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Comparative analysis of Dar Es Salaam and tema port performance by using a hybrid Dea(Ahp) model

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Abstract
This paper investigates the operational efficiencies of the Port of Dar Es Salaam and Tema Port from 2017 to 2022 using the DEA-AHP model. Quay length, storage area, and crane count are utilized as input variables, while cargo throughput and ship calls serve as output variables. The hybrid DEA model integrated with AHP has to be employed to determine the efficiency scores, accounting for all varied inputs and outputs. Through such an approach, a fair perspective of the comparative performance of both Dar es Salaam and Tema ports is enabled. The research further looks into the effects of externalities related to trade on port efficiency offering an inclusive perspective on the factors that define operational efficiency of the ports. The analysis reveals that the Port of Dar Es Salaam has consistently high efficiency, with scores ranging from 0.936 to 1 and an average efficiency of 0.970189267 for 2017-2019. Tema Port shows more variability in efficiency, ranging from 0.705 to 1, but demonstrates significant improvement over time, achieving an efficiency score of 1 in 2021, with an average of 0.871713025 for 2017-2019. Pearson's and Spearman's correlation analyses highlight strong positive relationships between trade levels and efficiencies at both ports. The paper underscores the importance of continuous infrastructure investment, implementation of best management practices, advanced data analytics, regular efficiency monitoring, and collaborative efforts to enhance port performance and manage increasing trade volumes effectively.

Keywords: Port efficiency, data envelopment analysis (DEA), analytic hierarchy process (Ahp), Port Of Dar Es Salaam, Tema Port, cargo throughput

Introduction

Background Information

Transporting goods (cargo) and people by sea and other waterways is the main focus of maritime transportation. From the places of manufacturing to the final destinations by sea, maritime transport accounts for over 80% of all trade worldwide.

Port analysis involves a comprehensive examination of various aspects of port operations, infrastructure, and management to ensure efficiency, productivity, and sustainability.

Dar es Salaam Port in Tanzania and Tema Port in Ghana are pivotal maritime hubs in their respective regions. Dar es Salaam Port, located in the Kurasini ward of the Temeke District, handles over 90% of Tanzania's cargo traffic and serves several landlocked neighboring countries.[4] Established in the late 19th century, it has grown to feature a quay length of about 2,600 meters with eleven deep-water berths, supporting a wide range of cargo types.[4] Tema Port, on the eastern coast of Ghana, is the largest port in the country, handling about 80% of national exports and imports [1]. Established in 1962, it covers an area of 3.9 million square meters and features 21 berths, including a dedicated container terminal [3]. Its strategic location near Accra and excellent connectivity make it a key gateway for international trade in West Africa. Both ports have undergone significant modernization to enhance their infrastructure and operational efficiency, playing crucial roles in regional trade and logistics [3].

According to the United Nations Conference on Trade and Development (UNCTAD), ports are classified into different generations based on their development and capabilities. Both Dar es Salaam Port and Tema Port are classified as third-generation ports [2]. This classification indicates that these ports have evolved to meet the complex demands of modern global trade, incorporating advanced logistics, technology, and services to support efficient operations [5]. this comparison shows how they have responded to the opportunities and challenges presented by the current state of international trade, offering insights into their relative strengths and weaknesses as third-generation ports.

Data Envelopment Analysis (DEA) is a performance measurement technique used to evaluate the efficiency of Dar Es Salaam and Tema ports by comparing their ability to convert inputs into outputs [2, 6]. DEA constructs an efficiency frontier from the most efficient port, serving as a benchmark. Ports on this frontier are considered efficient, while those below it are deemed inefficient [2]. This method allows for the relative efficiency of each port to be measured, with an efficiency score assigned to each, where a score of 1 indicates a port is on the efficiency frontier. DEA is particularly beneficial for benchmarking ports against each other, optimizing resource allocation, and identifying areas for performance improvement [2]. Its non-parametric nature and ability to handle multiple inputs and outputs simultaneously make it a flexible and comprehensive tool for assessing port efficiency.

AHP, on the other hand, is a structured technique for organizing and analyzing complex decisions. It involves breaking down a decision problem into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed independently. The results are then synthesized to determine the overall ranking of the decision alternatives [2]. The hybrid DEA (Data Envelopment Analysis) and AHP

(Analytic Hierarchy Process) model is used to compare the performance of Dar es Salaam and Tema ports. It combines DEA's efficiency measurement of resource usage with AHP's structured decision-making to weigh the importance of various inputs and outputs. This model helps identify which port is more efficient and highlights areas for improvement by analyzing data on resources and services provided by each port

Despite numerous studies on individual port performance, there is a notable scarcity of comparative analyses between Dar es Salaam and Tema ports. This gap highlights the need for research that directly contrasts these two significant ports in East and West Africa. Existing studies often neglect the impact of contextual factors such as regional trade policies, economic conditions, and geopolitical influences, which are crucial for an accurate comparison. Additionally, traditional metrics like throughput and turnaround time dominate the literature, leaving a gap for research incorporating advanced efficiency metrics from hybrid DEA models. The role of technological advancements, such as automation and digitalization, in enhancing port efficiency is also underexplored. Furthermore, there is limited research on the sustainability practices and environmental impacts of these ports. Including stakeholder perspectives, such as those of port authorities, shipping companies, and local communities, can provide a more comprehensive understanding of port performance. Addressing these gaps will contribute significantly to academic literature and offer practical insights for improving port operations, enhancing regional trade efficiency, and supporting sustainable development initiatives.

Policymakers can use this analysis of Dar es Salaam and Tema ports to enhance efficiency by targeting improvements, formulating effective policies, promoting sustainability, and fostering stakeholder collaboration. They can adopt best practices, allocate resources effectively, and support economic growth through informed decision-making. This research is a valuable tool for driving port performance and sustainable development.

The objectives of this comparative study is to evaluate and compare the operational efficiency of Tema Port in Ghana and Dar es Salaam Port in Tanzania by using hybrid DEA–AHP model and this involves assessing various factors influencing performance. For this study, data will be gathered on the infrastructure, operations, and management of both ports. The collected data will undergo preprocessing and normalization. Efficiency scores will then be determined using the DEA–AHP model. The study will apply statistical analysis techniques to interpret the results and pinpoint the strengths and weaknesses of each port. Additionally, it will identify variables that significantly impact port performance, using export and import trade levels as external factors. The finding of this sudy will lead to targeted operational improvements, informed policy and investment decisions, and competitive benchmarking. This can boost economic growth, regional integration, and customer satisfaction by reducing costs and transit times, attracting more business, and fostering cooperation between West and East Africa [7, 8].

Literature Riview

1. Port Assessment and Efficiency Reviews

The performance of ports has been a subject of extensive research in recent years. Several studies have explored the dynamics and competitiveness of multi-port gateway regions, particularly in the context of Southern Africa. For instance, a study examining the gateway and hinterland dynamics of the Southern African container seaport system found that the region's ports exhibit unique characteristics compared to typical port systems, with some ports demonstrating more potential to lead in terms of competition and concentration [9]. Another study on port development and competition in East and Southern Africa emphasized the need to improve stakeholder engagement, management systems, and institutional frameworks to ensure efficient use of port infrastructure and attract private investment [10].

Port performance relies on various indicators essential for effective management and optimizing efficiency. Known as choice variables, these performance factors are managed by port authorities to achieve their economic objectives [11]. These factors can be utilized in port efficiency evaluations from different viewpoints [12]. Key performance indicators frequently used include efficiency, productivity, utility, and expediency measures [13].

Another study [14] examines how smart port design affects maritime transport efficiency. Utilizing a three-step DEA-Tobit modeling approach, it assesses the performance of the top 20 maritime ports based on their throughput. The study identifies three key smart port aspects: automation, environment, and intelligence. Their weights are assigned through the analytic hierarchy process (AHP). The findings show that pollution control, under the environmental aspect, has the most significant positive impact on port efficiency. In contrast, information sharing, under the intelligence aspect, negatively impacts efficiency, likely due to technology demands, information complexity, and potential overload. This integrated measurement framework provides valuable insights, highlighting that not all design elements yield positive outcomes. Ultimately, it offers policy recommendations for prioritizing smart aspects in smart port development.

2. An Overview of DEA and AHP Methods and How They Are Used in Port Analysis.

Data Envelopment Analysis (DEA) and Analytic Hierarchy Process (AHP) are two powerful methods used for evaluating and improving decision-making processes. DEA is a non-parametric method that assesses the efficiency of decision-making units (DMUs) by comparing multiple inputs and outputs, providing a relative efficiency score.[19,] It is widely used in sectors like healthcare, education, transportation, and banking to benchmark performance and identify best practices. On the other hand, AHP is a structured technique for organizing and analyzing complex decisions through pairwise comparisons and hierarchical structuring.

Developed by Thomas L. Saaty, AHP helps in setting priorities and making decisions by quantifying subjective judgments and ensuring consistency. It is commonly applied in resource allocation, supplier selection, risk management, and urban planning. Combining these methods, the hybrid DEA-AHP model leverages the quantitative efficiency analysis of DEA with the qualitative decision-making criteria of AHP, offering a comprehensive evaluation framework. This hybrid approach is particularly beneficial in complex environments, such as port performance evaluation, where both operational efficiency and strategic importance need to be considered [20].

Reference [15] analyzed the efficiency of 26 Spanish ports using DEA-BCC models and found that higher complexity ports tended to be more efficient. Reference [16] examined the efficiency of 4 Australian ports and 12 other international container ports in 1996, utilizing DEA-CCR and DEA-Additive models. Results indicated that Melbourne, Rotterdam, Yokohama, and Osaka were among the least efficient ports, highlighting areas for improvement in container berths, terminal areas, and labor inputs. Reference [17] also applied the DEA-CCR model to compare port efficiency based on ownership type and organizational structure. This study analyzed 31 container ports out of the world's top 100 in 1998, finding that certain structural forms correlated with efficiency levels. Additionally, cluster analysis helped identify organizational structures.

In determining sources of inefficiency [18], applied DEA to the Portuguese port industry again for the years 1990 and 2000. The author found that although Portuguese ports exhibited high levels of technical efficiency over the period under study, technological change had superseded any advancement in the ports sector in Portugal. The paper attributed greater efficiency in the port sector to financial aid from EU Single Market program. Additionally, Tobit regression analysis applied in the study found that multi-cargo ports were less efficient than container ports. Market share and efficiency were found to be positively related and the study found that ports with greater public sector involvement exhibited relatively lower levels of efficiency.

3. Current Studies on Port Comparative Analysis

To evaluate the efficacy and efficiency of port operations, previous research has looked closely at port analysis and performance evaluation. These studies have concentrated on a number of topics, such as competitiveness, infrastructure, productivity, and logistics. Numerous methodologies have been utilized, including data envelopment analysis (DEA), econometric models, and traditional performance indicators.

A comparative analysis of port practices and activities in the Tri-City (Gdańsk, Gdynia, and Szczecin) and China reveals significant differences and potential areas for improvement. The Tri-City ports, while crucial to Poland's economy, face challenges in infrastructure and connectivity compared to the highly advanced Chinese ports like Shenzhen, Hong Kong, and Tianjin. Chinese ports benefit from extensive automation, superior cargo handling equipment, and robust hinterland connections, leading to higher efficiency and capacity. By studying these practices, Tri-City ports can identify opportunities to enhance their operational efficiency, adopt best practices, and improve their competitive edge in the global maritime industry [21].

The ports on the Eastern Baltic Sea Coast, such as Klaipeda in Lithuania, Riga and Ventspils in Latvia, and Tallinn in Estonia, each play pivotal roles in regional trade and logistics. Klaipeda stands out with its diverse cargo handling capabilities, including liquid bulk, dry bulk, and containerized cargo, making it a versatile hub. Riga and Ventspils are key players in bulk cargo, particularly oil and petroleum products, benefiting from well-established storage and transit facilities. Tallinn, on the other hand, leverages its strategic location for passenger ferry services alongside cargo handling. A comparative analysis highlights that while each port has its strengths in specific cargo types and operational efficiencies, they all face common challenges such as the need for technological upgrades and enhanced connectivity to hinterland regions. The insights from such comparisons can help these ports to adopt best practices, optimize their operations, and improve their competitiveness in the increasingly dynamic maritime industry [22].

Methodology

1. Overview

This section deals with measurement of performance using data envelope analysis method which involved data collection from both Tema and Dar es Salaam ports. The data were retrieved from the GPHA Annual Review and Bulletin of Statistics 2021 for Tema and TPA Statistics 2021 for Dar es Salaam respectively. Furthermore, to complement those externalities, import and export statistics were also obtained including the information for the Bureau of Statistics all Eastern West Africa Countries and Lloyds Bank for the AHP model. These data sets were combined into a single table, as exemplified in Table 1, which used as input variables, quay length, storage area, number of cranes, etc., and as output its cargo throughput and the number of ship calls.

Table 1: Inputs and output variables for Dar es Salaam and Tema ports.

Port	Year	Cargo Throughput	Number of Ship Calls	Quay Length	Storage Area	Number of Cranes
Port of Dar Es Salaam	2017	13,761,536	1428	2600	266076	28
	2018	15,400,876	1489	2600	266076	28
	2019	16,022,952	1425	2600	266076	28
	2020	15,857,870	1368	2600	266076	28
	2021	16,214,156	1487	2600	266076	28
	2022	18,342,084	1634	2600	266076	28
Tema Port	2017	14,045,787	1549	1400	102249	53
	2018	16,594,685	1520	1400	102249	53
	2019	17,316,276	1464	1400	102249	53
	2020	18,909,586	1639	1400	102249	53
	2021	22,529,615	1984	1400	102249	53
	2022	19,688,304	1679	1400	102249	53

Two models have been combined in this article to provide a thorough analysis of these ports' efficiency. Results regarding the effectiveness of these ports have been obtained using the DEA model, and environmental stimuli that influence or contribute to these ports' effectiveness have been identified using the AHP model.

2. Methodology

Normalization techniques were used in this study's data preprocessing step to guarantee consistency and comparability. Data envelopment analysis (DEA) was then performed on the normalized data in order to evaluate each port's efficiency levels between 2017 and 2022. The basis for suggesting methods to improve operational efficiency was this assessment.

DEA made it easier to evaluate relative efficiency, pointing out areas where overall performance could be improved. The Analytic Hierarchy Process (AHP) model is used to harmonize the results with external factors by integrating import and export data from nations using the ports of Tema and Dar es Salaam. This approach helps in understanding how trade volumes and patterns affect port efficiency and performance.

Ensuring a structured and transparent evaluation process, allowing for a comprehensive comparison of the two ports based on multiple performance dimensions. This approach helps in identifying areas for improvement and providing valuable insights for decision-makers to enhance port operations and competitiveness.

3. Data Normalization

A common normalization technique where data values are scaled based on their minimum and maximum values (Min-Max Scaling), were employed to standardize input variables, bringing them into a consistent range that usually ranges from 0 to 1.

$$N_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^2}} \text{.............Equation 1}$$

N—min/max value of X, X—input variables.

Table 2: Normalized data

Port	Year	Cargo Throughput	Number of Ship Calls	Quay Length	Storage Area	Number of Cranes
Port of Dar Es Salaam	2017	0.0000	0.2256	0.4082	12.9105	0.2815
	2018	0.3579	0.4556	0.4082	12.9105	0.2815
	2019	0.4936	0.2143	0.4082	12.9105	0.2815
	2020	0.4576	0.0000	0.4082	12.9105	0.2815
	2021	0.5352	0.4474	0.4082	12.9105	0.2815
	2022	1.0000	1.0000	0.4082	12.9105	0.2815
Tema Port	2017	0.0000	0.1635	0.2190	4.9616	0.5313
	2018	0.3004	0.1077	0.2190	4.9616	0.5313
	2019	0.3854	0.0000	0.2190	4.9616	0.5313
	2020	0.5735	0.3365	0.2190	4.9616	0.5313
	2021	1.0000	1.0000	0.2190	4.9616	0.5313
	2022	0.6650	0.4135	0.2190	4.9616	0.5313

4. Data Envelopment Analysis

DEA is a robust, non-parametric linear programming method employed to evaluate the relative efficiency of Decision-Making Units (DMUs) that utilize multiple inputs to produce multiple outputs. This methodological approach is particularly valuable in operational research and economics as it constructs a frontier over the data points, allowing for the assessment of each DMU's performance against this efficient frontier. DEA is adept at handling complex multi-input and multi-output scenarios, making it suitable for a myriad of applications including education, healthcare, and notably, port efficiency analysis.

Ratio (CCR) Mode; Equations (2)–(11) demonstrate how the CCR ratio model determines the unit's overall efficiency by combining its scale efficiency and pure technical efficiency into a single figure. Because it is continuously evaluated in relation to the field, the efficiency attained is never absolute.

Using the primordial model, the decision-making units (DMUs) under evaluation can choose the appropriate weights for each of its variables to maximize efficiency (in the following model, inputs are represented by x and outputs by y). The solution consists of a set of weights (y for inputs and x for outputs) chosen to ensure that no other unit using these weights will have an efficiency higher than 1, which is the threshold for a relatively efficient unit. Some authors prefer to use the term "primal model" instead of "dual model" because it more accurately conveys the core concept of DEA. We created the virtual input and output for every decision-making unit (DMU) using (yet-unknown) weights (v_i) and (u_r):

The optimal weights can vary from one decision-making unit (DMU) to another, and they typically do. Consequently, the "weights" in DEA are derived from the data rather than being preset. The optimal set of weights is assigned to each decision-making unit (DMU), though some DMUs may have different values. As they also deviate from traditional weightings in this case (for instance, in index number constructions), we will generally refer to these DEA weights as "multipliers" from now on to distinguish them from the other popular methods.

Equations in the CCR Model

The core equations of the CCR model are as follows:

Input-Oriented CCR Model:

Efficiency = minθ

Subject to:

$$\sum_{i=1}^{m} v_i \, x_{ij} = 1 \text{..................................Equation 2}$$

$$\sum_{i=1}^{s} u_r \, y_{rj} - \theta \sum_{i=1}^{m} v_i x_{ij} \leq 0 \text{............Equation 3}$$

$$u_r, v_i, \theta \geq 0$$

Output-Oriented CCR Model:

Efficiency = maxϕ

Subject to:

$$\sum_{i=1}^{m} \upsilon_i \, x_{ij} \leq 1$$ ....Equation 4

$$\emptyset \sum_{i=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} \upsilon_i x_{ij} \leq 0 = 1$$ .....Equation 5

$$u_r, \upsilon_i, \theta \geq 0$$

In these equations:

y_{rj} represents the r-th output of the j-th DMU.
x_{ij} represents the i-th input of the j-th DMU.
u_r and υ_i are the weights assigned to outputs and inputs, respectively.

The Analytic Hierarchy Process (AHP) is a pivotal multi-criteria decision-making tool employed in this research to systematically evaluate and prioritize alternatives based on multiple criteria.

Through pairwise comparisons, AHP quantifies the relative importance of each criterion and alternative, providing a robust framework for decision analysis. In this study, AHP is used to compare the efficiency of various ports, considering factors such as operational cost, throughput, and service quality.

The estimated regression coefficients and adjusted R-squared statistics for each model are first compared. Next, the statistical and practical significance (effect magnitude) of the models' port impacts are evaluated. Finally, we use scatterplots and Pearson's and Spearman's correlations to assess models according to how closely their performance impacts are related.

5. Application of AHP Model

The AHP is used to establish the relative importance of various performance criteria such as efficiency, capacity utilization, turnaround time, and customer satisfaction. By constructing pairwise comparison matrices and calculating the eigenvector method, the criteria are weighted accordingly. These weights are then utilized in the DEA model to evaluate the ports' performance by measuring the weighted inputs and outputs, such as the number of cranes, quay length, storage area and tons of cargo handled. The DEA efficiency scores are calculated by dividing the sum of weighted outputs by the sum of weighted inputs for each port.

Pairwise Comparison Matrix (A): This matrix A is constructed by comparing criteria or alternatives pairwise. The elements a_{ij} of the matrix represent the relative importance of criteria i to criteria j.

$$A = \begin{bmatrix} 1 & a_{12} & a_{13} \cdots a_{1n} \\ \frac{1}{a_{12}} & 1 & a_{23} \cdots a_{2n} \\ \frac{1}{a_{13}} & \frac{1}{a_{23}} & 1 \cdots a_{3n} \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \frac{1}{a_{3n}} \ddots \cdots 1 \end{bmatrix}$$ ....Equation 6

Normalization: To normalize the pairwise comparison matrix, divide each element by the sum of its column.

$$\text{Normalized matrix} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}$$ ....Equation 7

Priority Vector (w): Calculate the average of each row in the normalized matrix to derive the priority vector, which gives the weights of each criterion.

$$\omega_i = \frac{1}{n} \sum_{i=1}^{n} \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}$$ ....Equation 8

Consistency Ratio (CR): To ensure the consistency of the pairwise comparisons, AHP includes a consistency check. The Consistency Index (CI) and Consistency Ratio (CR) are calculated as follows:

Calculate the Consistency Index (CI):

$$\text{CI} = \frac{-n}{n-1}$$ ....Equation 9

Where -n is the maximum eigenvalue of the pairwise comparison matrix, and n is the number of criteria.

Calculate the Consistency Ratio (CR):

$$CR = \frac{CI}{RI}$$ ....Equation 10

Where RI is the Random Index, which is a predetermined value based on the size of the matrix. If CR is less than 0.1, the pairwise comparisons are considered consistent.

Results of DEA Window Model

The DEA model in this paper uses quay length, storage area, and crane count as input variables, and cargo throughputs and ship calls as output variables.

Table 3: The DEA results are presented in Table.

Port	Year	Efficincies. DMU	Efficincies.Eff	Average
	2017	1	0.936253789	
	2018	2	0.995478236	
	2019	3	0.961539000	0.970189267
Port of Dar Es Salaam	2020	4	0.937882432	
	2021	5	0.990982145	
	2022	6	1	
	2017	1	0.704578700	
	2018	2	0.832674250	
	2019	3	0.869238800	0.871713025
Tema Port	2020	4	0.950482300	
	2021	5	1	
	2022	6	0.873304100	

The table presents the efficiency analysis of two ports—Port of Dar es Salaam and Tema Port—over the years 2017 to 2022. It includes efficiency scores for each year, along with an average efficiency score. The efficiency scores for Port of Dar Es Salaam range from approximately 0.936 to 1 over the years. The average efficiency score for the years 2017 to

2019 is 0.970189267. This indicates that, on average, the port's performance was close to optimal efficiency during this period.

The efficiency scores for Tema Port range from approximately 0.705 to 1 over the years. The average efficiency score for the years 2017 to 2019 is 0.871713025. This shows that Tema Port's Performance was less efficient compared to Dar es Salaam during this period. Port of Dar Es Salaam shows a consistently high efficiency, with some fluctuations but generally maintaining scores close to 1.

Tema Port exhibits more variability in its efficiency scores but shows improvement over time, reaching an efficiency score of 1 in 2021.

Table 4: The table presents data on the total trade (import and export) and related parameters of countries using Dar es Salaam Port (Tanzania, Malawi, Zambia, Eastern DRC, Burundi, Rwanda, and Uganda). Tema Port (Burkina Faso, Mali and Niger).

Port	Year	Total Trade Level Import and Export) in MT	Efficincies.Eff	Parameter β (Cofficient)	Adjusted R Squared (R2)
	2017	13,884,992	0.936253789		
	2018	15,635,443	0.995478236		
	2019	16,757,242	0.961539000	3.87 x 10^{-6}	0.81250000
Port of Dar Es Salaam	2020	16,981,320	0.937882432		
	2021	17,201,477	0.990982145		
	2022	18,798,873	1		
	2017	14,160,000	0.704578700		
	2018	16,340,000	0.832674250		
	2019	18,120,000	0.869238800	1.2097×10^{-7}	0.56289137
Tema Port	2020	19,500,000	0.950482300		
	2021	19,500,000	1		
	2022	19,690,000	0.873304100		

The "parameter β (coefficient)" in our analysis indicates the direction and strength of the relationship between port efficiency and total regional trade levels. The model's ability to explain how trade levels affect port efficiency is gauged by the "adjusted R-squared (R2)," where higher values denote a more significant external factor.

2019: The efficiency at Dar Es Salaam Port was 0.961539000 with a total trade level of 16,757,242 MT. The Parameter β (coefficient) is calculated as 3.87 x 10^{-6}, indicating the relationship between the trade level and efficiency. The Adjusted R-Squared value is 0.81250000, which suggests that approximately 81.25% of the variability in efficiency can be explained by the trade level.

At the same year, the efficiency at Tema Port was 0.869238800 with a total trade level of 18,120,000 MT. The Parameter β (coefficient) is calculated as 1.2097 x 10^{-7}, indicating the relationship between the trade level and efficiency. The Adjusted R-Squared value is 0.56289137, which suggests that approximately 56.29% of the variability in efficiency can be explained by the trade level.

Parameter β: Indicates the sensitivity of port efficiency to changes in trade levels. For instance, in 2019, the Port of Dar Es Salaam has a β of 3.87×10^{-6}, meaning a small positive relationship between trade level and efficiency. For Tema Port, the β of 1.2097×10^{-7} indicates a much smaller relationship.

Adjusted R-Squared (R^2_{adj}): Reflects how well the trade levels explain the efficiencies. Higher R^2_{adj} values indicate a better fit of the model. For example, the Port of Dar Es Salaam has a higher R^2_{adj} in 2019 (0.81250000), suggesting a stronger explanatory power compared to Tema Port in the same year (0.56289137).

Efficiencies: This metric indicates how effectively the ports handle their trade volumes. In general, efficiencies closer to 1 denote higher performance. Notably, both ports show high efficiency, with Tema Port reaching an efficiency of 1 in 2021.

Pearson’s and Spearman’s correlations: The analysis of trade data and efficiencies for the Port of Dar Es Salaam from 2017 to 2022 reveals a significant positive relationship. Pearson’s correlation coefficient is approximately 0.65, indicating a moderate positive linear relationship, while Spearman’s rank correlation coefficient is around 0.85, showing a strong positive monotonic relationship. These findings highlight that higher trade volumes are generally associated with higher operational efficiencies at the port.

The analysis of Tema Port’s data from 2017 to 2022 shows a very strong positive relationship between total trade levels and efficiencies. Pearson’s correlation coefficient is approximately 0.958, indicating a very strong linear relationship, suggesting that as trade levels increase, efficiencies significantly improve. Spearman’s rank correlation coefficient is approximately 0.871429, indicating a strong monotonic relationship, meaning efficiencies rise as trade levels increase. These results highlight that higher trade volumes at Tema Port are closely associated with higher operational efficiencies.

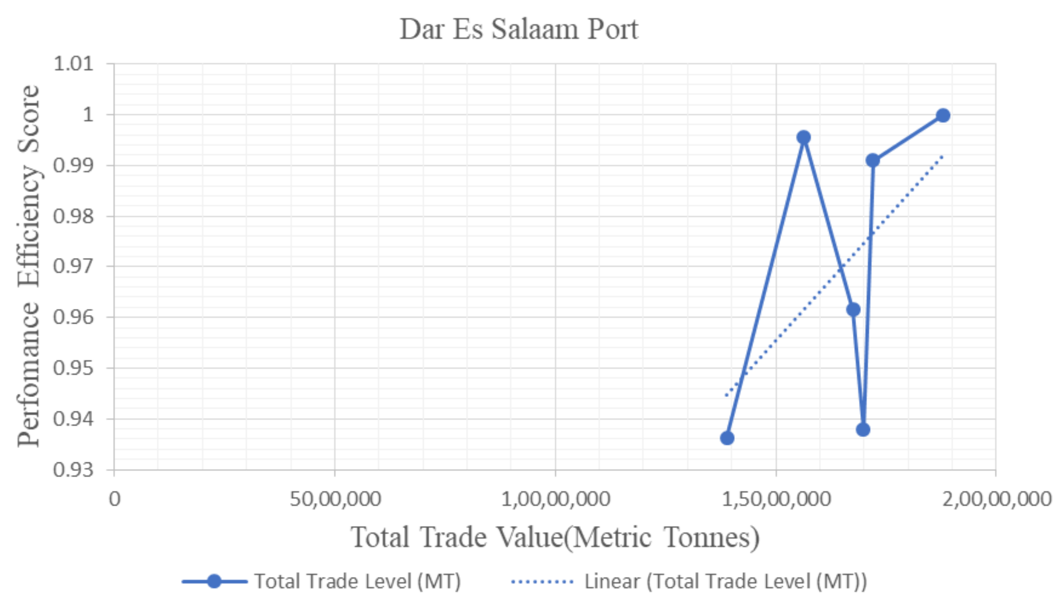

Fig 1: Dar es Salaam Port's scatter plot.

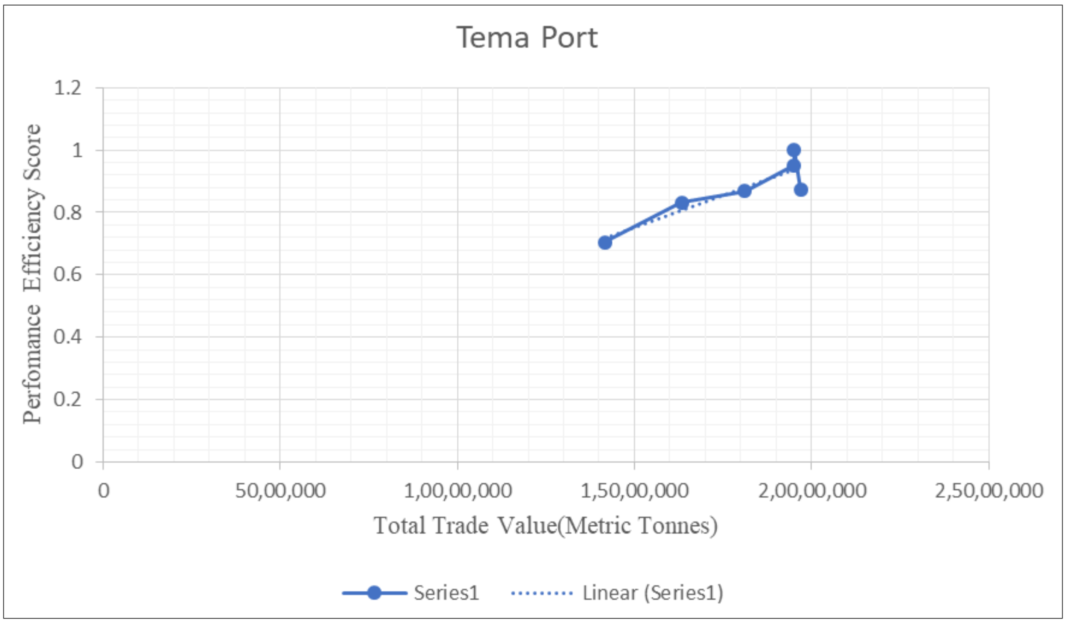

Fig 2: Tema a Port's scatter plot.

Efficiency and overall trade level are positively correlated in both ports, though there are some variances and departures from the general pattern. Although other factors probably also play a part, the adjusted R-squared values show that the total trade level can account for a portion of the efficiency variation. To identify the precise elements affecting each port's efficiency, more research and analysis are required.

Discussion.

The DEA model in this paper uses quay length, storage area, and crane count as input variables, and cargo throughputs and ship calls as output variables. The efficiency analysis for the Port of Dar Es Salaam and Tema Port over the years 2017 to 2022 provides valuable insights into their performance.

The Port of Dar Es Salaam's efficiency scores range from approximately 0.936 to 1, with an average of 0.970189267 for 2017-2019, indicating consistently high performance with minor fluctuations, while Tema Port's scores range from 0.705 to 1, averaging 0.871713025 for the same period, showing less efficiency compared to Dar Es Salaam but exhibiting more variability and significant improvement over time, reaching an efficiency score of 1 in 2021.

The table presents data on total trade (import and export) and related parameters for countries using Dar es Salaam Port (Tanzania, Malawi, Zambia, Eastern DRC, Burundi, Rwanda, and Uganda) and Tema Port (Burkina Faso, Mali, and Niger).

In 2019, the efficiency for the Port of Dar Es Salaam was 0.961539000 with a total trade level of 16,757,242 MT, showing a small positive relationship between trade level and efficiency (Parameter β of 3.87×10^{-6}) and an Adjusted R-Squared value of 0.81250000, explaining approximately 81.25% of the variability. For Tema Port, the efficiency was 0.869238800 with a trade level of 18,120,000 MT, indicating a much smaller relationship (Parameter β of 1.2097×10^{-7}) and an Adjusted R-Squared value of 0.56289137, explaining 56.29% of the variability. This highlights the stronger impact of trade levels on efficiency at the Port of Dar Es Salaam compared to Tema Port.

Pearson's correlation coefficient for the Port of Dar Es Salaam is approximately 0.65, indicating a moderate positive linear relationship between trade levels and efficiency, while Spearman's rank correlation coefficient is around 0.85, showing a strong positive monotonic relationship, suggesting that higher trade volumes are generally associated with higher operational efficiencies. For Tema Port, Pearson's correlation coefficient is approximately 0.958, indicating a very strong linear relationship between trade levels and efficiency, and Spearman's rank correlation coefficient is approximately 0.871429, indicating a strong monotonic relationship, highlighting that higher trade volumes at Tema Port are closely associated with higher operational efficiencies.

6. conclusion.

The findings reveal that both the Port of Dar Es Salaam and Tema Port exhibit positive correlations between trade levels and efficiency, though with varying degrees of strength. The Port of Dar Es Salaam maintains consistently high efficiency with minor fluctuations, while Tema Port shows greater variability but significant improvement over time. Trade levels significantly impact port efficiency, with stronger relationships observed at the Port of Dar Es Salaam compared to Tema Port.

For the Port of Dar Es Salaam, efficiency scores range from approximately 0.936 to 1, with an average score of 0.970189267 for 2017 to 2019, indicating consistently high efficiency with minor fluctuations. Conversely, Tema Port's efficiency scores range from 0.705 to 1, with an average of 0.871713025 for the same period, showing less efficiency compared to Dar Es Salaam but notable improvement over time, reaching 1 in 2021. In 2019, Dar Es Salaam had an efficiency score of 0.961539000 with a total trade level of 16,757,242 MT, a parameter β of 3.87×10^{-6}, and an adjusted R-squared value of 0.81250000. For Tema Port, the 2019 efficiency score was 0.869238800 with a trade level of 18,120,000 MT, a parameter β of 1.2097×10^{-7}, and an adjusted R-squared value of 0.56289137. Pearson's correlation for Dar Es Salaam is approximately 0.65, indicating a moderate positive linear relationship between trade levels and efficiency, while Spearman's rank correlation is around 0.85, showing a strong positive monotonic relationship. For Tema Port, Pearson's correlation is approximately 0.958, indicating a very strong linear relationship, and Spearman's rank correlation is approximately 0.871429, indicating a strong monotonic relationship. These findings highlight that higher trade volumes at both ports are generally associated with higher operational efficiencies.

Figures 1 and 2 (scatter plots) visually confirm these correlations, showing the relationship between trade levels and efficiencies for both ports. The DEA-AHP model proves to be an effective tool in evaluating and understanding port performance, providing valuable insights for improving operational efficiencies and guiding future strategies.

7. Reccomendations.

The analysis shows that efficiency and overall trade level are positively correlated in both ports, though there are some variances and departures from the general pattern. While other factors likely play a role, the adjusted R-squared values indicate that total trade level accounts for a significant portion of the efficiency variation. More research and analysis are needed to identify the precise elements affecting each port's efficiency.

To improve efficiency at both the Port of Dar Es Salaam and Tema Port, continuous investment in infrastructure, implementation of best practices in port management, utilization of advanced data analytics, regular efficiency monitoring, collaboration and knowledge sharing, focusing on key performance indicators, investing in technology, and providing training and development opportunities for staff are recommended. These measures will help both ports handle increasing trade volumes more effectively and contribute to regional economic growth.

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