port performance in contrast to variables metrics and attributes related to vessels times at port, loading and unloading rates, and inland influences.

The interrelationship between efficiency and productivity at berth operations was measured in cargo volume, which can be handled by a port terminal at a specific level of service, constrained by subsystem capacity. As efficiency metrics usually target benchmarking measures or key performance indicators (KPIs) PIANC WG 158 (2014).

From the design planning perspective of container seaport terminals, benchmark parameters address technical capacity such as berth design productivity between 1,000 - 1,400 TEUS per annum per linear meter of the quay; quay crane design productivity between 120,000 - 160,000 TEUs handled per crane per annum, and between 60,000 - 80,000 TEUs per equipment per annum if mobile crane. Underlying that, the Yard design productivity varies considerably according to layout operational system as influencing on stacking density, which ranges between 10,000 - 30,000 TEUs per yard area in hectares per annum.

The present KPIs are important to drive terminal managers and port planners to reach a better level of productivity, in the light of achievable operational capacity. From a sensitive perspective, Meisel and Bierwirth (2011) described the quality of service provided by seaport container terminals to liner shipping companies, as executed in the rights of contract at estimated service times to fulfill the berthing operation, in adjustment to the contractor expectations. In contrast, to satisfy vessel operators' expectations, the handling capacity of each terminal is appropriated to the quay layout design, and the number of quay cranes designated to match demand forecasting of vessel calls patterns. Underlining that the length of the quay and the quay crane average productivity are important considerations on terminal handling capacity, regarding desirable berth occupation.

However, the difficulty to evaluate the berth occupancy and capacity decision from an integrated process approach concerning quay crane efficiency enhancement, was a gap, as pointed by Meisel and Bierwirth (2011). Later reviewed at a follow-up publication of Meisel and Bierwirth (2011), the port-production challenge was the integration of a generalized problem, such as the Berth Allocation Problem (BAP), Quay Crane Assignment Problem (QCAP), Quay crane scheduling problem (QCSP).

Indeed, according to Pawellek and Schönknecht (2011), K. and Dwarakish (2018), and Lu and Wang (2018), the difficulty to examine the relationship of variables, even with DEA methods processing, was the incompatibility or insufficiency of databases for a robust statistical analysis. Either, consensus overs some activities index methods and measures over liner service operations and terminal operations are still unclassified, such as the ship utilization factor, port laytimes, berth time, berth occupancy, and quay crane productivity.

1.2. Purpose

The purpose of this article is to develop an integrated analytical process approach over a container ship round trip performance analysis, of a practical line service operational metric. The case of the study assessed the South American voyage loop of interest, among East South America and Europe (ESAm-EU) round trip voyage. The performance method reviewed was adapted from the Round-Trip transport Modelling Capacity, undertaking the Liner vessel operation from the shipping company operator and terminal operator perspectives.

Moreover, performance indexes were addressed concerning with benchmarking process approach. Accordingly, it was reviewed the berth productivity attending the Liners full-container vessels, comparing to the optimal berth capacities, quay crane handling performance, requested port-laytime, and optimal service time at berth, from different perspectives. As pointed before, this study will contribute to the advance liner services on the East Coast of South America, especially in Brazil, over the perception of container vessel round trip performance surveying. From the perspective of vessel operators, it was possible to explore the transportation capacity idleness per ship. From the perspective of terminal operators; it was possible to explore port call optimization over handling productivity maximization and port laytime reduction, as it is one the most influential parameters of profitability of a round trip (BÖSE, 2011).

2. Methodology

Based on the literature review and maritime statistics databases, the mathematical model procedures applied in this paper pursues key features that influence the container liner services' operational schedule as stated by the shipping companies within commercial portfolios. Also, concerning Port Call Optimization, as port logistics industry digitalization advances and international taskforces are supporting marine cross-industry data standardization. In terms of terminal performance statistics metrics, such as berth length utilization rate (TEU/berth/meter), quay crane utilization rate (TEU/QC), quay crane productivity (TEU/QC-hour), and the average number of quay cranes per berth, they were surveyed to be used on the process approach comparison of vessels´ Liner service efficiency along calling terminals.

The available container throughput data were collected mainly from governmental agencies, such as ANTAQ (2020), and contrasted with terminals' databases to assess the data quality and the port sharing information outlooks. By definition, the TEU factor (fTEU) represents the ratio of 1 TEU volume or 20ft size container in a unit box (NC_20ft) compared to 2 TEUs volume or 40ft size in a unit box (NC_40ft), that differs from terminal to terminal at each discharging and loading operations (PIANC, 2014). In other words, According to Pawellek and Schönknecht (2011) the fTEU - Eq. 3 - represents the relation between container quantity in units (NC) and volume (NTEU) in TEUs, as 1≤fTEU≤2. From this perspective, the number of containers carried between ports in unit boxes (NCS_Port i) – Eq. 1 - must be lower than the net loading capacity of the ship in units (NC_Ship) multiplied by its utilization factor (α), as 0≤α≤1. The container split annual throughput of 20ft and 40ft boxes at discharging and loading operations were also calculated for each port operation, to find the respective TEU factors.

$$N_{CS\_Porti} = N_{CS\_Port\,i-1} - (N_{C\_imp_{Port-i}} - N_{C\_exp_{Port-i}}) \quad (1)$$

$$N_{CS\_Porti} \leq N_{C\,Ship} \cdot \alpha \quad (2)$$

$$F_{TEU} = \frac{N_{TEU}}{N_C} = \frac{N_{C_{20ft}} + 2 \cdot N_{C_{40ft}}}{N_C} \quad (3)$$

$$1 \leq F_{TEU} \leq 2 \quad (4)$$

From these outputs, it was possible to estimate the overall throughput of containers handled and carried by (SAEC1) ESAm-EU liner vessels per voyage between the South American Ports round trip, and the average containers traded from European ports round trip. Noticing that, the interest of this study is narrowed among South America East Coast. In the sequence, the container ship's laytime in hours (TL_Port-i) as shown by Eq. 5 - defined as the rational time of arrival after tendering the Notice of Readiness (NOR) agreed in contract terms, known as time allowed to start and complete the cargo handling services (ITPCO, 2019).

The laytime in port (i) can be expressed from the aggregation of the berth clearance total time (TH_Port-i) and the total handling time. To calculate the total handling time, it must be estimated the overall number of lifts and the specific time to complete a single loading or unloading shift action (TUMH_Port-i) in hours – Eq. 6 - as it was specified the average number of quay cranes per operation. The productivity of a berth operation is directly influenced by the number of quay cranes (NCBH_Port-i) – Eq. 7 - designated to complete the handling operation of container boxes break-in; discharging at importation (NC_imp_Port-i) in units and loading at exportation (NC_exp_Port-i) in units. It is also important to note that the rearrangement of containers are directly influenced by the stowage plan accuracy (PAWELLEK & SCHÖNKNECHT, 2011).

$$T_{L_{port-i}} = T_{H_{port-i}} + (N_{C_{imp_{port}}-i} + N_{C\_\exp\_port-i}) \cdot \frac{T_{UMH_{port-i}}}{N_{CBH_{port-i}}} \quad (5)$$

$$T_{UMH_{port-i}} = \frac{(T_{L_{port-i}} - T_{H_{port-i}}) \cdot N_{CBH_{port-i}}}{(N_{C\_imp\_port-i} + N_{C\_exp\_port-i})} \quad (6)$$

$$N_{CBH_{port-i}} = \frac{\left(N_{C_{imp_{port}}-i} + N_{C\_\exp\_port-i}\right)}{\left(T_{L_{port-i}} - T_{H_{port-i}}\right)} \cdot T_{UMH_{port-i}} \quad (7)$$

According to PIANC WG 158 (2014), the typical industry benchmark and gross productivity for a ship to shore crane (STS) are classified as:

- Low, for 20 - 25 moves per hour;
- Medium, for 25-30 moves per hour;
- High, for 30-35 moves per hour.

Based on the Pawellek and Schönknecht (2011) and PIANC WG 158 (2014), the Berth Occupancy Factor (M_BERTH) – Eq. 9 - due to the Line Service can be estimated from the combining equation – Eq. 8 - on the average number of quay cranes per vessel, as the berth performance evaluation are derived from the gross productivity per berth due to line service (C_BERTH) - (TEU/ year) operational hours per year (Nhy) gross productivity per crane (P_CRANE) (moves/hour).

$$N_{CBH_{Port-i}} = \frac{C_b}{P \cdot f_{TEU} \cdot n_{hy} \cdot M_{berth}} \quad (8)$$

$$M_{berth} = \frac{C_b \cdot}{P \cdot f_{TEU} \cdot n_{hy} \cdot T_{UMH_{Port-i}}} \cdot \frac{\left(T_{L_{Port-i}} - T_{H_{Port-i}}\right)}{(N_{C_{imp_{Port-i}}} + N_{C_{exp_{Port-i}}})} \quad (9)$$

As discussed before, container handling productivity is one of the most influential parameters of round-trip profitability, as it is related to berth operational efficiency. Therefore, the performance indicator on the quay cranes productivity and berth productivity as were compared with benchmark KPIs, for each seaport Terminals on the South America Loop.

3. Results and discussion

The observations over of the Container Vessel Round Trip Performance Analyzes, based on expert judgment and perception surveys, from the perspective of terminal operators, shows the Quay crane productivity assessment in the chase of required performance capacity; Berth occupancy evaluation related to line services attendance; Port / Berth call optimization window related to schedule assessment of container ships, also VTMIS contribution and technology level improvement. Reduction port congestion and anchoring time, aligning nautical services provision with berth's capacity (JIT arrival) Port data sharing benefits and reliability improvement to stakeholders (standardization of data).

From the perspective of container vessel operator Vessel schedule optimization and requested charter speed performance at sea (less fuel consumption and time at anchorage); More accurate requested arrival time at berth and departure time per operation, and reduced delays with updated berth performance (JIT - larger container ship to be operated). Enhancement of supply chain visibility due to cargo tracking services on updates.

Based on the mathematical procedures presented in this paper; on one hand, the respective outcomes of the cases on the study were developed and structured according to access data sources. On the other hand, the restricted statistics data were presumed from Annual Reports on Container Throughputs, Shipping Liner Services Notes, and Schedule Portfolios.

3.1. The round-trip voyage schedule analyzes

The selected ESAm-EU Liner Shipping service is operated by eight Hamburg-Sud Large Post-Panamax Class full-cellular container vessels of up to 9860 TEUs of capacity. The line was operated jointly by Hamburg-Sud (flag-ship), MAERSK, MSC, COSCO Shipping, CMA-CMG , and Happag-Lloyd. The respective vessels in operation were described on the sequence with relative IMO numbers; It is important to note, that this Line Service Route was based on the 2018 Schedule; and was updated on the 2020 Schedule. Figure 2 shows the Cap San Antonio (IMO:9622241) in its relevant dimensions.

- CAP San Antonio (9622241);
- CAP San Artemissio (9633939);
- CAP San Augustin (9622239);
- CAP San Lorenzo (9622227);
- CAP San Maleas (9633941);
- CAP San Marco (9622215);
- CAP San Nicolas (9622203);
- CAP San Raphael (9622253).

Based on the service line operator commercial schedule, each vessel calls weekly 14 ports in 54 days of a round trip on average, estimating a total of 280 calls at Brazilian ports; taking in each round trip 2 calls at Santos S/A, 2 calls at Paranaguá TCP and 1 call at Itapoá Container Terminal. However, it was recorded in 2018 a total of 228 calls at Brazilan ports from this line service, according to the ANTAQ database. As a fraction of it, the Santos Brasil S/A Terminal has recorded in 2018, the total of 95 calls, with an average of 47 days vessel return on the same round trip direction, counting by the difference of the last Actual Time of Departure (ATD) and the first Actual Time of Berth (ATB) after the voyage loop, with a weekly frequency of around 7,76 days. Figure 2 shows the line service about COSCO Shipping.

Figure 2: Cap San Antonio (IMO:9622241): Gross Tonnage: 119441; Overall Length (LOA) 333.2 m; Breadth Extreme: 48,32 m; Loaded Draught: 14,2 m; construction year 2013/2014; Design Speed: 22 knots (MARINE TRAFFIC, 2020)

According to Figure 3, the start point of the voyage was assumed in Rotterdam ECT Container Division on day 0. After calling London Gateway Terminal, Hamburg Burchardkai Terminal, Antwerp Gateway, and Atlantic Terminal Le Havre, it took 12 days of transit time to reach Algeciras ML Terminal. Assuming Algeciras Port as the inflection node of this studied round trip loop to sail at East South America voyage (SA). After departing from Algeciras, the first berthing at Atlantic overseas on the Southbound direction was the Santos Brasil S/A Terminal on day 22.

According to Santos Brasil S/A 2018 data throughputs, the SAEC1 line service handled on average 1.203 container boxes discharging compared to 253 units loading, a proportion of 4,75 times more import than export, at this first call. However, in the second call at Santos S/A terminal, after 16,5 days on average of the vessel transit time, this proportion reversed to 1.247 container box units loading and 293 discharging, as the recorded annual average throughputs. Moreover, only Santos Brasil S/A shared the respective; handling throughputs of containers, operational times (ETA, ATA, ETB, ATB, ETD, ATD), and vessel schedules details; according to International standards of data file format and content (ITPCO, 2019).

The Figure 4a and Figure 4b present the average recorded 2018 Handling Throughputs (TEUs) of the SAEC1 vessels alongside Santos Brasil S/A Terminal, divided between Discharged, Loaded, and Rehandled volume of the container in each sailing direction; Northbound and Southbound.

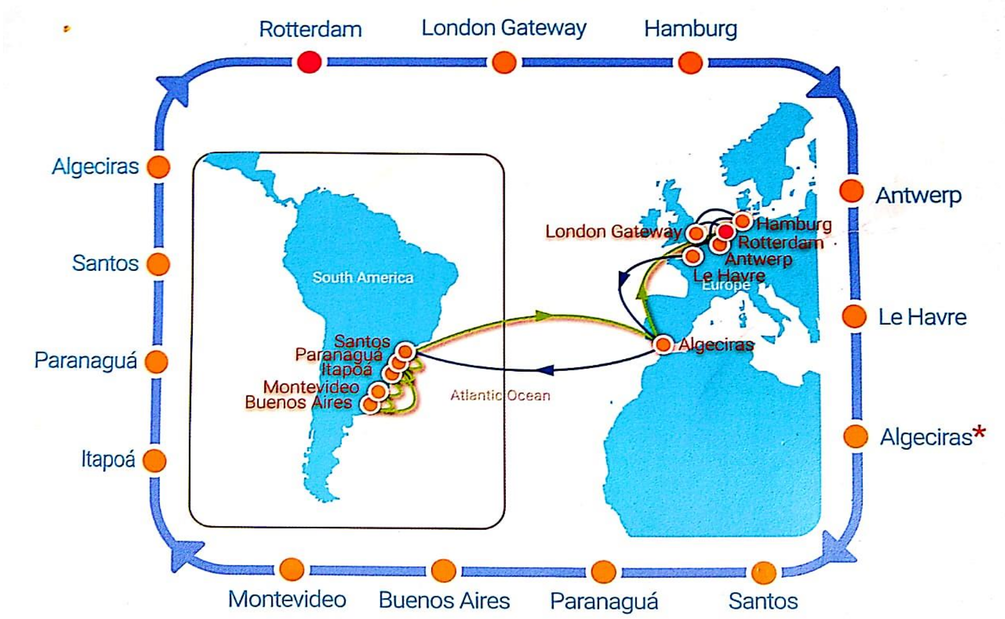

Figure 3: SAEC1 Line Service reference ESAm - East Coast of South America/ EU - Europe of COSCO Shipping 2018 Commercial Flyer (COSCO SHIPPING, 2020)

Moreover, Figure 5 presents the Average 2018 SAEC1 Vessels' Recorded Timeline at Santos S/A Terminal based on the Time at Port (ATD-ATA) and the Time at Berth (ATD-ATB). Reminding from the first call at Santo S/A terminal, according to the Service 2018 schedule, the next stop was at Paranaguá TCP on day 24, later the last call in Southbound direction was Buenos Aires Río de La Plata Terminal (RTP) at day 27 of transit time. After sailing from Buenos Aires, the next call was in the Northbound direction at Montevideo Katoen Natie Terminal TCP on day 30 of transit time. However, as pointed out before, the actual 2020 schedule shifted Buenos Aires and Montevideo calling sequences, but it was not noted a significant transit time reduction after these calling shifts.
In the sequence, the next call was at Itapoá Port Container Terminal on day 33; then the second call at Paranaguá TCP was on day 34 and the next call was the second visit at Santos S/A Terminal at day 36. After the last sailing from Brazil, the next stop was the second visit to Algeciras on day 49, then the last vessel call was at the starting point at Rotterdam ECT Container Division on day 54.
Figure 6 presents the summarized ANTAQ 2018 Statistics database, obtained from the recorded time series of the SAEC1 Line Service for each respective Brazilian Terminals, as Paranaguá TCP; Santos Brasil S/A, and Itapoá Port Terminals.
Noticing that the average time at berth from ANTAQ 2018 database must be loyal to Santos S/A terminal database (SANTOS BRASIL, 2020). Thus, on one hand, it was observed an average Time at Berth (ATD-ATB) of around 35 hours, which is similar to both sources. On the other hand, it was observed a clearance average time or dwell time at the berth of respectively; 5 hours to Paranaguá TCP; 9 hours to Santos Brasil S/A, and 6 hours to Itapoá Port Terminal.

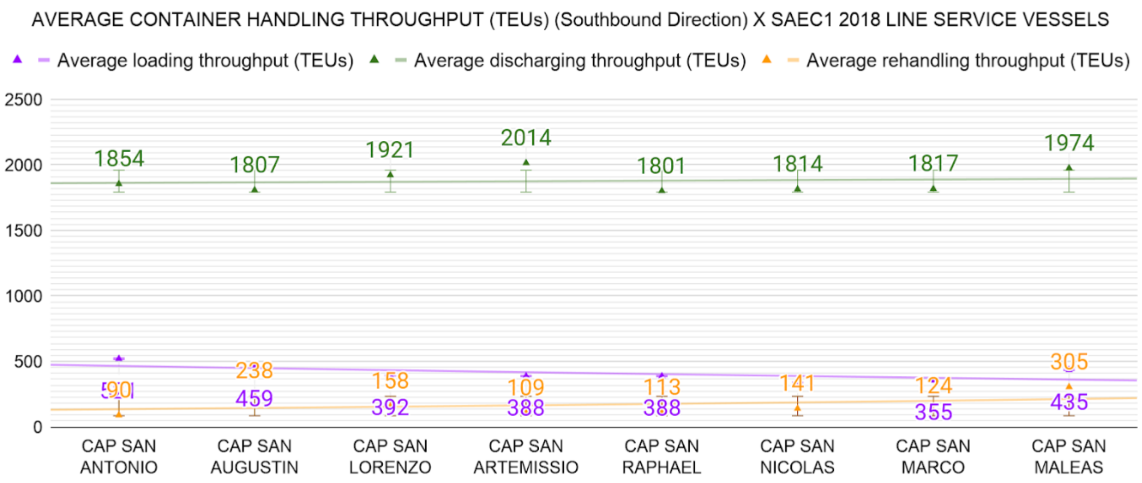

Figure 4a: Volume of the container in each sailing direction; Northbound and Southbound.

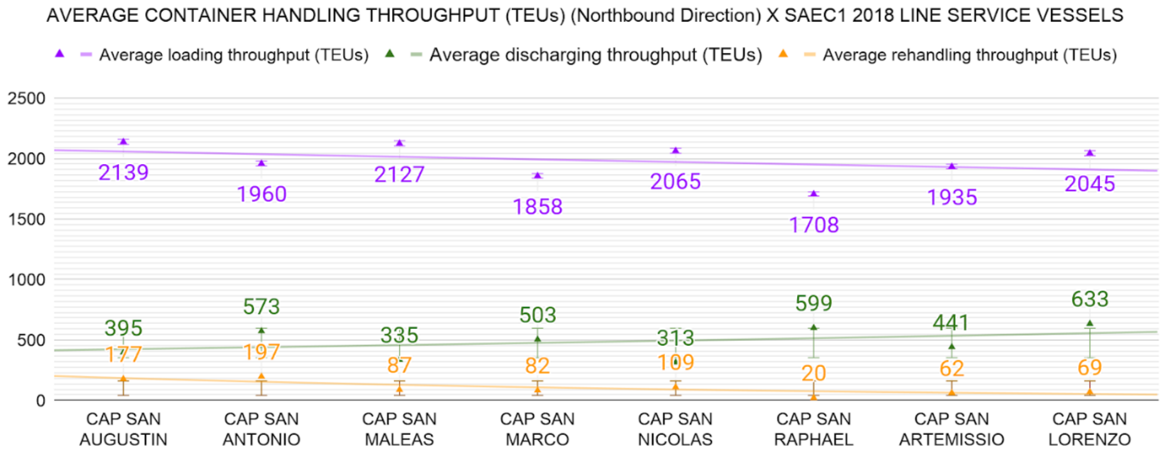

Figure 4b: Volume of the container in each sailing direction; Northbound and Southbound.

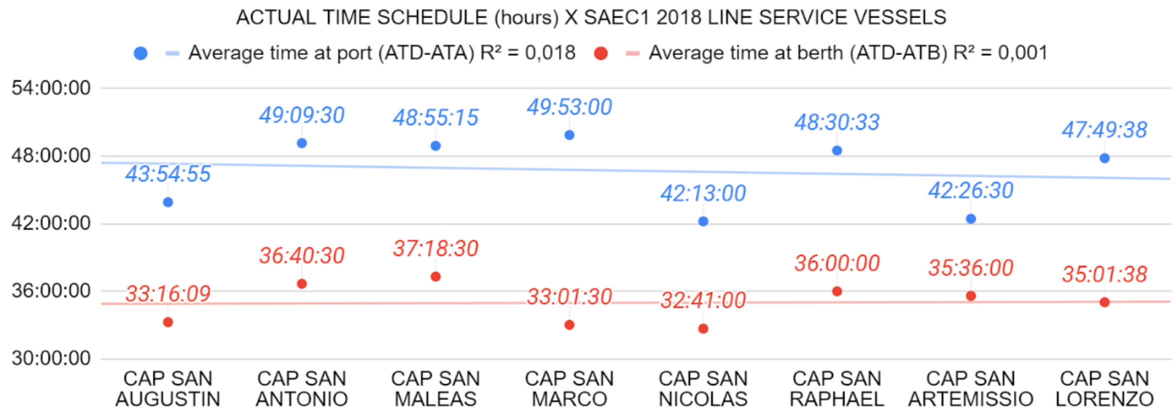

Figure 5: Average Recorded 2018 ESAm-EU Line Times Series at Santos Brasil S/A Terminal

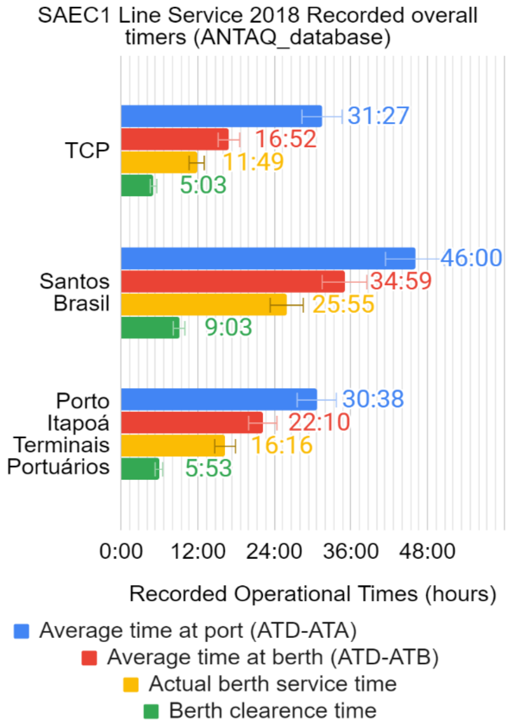

Figure 6: Summarized ANTAQ 2018 Statistics database

3.2. The round-trip voyage container handling throughputs

The following Container Terminals handling throughputs; Paranaguá TCP and Itapoá Port; only were obtained from the ANTAQ database (ANTAQ, 2020). While Buenos Aires and Montevideo Terminals did not share those required data. Thus, those handling throughputs were assumed in proportion to Santos S/A productivity. Figure 7 shows the discharged and loaded average 2018 throughputs proportion of 40ft and 20ft containers handled in each terminal of call at Southern loop. Noticing that, the average rearranged containers was around 135 boxes only in Santos S/A, counting a total of 13,066 boxes in the year of 2018. These numbers reflect on quay crane productivity and point to the accuracy of the Stowage Plan.

It was also observed a greater proportion of discharging container boxes than loading from Southbound direction at the first call at Paranaguá TCP, as observed in Santos S/A. These imbalances of import-export can be explained by the higher demand for cargo exchange between European Market at Santos and Paranaguá. Similarly, the second call at Paranaguá TCP terminal might be a requirement to attend sanitary transit time conditions of refrigerated cargoes, once Paranaguá TCP recorded in 2018 more than 35% of handling Reefer Container, according to ANTAQ (2020). This high refrigerated cargo demand reflects on the need for a greater Reefer Plugs on the trading vessels and the container yards.

In the sequence, from the handling throughputs at each terminal, the average number of containers moved between ports was calculated. Therefore, it was possible to estimate the number of containers carried from port to port, such as the total of 3,599 container boxes exported to the European Market from South America, and an estimated 3,000 containers imports, based on an optimist assumption of discharged balance container of discharged containers in ESAm Port Calls. As the vessel, FTEU was estimated in 1.66, according to the average ratio. Thus, the average volume of containers carried was around 5,975 TEUs in Northbound direction and 4,980 TEUs in Southbound direction. Therefore. based on the total of 48 completed round trip voyages, the estimated annual throughput of the ESAm-EU Line Service was handling overseas around 525,840 TEUs in 2018. – Figure 8 shows the average volume of containers moved between ports in the South America voyage Loop.

Moreover, due to the container split of 20ft and 40ft, the TEU factor was calculated for each port terminal as presented in Figure 9. According to PIANC WG 158 (2014), the berth occupancy factor is inversely proportional to the TEU factor, as the gross productivity per berth is directly proportional. Therefore, an increased number of 40ft container handling implies an increase of the FTEU. ($1 \leq fTEU \leq 2$)

Due to the lack of available data from terminals, the fTEU of Paranaguá and Itapoá port terminals were estimated based on the overall proportion of container volume according to ANTAQ 2018 database (ANTAQ, 2020). However, in Buenos Aires and Montevideo, the fTEU was assumed near to the vessel fTEU.

It can be observed that the fTEU KPI is higher at Paranaguá and Itapoá container terminals, due to the greater amount of 40ft Reefer Containers handled, according to ANTAQ Statistics (ANTAQ, 2020).

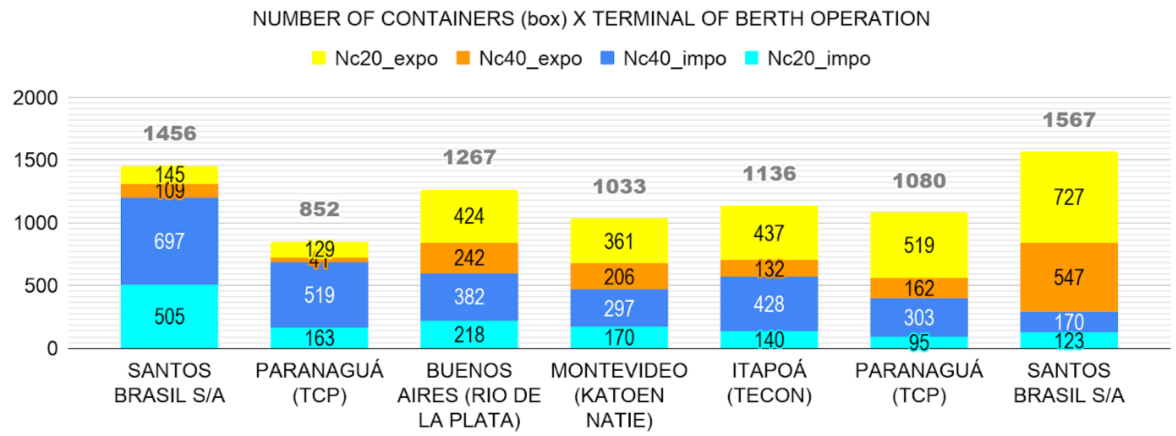

Figure 7: Total number of containers handled on average per ESAm-EU Liner ship calls, in each terminal at 2018.

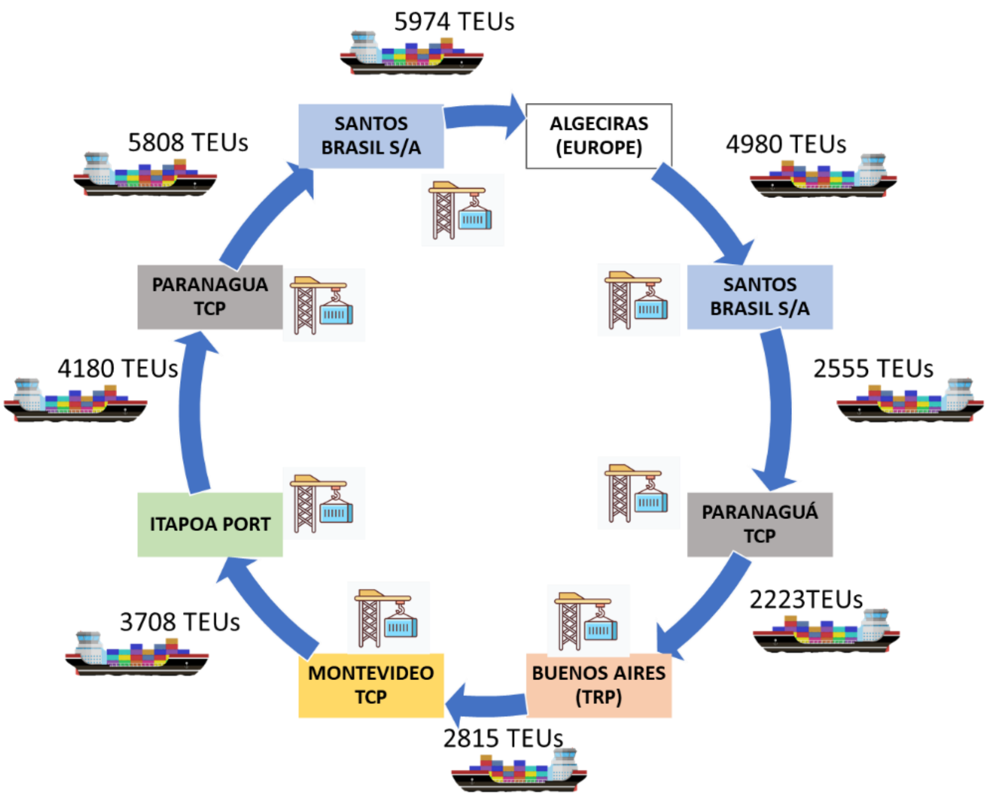

Figure 8: Average volume of containers moved between ports in the South America Voyage Loop. The number of shipping containers are displayed in TEUS/ per voyage path. The European Voyage Loop were not detailed in this study. (Ref; author creation)

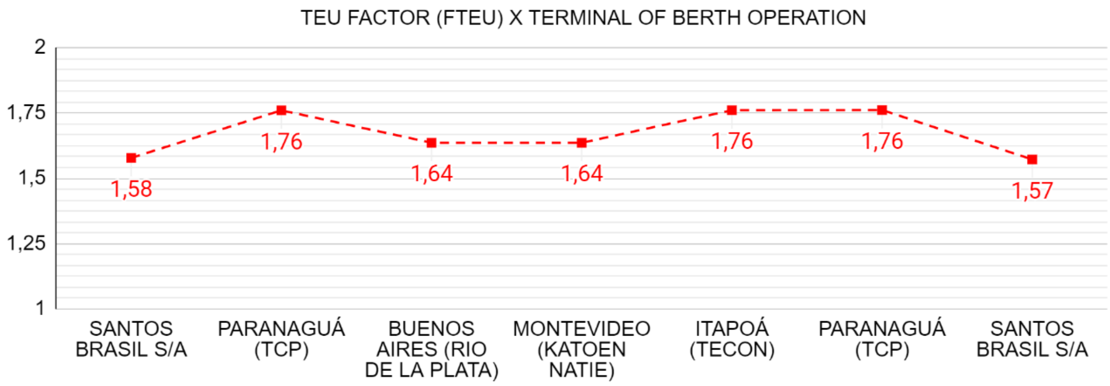

Figure 9: Respective terminals' TEU factor (fteu)

3.3. Terminal's performance indicators analysis at ESAm-EU line service operations

The Performance Evaluation of Container Vessel operations at Seaport Terminals was mathematically based on the recorded sequence times of arrivals and departures, with the detailed arrangement of service times at the port and the sea. Also, the overall recorded throughput in each port call operation was discretized between the handling of 40ft and 20ft containers, loaded and discharged at exportation and importation respectively. Also, it was observed the rearrangement of container boxes in the ship's deck (PAWELLEK & SCHÖNKNECHT, 2011). However, to simplify the analyzes, it was not considered the container rearrangement as it is due to the Stowage Plan accuracy evaluation. But the difference of total container handled from the perspective of the vessel operator and the perspective of the terminal operation gave the expected proportion of total rearrangement throughput as discussed in section 3.3.4;

3.3.1 Berth's performance indicators from the perspective of the vessel's operators

To estimate the average container ship's laytime (TL_Port-i) at the studied berths, assuming 24/7 operation and from the planning perspective of Vessel operators, it was supposed to know the number of quay cranes deployed and its respective productivity. However, in the sense of critical analysis, it was assumed the lower quay crane practical productivity of 25 moves/hour, and it was reasonably allocated 3 Ship to Shores cranes (STS), *as spotted from satellite images*. Moreover, it was assumed a Clearance Times figured at *Figure 6*, considering the berth dwell times and the vessel Port Passage Plan time between waypoints, that consists of the pilot boarding place to the berth position, *vis-à-vis.* The Figure 10 shows the calculated port laytimes according to the 2018 data analyzes

As the estimated operational laytimes might be related to the difference of the Estimated Time of Departure (ETD) with the Estimated Time at Berth (ETB), the berth productivity is related to the quay crane's performance. At the specific case of Santos Brasil S/A Terminal (SANTOS BRASIL, 2020), it was recorded in 2018 on average, port laytime differentiated on Southbound and Northbound directions with respectively 27 and 28 hours.

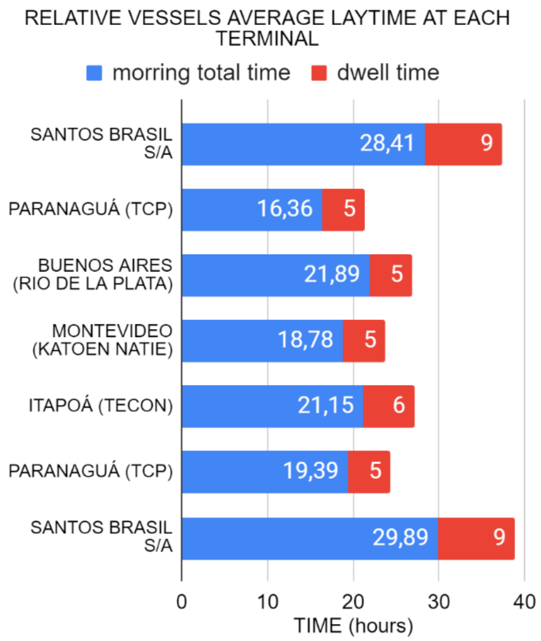

Figure 10: Port laytimes according to the 2018 data analyzes

3.3.2 Berth's performance from the perspective of the terminal's operators

Based on the estimated operational laytimes (T_{L_Port-i}), also considering estimated berth clearance time (T_{H_Port-i}), a single quay crane's productivity ($P_{\_CRANE}$) can be estimated from the time to complete each handling move (T_{UMH_Port-i}). Therefore, the berth productivity was estimated from each terminal, as the achieved performance plotted in Figure 11. The sizes of each ball are proportional to the number of quay cranes allocated, assumed as 3 STS to all terminals.

In particular, from Santos S/A 2018 database It was calculated the average berth productivity of 77,13 TEUs/hour with 2,3 quay cranes allocated. It implies productivity of 21,22 moves/hour per quay crane, which is lower than desirable of 25 moves/hour.

3.3.3 Berth's capacity performance from the perspective of terminal's operators

Within the same operational throughputs and operational times considered on the Terminal's performance indicators analysis *3.3.2*

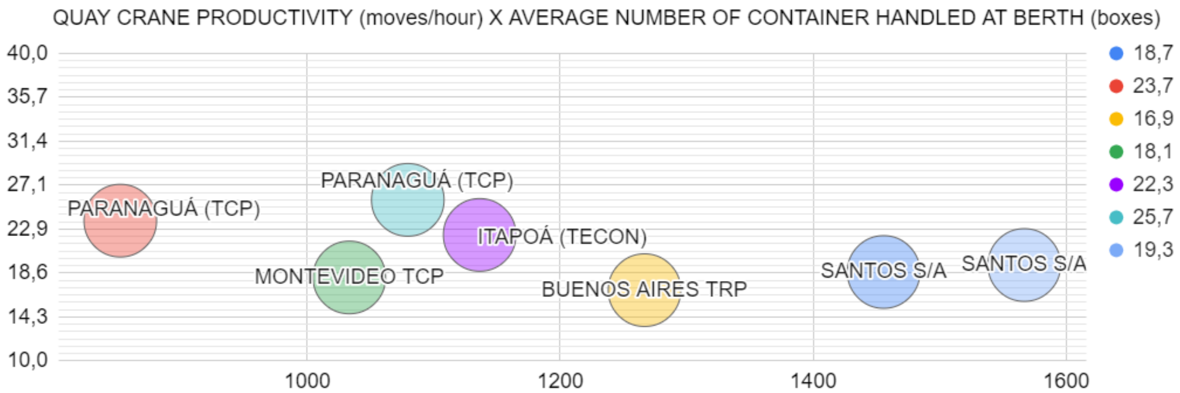

Figure 11: Quay cranes achieved performance with the same allocated number of 3 cranes per operation

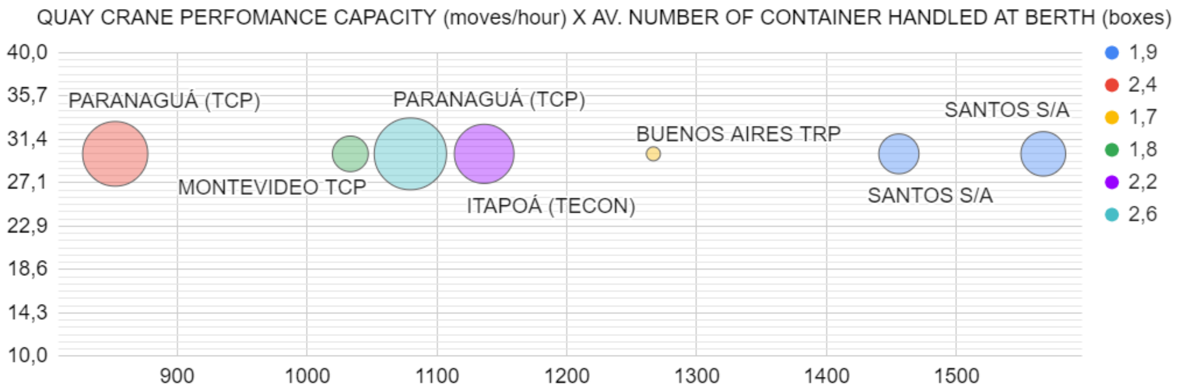

Figure 12: Number of quay cranes required with the stated performance of 30 moves/hour.

the berth capacity performance was analyzed from the desirable quay crane productivity improvement to 30 moves/hour. Therefore, it was possible to analyze the reasonable number of quay cranes required to be allocated at those berths' operations. Noticing that the quantity of quay cranes is a considerable parcel of berth operational cost to the Terminals. Figure 12 reflects the optimized proportion of quay cranes that could be allocated with constant berth productivity performance.

3.4 Berth's occupancy from the quay cranes performance and capacity perspective

The Berth Occupancy Factor ($M_{\_BERTH}$) is an important parameter to estimate more precisely the Berth Operational Capacity, as the Berth Productivity is limited tactically to the Quay Cranes productivity. Therefore, based on the figured quay crane practical gross productivity (moves/hour) section 3.1 the estimated annual gross productivity per berth due to respective 2018 operational throughputs (TEUs/year), related to the frequency of the line service calls at each terminal, and sailing direction section 3.3 Assuming an estimated time to complete each handling move derived assumed the practical quay crane productivity, calculated at section 3.3.3. Also, assuming a 24/7 operational hours per year; Therefore, the Berth Occupancy factor related to ESAm-EU service attendance at each Terminal in each sailing direction was expressed in Figure 13.

Although, the liner vessel calls twice at Santos S/A and Paranaguá TCP that implies an accumulated berth occupancy as the line service usually mooring in the same Berth Position as shown in Figure 14.

The design principles of dimensioning a container terminal are related to the operational productivity rates, as the Berth Occupancy assumed at an acceptable level of vessel waiting times in queue. According to PIANC WG 158 (2014) and UNCTAD (2019), the acceptable berth occupancy figures vary from berth to berth, and the number of operational berths, as the average waiting time of a vessels were based on the queueing theory statistics approach with random vessel arrivals (M), Ealing 2 distributed service time (E2), assuming an M/E2/n pattern.

Therefore, the estimated acceptable vessel waiting times was around 32% service time, for a single berth utilization of the Line Service, as usually

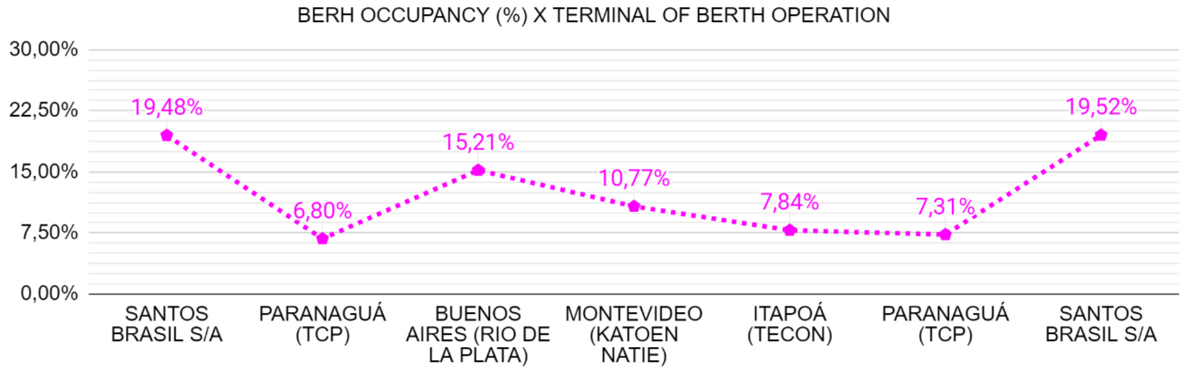

Figure 13: Berth occupancy related to the saec1 line service quay cranes gross productivity

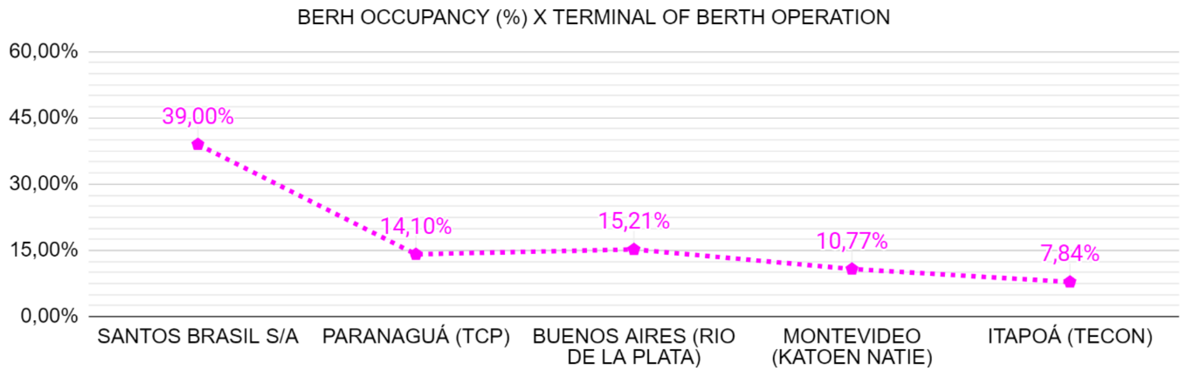

Figure 14: Accumulated berth occupancy related to the saec1 line service quay cranes gross productivity

observed according to ANTAQ 2018 database, where the berth IDs and statistics were described, according to ISO/IEC 6523 - as recommended by GS1 Standards. Santos S/A Terminal (Berth ID): SSZ0813 - 86,6% berth position frequency; Parenguá TCP (Berth ID): PNG0217 - 98,74% berth position frequency; Itapoá Port Terminal (Berth ID): BRSC011002 - 77,78% berth position frequency

The design of container berth terminals occupancies must be typically around 90% of factual service time, as any vessel delay is undesirable for Line Service Schedule Planners. Therefore, as observed that the SAEC1 Line Service occupies almost 40% of SSZ0813 Santos S/A berth productivity, it is possible to argue that this berth is mostly operated by those liner vessels.

Moreover, based on the berth occupancy parameters, the figured terminals' participation in the total gross productivity reveals that the estimated Quay Cranes Throughput operating the SAEC1 Line Service might be around 600,722 TEUs per year, from the Terminal operators perspective. Compared to the estimated voyage handling throughput of 525,840 TEUs per year*),* from the vessel's perspective, the quay cranes' annual throughput is higher than the vessel carrying throughput as expected. As the difference between these annual throughputs, might be critical rehandling movements estimated at 74,882 TEUs, that might catch the attention of Ship Planers.

Figure 15 refers to each terminal's participation on the 2018 SAEC1 Line throughputs from the berth's performance perspective.

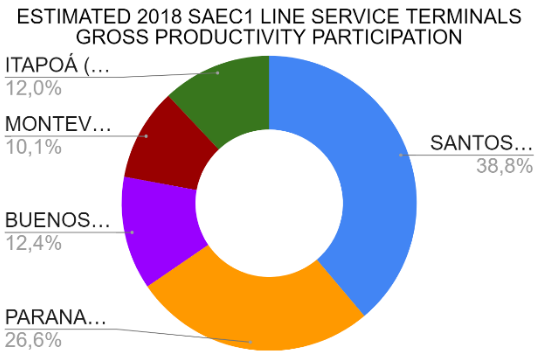

Figure 15: Terminal's participation on the 2018 ESAm-Eu Line throughputs (TEUs/year)

4. Conclusion

In Summary, the performance evaluation and survey of container vessel operations along with the 2018 ESAm – EU Line Service to Seaport Terminals were figured based on, a clear and plain analysis of the relationship of the main variables that affect the quay cranes handling productivity and throughputs. It was observed, that the time to accomplish each loading or discharging action (TUMH_Port-i), is directly affected by independent variables that regard attention, such as the stevedoring gang ability to accomplish each handling move at vessel's hols, the cross-rail problem of the ship to shore crane haulage, the trolley speed, the net lifting capacity, and the spreaders hoist design, that distinguish from manufacture providers of the grant cranes. Therefore, to simplify the interrelations of variables, they were correlated by the average single handling micro performance time and generalized to the quay crane gross productivity (P), further radiated to the macro performance of the allocated set of quay cranes at berth operation. Such as, at Santos Brasil S/A Terminal, it was figured and handling gross productivity of around 18,7 moves per hour per quay crane, considering an average handling accomplishment of 3 minutes per move. However, the desired performance was assuming an allocation of 3 quay cranes per operation at a regular layout. In contrast, assuming the same operational laytime, the desired quay crane gross productivity was the reference performance to assign the quay crane berth allocation problem, as plotted in the Figure (1X). Therefore, the mathematical modeling of this paper demonstrated a dynamic and plain tool to assess different quay crane setup arrangements, contrasting the average gross productivity with the desirable performance, at the Operational Capacity Planning Level. From a shared perspective, the Berth Occupancy ratio based on the quay cranes productivity, demonstrated the interdependency approach of the terminal on the liners service, as a high occupation ratio means of a dedicated berth for the line service.

Moreover, from the perspective of the vessel operator, the maximum load capacity of the vessel must be taken into account gathered by the volume of the container measured in TEUs. Therefore, as the suggested analysis of the TEU factor for each terminal is an important KPI to improve the Line Service operations at berths, once the proportion of 40ft and 20ft containers loaded for exportation, discharged for importation was read by the TEU factor. Thus, the limit of containers carried by a vessel must be assessed for the critical voyage path, indeed if was considered navigation depth nautical restrictions at some port. From the case of study, the ESAm - EU Line Service has not noted any navigation restriction at the calling terminals, but the critical voyage between port sea waypoints was over the Atlantic sea crossing after sailing from Santos S/A terminal in Northbound direction, within the vessel carrying 3599 container boxes, estimated in 5,974 TEUs, converted from the TEU factor figured for the vessel 1,66.

However, these KPIs could be more accurate if the data were provided according to nominal standards. Therefore, the data estimated according to each port call operation; from the recorded sequence times of arrivals and departures of the Line Service in the study, were based on benchmarking records. Also, due to the lack of detailed containers handling throughputs data, the proposed Round-Trip Voyage Performance Model Analysis could not be precisely compared to the factual throughputs. Indeed, without the detailed arrangement of service time Schedules at the ports and navigating at the sea, the operational performance and efficiency between the vessels at the port could not be precisely compared to factual timelines. Instead of those factual parameters, it was applied to benchmark Key Performance Indicators (KPIs) as perceived by PIANC WG 158, UNCTAD (2018), and Drewy (2017).

In this study, the advantages of the Container Vessel Round Trip performance analyses contributed to developing a shared understanding from both perspectives of Terminal operator and Container vessel operators, as it is a crucial baseline for stakeholders on the Line Service charter party terms. Therefore, from the perspective of terminal operators; the quay cranes productivity assessment compared to required performance; and the berth occupancy evaluation, are important decision-making analyses before any Terminal investment on capacity enhancement at a Hub-and-Spoke System. Besides, in the light of the state-of-art, as it could be seen accelerating of the digitization process on global leaders container industry, the Port's Berth call Optimization process, might be a successful key strategic practice to reduce the port congestion and anchoring times, as well as emission reduction of Green House Gases (GHG); as it follows the Just-in-Time Arrival Guide arrangement, in accordance to the International Maritime Organization (IMO) best practices for the sector. Also, the data sharing and standardization is an enormous benefit to stakeholders' reliability, academy scientific disclosures, and governmental statistics forecasting on infrastructure improvement. Moreover, from the perspective of container vessel operators, the shipping schedule optimization might be rearranged as a need for speed performance improvement at sea, regarding upcoming restrictive regulations of less fuel consumption and GHG emissions. Also, the volume of container handled per operation can be more precisely assed, as the economy of scale of - larger container ships are a goal for any Shipping company.

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