

Port Efficiency: The Implication of Blockchain Technology in the Construction Material Supply Chain

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Abstract

The Port of Durban has recently been experiencing operational delays that are affecting its performance. Delays at the port adversely affect the timely completion of projects in the construction sector of South Africa. This exploratory research focuses on identifying through literature the application and implications of blockchain technology in facilitating the supply chain of construction materials. Furthermore, the drivers of port productivity for the Port of Durban are compared with those of the Port of Rotterdam. This research adopts a Quantitative Research Approach. For Data analysis, the Data Envelopment Analysis is a non-parametric tool used to evaluate port efficiency. The Malmquist Productivity Index will be used to determine the drivers of Port Productivity for the selected Ports from 2017 to 2023. The heterogeneity of the port cases limits the generalisation of findings. This study informs policymakers, project managers, investment planners, and operational practitioners about the possibilities of blockchain technology in enhancing the supply chain of construction materials. Technology is a major driver of port productivity for the port of Rotterdam. The application of various customised and specific technologies has improved the productivity of the Port of Rotterdam. The application of smart contracts in Blockchain technology will assist in improving the construction material supply chain.

Keywords: Blockchain, Construction Material Supply Chain Management, Efficiency, Port Congestion, South African Ports

1. Introduction

The Port of Durban has recently been experiencing operational delays, which affect its performance. According to the World Bank CPPI (2023), the ports of Cape Town, Durban, and Port Elizabeth in South Africa have been ranked among the world's worst-performing container ports. Griessel (2024) states that along the shores of Durban and Richards Bay in South Africa, almost a hundred cargo vessels, laden with fuel, bulk dry goods, containers, and cars, are held up because of delays attributed to a combination of adverse weather conditions and ageing terminal equipment. The implication of port congestion on the construction sector and the challenges thereof is the rapid increase in material and labour costs (Griessel, 2024). Delays at the port can adversely affect the timely completion of projects in the construction sector of South Africa (Nemakhavhani et al., 2024). This is known as time overruns in the construction sector, specifically delays attributed to the importation of construction materials. The implication of bottlenecks at the port has a multiplier effect not only on the Construction sector but on the South African economy at large. This exploratory research focuses on identifying through literature the application of blockchain technology (BCT) in facilitating the supply chain of construction materials.

Furthermore, the research also focuses on the drivers of port productivity for both the Port of Durban and the Port of Rotterdam. The Port of Rotterdam is used as a

benchmark because of its proven success in the application of blockchain Technology. Soni et al. (2023) opine that the construction sector plays a significant role in the development of the South African Economy because it contributes to the development of infrastructure, amongst others. Port Efficiency is a significant parameter for the success of the construction material supply chain (Obasi et al. 2024). Nikjow et. al. (2021) also attest that one of the major causes of delays in the procurement of construction materials is inefficient logistics and supply chain. An inefficient port should examine other options, such as blockchain Technology, which can assist in expediting the entire process. The implication of bottlenecks at the port has a multiplier effect not only on the Construction sector but on the South African economy at large.

Leah (2024) elaborates further by citing examples that can affect the construction materials supply chains, such as shortages of construction materials, disruptions in the supply chain, inflation, and delays due to customs procedures. The following are the aims and purpose of the research: identification of the application of blockchain technology in facilitating the supply chain of construction materials; to determine the drivers of port productivity for the Port of Durban and the Port of Rotterdam; and the comparison of the various applications of technology at the Port of Durban and Rotterdam. The study employs a quantitative research design that utilises secondary data extracted from the respective port websites. Kao (2023) states that efficiency is calculated as the ratio of output to input.

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The heterogeneity of the port cases limits the generalisation of findings.

This study informs policymakers, project managers, investment planners, and operational practitioners about the possibilities of blockchain technology in enhancing the supply chain of construction materials in South Africa. Due to time constraints, the data is limited to the period of 2017-2023. The research findings show that technology is a major driver of port productivity for the port of Rotterdam. The application of various customised and specific technologies has improved the productivity of the Port of Rotterdam. The construction sector is in dire need of an effective and efficient supply chain. The application of blockchain technology to contracts will improve the construction material supply chain. The following is the outline of the paper. Section 2 describes fundamental concepts in detail in the Literature Review, Section 3 examines the research methods, Section 4 discusses the findings and discussion, and Section 5 concludes with future research.

2. Literature Review

According to Meersman et al. (2012), a Port is congested when it cannot meet the demand of the port users either at the quayside, crane, yard side, or the gate. Congestion is a major restricting element of international trade and economic development, especially during the COVID-19 epidemic (Lin et al., 2022). Container ships tend to wait less time in ports in developed economies than in developing countries, due to a combination of faster clearance times, better infrastructure, and higher labour productivity (UNCTAD, 2023). Herein lies the importance of blockchain technology. The application of blockchain technology in the maritime industry can improve customs clearance efficiency and logistics transparency in the various container cargo supply chains (Wang et al., 2021). Ports are adversely affected by procedural complexities, redundancy, unintegrated information and document flow, which affects various port users and stakeholders involved in seaport operations (Mthembu and Chasomeris, 2024). According to the USDA Report (2024), the South African ports have, over the years, been experiencing chronic and acute operational challenges. Blockchain technology has emerged as a focal point of attention among these technological innovations (Guan et al. 2024). This section examines the various concepts that provide the essence of this study. The various concepts include the construction sector, port, port efficiency, the implications of port inefficiency, and the application of blockchain technology.

2.1. The Construction Sector and the Construction Material Supply Chain

According to the Department of Trade, Industry, and Competition (2024), the construction industry is a

driver of socio-economic development and a key employment multiplier, contributing 5.3% and 7.8% of South Africa's formal and informal sector employment, respectively. Ghamari et al. (2024) posit that the Construction Material Supply Chain is a network series that shows how construction materials are imported from origin to destination. In the construction sector, the supply chain manager has a critical role in strategically planning the consignment from the port of origin to the port of destination. Steel is a critical component for materials in the construction sector (Putri and Firmansyah, 2020). For instance, South Africa imports steel from the United States and Cement from China. Other imported construction materials include sand, gravel, crushed stone, Plywood, Hardboard, Pine, eucalyptus transmission poles, and Industrial electrical cables (STATS SA, 2024). South Africa's leading international trading partners include China, the United States, Germany, and Japan, which send shipments via the ports.

2.2. The Ports: South Africa and Rotterdam

Peng et al (2023) affirm that the Ports are central to the maritime supply chain. The implication of this is that without the port, the maritime supply chain is spineless and scattered. Ayesu and Boateng (2024) posit that Ports are pivotal in serving as vital corridors for the movement of goods across the African continent and beyond. Not only are ports of essential value to the global supply chain, but their productivity is also critical. Therefore, seaports and their efficiency remain essential for the success of global international trade (Ayesu et al, 2024). Mazibuko et al. (2024) assert that a container port's competitiveness depends on the productivity of its container terminal. Port evaluation serves as an impetus for port management to make informed strategic decisions. Port Evaluation reveals the actual state of the Port and enables Port management to make a decisive decision on how to improve port efficiency. The Ports in South Africa are critical to the South African export-led strategy (Transnet, 2024). According to Statista (2022), in 2022, 67% of South African International trade was done via sea. International Trade Administration (2024) opines that the South African geographical location presents a considerable opportunity for investing in a diversified maritime market. Nevertheless, the South African ports have been sinking with challenges that are accentuating delays in operations and causing financial losses (United States Department of Agriculture -USDA, 2024).

The World Shipping Council (2022) states that the port of Rotterdam is ranked as the 10th amongst the top 60 container ports globally, and it is the largest port in Europe. The Port of Rotterdam website (2024) asserts that the Port of Rotterdam is deliberate and committed to digitisation and port efficiency. According to Farah et al (2024), the Port of Rotterdam has used blockchain technology since 2016 to facilitate the tracking and

tracing of container shipments of flowers. The service allows for a seamless flow of information with customs authorities, hence allowing exporters to have the full ability to track and trace shipments (Farah et al., 2024).

2.2.1. *The Ports: Efficiency and Inefficiency*

Yen and Mulley (2023) state that Transport Efficiency is critical in transport. The evaluation of port performance is primarily aimed at assisting in improving port operations and providing useful information for port development planning and strategy (Suárez-Alemán et al., 2016). When a Port is efficient, it is obvious because there are limited delays at the Port, especially at the various operational levels. The operational areas include the quayside, crane, yard, and gate operations. According to Pallis and Rodrigue (2022), Port efficiency is multidimensional and it describes operational performance with emphasis on output maximisation and cost minimisation. Efficiency drives port competitiveness (Danladi et al, 2024).

According to Danladi et al. (2024), various indices, such as delays, show that ports are inefficient. Congestion resulting from poor management of seaports can also affect shipping lines, manufacturers, distributors, freight forwarders, warehouses, consumers, and everyone else along the supply chain (Prasad and Gavirneni, 2010). Port congestion is one of the many factors that can disrupt schedules and, as such, negatively affect schedule reliability (Notteboom, 2006). Delays have a substantial impact on money. The performance of the container process affects the amount of time a ship is required to stay at the port (Wong and Kozan 2010).

2.2.2. *Blockchain Technology*

According to Farah et al. (2024), Blockchain technology is a credible and essential solution to address the cry for enhancing security, transparency, and efficiency in the maritime industry, where increasing reliance on digital systems and data prevails. According to Monrat et al. (2019), Blockchain has the following features: decentralisation, immutability, transparency, and auditability. These features make transactions more secure and tamper-proof (Monrat et al, 2019). A predominant feature of the maritime supply chain is prolonged service cycles, complex structures, and information generated from multiple sources (Liu et al, 2021).

3. Research Methodology

This research employs a monomethod, the Quantitative Research Approach, to calculate efficiency, which is the ratio of the outputs to the inputs. The measurable parameters of inputs are obtained for the respective port statistics. The inputs are the number of container berths, the number of tug boats, the number of terminals, the number of cranes, the number of port employees, and the length of the quay, whilst the outputs are vessel

visits and container throughput. This secondary data for 2017-2023 is sourced from the Port of Rotterdam and Transnet Port statistics. This data set has been confirmed and validated by another source, such as the World Bank CPPI (2023) report. The sampling technique used is nested purposive sampling because the Port of Rotterdam is among the few smart ports that have applied blockchain technology.

This research adopts the Malmquist Productivity Index to measure efficiency over time. The Malmquist index (MI) evaluates the efficiency change over time. It is a non-parametric framework that is measured as the product of catch-up (or recovery) and frontier-shift (or innovation) terms, both coming from the DEA technologies (Tone, 2004). This research uses the Malmquist Productivity Index of the data envelopment analysis to evaluate port efficiency and productivity for South African ports. MPI deals with efficiency over time, instead of examining the snapshot of performance at one specific time, MPI considers performance (changes) across different periods (Ohene-Asare, 2018). The following shows the importance of the inputs and outputs:

Inputs: Number of Container Terminals: This is critical as they provide the main infrastructure responsible for loading and unloading the containers full of materials (Martinez-Moya, 2025). **Number of Container Berths:** The very first place of arrival at the port is the berth, where offloading and unloading container terminal operations begin (Jiang et al., 2024). Hence, to prevent delays, there must be more berths or a process of improving vessel flow. **Number of Cranes:** The number of cranes is hinged to port productivity (Ningrat et al., 2024). **Number of Tugs:** Tugs are essential navigational tools for Vessels entering the ports (Bošnjak, et al, 2021). **Length of Quay:** This determines the type and size of a ship, which can be granted an allocation at a particular time for an unused berth and is crucial for port productivity (Jeong et al, 2024). **Port Employees:** This has a positive impact on port productivity (Ayesu et al, 2024).

Outputs: Container Throughput: The output of a container terminal is critical for port employment. (Ayesu et al, 2024). **Vessel Visits:** Chu et al (2023) posit that the punctuality of vessel visits or calls is crucial for port operations.

According to Negar and Rostamy-Malkhalifeh (2017), MPI shows the regression and progression of decision-making units, such as ports, over time. The two periods are the efficiency change and the technology change. Negar and Rostamy-Malkhalifeh, (2017) state that the MPI expresses that the regression and progress of a unit from one period to the next depends not only on its efficiency changes during these two periods, but also on technological changes in the population, or

boundary shift of the evaluated population in the same period Equation 1 is the MPI formula. The Pim-Dea V.3.0 software, developed by Emrouznejad and Thanassoulis (2011), calculates the efficiency change for the selected ports from 2017 to 2023.

$$M(Y_{t+1}, X_{t+1}, X_t) = \underbrace{\frac{D^t(Y_{t+1}, X_{t+1})}{D^t(Y_t, X_t)}}_{\text{Efficiency change}} \underbrace{\frac{D^t(Y_{t+1}, X_{t+1})}{D^{t+1}(Y_{t+1}, X_{t+1})} X \frac{D^t(Y_t, X_t)}{D^{t+1}(Y_t, X_t)}}_{\text{Technology change}}$$

Equation (1): The Malmquist Productivity Index Formula. Source: Malmquist (1953).

Where: X_t and X_{t+1} are the input vectors of dimension at time t and $t+1$, respectively, and Y_t and Y_{t+1} are the corresponding k -output vectors.

D_t and D_{t+1} denote an input

$$D(x, y) = \max(\rho : (s/\rho s \in L(y) \quad (1)$$

Where $L(y)$ represents the number of all input vectors with which a particular output vector y can be produced, that is, $L(y) = \{x : y \text{ can be produced with } x\}$.

P in equation (2) can be understood as a reciprocal value of the factor by which the total inputs could be maximally reduced without reducing output.

M measures the productivity change between periods t and $t+1$. Productivity declines if $M < 1$, remains unchanged if $M = 1$, and improves if $M > 1$.

4. Findings and Discussion

This section is categorised into three major sections based on the research objectives: the application of BCT on CMSC, the Application of Blockchain Technology at the Port of Rotterdam, and determining the drivers of port productivity for the Port of Durban and the Port of Rotterdam.

4.1. The Application of BCT in the Construction Materials Supply Chain

Blockchain technology is suitable for facilitating the construction material supply chain. Based on a literature search of over 50 articles using keywords like BCT and construction materials supply chain. The Application of blockchain has been streamlined into four major categories. These are smart contracts, track and trace, acceleration of document flow, and authentication and validation of documentation and stakeholders. Shojaei (2019) posits that the implementation of blockchain technology in the construction industry can also result in the use of smart contracts, which will reduce administrative struggles and improve the flow of the project, materials, and service delivery. Elmay et al. (2022) attest that

blockchain accelerates the inefficient shipping process by digitising ownership transfer and process documentation. Wang et al (2021) posit that blockchain enables simultaneous auditing and makes real-time optimisation possible for partners and organisations. Nasih et.al. (2024) confirm the use of BCT to improve tracking and tracing services, ensuring data integrity, transparency, and traceability across supply chains.

4.2. Application of Blockchain Technology at the Port of Rotterdam.

Wang et al. (2021) posit that the application of blockchain technology in the maritime industry can improve customs clearance efficiency and logistics transparency in the container cargo supply chains. Quay Connect was born out of the challenges of importing and exporting between the Netherlands and the United Kingdom. It was developed as an independent blockchain platform to facilitate the exportation of shipments from the Netherlands to the United Kingdom (Port of Rotterdam, 2025). The benefit of this application is the automatic exchange of information with the customs authorities at ports in the United Kingdom (Farah et al., 2024). The implication is that exporters from the Netherlands can digitise and streamline the export and customs process. This results in a savings of 30% on the cost of each customs clearance (Port of Rotterdam, 2025).

4.3. Determine the drivers of port productivity for the Port of Durban and the Port of Rotterdam

Port productivity is an important measure of port stakeholders (Gonzalez, 2022). The port productivity of both the port of Rotterdam and Durban is analysed for 2017 to 2023. The results of these analyses are categorised into efficiency change and technology change. The product of the efficiency changes and technology makes up the Malmquist Productivity Index. The Pim-Dea V.3.0 software developed by Emrouznejad and Thanassoulis (2011) calculates the efficiency change for the selected ports from 2017 to 2023.

4.3.1. Efficiency Change and Technology Change

The efficiency change component measures how well a firm, in this case the Port of Durban and Rotterdam, makes use of its resources to produce a given level of output. Both the Port of Durban and Rotterdam make use of their resources optimally, as indicated by level 1. Technological change measures how the production frontier shifts over time. As the frontier shifts upward, more outputs can be obtained from the same level of inputs. Technology is a major driver of productivity. There is a clear-cut demarcation of the impact of technology on port productivity for the Port of Rotterdam. The Port of Durban still has much room for improvement in terms of the application of suitable and customised technology on port performance.

4.3.2. The Malmquist Productivity Index

According to Negar and Rostamy-Malkhalifeh (2017), when the Decision-making unit has an MPI value of greater than one, as in the case of the Port of Rotterdam, it means that progress occurred consistently in the period 2017 to 2023, as indicated for 2017/2018 for the Port of Durban. However, if the decision-making unit has an MPI of less than 1, as in the case of the Port of Durban for the year 2019/2020, a regression occurs in the period. When the Port of Durban experienced MPU 1 in 2020/21 and 2022/23, it means that no progress or regression occurred. From Figure 1, the Port of Rotterdam has a higher Malmquist Productivity Index than the Port of Durban. The Technology factor plays a crucial role in the performance of the Port of Rotterdam. Figure 1 shows the implications of technology on the Port of Productivity for the Port of Rotterdam. Over the years, we have examined except for 2018-2019. The Port of Rotterdam has improved in its productivity due to the application of technology.

Operating System, and AVEVA Software to reduce the risk of load shedding (Transnet 2024).

5. Conclusion and Further Research

Gidado (2015) attests that congestion in ports is associated with delays, queuing, and extra time for the voyage and dwelling of ships and cargo at the port. This research was conducted because of the incessant delays experienced by importers of construction materials via the port of Durban. The research further used the Port of Rotterdam as a basis for comparison, as it is not only a smart port but has also made use of Blockchain Technology. This study identified the various applications of blockchain technology in facilitating the supply chain of construction materials. This lends credence to the importance of blockchain in the area of smart contracts, tracking and tracing of shipments, acceleration of document flow, and authentication and validation of documentation among stakeholders. The study proved that technology is a major driver of port

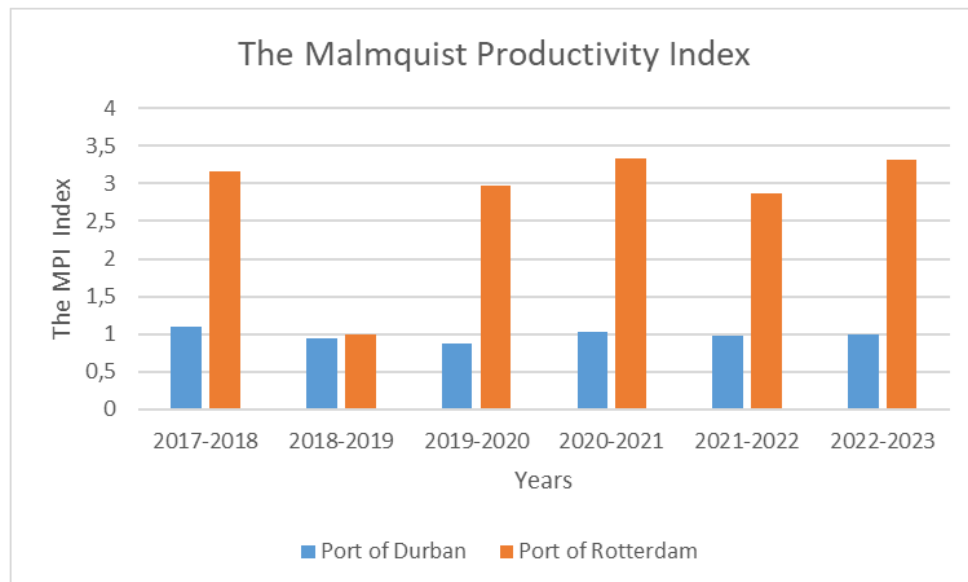


Figure 1: The Malmquist Productivity Index
(Source: Author's 2024)

4.4. Compare the various applications of technology at the Port of Durban and the Port of Rotterdam

The Port of Rotterdam is heavily automated and uses several technologies such as Blockchain (Quay Connect), HAMIS- Haven Management Information System, Artificial Intelligence and Twin Digitalisation to drive its operational efficiency (Farah et al, 2024). Elhussieny (2025) posits that the Port of Rotterdam is ranked highly in Europe and globally. However, CPPI (2023) indicates that the port of Durban is struggling in terms of its performance. The Port of Durban is still traditionally based, even though it uses various technologies such as Navis Sparscs N4, Electronic Data Interchange, General Cargo

productivity.

Furthermore, the gap in port productivity, as shown in Figure 1, shows the impact of technology on the MPI of the Port of Rotterdam. Finally, the study compares the various applications of technology at the Port of Durban and Rotterdam. The implication of this research is for the port authority, construction companies, and other stakeholders to know the benefits of blockchain in facilitating the construction material supply chain. For instance, Quay Connect is a collaboration between the Port of Rotterdam, Brexit, and Importers and Exporters. This customised BCT was developed to curb the struggles of importing and exporting between the European nations. Particularly since BCT provides a

way forward to handling port inefficiencies, for instance, Smart contracts can activate real-time actions or transactions, respectively, as soon as the pre-defined contractual clauses and rules are fulfilled (Phillip et al, 2019). The Port of Rotterdam engages its stakeholders in such a way that the technology used in the ports is well-suited to meet the needs of the port and its stakeholders. Further research can be pursued on the dynamics and criteria of collaboration amongst the

critical stakeholders. It is also necessary to monitor the efficiency of the ports in subsequent years to see if there is an improvement or a further decline in port efficiency.

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