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Optimising Supply Chain Efficiency: Addressing the Ship

Queuing Problem at Dar es Salaam Port - Tanzania

by

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Acknowledgements

I have completed my thesis, marking the end of my academic journey at Erasmus University. As I graduate and transition into professional life, I find myself reflecting on the path that has led me to this point. My time in Rotterdam, a dynamic and ever-changing city, has fuelled my passion for maritime activities and global commerce.

This course has been a significant personal challenge and one of my most demanding projects. I am grateful for the support I have received along the way.

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Abstract

This study investigates the causes of and proposes solutions to ship queuing at Dar es Salaam Port, a critical gateway for international trade in East Africa. By employing a mixed-methods approach, combining quantitative and qualitative research techniques, this study provides a comprehensive understanding of the factors contributing to congestion and its implications for port stakeholders.

Quantitative analysis using the M/M/s queuing model reveals the significant impact of ship queuing on port performance, with high utilisation rates and prolonged waiting times. Qualitative research, through stakeholder interviews, sheds light on the challenges faced by shipping lines, cargo owners, and port authorities.

The study identifies infrastructure limitations, operational inefficiencies, and external factors as the drivers of congestion. To address these challenges, recommendations are proposed, including infrastructure expansion, operational improvements, technology adoption, and public-private partnerships.

By implementing these strategies, Dar es Salaam Port can enhance its efficiency, reduce congestion, and improve its competitiveness as a regional trade hub. This research contributes to understanding port congestion and provides valuable insights for policymakers and port operators in developing effective solutions.

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List of Abbreviations

CFSs	Container Freight Stations
DSM	Dar es Salaam
ICDs	Inland Container Depots
KOJ	Kurasini Oil Jet
KPIs	Key Performance Indicators
MEL	Maritime Economics and Logistics
MT	Metric Tons
PMF	Poisson Probability Mass Function
RoRo	Roll-on Roll-off
SPM	Single Point Mooring
PPPs	Public-private partnerships
TAFFA	Tanzania Freight Forwarders Association
TASAC	Tanzania Shipping Agencies Corporation
TEUs	Twenty Equivalent Units
TPA	Tanzania Ports Authority
UNCTAD	United Nations Trade and Development

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1. Introduction

1.1 Background and Problem Identification

Global trade relies heavily on efficient port operations. Ports act as critical gateways for the movement of goods, playing a vital role in international supply chains. According to the UN Trade and Development (UNCTAD, 2023) report, shipments by sea reached 11.0 billion tons worldwide in 2021. Delays at ports can have a significant ripple effect, disrupting supply chains, increasing transportation costs, and impacting global trade competitiveness.

Dar es Salaam Port, located in Tanzania's largest city, is a crucial seaport for East Africa, acting as the primary gateway for international trade for Tanzania and neighbouring landlocked countries such as Zambia, the Democratic Republic of Congo, Rwanda, Burundi, and Malawi. Positioned strategically on the Indian Ocean, the port facilitates connectivity between East Africa and global markets. It handles around 23 million tons of a wide range of cargo types, as addressed in TPA, (2023) statistical bulletin. It plays a vital role in regional economic growth and integration. Established in the early 1900s, the port has undergone significant development to accommodate increasing trade volumes and industrialisation. It features specialised terminals equipped with modern handling equipment and technology.

The port boasts a well-developed infrastructure with a total quay length exceeding 2,600 meters and eleven deep-water berths to accommodate large cargo ships. It features dedicated areas for handling various cargo types, including general cargo, containers, bulk liquids, and grains. General cargo berths are equipped to handle break bulk and dry bulk cargo, while a separate RoRo berth facilitates efficient vehicle movement. Container terminals handle the ever-increasing volume of containerised cargo. Additionally, the port features grain storage silos with a capacity of 30,000 tons.

The port utilises Inland Container Depots (ICDs) and Container Freight Stations (CFSs) for further cargo handling and storage. These facilities offer a combined capacity of 24,300 TEUs and 6,000 RoRo vehicles. Finally, the port caters to liquid bulk cargo with a Single Point Mooring (SPM) capable of handling 150,000 MT of crude and refined oil.

The Kurasini Oil Jetty (KOJ) provides additional refined product handling capabilities for handling tanker sizes up to 45,000 MT.

Despite this impressive infrastructure, the Port of Dar es Salaam, Tanzania, faces a persistent challenge of ship queuing. Ships are often forced to wait for extended periods before being able to berth and unload their cargo. This ship congestion not only disrupts the efficient flow of goods in and out of Tanzania but also impacts the broader East African region and the neighbouring landlocked countries of Zambia, the Democratic Republic of Congo (DRC), Burundi, Rwanda, Malawi, Uganda, and Zimbabwe, which relies on Dar es Salaam as a key trade hub as studied by Morisset et al., (2013).

Several factors contribute to ship queuing at Dar es Salaam Port, hindering its efficiency and impacting the Tanzanian economy. The port's current infrastructure may not be sufficient to handle the ever-increasing volume of cargo traffic, leading to congestion (Komaromi et al., 2022). Insufficient berth capacity to handle peak arrival periods, limited yard space for cargo storage, and outdated cargo handling equipment can all significantly contribute to delays (Bai et al., 2022). Inefficiencies within the port's operational procedures can worsen ship queuing. This can include factors like slow customs clearance procedures and complex documentation requirements, as studied by Bai et al., (2022) and inadequate cargo handling processes within the yard, leading to bottlenecks and delays in loading and unloading (Stopford, 2009). Poor communication and information sharing between different stakeholders involved in the port call (Yıldırım et al., 2020).

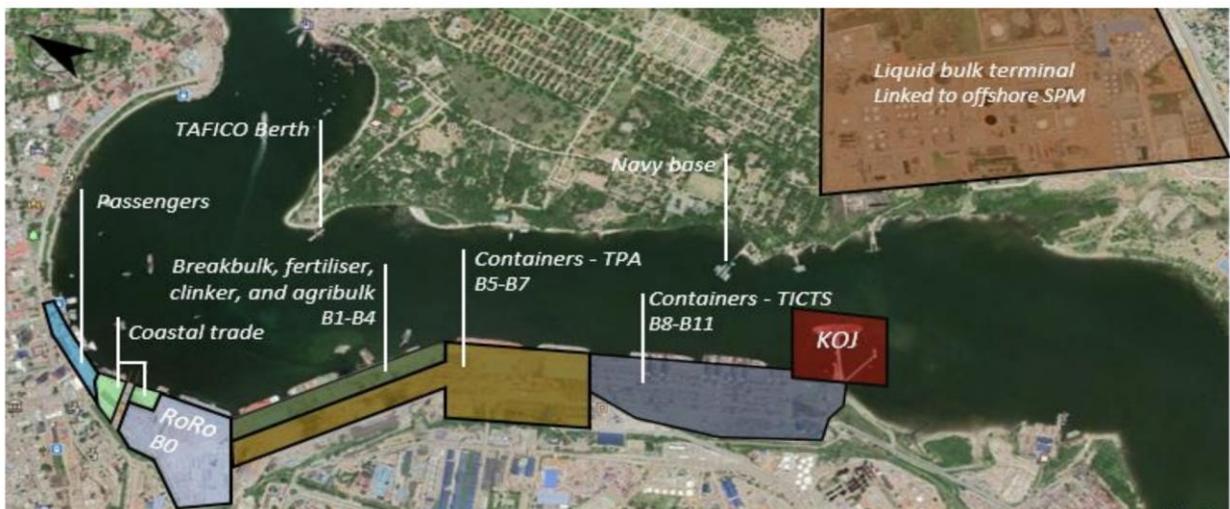


Figure 1: Layout of Dar es Salaam Port

Source: NPMP, 2021

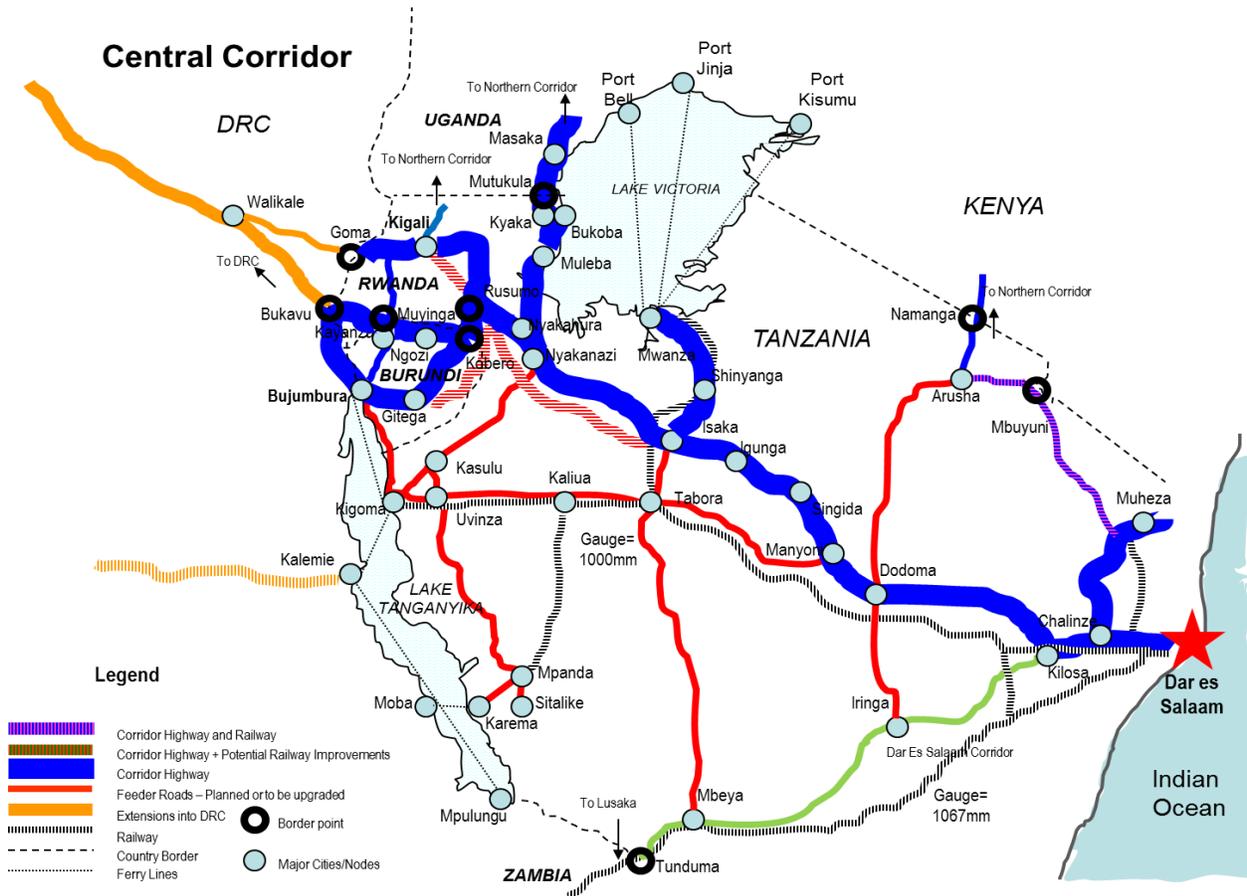


Figure 2: Hinterland Connectivity

Source: CCTTFA, 2024

1.2 Research Question and Sub-Questions

This research aims to identify causes and strategies for optimising ship queuing at Dar es Salaam Port, thereby improving overall supply chain efficiency.

To achieve this objective, the following sub-questions will be addressed:

- What factors contribute to ship queuing at Dar es Salaam Port?

- What are the potential benefits of reducing ship queuing times for port stakeholders, including shipping lines, cargo owners, and the Tanzanian economy?
- What specific recommendations can be made for implementing optimisation strategies at Dar es Salaam Port to mitigate ship congestion and improve efficiency?

1.3 Relevance of the Study

Optimising ship queuing at the Port of Dar es Salaam has the potential to generate far-reaching positive economic, logistical, and environmental benefits beyond Tanzania's borders. Dar es Salaam Port is a vital trade gateway for landlocked countries in East Africa. By addressing the queuing problem, Tanzania can significantly reduce transportation costs for its neighbours. This translates to increased trade volumes and economic activity throughout the region.

Currently, ship queuing disrupts supply chains in a domino effect. Manufacturers face delays in receiving raw materials, impacting production schedules. Consumers, in turn, experience shortages of finished goods. Optimising the port can lead to a significant improvement. Faster turnaround times for ships would mean more predictable delivery schedules, allowing businesses to plan their operations efficiently and, ultimately, keep customers satisfied. Jude Abraham, (2024) highlights the negative consequences of port congestion, including production slowdowns and inventory shortages. A streamlined Dar es Salaam Port would be a game-changer for regional supply chains.

Dar es Salaam Port faces competition from regional players like Mombasa in Kenya. Tanzania can position itself as a more attractive trade partner by minimising waiting times and optimising infrastructure capacity. By increasing efficiency, Dar es Salaam can attract more shipping lines, leading to increased trade volumes and diversification of goods.

With ships idling outside the port, the current situation contributes significantly to air and noise pollution. Optimising port operations can lead to a substantial reduction in harmful emissions. Kockelman, (2004) highlights that the costs of congestion extend beyond just travel delays. They include higher prices for goods and services due to

increased operational costs for commercial delivery services that face the same traffic delays as personal vehicles. This results in a broader economic impact that can be quantified in terms of increased prices for consumers. A more efficient port creates a good business environment, benefitting Tanzania and the entire region.

The learnings from optimising Dar es Salaam Port can be invaluable for other ports facing similar challenges. By sharing best practices and solutions, Tanzania can significantly contribute to a broader discussion on improving global maritime efficiency. This research has the potential to not just serve as a blueprint for ports worldwide, but to significantly impact and reshape the global maritime logistics landscape, fostering a more streamlined and sustainable global trade network.

In conclusion, addressing ship queuing at Dar es Salaam Port goes beyond improving Tanzania's local economy. It presents a unique opportunity to create a regional economic powerhouse, streamline supply chains, gain a competitive edge, promote environmental responsibility, and contribute valuable knowledge to the global maritime logistics landscape.

1.4 Research Design and Methodology

This research will employ a unique mixed-methods approach, a novel strategy in investigating the challenges and potential solutions related to ship queuing at Dar es Salaam Port. By combining quantitative and qualitative research techniques, we aim to gain a deeper understanding of the problem and develop effective strategies for improvement.

1.4.1 Quantitative Analysis:

The quantitative component of the research will utilise the M/M/s queuing model to analyse the port's performance. This model will be applied to existing data on ship arrival and service times at Dar es Salaam Port. By analysing the model's output, we can identify key performance indicators such as the average waiting time, queue length, and system utilisation.

1.4.2 Qualitative Analysis:

In addition to the quantitative analysis, we will conduct qualitative interviews with stakeholders involved in port operations, including port officials, shipping line representatives, and businesses affected by queuing delays. These interviews will provide valuable insights into the experiences and perspectives of those directly impacted by the problem.

1.4.3 Integration of Methods:

The quantitative and qualitative data will be integrated to provide a more comprehensive understanding of Dar es Salaam Port ship queuing. By triangulating the findings from both approaches, we can validate our conclusions and identify potential areas for improvement.

1.4.4 Expected Outcomes:

Through this mixed-methods approach, we anticipate gaining valuable insights into the causes, impacts, and potential solutions to ship queuing at Dar es Salaam Port. The findings will inform policy recommendations and contribute to developing strategies for improving the port's efficiency and competitiveness.

1.5 Structure of Thesis

Chapter 2 will review existing literature on port congestion and optimisation strategies. Chapter 3 will detail the research methodology used in this study. Chapter 4 will present the DSM case's results, analysis, and findings, including limitations and potential analytical generalisation/replicability. Chapter 5 will be the conclusions and policy recommendations.

2. Literature Review

2.1 Transport Infrastructure Congestion and its Impacts

Global trade relies heavily on efficient transport infrastructure networks. These networks, encompassing roads, railways, airports, and ports, play a vital role in moving goods and people around the world, as explained by Notteboom * & Rodrigue, (2005). However, a significant challenge plagues these systems: congestion.

Congestion occurs when the demand for a transport infrastructure network exceeds its capacity. This can manifest in various ways, such as traffic jams on roads as addressed by Transportation Research Board, (2016) report, delays and cancellations at airports as explained in Federal Aviation Administration, (2023) report, and long queues for ships waiting to berth at ports as indicated by Bai et al., (2022). Port congestion affects the entire supply chain, including shipping lines, cargo owners, and regional economies.

Congestion has a rippling effect, negatively impacting the economy and society. Increased transportation costs, delayed deliveries, and disrupted supply chains reduce productivity and economic growth as addressed by Jansson & Shneerson, (1982) and Stopford, (2009). Traffic congestion and idling vehicles contribute to air and noise pollution, harming the environment and public health (Stopford, 2009). Additionally, congestion can limit access to vital services and opportunities.

2.2 Focus on Ports

This thesis focuses explicitly on congestion within ports, which serve as critical gateways for international trade. Delays and inefficiencies at ports can have a particularly significant impact on Shipping Lines as Increased waiting times result in higher operating costs and schedule disruptions, as explained by Bai et al., (2022) studies. Delayed deliveries lead to lost sales and production slowdowns, as explained by Stopford, (2009). Congestion at a major port can hinder trade for a whole region, impacting economic growth and development (Rodrigue et al., 2013).

The Need for Solutions

Addressing congestion in transport infrastructure networks, particularly ports, is crucial for fostering a more efficient, sustainable, and resilient global trade system. This research aims to contribute to this effort by focusing on ship queuing at Dar es Salaam Port, Tanzania.

2.3 Theoretical Overview: Understanding Port Congestion in the Maritime Logistics

2.3.1 Conceptualizing the Maritime Logistics Chain

The maritime logistics chain is a complex system where goods travel from their origin to their destination through various stages. Inland transportation (pre-carriage) brings goods to the port, where customs clearance, documentation, and cargo preparation (port interface) take place. Ships then berth, load or unload cargo and store goods in the port's yard (port operations). After leaving the port, cargo is transported inland to its final destination (port hinterland interface) before being delivered to the recipient (onward carriage), as studied by Notteboom * & Rodrigue, (2005).

2.3.2 Theoretical Framework for Port Congestion

Congestion can occur at any stage of the maritime logistics chain, but ports are particularly vulnerable due to several factors. This framework highlights the key sources of congestion within ports:

2.3.3 Infrastructure Limitations

Infrastructure limitations pose significant challenges to the efficiency of Dar es Salaam Port. Insufficient berth capacity often results in queues of waiting ships during peak arrival periods, leading to delays and increased congestion (Komaromi et al., 2022). Limited yard space for containers and other cargo can create bottlenecks in the offloading and movement of goods, further exacerbating congestion, outdated cargo handling equipment, such as cranes and forklifts, can also contribute to inefficiencies, slowing down the loading and unloading processes and causing overall delays (Bai et al., 2022). These

infrastructure limitations collectively contribute to the challenges faced by Dar es Salaam Port in managing ship queues and ensuring smooth port operations.

2.3.4 Operational Inefficiencies

Operational inefficiencies might contribute to ship queuing at Dar es Salaam Port. Slow customs clearance procedures due to complex documentation requirements and bureaucratic red tape often result in delays (Yıldırım et al., 2020). Bai et al., (2022) stated that inefficient cargo handling processes, such as poorly designed yard layouts and slow cargo movement, can create bottlenecks and impede the smooth flow of goods. Additionally, gaps in information sharing between stakeholders, including port authorities, shipping lines, and customs officials, can hinder coordination and planning, leading to further delays and inefficiencies, as explained by Gu et al. (2017).

2.3.5 External Factors

External factors can also contribute to ship queuing at Dar es Salaam Port. Bad weather conditions, such as storms or fog, can disrupt port operations by slowing cargo handling and ship movements, as studied by Bai et al., (2022) and Stopford, (2009). Additionally, labour disputes, including strikes or work stoppages by port workers, can significantly impact port operations and lead to delays, as explained by Stopford, (2009). Moreover, fluctuations in trade can overwhelm existing port capacity, especially during peak periods or unexpected surges in arrivals or departures (Komaromi et al., 2022). These external factors can exacerbate congestion and further challenge the port's ability to handle ship queues effectively.

Visualising the Framework

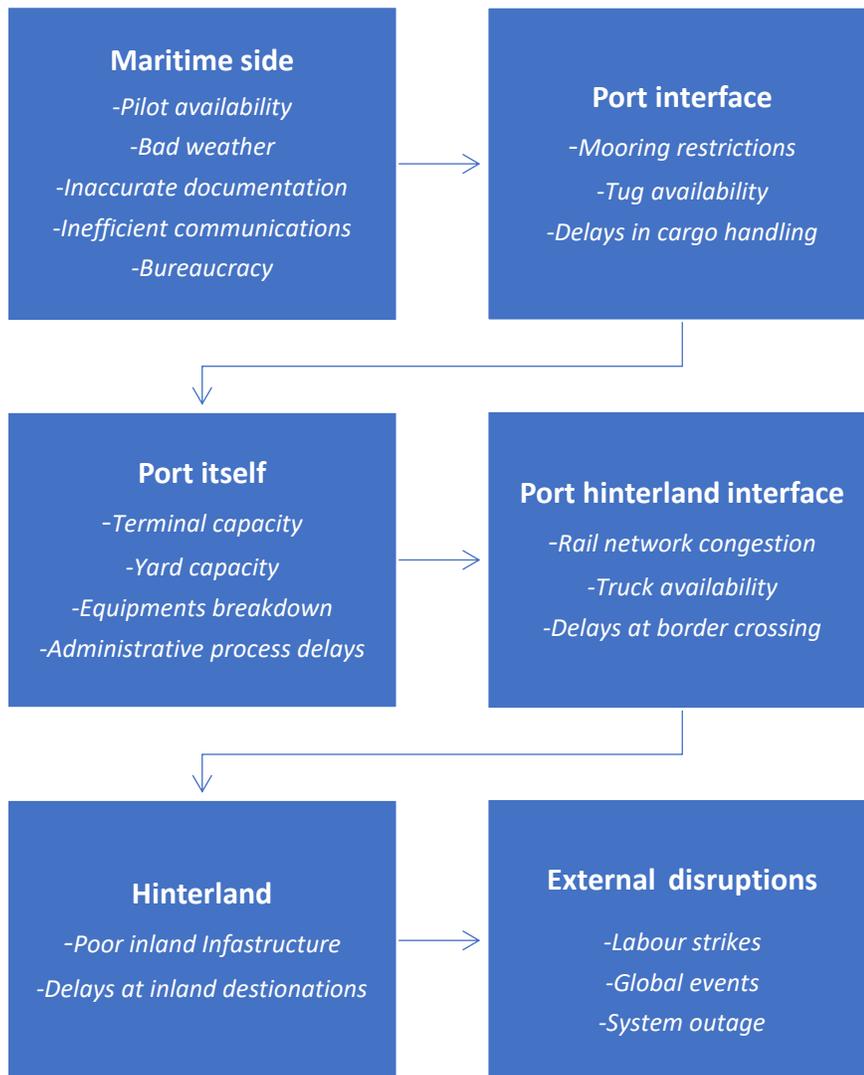


Figure 3: Conceptual framework of stages involved in Queuing process

Diagram Analysis

The diagram presents a comprehensive overview of the various stages involved in the ship queuing process at Dar es Salaam Port, categorising them into five main stages:

Maritime Side: This stage encompasses factors related to the ship and its immediate surroundings, such as pilot availability, weather conditions, and documentation issues.

Port Interface: This stage focuses on the initial interaction between the ship and the port, including tug availability, mooring restrictions, and delays in cargo handling.

Port Itself: This stage highlights the port's internal operations, such as terminal capacity limitations, yard congestion, equipment breakdowns, and administrative process delays.

Port-Hinterland Interface: This stage covers the connection between the port and the hinterland, including rail network congestion, truck availability, and delays at border crossings.

Hinterland: This final stage encompasses factors beyond the port's direct control, such as poor inland infrastructure and delays at inland destinations.

Understanding the Interplay

These factors often interact, creating a domino effect. For example, slow customs clearance can exacerbate limited yard space, leading to further delays and congestion.

This framework provides a theoretical foundation for understanding the various sources of congestion within ports. By analysing these factors in the context of Dar es Salaam Port, we can identify specific causes of ship queuing and develop targeted solutions for optimising port operations.

2.4 Literature Discussion: Unveiling the Bottlenecks - Causes and Impacts of Port Congestion

Port congestion, a persistent challenge plaguing maritime trade, has garnered significant attention in academic research. This section delves into the existing literature, dissecting the various causes identified by scholars and exploring the detrimental impacts of congestion on port operations and efficiency.

2.4.1 Causes of Port Congestion:

Infrastructure Limitations: Studies by Komaromi et al., (2022) and Bai et al., (2022) highlight the critical role of infrastructure in port efficiency. Insufficient berth capacity to handle peak arrival periods leads to ship queuing, as documented by Stopford (2009). Similarly, limited yard space for cargo storage, as mentioned by Bai et al. (2022), creates

bottlenecks in offloading and movement. Additionally, outdated cargo handling equipment can significantly slow loading and unloading processes, as studied by Bai et al., (2022).

Operational Inefficiencies: Research by Yıldırım et al., (2020) points to the detrimental effect of poor communication and information sharing between stakeholders within the port. This lack of coordination can lead to delays and inefficiencies. Furthermore, Stopford (2009) emphasises the negative impact of slow customs clearance procedures, often characterised by complex documentation requirements and bureaucratic hurdles. Additionally, poorly designed cargo handling processes within the yard, as identified by Bai et al., (2022), can create bottlenecks and disrupt smooth operations.

Juma Mwendapole & Zhihong, (2020) identified Hinterland Connections, deficiencies and inadequacies in port facilities, a shortage of know-how and skilled labourers, a deficiency in the Management Information System, inefficiency in supervision, motivation, and operation planning, and social, economic, and Political challenges as key causes of congestion at Dar es Salaam port. Nze & Onyemечи, (2018) conducted a study of five African ports found that congestion stemmed from weaknesses in planning, regulations, port capacity, inefficiency, or a combination of these factors.

External Factors: Unforeseen events outside the port's direct control can disrupt operations and lead to congestion. Bad weather conditions can impede safe navigation and slow down cargo handling processes, as noted by Bai et al., (2022) and Stopford, (2009). Labour disputes or strikes by port workers, as mentioned by Stopford, (2009) can cause significant disruptions. Fluctuations in global trade patterns, leading to sudden spikes in arrivals or departures, can overwhelm existing port capacity (Komaromi et al., 2022). Chen et al., (2023) claim port congestion is a growing problem due to larger ships, bad weather, and increased cargo volumes.

2.4.2 Impacts of Port Congestion:

The negative impacts of port congestion are far-reaching and can be categorised as follows:

Economic Impacts: Increased waiting times for ships translate into higher operating costs for shipping lines, as Bai et al. (2022) explain. Additionally, delays in cargo delivery

can lead to lost sales opportunities and production slowdowns for businesses, as Stopford (2009) studied. Jansson & Shneerson, (1982) studied the ripple effect, which disrupts entire supply chains, hindering economic growth.

Efficiency and Productivity: Congestion significantly reduces port efficiency and productivity. Studies by Komaromi et al., (2022) and Bai et al., (2022) highlight the negative impact on ship turnaround times and cargo throughput. Inefficient ports become bottlenecks within the maritime logistics chain, causing delays throughout the system.

Environmental Consequences: Increased idling times for ships and congestion on access roads contribute to air and noise pollution, as explained by Stopford, (2009). This environmental impact poses health risks and raises sustainability concerns for port operations.

2.4.3 Optimization Models and Strategies for Port Operations

Queuing Theory Applications: Queuing theory models can be used to analyse port capacity, predict waiting times, and optimise berth allocation strategies (Yıldırım et al., 2020).

Case Studies of Successful Port Optimization Initiatives: Singapore's Port Authority Terminals implemented automated container handling systems and streamlined customs clearance processes that reduced ship waiting times significantly (Lee-Partridge et al., 2000). A case study by Dekker et al., (2002) analyses the Port of Rotterdam's proactive approach to capacity expansion, infrastructure upgrades and stakeholder collaboration to maintain efficiency despite increasing cargo volumes.

Technological Advancements and Automation: Li et al., (2023) explore the role of emerging technologies in port optimisation, including Automated container handling systems (e.g., automated stacking cranes) that can improve cargo handling efficiency and yard operations. Terminal operating systems that provide real-time data and analytics to optimise ship scheduling, berth allocation, and resource utilisation.

Port congestion is a growing problem due to larger ships, lousy weather, and increased cargo volumes. This article proposes using data collected by Automatic Identification Systems (AIS) on ships to track their movements and identify congestion. By analysing these movements with data mining techniques, the system can calculate a congestion index, time costs due to delays, and the economic impact. This information can be used by ports, shipping companies, cargo owners, and agents to improve efficiency, reduce costs, and make better decisions throughout the supply chain (Chen et al., 2023).

Bigger cargo ships are causing problems on land at ports, especially in regional areas. This leads to traffic jams and other issues that cost money and hurt the environment. Traditionally, people have tried to fix this by improving ports' operations or getting shipping companies and ports to work together better. This new research suggests a different approach: looking at the whole supply chain and using integrated information systems to get everyone involved (like trucking companies and port operators) to work together. So far, it seems like this approach might be a good way to find solutions that reduce congestion and keep the supply chain running smoothly (Neagoe et al., 2017).

Category	Description	Examples from Literature
Causes of Congestion	Infrastructure Limitations	Insufficient berth capacity, limited yard space, outdated cargo handling equipment (Bai et al., 2022; Komaromi et al., 2022)
	Operational Inefficiencies	Slow customs clearance procedures, poor communication and information sharing, and inefficient cargo handling processes (Bai et al., 2022; Stopford, 2009; Yildirim et al., 2020; Oyatoye et al. (2011))
	External Factors	Bad weather conditions, labour disputes, fluctuations in trade patterns (Bai et al., 2022; Stopford, 2009)
Impacts of Congestion	Economic Impacts	Increased operating costs for shipping lines, lost sales opportunities and production slowdowns for businesses hindered economic growth (Bai et al., 2022; Jansson & Shneerson, 1982; Stopford, 2009)
	Efficiency and Productivity	Reduced ship turnaround times decreased cargo throughput (Bai et al., 2022; Komaromi et al., 2022)
	Environmental Consequences	Increased air and noise pollution (Stopford, 2009)
Proposed Solutions	Infrastructure Development	Expanding berth capacity, optimising yard space, modernising equipment (Notteboom & Rodrigue, 2005; Stopford, 2009; Wang & Linn, 2013)
	Operational Improvements	Streamlining customs clearance, enhancing information sharing, and improving cargo handling processes (Gu et al., 2017; Sun & Wang, 2015; Wang & Linn, 2013; Neagoe et al., 2017, Chen et al., 2023)
	Technological Advancements	Implementing smart port technologies (automated vehicles, blockchain, AI) (Wang & Notteboom, 2017)
	Policy and Regulatory Reforms	Trade facilitation measures, public-private partnerships (PPPs) (Rodrigue et al., 2013; Notteboom & Rodrigue, 2005)
Impact of Solutions	Reduced Queuing Times & Improved Efficiency	Increased capacity, faster cargo handling, improved coordination, reduced delays
	Long-Term Sustainability	Balancing initial investment with long-term benefits

Table 1: Causes, Impacts, and Solutions of Port Congestion

Limitations of the Methods used

Most of the studies rely on Automatic Identification System (AIS) data for monitoring ship operations (Chen et al., 2023). While AIS data is valuable, it may not capture all relevant operational details, such as specific delays caused by external factors like weather or labour issues. This limitation can affect the accuracy of the congestion evaluation.

Bai et al., (2022) is identifying port congestion's impact on maritime logistics using real-time data. They propose the DBSCAN algorithm for congestion analysis and economic implications assessment. This method is suitable for tramp ships of the same size only.

The paper "Port Congestion Chaos and Our Remedy" by Singer et al., (2023) presents a thorough analysis of port congestion issues, but it also has several limitations that should be acknowledged: The research relies heavily on secondary data collected from various sources, including news articles and business reports. This dependency may introduce biases or inaccuracies, as the quality and reliability of these sources can vary significantly.

Oyatoye et al., (2011) used a queuing model to analyse congestion at Tin Can Island Port in Nigeria and to predict ship arrival and service rates. The study found that the number of berths at Nigerian ports is sufficient for ship traffic, but identified other factors contributing to port congestion through stakeholder interviews. The study also proposed policy recommendations to improve ships' cost-effectiveness, attractiveness, and turnaround time at Nigerian ports. The method's limitations include data dependency and simplified assumptions of the model that highlight the need for a more nuanced approach that considers various real-world complexities and operational factors.

2.5 Summary

This chapter reviewed existing research on port congestion, highlighting common causes like infrastructure limitations, inefficient operations, and external factors. However, a gap exists in understanding these challenges, specifically within the context of Dar es Salaam Port.

Analysing the ship and cargo handling continuum, we identified under-researched areas that could offer valuable insights. The maritime side, often overlooked, might contribute to delays through factors like bad weather or shipping line scheduling inefficiencies. Similarly, the connection between the port and its hinterland deserves exploration. Bottlenecks in inland transport or underdeveloped infrastructure beyond the port itself could be causing delays.

This research aims to address these knowledge gaps by delving deeper into these under-researched stages of the ship handling continuum. By comprehensively understanding ship queuing at Dar es Salaam Port, we can develop targeted solutions to optimise operations across the entire cargo flow. This will ultimately lead to a more efficient and competitive port.

3. Research Methodology

This chapter outlines the methodological approach employed to study ship queuing at Dar es Salaam Port, Tanzania. It will explain why DSM Port serves as a relevant and interesting case study, detail the research methods used, discuss the chosen data sources, and address potential limitations of the methodology.

Why Dar es Salaam Port (DSM) is a Relevant and Interesting Case Study

Dar es Salaam Port is a compelling case study for investigating ship queuing due to several key factors. DSM is the main gateway for Tanzania's international trade, handling a significant portion of the country's imports and exports (TPA, 2023) statistical bulletin. Additionally, it serves as a crucial link for landlocked countries in East and Central Africa, connecting them to global markets (World Bank, 2020). This strategic location translates to significant cargo volumes, making the port susceptible to congestion (Komaromi et al., 2022).

East African economies are experiencing steady growth, leading to a rise in maritime trade, as studied by the World Bank (2020). This increasing demand for port services can strain existing infrastructure and lead to bottlenecks, as explained by Stopford, (2009). Studying how DSM manages this growth in relation to queuing times can provide valuable insights.

Studies indicate that Dar es Salaam Port has faced challenges with ship queuing in recent years, as highlighted by Maneno (2019). Investigating the specific causes of these issues can contribute to a broader understanding of port congestion and identify potential solutions applicable to other ports as Rodrigue et al., (2013) addresses.

While DSM boasts a well-developed infrastructure, some limitations can contribute to congestion, as the TPA (2023) statistical bulletin addresses. These include a potentially insufficient number of berths to handle peak arrival times, limited yard space for storing cargo as studied by Bai et al., (2022), and outdated cargo handling equipment, as explained by Stopford, (2009). Studying how these limitations impact queuing times can inform potential infrastructure improvement strategies.

DSM handles various cargo types, including general cargo, containers, bulk liquids, and grains as indicated in TPA, (2023) statistical bulletin. This diversity presents unique challenges in terms of storage and handling, potentially leading to congestion if not

managed effectively (Notteboom * & Rodrigue, 2005). Analysing how DSM handles different cargo types can reveal best practices for optimising queuing times across various cargo categories.

By investigating ship queuing at Dar es Salaam Port, this research can contribute valuable insights applicable to a broader range of ports facing similar challenges. Understanding the factors influencing congestion at DSM Port can inform targeted solutions to improve port efficiency and reduce queuing times, benefiting the East African region.

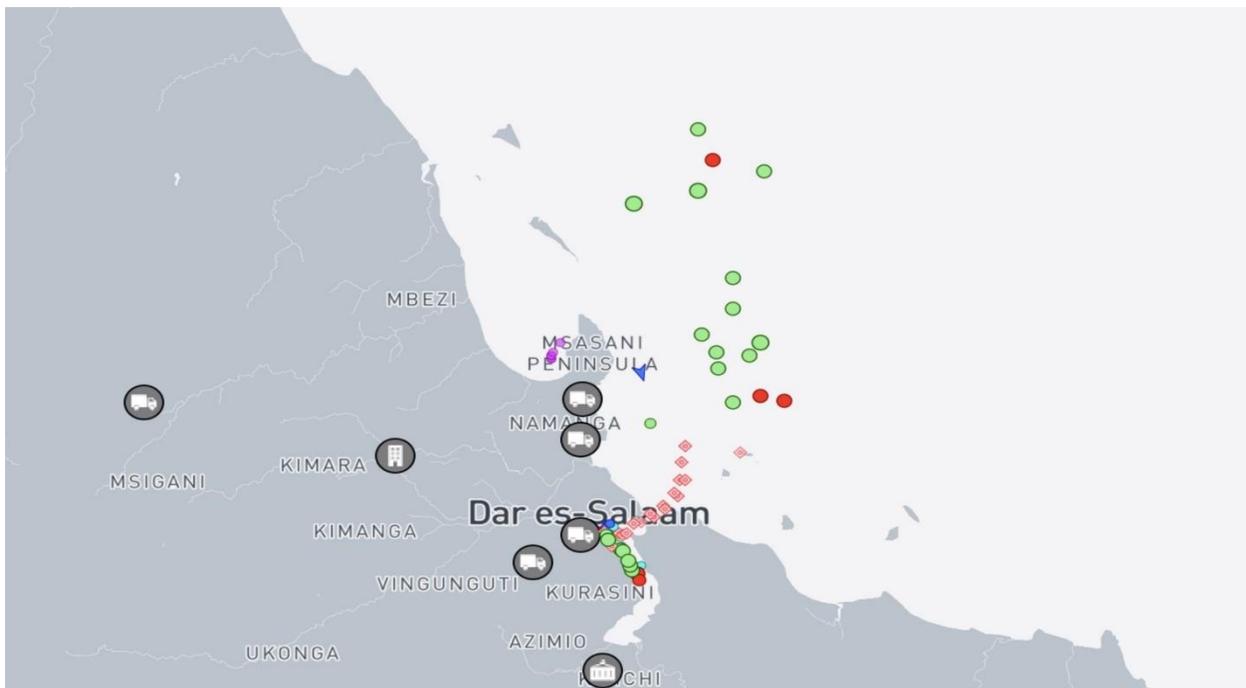


Figure 4: Ship Queuing at Dar es Salaam Port

3.1 Methodology Details

This research will employ a mixed-methods approach, combining quantitative data analysis with qualitative interviews to comprehensively understand ship queuing at Dar es Salaam Port (Creswell & Plano Clark, 2018).

3.1.1 Quantitative Data Analysis:

We will collect data on ship arrivals, departures, waiting times, cargo volumes, and throughput from DSM port authorities. This data will span several years to capture seasonal variations and identify trends in queuing times.

We will obtain trade data from relevant government agencies or international trade organisations (e.g., World Trade Organization) to understand import and export volumes moving through DSM. This data will help assess the relationship between trade fluctuations and queuing times.

3.1.1.1 Port Authority Data:

Quantitative data was accurately collected from the Tanzania Ports Authority to fulfil the model's specific requirements and gain insights into the various factors influencing trade patterns in Dar es Salaam. The data collection involved thoroughly examining and analysing pertinent information to ensure comprehensive and accurate results.

Ship waiting time

The average waiting time for all ships is 12.9 days. RoRo car carriers stand out with an impressive average waiting time of 1.9 days, while container ships face the longest waiting time at 13.9 days. The distribution of ship types is as follows: 42% for container ships, 11% for dry bulk, 15% for break bulk, 14% for RoRo, and 18% for liquid bulk ships, as shown in Figure 5. The long waiting time indicates a significant queue at Dar es Salaam Port.

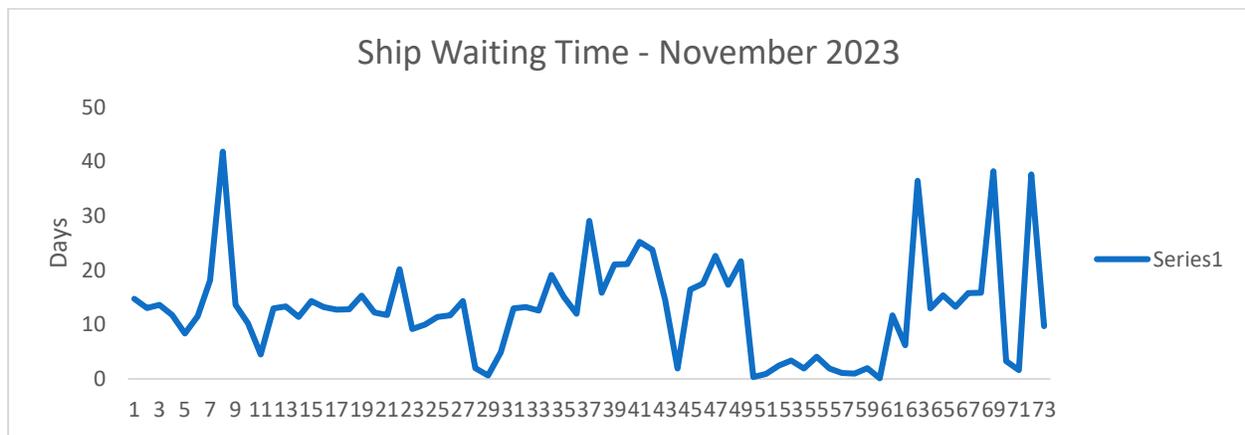


Figure 5: Ship waiting time for November 2023.

Ship Arrival

Based on the data analysis, the average arrival rate for all categories of ships is 2.8 days per day. Figure 6 visually represents the trend, depicting the significant fluctuations and unpredictability in the daily arrival pattern.

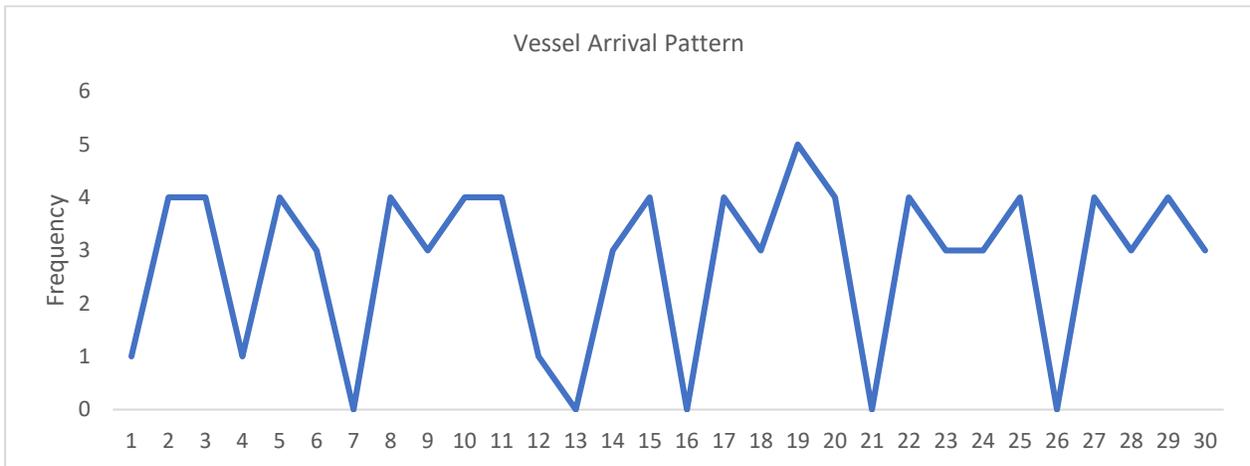


Figure 6: Ship Arrival for November 2023

Ship Service Time

The data show that the average service time for all ships is 4.3 days. Dry bulk ships have the highest service time, followed by breakbulk ships, as depicted in Figure 7. This data reveals that RoRo car carrier ships tend to have a relatively shorter service time

than other types of ships.

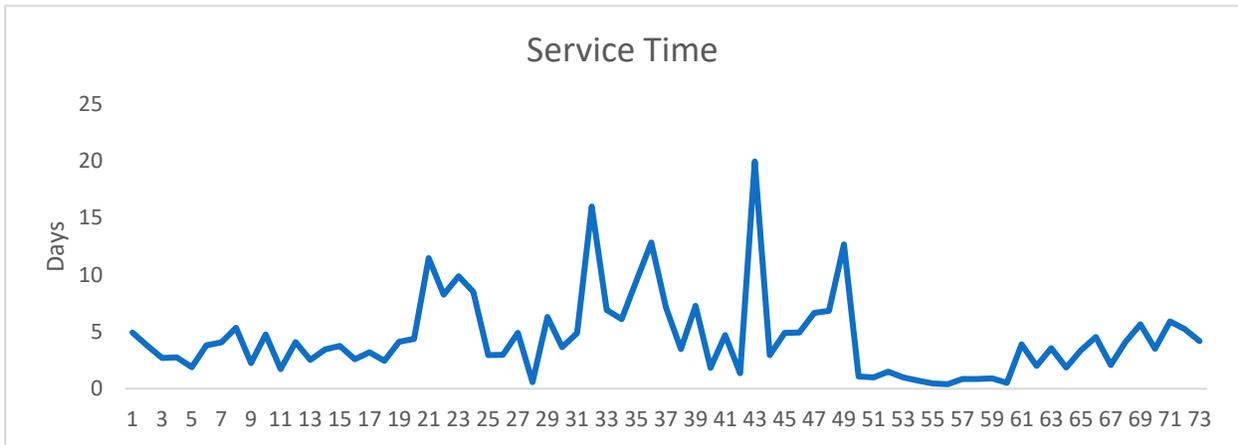


Figure 7: Ship Service Time for November 2023

DSM Port Cargo throughput

Over the last five years, the yearly cargo throughput has consistently increased by 8.2%. This upward trend was observed annually, except in 2020, when the throughput unexpectedly declined.

Cargo Type	2018	2019	2020	2021	2022	2023
Import (M)						
Dry Bulk	1,971,617	1,855,201	2,459,713	1,968,222	2,485,040	3,530,968
Break Bulk	1,170,044	1,193,516	1,066,048	1,994,921	2,342,846	2,186,545
Liquid Bulk	5,483,270	5,715,071	5,202,913	5,703,202	6,180,874	7,206,221
Containerised	4,056,881	4,363,373	4,254,867	4,253,831	5,173,173	5,801,612
Total Imports	12,681,812	13,127,161	12,983,541	13,920,176	16,181,933	18,725,346
Export (X)						
Break Bulk	289,496	334,790	332,027	359,691	535,475	693,058
Liquid Bulk	99,069	100,748	80,790	68,789	34,488	53,038
Containerised	2,063,210	2,373,728	2,441,677	2,581,873	3,218,220	3,424,862
Total Export	2,451,775	2,809,266	2,854,494	3,010,353	3,788,183	4,170,958
Total (M+X)	15,133,587	15,936,427	15,838,035	16,930,529	19,970,116	22,896,304
Transhipment	528,277	181,371	40,851	6,878	9,472	59,774
Restow	31,155	20,488	26,568	88,045	41,081	20,586
Transhipment + Restow	559,432	201,859	67,419	94,923	50,553	80,360

Grand Total	15,693,019	16,138,286	15,905,454	17,025,452	20,020,669	22,976,664
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Table 2: DSM Port Cargo Throughput Data

DSM Port Container Throughput (TEUs)

The annual growth of containerised cargo over the past five years has averaged 6.7%. This growth has been consistent and reliable, except for a decline in 2020, during which the number of containers handled decreased.

TEUs		2018	2019	2020	2021	2022	2023
Import	Full	335,037	358,743	347,888	379,967	432,095	487,356
	Empties	3,224	3,201	3,419	5,826	11,044	19,034
	Total	338,261	361,944	351,307	385,793	443,139	506,390
Export	Full	118,884	138,765	148,800	156,396	196,481	215,541
	Empties	202,188	209,454	214,714	207,297	241,326	253,612
	Total	321,072	348,219	363,514	363,693	437,807	469,153
Subtotal	Full	453,921	497,508	496,688	536,363	628,576	702,897
	Empties	205,412	212,655	218,133	213,123	252,370	272,646
	Total	659,333	710,163	714,821	749,486	880,946	975,543
Transhipment	In	23,334	6,833	1,742	362	392	3,106
	Out	23,890	7,861	1,763	148	200	2,072
	Total	47,224	14,694	3,505	510	592	5,178
Restow		3,663	1,984	2,540	9,906	3,940	2,086
Total		710,220	726,841	720,866	759,902	885,478	982,807

Table 3: DSM Port Container Throughput (TEUs)

Port infrastructure capacity information (berth availability, yard space limitations).

Dar es Salaam Port, a primary gateway for international trade in East Africa, offers a range of facilities to accommodate various cargo types and ship sizes. Key facilities include deep-water berths for large ships, bulk oil jetties, a grain silo, and extensive storage areas. The port's infrastructure enables efficient handling of containers, bulk cargo, and other goods.

The port also has dedicated facilities for lighterage and dhow ships, catering to smaller ships and traditional modes of transportation. Additionally, the port features transit depots

for temporary storage and cargo handling. These facilities collectively contribute to the port's capacity and efficiency in serving the region's trade needs.

S/n	Facility	Dar es Salaam	Tanga	Mtwara
1.	Deep Water Berths No.	13	2	3
2.	Total Length (m)	2,600	450	685
3.	Depth Dredged (m)	10.5 - 14.5	13	9.8 - 13
4.	Bulk Oil Jetty (Tanker Berth) No.	2	0	0
5.	Single Buoy Mooring (SBM) No.	1	0	0
6.	Grain Silo (30,000 Tons)	1	0	0
7.	Lighterage & Dhow Wharves No.	1	0	1
8.	Lighterage & Dhow Wharves Length	185	0	12.3
9.	Sheds (m ²)	23,219	13,400	15,000
10.	Paved Open Storage (m ²)	279,613	29,300	124,100
11.	Transit Depots	-	-	-
	Ubungo (m ²)	29,745	0	0
	Kurasini (m ²)	40,385	0	0

Table 4: Port Infrastructure Capacity Information

3.1.2 Qualitative Interviews:

Data will be collected through **semi-structured interviews** with key stakeholders involved in port operations at DSM. These may include port authority representatives, terminal operators, shipping line agents, and customs officials, as addressed by Bai et al., (2022). The interviews will explore their perspectives on the causes of ship queuing, current challenges, and potential solutions, as studied by Yıldırım et al., (2020).

Data Sources and Potential Limitations:

Access to comprehensive and high-quality data from port authorities may be limited due to confidentiality concerns. We may need to employ data cleaning and validation techniques to ensure the accuracy of the data used in the analysis.

When interpreting qualitative data, the interview participants' time constraints and potential biases in their perspectives need to be considered.

Addressing Limitations:

We will explore publicly available data sources (e.g., port statistics reports) and triangulate findings from interviews with relevant experts to mitigate data access limitations. We will conduct pilot interviews to refine interview questions and ensure they capture diverse perspectives while minimising bias.

This research strives to gather robust data and paint a clear picture of the causes and consequences of ship queuing at Dar es Salaam Port by employing a mixed-methods approach and addressing potential limitations. The findings will contribute to knowledge in the field and offer valuable insights for optimising port operations in DSM and other ports facing similar challenges.

3.2 Data Analysis Model

A statistical queuing model will be employed to analyse the quantitative data on ship arrivals, waiting times, and service times (cargo loading/unloading). This model will help us understand the relationship between these factors and predict potential queuing behaviour under different scenarios. For example, we can use the model to simulate the impact of adding new berths or improving cargo handling efficiency on queuing times.

Queuing theory is recognised as a vital analytical tool for addressing congestion issues, allowing for estimating key parameters such as the average waiting time of ships, queue length, the average number of ships in the port, and the average berth utilisation factor. According to Jansson and Shneerson (1982), ship arrivals at a port are primarily random, leading to fluctuating demands for port resources in the short term. This variability means that the supply of port services, or the service time of ships, is also highly variable. Therefore, to determine the optimal port capacity, it is crucial to analyse the trade-off between maximising port facility utilisation and minimising the likelihood of delays for port users.

3.2.1 Data Analysis Steps:

Descriptive Statistics: The collected data will be analysed to understand its basic characteristics. Calculate measures like mean, standard deviation, and percentiles for ship arrival times, waiting times, and service times.

Distribution Analysis: The next step is identifying the probability distributions that best fit the observed data patterns. Common distributions used in queuing models include Poisson (for random arrivals) and exponential (for service times with no fixed duration). Goodness-of-fit tests will be employed to assess how well these distributions fit the data.

Model Selection: Based on the findings from steps 1 and 2, select the most appropriate queuing model. Here are some potential candidates, as discussed earlier:

M/M/1: A basic model assuming random arrivals (Poisson distribution) with an exponential service time distribution and a single server (berth).

M/M/s: This model allows for multiple servers (s, representing the number of available berths).

M/G/1: This model retains the random arrival assumption but allows for a more general service time distribution (G).

M/G/s: This model considers multiple servers and a general service time distribution.

The chosen model will analyse the collected data and estimate key performance measures, such as average queue length, average waiting time, and server utilisation. These metrics will provide insights into the queuing behaviour at Dar es Salaam Port.

Limitations:

- Queuing models are simplifications of real-world systems and may not capture all complexities of port operations.
- Data availability and quality can impact the accuracy of model results.

3.3 Qualitative Analysis

We will gather data through a combination of closed- and open-ended questionnaires administered to 38 stakeholders. To ensure a representative sample, we will use random sampling for the questionnaires and purposive sampling for the interviews. The primary objective is to understand the queuing situation at Dar es Salaam port comprehensively.

3.4 Conclusion:

Combining quantitative and qualitative methods will provide a comprehensive understanding of ship queuing at Dar es Salaam Port. Queuing models will help analyse the impact of various factors on queuing behaviour and inform potential solutions for improving port efficiency.

4. Results, Analysis, and Findings

4.1 Quantitative Analysis: M/M/s Model Results

In this section, the quantitative analysis focuses on evaluating the performance of the Dar es Salaam Port using the M/M/s queuing model. The M/M/s model is a standard queuing theory model used to analyse systems with multiple servers, where arrivals and service times are assumed to follow exponential distributions.

4.1.1 Distribution Analysis

Applying the Chi-Square Goodness-of-Fit Test to Dar es Salaam Port Data

The distribution pattern of ship arrivals has been analysed to determine whether the data collected suits the queuing methodology. The chi-square fit test is applied to check the Poisson distribution for ship arrivals. The null hypothesis is that the actual frequency distribution of the daily number of ships fits the Poisson distribution.

Data Preparation:

We conducted a comprehensive data collection process to gather information on ships' arrivals and service times over a specific period. Subsequently, we organised the gathered data into daily intervals for arrivals and service times.

Calculation of Expected Frequencies:

Arrival times: Using the estimated arrival rate (λ), we have to calculate the expected number of arrivals in each interval using the Poisson probability mass function using the formula below:

$$P(X = k) = (\lambda^k * e^{(-\lambda)}) / k!$$

Where: $P(X = k)$ is the probability of k arrivals in an interval

λ is the arrival rate

k is the number of arrivals

e is Euler's number (approximately 2.71828)

$k!$ is the factorial of k

Number of Arrivals	Probability of arrival
0	0.061
1	0.170
2	0.238
3	0.223
4	0.156
5	0.087
6	0.041
7	0.016
8	0.006
9	0.002
10	0.001

Table 5: Poisson probability mass function for ship arrivals

Interpretation:

The most likely number of arrivals per day is 2, with a probability of 23.8%. The probability of very low or very high arrivals is relatively low. For example, the probability of 0 arrivals is only 6.1%, and the probability of 10 or more arrivals is less than 1%. The average number of arrivals per day is 2.8, as expected from the Poisson distribution, as depicted in Figure 8.

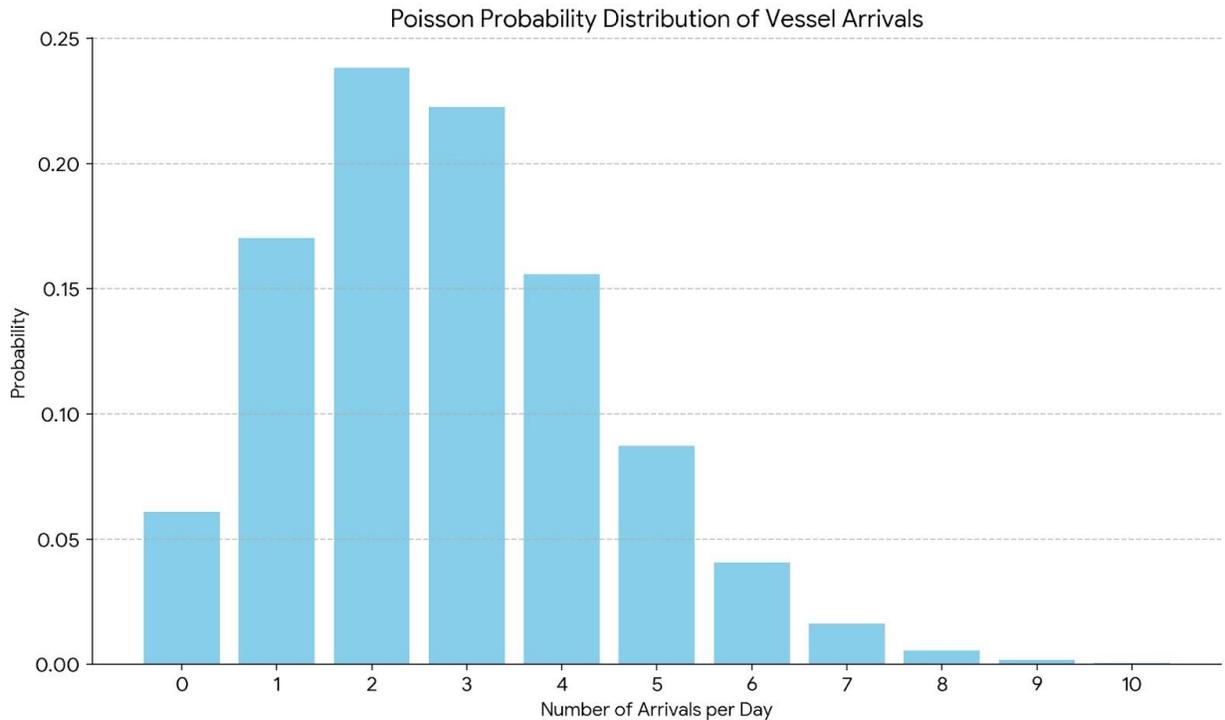


Figure 8: Poisson Probability Distribution of Ship Arrivals

Service times: Using the estimated service rate (μ), calculate the expected number of ships served within each interval using the exponential probability density function using the formula below:

$$f(x) = \mu * e^{(-\mu x)}$$

Where: $f(x)$ is the probability density of a service time x
 μ is the service rate
 e is Euler's number

Exponential probability density function for Service Time at Dar es Salaam Port ($\mu = 0.23$ ships/berth)

Here is a table showing the probability density $f(x)$ for service times x ranging from 1 to 10 hours, using the exponential distribution with a service rate of 0.23 ships per berth:

Service Time (x) in Hours	Probability Density f(x)
1	0.1845
2	0.1479
3	0.1153

4	0.0899
5	0.0701
6	0.0547
7	0.0428
8	0.0335
9	0.0263
10	0.0207

Table 6: Exponential probability density function for service time

This value represents the likelihood of the service time being exactly (x) hours, calculated using the exponential distribution formula. The probability density decreases as the service time increases, which is typical for an exponential distribution.

Calculate the Chi-Square Statistic:

Use the chi-square test formula:

$$\chi^2 = \sum [(O_i - E_i)^2 / E_i]$$

Where: χ^2 is the chi-square statistic
 O_i is the observed frequency for interval i
 E_i is the expected frequency for interval i
 Σ is the summation over all intervals

Determine Degrees of Freedom:

Calculate the degrees of freedom (df) as:

$$df = k - 1 - p$$

Where: k is the number of intervals
p is the number of estimated parameters (in this case, 2: λ and μ)

Find the Critical Value:

Using a chi-square distribution table, we will find the critical value for a chosen significance level (e.g., 0.05) and the calculated degrees of freedom.

Compare Calculated and Critical Values:

If the calculated chi-square statistic is greater than the critical value, we reject the null hypothesis (i.e., the data does not fit the distribution). If the calculated chi-square statistic

is less than or equal to the critical value, we fail to reject the null hypothesis (i.e., the data fits the distribution).

Analysing the Observed Arrival Data with the Chi-Square Test

Data Analysis:

Based on the collected data, I've extracted the following arrival data:

Calculations:

Total arrivals: 84

Average arrivals per day: $84 / 30 = 2.8$

Expected frequencies: Using the Poisson PMF with $\lambda = 2.8$, to calculate the expected number of arrivals for each day.

Chi-square statistic: Using the formula:

$$\chi^2 = \sum [(O_i - E_i)^2 / E_i]$$

Calculating the Chi-Square Statistic for Ship Arrivals

Given:

Observed arrival data (from the previous prompt) and Expected arrivals calculated using the Poisson distribution with $\lambda = 2.8$

Steps:

1. Calculate the difference between observed and expected frequencies:
2. Sum the $(O - E)^2 / E$ values:

$$\sum [(O_i - E_i)^2 / E_i] = 3.304 + 0.097 + 0.097 + \dots + 2.023 = 38.477$$

Therefore, the calculated chi-square statistic is 38.477.

Day	Observed (O)	Expected (E)	O - E	(O - E) ²	(O - E) ² / E
1	1	5.108	-4.108	16.876	3.304
2	4	4.672	-0.672	0.452	0.097
3	4	4.672	-0.672	0.452	0.097
4	1	5.108	-4.108	16.876	3.304
5	4	4.672	-0.672	0.452	0.097
6	3	6.675	-3.675	13.506	2.023
7	0	1.824	-1.824	3.327	1.824
8	4	4.672	-0.672	0.452	0.097
9	3	6.675	-3.675	13.506	2.023

10	4	4.672	-0.672	0.452	0.097
11	4	4.672	-0.672	0.452	0.097
12	1	5.108	-4.108	16.876	3.304
13	0	1.824	-1.824	3.327	1.824
14	3	6.675	-3.675	13.506	2.023
15	4	4.672	-0.672	0.452	0.097
16	0	1.824	-1.824	3.327	1.824
17	4	4.672	-0.672	0.452	0.097
18	3	6.675	-3.675	13.506	2.023
19	5	2.616	2.384	5.683	2.173
20	4	4.672	-0.672	0.452	0.097
21	0	1.824	-1.824	3.327	1.824
22	4	4.672	-0.672	0.452	0.097
23	3	6.675	-3.675	13.506	2.023
24	3	6.675	-3.675	13.506	2.023
25	4	4.672	-0.672	0.452	0.097
26	0	1.824	-1.824	3.327	1.824
27	4	4.672	-0.672	0.452	0.097
28	3	6.675	-3.675	13.506	2.023
29	4	4.672	-0.672	0.452	0.097
30	3	6.675	-3.675	13.506	2.023
Sum	84				38.647

Table 7: Chi-square statistic

Degrees of Freedom: $df = 30 - 1 - 1 = 28$

Critical Value: The critical value for a significance level of 0.05 and $df = 28$ is approximately 41.337.

Interpretation:

Since the calculated chi-square statistic (38.647) is less than the critical value (41.337), we **fail to reject the null hypothesis**. This suggests that the observed arrival data fits the Poisson distribution, supporting the assumption of random arrivals in the M/M/s model. The analysis indicates that the Poisson distribution is a reasonable model for describing

the arrival process of ships at Dar es Salaam Port. This supports the use of the M/M/s queuing model to analyse the port's performance.

4.1.2 Running the M/M/s Model

The M/M/s model is a well-established tool for analysing queuing systems. By applying this model to the data from Dar es Salaam Port, we aimed to gain insights into the port's utilisation, waiting times and length, and the impact of various factors on congestion.

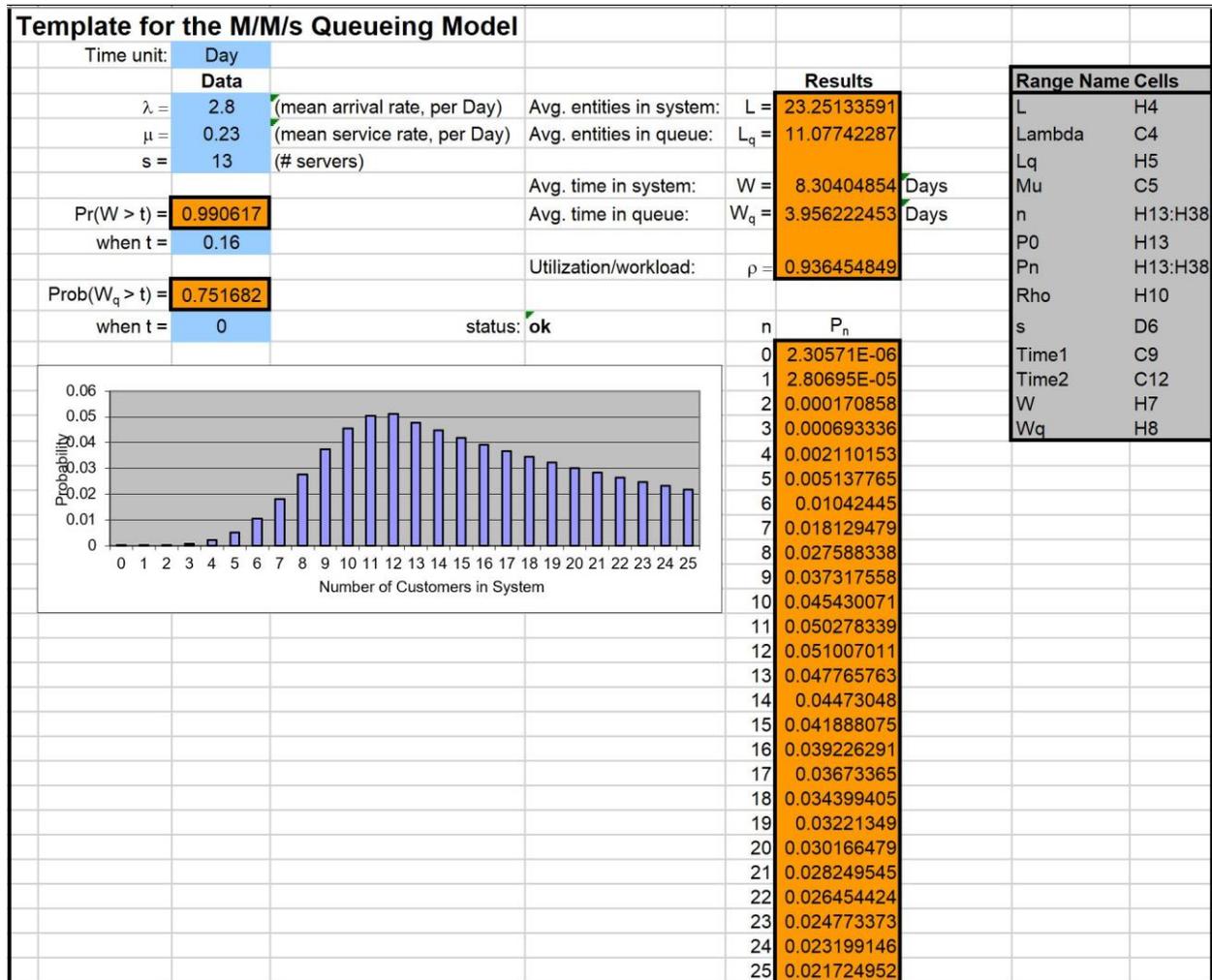


Figure 9: M/M/s Queuing model

4.1.3 Interpreting the M/M/s Model Results

Key Performance Indicators (KPIs): After running the model, the following results were obtained:

Average entities in the system (L): 23.2513

This metric represents the average number of ships serviced or waiting in the system. A value of 23.2513 indicates that, on average, there are around 23 ships at any given time within the port system, including those in the queue and those being served.

Average entities in the queue (Lq): 11.0774

Lq reflects the average number of ships waiting in the queue for service. With an average of 11.0774 ships, this highlights the extent of backlog, showing that many ships are waiting before they can be attended to.

Average time in the system (W): 8.3040 days

This KPI denotes the average time a ship spends within the system, from arrival to departure. The result of 8.3040 days suggests that, on average, a ship remains in the port system for over 8 days, which includes both waiting and service time.

Average time in the queue (Wq): 3.9562 days

Wq represents the average time a ship spends waiting in the queue before receiving service. The result of nearly 4 days indicates significant delays before ships can be serviced.

Utilisation (ρ): 0.9365

Utilisation, denoted by ρ , measures the proportion of time that the port's service facilities are busy. A utilisation rate of 93.65% indicates that the port is operating near full capacity, leaving little room for additional demand without further delays.

4.1.4 Scenarios Testing

In scenario analysis, we will test the variation of the controllable variables and analyse the impacts of increasing either the number of berths or reducing the service time on Key performance indicators such as the number of ships in the queue and the time they spend in the queueing system.

4.1.4.1 Scenario 1: Change the number of Berths

Our model used 13 berths to arrive at the discussed results while keeping other variables constant; if we change the number to 15 berths, the average number of ships serviced or waiting in the system will change from 23 to 13 ships while the utilisation rate will be 81% from the previous 94% indicating an improvement. On the other hand, the time spent in the system will change from 8 to 5 days.

4.1.4.2 Scenario 2: Change the Service Time

The second scenario is about changing the service time while keeping other variables constant; if we change the service time from 4.2 days to 3 days, the average number of ships serviced or waiting in the system will change from 23 to 8 ships while the utilisation rate will be 65% from the previous 94% indicating an improvement. On the other hand, the time spent in the system will change from 8 to 3 days.

4.1.4.3 Scenario 3: Change both the number of Berths and Service Time

In the third scenario, when we change the service time from 4.2 days to 3 days and the number of berths from 13 to 15, the average number of ships being serviced or waiting in the system will change from 23 to 8. This will result in a utilisation rate of 57%, a significant improvement from the previous 94%. Furthermore, the time spent in the

system will decrease from 8 to 3 days.

4.1.4.4 Scenario 4: Change both the number of Berths and Service Time

The fourth scenario involves controlling the arrival rate either through communication or other means. This option is complicated compared to the others. If we change the arrival rate from 2.8 to 2.5 vessels per day, the average number of ships serviced or waiting in the system will change from 23 to 13 ships while the utilisation rate will be 84% from the previous 94% indicating an improvement. On the other hand, the time spent in the system will change from 8 to 5 days.

4.2 Qualitative Findings: Stakeholder Interviews

This section presents the qualitative findings from structured questionnaires and semi-structured interviews conducted with various stakeholders involved in or affected by the port operations. We gathered data through a combination of closed and open-ended questionnaires administered to 38 stakeholders. In order to obtain a representative sample, we utilised random sampling for the majority of participants and carried out semi-structured interviews with 5 stakeholders who were specifically selected for their roles and expertise. The interviews were conducted in person and lasted 10 to 15 minutes. The majority of the participants were port authority managers and technical staff. Our primary objective was to gain a comprehensive understanding of the queuing situation at Dar es Salaam port. The findings were consistent with the stakeholders' expectations, with a significant number of respondents reporting daily ship queuing periods exceeding four days.

4.2.1 Organisations Involved in Data Collection

More than five organisations were involved in data collection, including the Ports Authority (TPA), TASAC (Tanzania Shipping Agencies Corporation), shipping lines, customs,

TAFFA (Tanzania Freight Forwarders Association) and logistics providers, as indicated in the figure below.

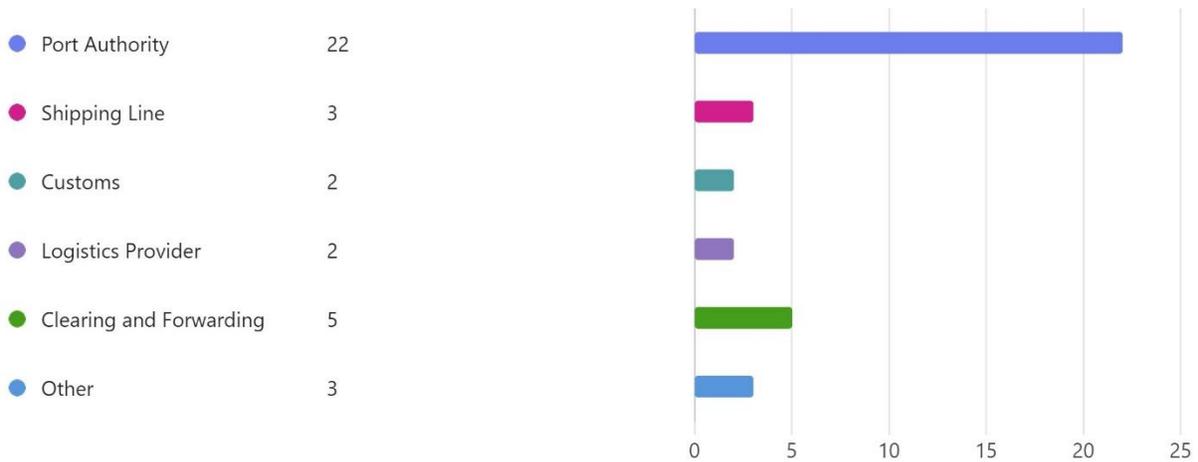


Figure 10: List of Stakeholder’s Organisations

4.2.2 Experience of the Stakeholders

A significant percentage of the stakeholders participating in this study had between 5 and 10 years of experience in the maritime industry.



Figure 11: Experience of the stakeholders in the industry

4.2.3 Causes of Ship Queuing

Insufficient berth capacity is frequently identified as a primary contributor to port congestion, emphasising the pressing need for expanded berths or more effective utilisation of existing ones. Limited space in the yard can exacerbate congestion, especially during peak times. Inefficient cargo handling can lead to sluggish cargo movement and prolonged waiting times, often stemming from ineffective processes and equipment. Inadequate planning and coordination may result in bottlenecks and delays. While less frequent, adverse weather conditions can still disrupt port operations. Additionally, equipment breakdowns can cause temporary disruptions and delays. A surge in trade volumes can strain the port's capacity, ultimately leading to congestion. Some of the responses recorded regarding the causes of queuing were:

... "Inadequate port capacity in terms of berthing facilities and cargo handling equipment"...

... "Limited berths compared to growing throughput"...

... "1. Limited number of berth 2. Lack of Automated Port Operations 3. Un-integrated ICT system amongst stakeholders"...

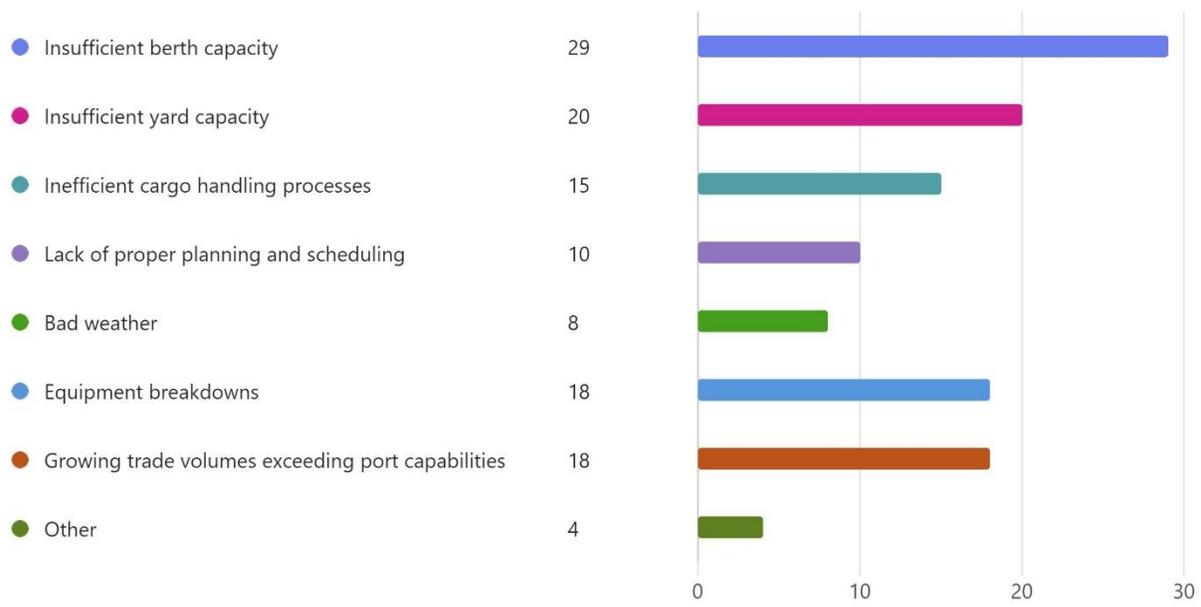


Figure 12: Causes of ship queuing

4.2.4 Impact of Ship Queuing

The queuing of ships poses a significant problem for stakeholders at Dar es Salaam Port. As identified by stakeholders, the main challenges related to ship queuing include higher transportation costs, delayed deliveries, and difficulties in managing inventory. Additionally, decreased port efficiency is a significant concern, as congestion has a negative impact on the port's overall performance. Here are some of the recorded responses:

...“Rise in transportation costs & diversion of customers to Mombasa port”...

...“Increase overall costs (e.g. freight, clearance, insurance etc.) for cargo destined to DSM Port which may lead to vessel diversion to other efficient ports”...

...“Untimely delivery of cargo, Re-rooting of Feeder vessels and Shifting of the customer to other ports”...



Figure 13: Impact of ship queuing

4.2.5 Potential solutions for ship queuing

The most popular response was chosen by 26 out of 28 respondents as an effective solution. This indicates that stakeholders consider investing in physical infrastructure crucial for addressing congestion. Additionally, 21 respondents recognised the potential benefits of technology in improving port efficiency. There is a growing recognition of this solution. Seventeen respondents emphasised the importance of better coordination and communication between different stakeholders involved in port operations. Nine respondents highlighted the need for improved planning and coordination to optimise port utilisation. Finally, 11 respondents suggested that regulatory reforms could help reduce bureaucratic delays and improve efficiency. Here are some of the recorded responses:

...“Port Infrastructure Upgrades, Advanced Scheduling and Coordination, Efficient Cargo Handling”...

...“1. Improve infrastructures including new berths 2. Using the modern technology 3. Using modern handling tools and machinery”...

...“Do not allow 50kg bags and bagging in the port. And give priority to vessels that offload faster.”...

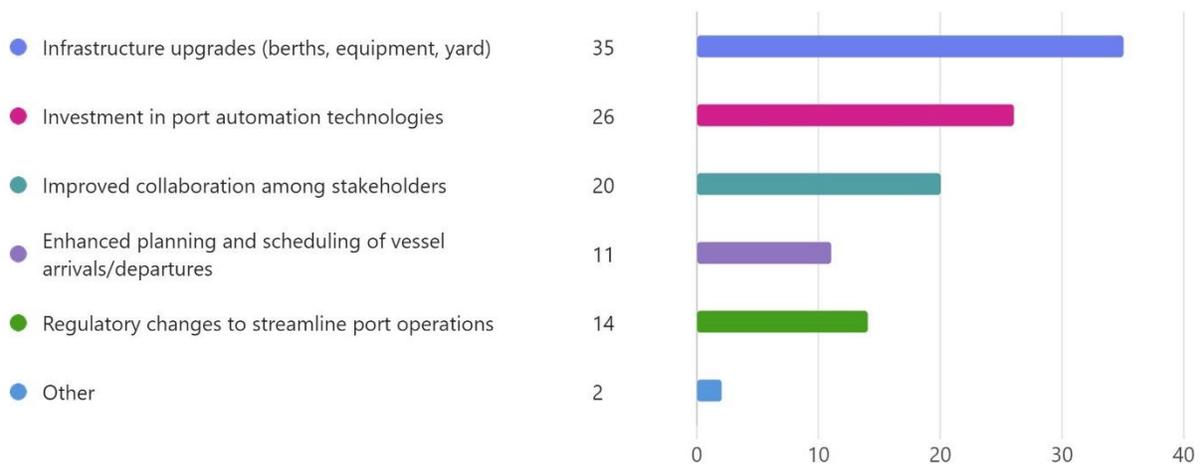


Figure 14: Potential solutions to queuing

4.2.6 Stages that contribute to ship queuing

The main contributor to ship queuing at Dar es Salaam Port is the handling and storage of cargo. This delay might be due to insufficient space at the berth and in the yard, as addressed by most stakeholders, highlighting the need for infrastructure investments and cargo handling processes. Efficient allocation of berths and handling of ships is also crucial at this stage. Delays can also occur due to customs procedures acting as a bottleneck. Furthermore, inefficiencies in the transportation network in the surrounding area can affect port operations and cause delays.

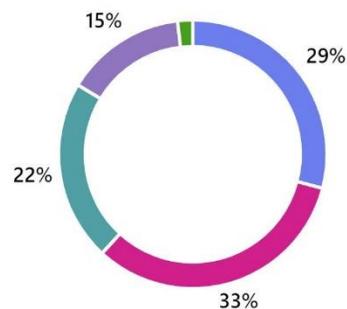


Figure 15: Stages that contribute to queuing

4.3 Integrated Analysis: Comparing Quantitative and Qualitative Findings

This section integrates the quantitative results from the M/M/s model with the qualitative insights from stakeholder interviews to provide a comprehensive understanding of the port's challenges. Key Insights:

4.3.1 Validation of Model Results:

The high utilisation rate and waiting times observed in the quantitative analysis are corroborated by the qualitative findings. Stakeholders confirmed that the port is operating near capacity, leading to extended delays and inefficiencies. The alignment between the quantitative and qualitative data strengthens the validity of the findings.

4.3.2 Identification of Bottlenecks:

While the M/M/s model quantifies the extent of congestion, the qualitative data provides context by identifying specific bottlenecks. Infrastructure limitations, such as berth and yard capacity, and operational inefficiencies, such as slow customs procedures, are key factors contributing to the observed congestion.

4.3.3 Central Corridor Dashboard

The most recent report from the Central Corridor Observatory in 2022 delved into the topic of ship waiting time, highlighting that the average ship turnaround time for the year was 10.0 days. It was noted that waiting time comprised 56% of the total turnaround time, amounting to 5.6 days, while berth time represented 4.3 days, equivalent to 43% of the total turnaround time. This report's findings were in line with both qualitative and quantitative data from this research. The report went further to discuss the concern on lack of progress in reducing berth time in 2022 compared to the levels of 2021. It emphasised the significant impact of reducing berth time/service time on ship turnaround time and shipping costs. The report also highlighted a new challenge in tracking the waiting time of ships at outer anchorage, which has not been effectively addressed in the first year of observation, 2022.

Moreover, it pointed out that several complex issues need to be resolved to improve ship turnaround time, including processes related to the quantity of cargo handled by vessels, the vessel types and characteristics, and the types of port equipment and resources used at berth.

4.3.4 Understanding Stakeholder Perspectives:

The interviews reveal the direct impacts of congestion on various stakeholders, including shipping lines, cargo owners, and logistics providers. These perspectives highlight the broader implications of port inefficiencies on the supply chain and the need for targeted interventions. Additional funding and expertise enable the port to expand and modernise its facilities more effectively.

4.4 Conclusion:

The findings from both the quantitative and qualitative analyses reveal that the Dar es Salaam Port is currently operating under significant strain, with high utilisation rates, extended waiting times, and long queues being the norm. The primary challenges identified include infrastructure limitations, operational inefficiencies, and hinterland transportation issues, all of which contribute to the observed congestion.

To address these challenges and improve the port's performance, a multi-faceted approach is required. This should include investment in infrastructure expansion, modernisation of operational processes, and enhanced coordination among port stakeholders. Additionally, addressing the hinterland transportation issues will be critical to ensuring the smooth flow of cargo to and from the port.

Ultimately, the findings of this chapter underscore the urgency of implementing targeted interventions to enhance the efficiency of the Dar es Salaam Port, thereby reducing congestion and improving the overall effectiveness of the port in supporting the region's economic growth.

5 Conclusions, Recommendations, and Implications

5.1 Conclusions

The research delved into the factors contributing to ship queuing at Dar es Salaam Port and explored potential remedies by employing a combination of quantitative and qualitative research methods. The port's operational performance was scrutinised using the M/M/s queuing model, while stakeholder interviews unearthed invaluable insights into the challenges and experiences of port users, enriching the study. The findings from the quantitative analysis concurred with the stakeholders' expectations, underscoring the significance of their perspectives. The key findings are;

5.1.1 High Utilization Rate:

The quantitative analysis using the M/M/s queuing model revealed that Dar es Salaam Port operates at a high utilisation rate, this means the port is under significant pressure to meet the growing service demand. While high utilisation is a sign of the port's importance and activity, it also indicates a risk of congestion and potential overloading of port facilities.

5.1.2 Prevalence of Ship Queuing:

The study found that ship queuing is a common and persistent issue at the port. The high queuing levels lead to increased waiting times for ships, which causes delays in cargo handling, higher operational costs, and a reduction in the efficiency of the entire port operation.

5.1.3 Primary Causes of Congestion:

The research identified several key factors contributing to port congestion, including:

Infrastructure Limitations: Insufficient berth capacity and yard space constrain the port's ability to efficiently handle the increasing volume of ships and cargo.

Operational Inefficiencies: Slow customs clearance processes, inadequate cargo handling procedures, and poor communication between stakeholders were identified as significant bottlenecks.

External Factors: Weather conditions during the rainy season, economic fluctuations, and global trade dynamics, with growing cargo volumes at times as shown there is 8.2% annual growth, were also noted as contributing to port congestion, though these are factors beyond the control of port management.

5.1.4 Stakeholder Impacts:

Interviews with stakeholders, including shipping lines, cargo owners, and logistics providers, revealed the negative impacts of congestion. These include increased costs, delays in the supply chain, and dissatisfaction with port services. The broader economic impact is also significant, as port inefficiencies can ripple through the economy, affecting trade and commerce in Tanzania and the East African region.

5.2 Recommendations

Based on the findings, this study offers several actionable recommendations aimed at addressing the challenges faced by Dar es Salaam Port:

5.1.1 Infrastructure Expansion:

To cope with the growing demand for port services, it is essential to invest in expanding berth capacity and improving other critical infrastructure. This includes constructing additional berths, expanding yard space, and enhancing port facilities to accommodate larger cargo volumes and more ships simultaneously.

5.1.2 Operational Efficiency:

Enhancing the efficiency of port operations is critical to reducing delays and improving throughput. This can be achieved by streamlining customs clearance procedures, optimising cargo handling processes, and improving coordination

among various stakeholders. Implementing best practices and adopting lean management principles in port operations can increase efficiency.

5.1.3 Technology Adoption:

Leveraging advanced technologies is another key strategy for optimising port operations. Automated systems for cargo handling, data analytics for predictive maintenance, and real-time tracking systems can help reduce inefficiencies and enhance decision-making. Technology adoption can also facilitate better coordination between different entities within the port ecosystem. Stakeholders stressed the use of automated equipment and enhanced port operation ecosystems.

5.1.4 Hinterland Development:

Improving the hinterland transportation infrastructure is essential to alleviating congestion within the port. Investments in road and rail networks and better intermodal connections can reduce bottlenecks and ensure smooth cargo movement between the port and its hinterland. This can also help to distribute the cargo load more evenly across the region. As one of the Directors of the Logistic Company described ...*“There are many delays in delivering cargo to rural areas due to poor road conditions in most parts of the country causing container demurrages and high turn around time”*...

Another stakeholder highlighted ...*“Improve infrastructure such as train inside the terminal and those linking the mainland to the Port for smooth cargo offtake”*...

Furthermore, the Central Corridor Observatory report addressed that the port has experienced a notable drop in cargo transported by rail over the last ten years, with rail's share of overall cargo decreasing from 17.4% in 2013 to 1.3% in 2022. This has been a significant factor contributing to the extended dwell times at the Dar port due to a mismatch between cargo volume growth and the rail infrastructures. The Central Rail Line, which connects Dar es Salaam to the western Tanzanian city of Kigoma and the northern city of Mwanza, was designed to handle 5 million

metric tons of cargo annually. However, it currently only transports less than 2% of its capacity.

5.1.5 Public-Private Partnerships:

Exploring partnerships with private sector entities can provide additional resources and expertise for port development. Public-private partnerships (PPPs) can be a viable solution for funding infrastructure projects, modernising port operations, and bringing in innovative solutions that might be beyond the capabilities of public sector entities alone. Stakeholders highlighted that the arrival of DP World at Dar es Salaam Port could impact congestion significantly. As a global port operator with a proven track record, DP World can bring expertise, investment, and operational efficiencies to the port. However, its impact will depend on several factors, such as investment strategy and collaboration with other stakeholders.

5.3 Implications

The findings and recommendations of this study have significant implications for the development and management of Dar es Salaam Port:

5.3.1 Improved Efficiency:

By implementing the recommended strategies, the port can significantly reduce ship waiting times and improve its overall throughput. This would enhance the port's operational efficiency, leading to faster turnaround times and better service levels for shipping lines and cargo owners.

5.3.2 Enhanced Competitiveness:

Dar es Salaam Port's ability to handle cargo efficiently and reliably is crucial for its competitiveness as a regional trade hub. By addressing congestion issues and improving service quality, the port can attract more business, bolster its reputation, and play a key role in facilitating trade in the East African region.

5.3.3 Stimulated Economic Growth:

Efficient port operations are vital for economic development. By improving the performance of Dar es Salaam Port, the study's recommendations can contribute to the broader economic growth of Tanzania and neighbouring countries. This includes creating jobs, supporting trade, and fostering economic activities that rely on effective port services.

5.3.4 Environmental Considerations:

Reducing congestion at the port can also have positive environmental impacts. Fewer ships waiting at anchor and shorter port stays can reduce emissions, fuel consumption, and the overall carbon footprint of port operations. This aligns with global sustainability goals and helps mitigate the environmental impact of maritime logistics.

5.4 Future Research Directions

While this study provides valuable insights into the challenges and solutions for Dar es Salaam Port, it also opens up avenues for further research:

5.4.1 Long-term Forecasting:

Future research could focus on developing models to predict long-term trends in ship arrivals, cargo volumes, and the demand for port services. Such models would help port authorities plan for future capacity needs and avoid the pitfalls of congestion.

5.4.2 Environmental Impact Assessment:

A comprehensive assessment of the environmental impacts of port congestion is necessary. Future studies could explore the specific environmental consequences of delays and inefficiencies, such as increased emissions, and propose strategies for mitigating these impacts.

5.4.3 Economic Analysis:

Quantifying the economic costs and benefits associated with port congestion and the proposed solutions would provide a deeper understanding of the financial implications. This could involve cost-benefit analyses, economic impact assessments, and evaluations of the return on investment for infrastructure projects.

5.4.4 Technology Advancements:

Emerging technologies, such as blockchain, the Internet of Things (IoT), and artificial intelligence (AI), have the potential to revolutionise port operations. Future research could explore these technologies' applications in port management, their potential benefits, and the implementation challenges.

By conducting thorough research in these key areas, we can actively contribute to the continuous improvement and enhancement of Dar es Salaam Port. This approach is crucial in sustaining the port's competitiveness and ability to effectively cater to the evolving demands of the global trade landscape.

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