A CORRELATION ANALYSIS OF VESSEL CHARACTERISTICS AND CONTAINER THROUGHPUT FOR SELECTED COUNTRIES (2018-2023)

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Abstract

This study investigates the relationship between vessel characteristics and container throughput from 2018 to 2023. Using Pearson correlation analysis, three major vessel parameters—age, average size, and carrying capacity—were examined to determine their influence on throughput performance. The findings reveal that vessel age exhibits a strong negative correlation with container throughput across all years, indicating that older vessels contribute less to port efficiency. Conversely, vessel size and carrying capacity display moderate positive correlations with throughput, although their effects slightly weaken over time. These results underscore the importance of fleet modernization and port infrastructure improvement to sustain throughput growth. The study concludes that technological advancement, green fleet renewal, and enhanced port capacity are essential for optimizing container handling performance and achieving competitiveness in the global shipping network.

Keywords: Container throughput, Vessel characteristics, Port performance, Fleet modernization, Maritime efficiency.

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Introduction

The container shipping industry remains the backbone of global trade, facilitating the movement of goods across continents with increasing efficiency and scale. In recent decades, maritime industry has experienced rapid structural transformation driven by technological innovation, vessel upsizing, and port automation, to measure up with increasing global trade via sea (Stopford, 2020; UNCTAD, 2023). As ports across the globe compete for share of global trade in terms of throughput and connectivity, vessel characteristics, such as size, capacity, and age, have become critical determinants of operational performance and competitiveness.

Vessel size and carrying capacity have been widely associated with economies of scale and improved cost efficiency (Cullinane & Khanna, 2000). Larger ships have capacity to transport more containers per voyage, thus reducing average costs incurred by shippers and increasing overall port throughput. However, the benefits of vessel upsizing are not linear as ports require sufficient requisite port-side infrastructure such as deep berths, high-capacity cranes; and efficient hinterland connections to accommodate these ships (Merk & Dang, 2012). Similarly, carrying capacity reflects the vessel's potential contribution to throughput but depends on supporting terminal and logistical systems for effective utilization (Munim & Schramm, 2018).

On the contrary, vessel age represents a critical measure of technological relevance and operational efficiency. While older vessels tend to have lower energy efficiency, reduced reliability, and higher maintenance costs, which can hinder port performance and turnaround speed (Notteboom & Vernimmen, 2009), modern and more innovative fleet has thus become a key strategy for ports and shipping lines seeking to improve competitiveness, reduce cost and achieve environmental compliance.

Despite the extensive literature on port efficiency, relatively few empirical studies focus on the direct relationships between vessel attributes and container throughput over time, particularly in developing maritime contexts. This study addresses this gap by analyzing the correlation between vessel characteristics (age, size, and carrying capacity) and container throughput from 2018 to 2023. The objective is to identify the vessel characteristics that most strongly influence throughput performance and to provide policy recommendations for sustainable maritime development.

Literature review

Studies on port performance have focused on multi-dimensional and multi-stakeholder approaches (Notteboom, 2006; Minho, 2017; Jamain et al., 2023). Port performance measurements have been linked to several indicators that affect regional competitiveness and optimum throughput. There are traditional studies that focused on metrics using the ship-to-shore interface. These studies examined ship turnaround time (total time a vessel spends in port from arrival to departure) (Ducruet and Itoh, 2022; Mazibuko et al., 2024); berth time and quay crane productivity (Kurniawan et al., 2021; Singh et al., 2025), as key indicators of port performance. Within the traditional studies, geographical location, which in a way describes the distance of a port to markets, and can also be interpreted as a function of demand and distance of ports, has been identified as key factor influencing port performance (de Langen, 2007). According to Notteboom et al. (2021), changing geography of seaports is impacted by technical constraints such as the port users, inter modal connectivity, and maritime shipping networks.

Other traditional methods include dwell time, truck turnaround time and container throughput measured in twenty-foot equivalent units (TEUs) which is the total volume of containers handled over a period (Zheng and Park, 2016; Aminatou et al., 2018; Shetty and Dwarakish 2018; Du et al., 2022a). From the perspective of methodology, studies have employed various analytical techniques to assess the performance of various ports including container ports globally. These techniques in assessing port performance are evenly distributed between Data Envelopment Analysis (DEA), Stochastic Frontier Analysis (SFA) and Multi-Criteria Decision Analysis (MCDA) (Tongzon 2001; Estache et al., 2004; Cullinane et al., 2006; Tongzon, 2009; Odeck & Bråthen, 2012; Wang et al., 2021).

However, studies have highlighted that port performance is influenced by a combination of internal and external factors with the dominant internal factors influencing terminal performance relating to operational capacity and management practices. For instance, availability of quality port infrastructure and equipment with capacity to handle mega-vessels; berth depth, storage capacity, and multi-modal connections to the hinterland ensures smooth container shipping operations (Cullinane and Wang, 200). Also, introduction and adoption of integrated information systems solutions which are essential for reducing delays, streamlining customs, and optimizing processes have significant impact on port throughput (Kia et al. 2000; Ally & Mbamba 2009; Panayides, 2017). In addition, appropriate strategic management practices such as labour optimization, and maintenance strategies are significant influencers of port performance and efficiency (Mabinga and Mwalukasa, 2024; Adeyemi, 2024).

Port performance is highly susceptible to external shocks and the broader economic environment. For instance, changing global and regional trade volumes directly affect cargo throughput (Port Economics, 2021). Also, the trend toward ultra-large container vessels (ULCVs) poses not only challenges for the design of container cranes, quay walls, and other maritime infrastructure, such as access channels, turning and port basins, and berth pockets, but also for the design of the mooring system (Veloqui et al. 2014; Haralambides 2019). In addition, turnaround time for ULCVs may cause serious concerns, especially in light of the high capital investments and maintenance costs (Bielli et al. 2006; Qiang et al. (2017).

In relation to container ports, studies on container port performance consistently show that ship-level attributes such as vessel size, carrying capacity, and age of vessels interact with port infrastructure and other performance indicators to determine throughput outcomes. Economies of scale from vessel upsizing are a foundational theme. While larger containerships present a potential for reducing unit transport costs at sea and raising throughput per call, these benefits depend critically on ports' ability (in terms of berth depth, crane reach, yard capacity) to handle larger ships (Cullinane & Khanna, 2000).

Empirical and policy-oriented studies have emphasized the diminishing or conditional returns to upsizing when port-side constraints exist. According to World Bank's Container Port Performance Index, throughput gains from larger ships is strongly influenced by terminal productivity and congestion, not just ship capacity (Tran and Haasis, 2015). Where terminal productivity is low, larger ships may cause congestion and longer dwell times that erode expected throughput gains.

Vessel age and technological sophistication have emerged as important determinants of operational efficiency as newer vessels typically offer better fuel efficiency, faster handling compatibility and lower breakdown or maintenance delays—factors that improve vessel turnaround times and container port throughput. Notteboom and Vernimmen (2009) show how changes in vessel design and operational practices (driven in part by fuel costs and regulation) alter service configurations in ways that affect port calls and throughput dynamics.

Policy and performance monitoring reports further show that heterogeneity in port performance (vessel time in port, crane productivity, waiting time) moderates the translation of vessel carrying capacity into throughput. Most of the studies and reports on port performance analysis have not examined the correlation of multi-characteristics of vessel with container throughput using data from different countries. This study examined the relationship between the combination of vessel age, vessel size and carrying capacity, and container throughput from a multi-country perspective. To the best of our knowledge, this is the first of this kind of study which is expected to shift attention away from traditional metrics to the examination of the combination of other determinants of port performance.

Methodology

The study utilized secondary data covering 10 countries which are China, Denmark, Germany, Indonesia, Netherlands, Spain, Sweden, Turkey, the United Kingdom and the United States of America. The choice of these countries was premised on the fact they possessed technologically advanced and operationally efficient ports in the world. The data was collected from the United Nations Statistics (UNStats) between 2018 and 2023. The data included container throughput (measured in Twenty-foot Equivalent Units, TEUs) (Table 1); age of vessels (years) (Table 2); average size of vessel (Table 3); and carrying capacity of vessels (Table 4). The study adopted quantitative research design using Pearson correlation analysis to determine the relationships between container throughput (measured in Twenty-foot Equivalent Units, TEUs) and three vessel characteristics: age of vessels (years), average size of vessel, and carrying capacity. The correlation coefficients (r) range between -1 and +1, where positive values indicate direct relationships and negative values indicate inverse relationships. Heat maps of the correlations were also generated to present visual understanding of the relationships between the variables. The analysis allowed for assessment of the strength and direction of association between vessel parameters and container throughput performance.

Table 1: Container throughput for the selected countries

	2018	2019	2020	2021	2022	2023
China	229127700	237570000	240480000	256945700	269030000	279793800
Denmark	833857	880039	933622	1054552	1079406	926423

Germany	15123221	15022386	13946212	14710963	13733867	12660224
Indonesia	12616970	12704578	11771309	13008301	12427811	0
Netherland	14802257	15198050	14757227	15781756	14929333	14111298
Spain	17165709	17464920	16745921	17712459	17161676	16379282
Sweden	1600175	1623363	1612953	1635183	1631248	1607998
Turkey	10801305	11591414	11626578	12591327	12366172	12554581
UK	10315140	10508000	9732000	10290181	9749676	9090140
USA	53045976	54259399	53035170	60771719	61033758	54282705

Table 2: Age of vessels (in yrs)

	China	**Denmark**	**Germany**	**Indonesia**	**Netherland**	**Spain**	**Sweden**	**Turkey**	**UK**	**USA**
2018	11	13	11	14	12	13	13	15	13	13
2019	12	17	13	14	13	14	14	16	14	13
2020	12	16	13	14	14	14	15	16	15	14
2021	13	15	13	15	15	15	16	17	16	15
2022	13	15	14	16	16	16	17	18	17	15
2023	13	15	14	16	16	16	17	18	17	15

	China	**Denmark**	**Germany**	**Indonesia**	**Netherland**	**Spain**	**Sweden**	**Turkey**	**UK**	**USA**
2018	50155	21242	42651	15430	31216	35327	16250	33910	37344	59644
2019	50062	19536	42018	15475	32385	35592	16380	34599	36766	59336
2020	49495	19470	48831	15475	32000	35736	16328	33437	37553	59997
2021	47249	21530	49641	13513	30474	32737	17014	32607	33874	60554
2022	47751	22103	49851	13226	30500	33592	17352	30287	35218	59849
2023	48856	21745	54461	14237	34096	34894	18512	30488	38169	63680

Table 3: Average size of vessel

Table 4: Carrying capacity of vessels

	China	Denmark	Germany	Indonesia	Netherland	Spain	Sweden	Turkey	UK	USA
2018	4645	1942	3901	1440	2886	3219	1504	3075	3464	5326
2019	4664	1785	3855	1469	2990	3235	1505	3130	3383	5322
2020	4637	1787	4442	1509	2942	3258	1516	3034	3465	5347
2021	4401	1932	4497	1218	2819	3029	1579	2969	3114	5417
2022	4482	2007	4587	1168	2832	3100	1626	2784	3252	5345
2023	4561	1978	5015	1280	3151	3194	1709	2815	3467	5691

Results and Discussion

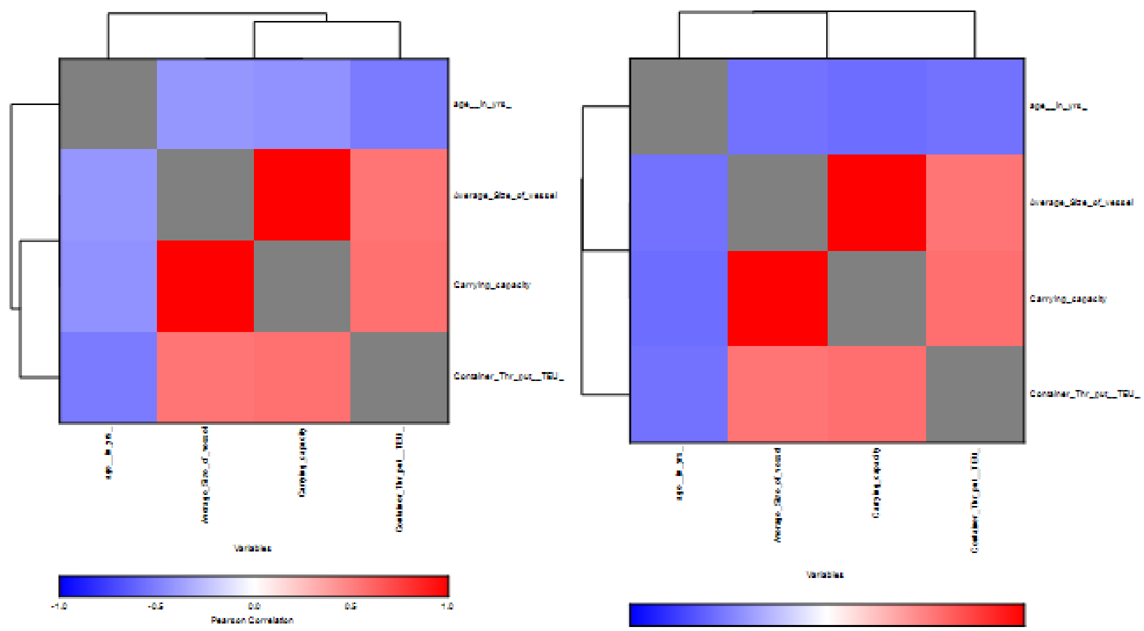
Table 5 and Plates 1a-1c present the Pearson correlation coefficients between container throughput (in TEUs) and three key vessel characteristics—age of vessels, average vessel size, and carrying capacity—from 2018 to 2023. The correlations provide insights into how ship attributes influence the volume of containerized cargo handled at ports during the study period. For instance, across all years, vessel age shows a consistently negative correlation with container throughput, ranging from –0.517 in 2018 to –0.780 in 2023. This indicates that as vessels become older, their efficiency and productivity in handling containerized cargo decline. The strength of the negative correlation increases over time, suggesting that the technological obsolescence of older ships may be more pronounced in recent years, possibly due to advancements in design, automation, and propulsion systems that newer vessels possess (Hilling, 1983; Notteboom & Vernimmen, 2009; Stopford, 2020; Ge et al., 2021). The implication is that fleet modernization is a significant determinant of port performance. Ports that accommodate younger and technologically advanced vessels tend to record higher throughput levels because such ships are faster, larger, and better optimized for container handling (Chaula and Luambano, 2025; Cullinane & Khanna, 2000). The trend also aligns with global shifts toward eco-efficient shipping, where newer vessels are not only larger but also more fuel-efficient and compliant with international environmental standards (UNCTAD, 2023). In respect of the average size of vessel and container throughput, the result showed moderately positive correlations between average vessel size and container throughput throughout the study period, ranging from 0.448 to 0.542. This implies that larger vessels generally contribute to higher container throughput at ports. However, a slight weakening trend is observed from 2018 to 2023. This could imply that despite the deployment of larger vessels, port infrastructure constraints such as limited berth depth, inadequate cranes, or congestion may limit the full benefits of increasing vessel size (Tongzon, 1995; Tongzon & Heng, 2005). This supports the arguments that most of the time, improving and developing the port infrastructures are required to enhance the port capacities throughput to cope with the increased demand on its resources and minimize congestion (Souf-Ajen et al. 2016; Wang and Wang 2019; Cong et al. 2020; Guo et al. 2021; Komaromi et al. 2022). Moreover, the marginally declining relationship could reflect diminishing returns to scale in vessel deployment. This means that as a port reaches a certain operational threshold, further increases in ship size may not translate into proportionally higher throughput unless corresponding investments in port handling capacity are made (Merk & Dang, 2012).

The correlations between carrying capacity and container throughput are also moderately positive, ranging between 0.469 and 0.564. The positive direction of association suggests that vessels with higher capacity generally facilitate greater cargo movement. However, similar to vessel size, the strength of this relationship declines slightly over time. This could indicate that operational bottlenecks such as yard space limitations, hinterland connectivity, or turnaround delays may moderate the benefits of increased carrying capacity (Munim & Schramm, 2018). This was clearly in relation to previous findings by Taudal and Sampson (2020) who submitted that landside congestion can impact the logistics operations of the entire supply chain resulting in time losses in queuing, increasing costs, fuel consumption, emissions and decreasing asset productivity.

Table 5: Pearson correlation

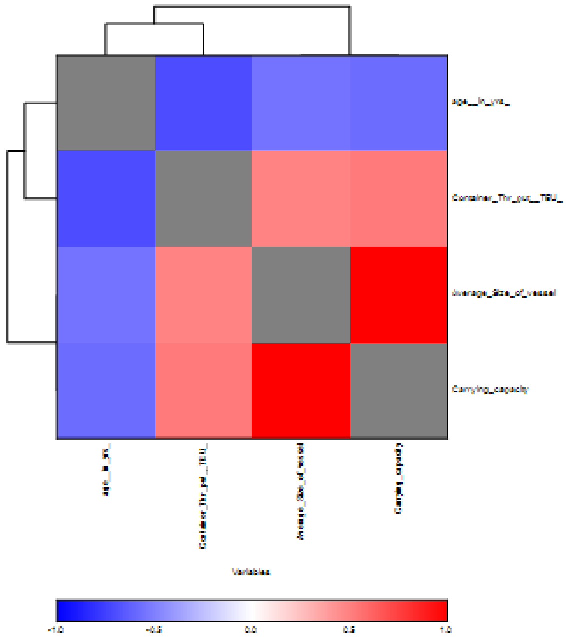
Year	Age of Vessels (yrs)	Average Size of Vessel	Carrying Capacity
2018	-0.517	0.542	0.560
2019	-0.554	0.540	0.564
2020	-0.696	0.486	0.517

2021	-0.579	0.466	0.488
2022	-0.669	0.467	0.490
2023	-0.780	0.448	0.469

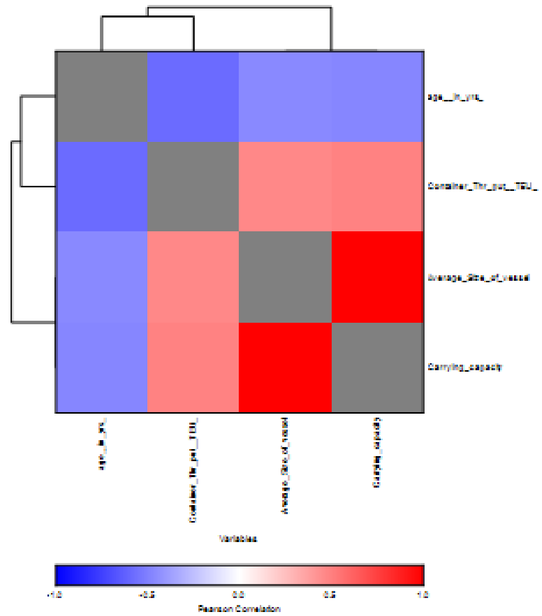


2018 **2019**

Plate 1a: Map of Pearson correlation between the variables

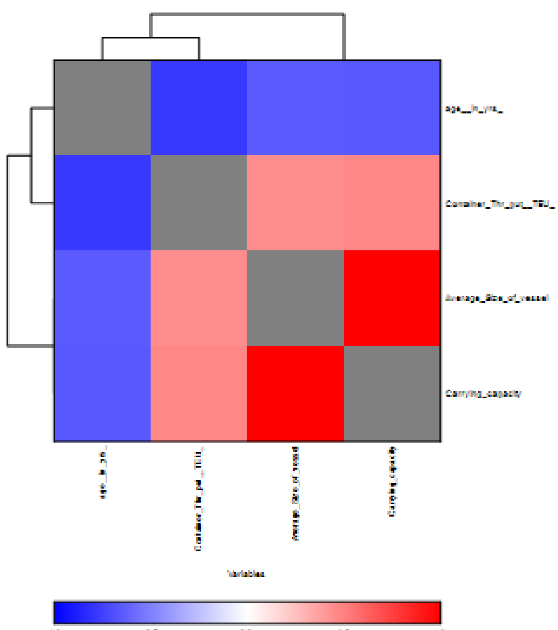


2020

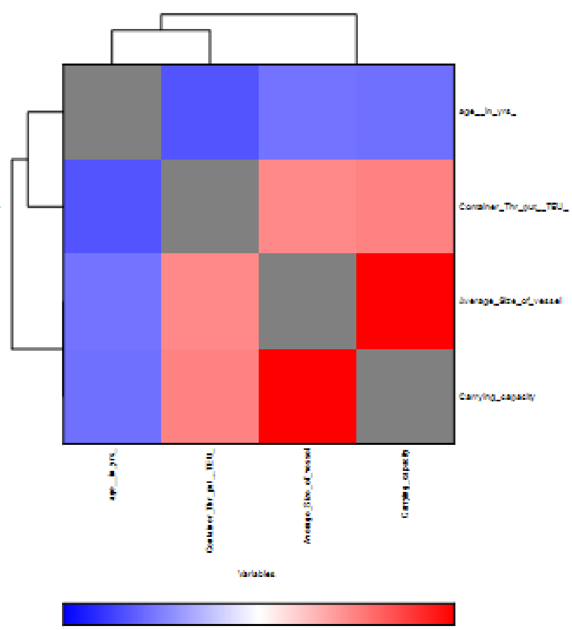


2021

Plate 1b: Map of Pearson correlation between the variables



2022



2023

Plate1c: Map of Pearson correlation between the variables

Conclusion and Policy Recommendations

The correlation analysis between vessel characteristics and container throughput from 2018 to 2023 provides valuable insights into the determinants of port efficiency. The results reveal that vessel age has a strong negative association with throughput, highlighting the critical role of modern fleets in enhancing operational performance. Vessel size and carrying capacity show moderate positive relationships, indicating that larger and more capacious vessels support throughput growth but require robust port infrastructure to fully realize their potential. The findings align with empirical evidence from global ports, which indicates that the technological modernization of fleets and supporting port infrastructure is strongly correlated with improved productivity and competitiveness (Cheon, Dowall, & Song, 2010; Wilmsmeier & Notteboom, 2011). Therefore, port authorities and policymakers must prioritize vessel renewal programs, green port initiatives, and infrastructure upgrades to enhance throughput capacity and maintain efficiency in containerized trade operations.

Conflicts of Interest

Author declares no conflicts of interest to report regarding the present study.

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