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Analysing intermodal connectivity for the functionality of Namibia's regional logistics hub

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Background: In today's interconnected global economy, logistics and supply chain management are pivotal in facilitating the movement of goods and services across regions. Supply chains have become increasingly complex, involving multiple stakeholders, diverse transportation modes, and intricate global networks. The efficient management of these supply chains has emerged as a critical determinant of competitiveness and economic growth for businesses and nations.

Objectives: The study aims to analyse the level of intermodal connectivity and how it enhances the functionality of a regional logistics hub using Namibia as a case study.

Method: The research study adopted a mixed-method design, collecting data through interviews, questionnaires, and documentary analysis to examine intermodal connectivity and its impact on the functionality of the Namibian regional logistics hub.

Results: The study's key findings reveal a fragmented railway system and a significant reliance on road transportation within the Namibian transport system. The level of intermodality is found to be low, indicating limited connectivity and integration between different modes of transport in Namibia.

Conclusion: The study highlights the need to address the fragmentation within the railway system, reduce the heavy reliance on road transportation, and improve intermodal connectivity to enhance the functionality and efficiency of the Namibian transport system.

Contribution: This research contributes to the existing knowledge of transportation and logistics hubs within the Namibian context. By exploring the role of intermodal connectivity, the study builds upon the theoretical frameworks of transport geography, logistics management, and infrastructure planning.

Keywords: intermodal connectivity; logistics hub; regional integrations; transport system; degree of centrality.

Introduction

In a rapidly globalising world, where the efficient movement of goods and people lie at the heart of economic progress, the concept of a regional logistics hub has become increasingly significant. As nations strive to position themselves as pivotal nodes in the ever-expanding web of global trade, the quest to master intermodal connectivity takes centre stage (Savage et al. 2014). Among these aspiring contenders, Namibia emerges as a unique and compelling case study in the realm of logistics and supply chain management.

Namibia's strategic geographical location within the Southern African region makes it a pivotal crossroads for international trade (Petrus 2020). Its ambition to establish itself as a regional logistics hub, facilitating the seamless movement of goods and services within southern Africa and beyond, is a testament to the country's dedication to economic development and regional integration (Savage et al. 2014). This ambitious vision has, in turn, ignited a discourse surrounding the crucial role of intermodal connectivity in realising this dream.

This article embarks on critically examining the multifaceted and intricate world of intermodal connectivity, elucidating its importance in shaping the functionality of Namibia's logistics hub. In this pursuit, the study delves into the essence of the interplay between diverse modes of transportation within the Namibian context, including road, rail and air. Furthermore, dissecting the elements that hold together the logistics ecosystem reveals Namibia''s unique challenges, opportunities, and intricacies. In the context of Namibia, a country with strategic coastal access to the Atlantic Ocean and connections to various landlocked countries in the region, the role of intermodal connectivity becomes even more crucial. This article explores and analyses the role of intermodal connectivity in enhancing the functionality of Namibian regional logistics hubs, contributing to both the social and scientific understanding of this topic.

Conceptual framework

Developing a comprehensive conceptual model was the cornerstone of the study's analytical framework, enabling the researcher to dissect and understand the intricate dynamics within modern logistics ecosystems. The framework especially evaluated the ports and further extended the assessment of the various transportation modes, thus allowing to comprehensively address key facets that impact the efficiency and effectiveness of these hubs. The model's emphasis on intermodal connectivity, centrality, and accessibility fostered a deeper understanding of the factors underpinning their functionality within the broader transport network. The resulting insights will empower decision-makers and contribute significantly to the evolving field of transport and supply chain studies, shedding light on the critical role of logistics hubs in the modern global supply chain. In an era of complex logistics operations and globalised trade, this model plays a pivotal role in unravelling the dynamics that govern the efficiency and sustainability of logistics hubs within ports, paving the way for enhanced policy considerations and future research endeavours.

The conceptual framework of this study, as reflected in Figure 1, examines the interplay between intermodal connectivity and the functionality of Namibia's regional logistics hubs. This framework breaks down the broader concept of transport into its fundamental modal components: road, rail, and air transportation. Each mode is subdivided to account for specific attributes, capturing the critical elements crucial for investigating intermodal connectivity within Namibia's Regional Logistics Hub.

Establishing a resilient logistics hub necessitates integrating diverse transportation modes, fostering intermodal connectivity for seamless goods and passenger transfer (Rodrigue, Comtois & Slack 2013). This integration includes railway systems, road transportation, air travel, and access to ports, creating a holistic infrastructure. The nexus between railway networks and roads involves trucks facilitating the transfer of goods and passengers. Well-maintained road infrastructure complements this, featuring pavements, bridges, tunnels, and interchanges. Air transportation involves freighters, unmanned aerial vehicles, and regional cargo aircraft, supported by airport infrastructure such as runways, taxiways, terminals, and control towers (Kalić, Dožić & Babić 2022). Ports, serving as gateways to the sea, enhance global supply chains with efficient and well-connected facilities (Notteboom & Rodrigue 2022).

This holistic integration and infrastructure consolidation underpins intermodal connectivity, amplifying supply chain efficacy, reducing transit times, optimising cost structures, and providing necessary flexibility. Network metrics, such as degree centrality, betweenness centrality, degree of accessibility, and network density, are crucial for evaluating the efficiency and effectiveness of this intermodal logistics network (Ezaki, Imura & Nishinari 2023). These metrics assess interconnectedness, identify critical hubs, and ensure overall network robustness.

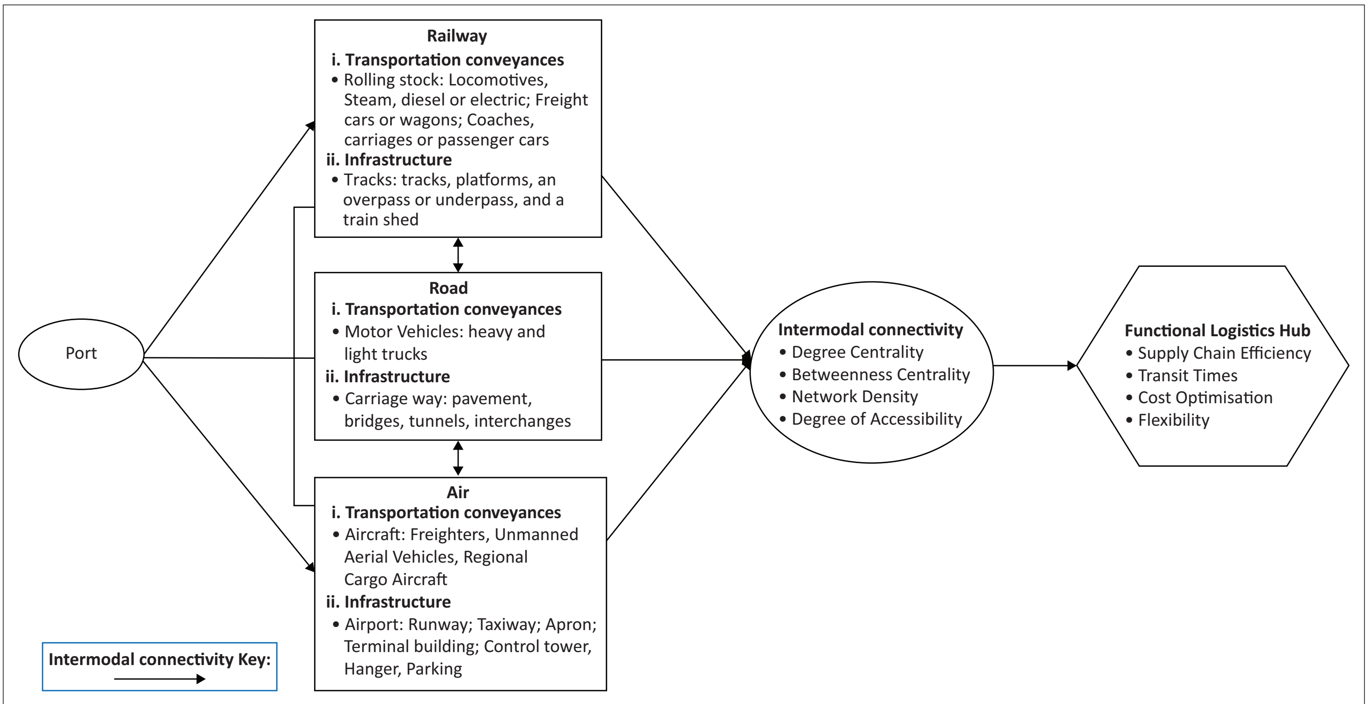


FIGURE 1: Optimizing intermodal logistics connectivity framework.

Accessibility, defined as the degree to which transport networks and land use facilitate reach to specific destinations or economic activities via various transport modes (Albacete 2017; Rodrigue 2020), is a critical factor in infrastructure development and regional growth. Accessibility involves location importance and distance measured through connectivity, emphasising its significance in transportation activities (Rodrigue 2020). Improved accessibility benefits both transport users and operators, offering time savings and economic advantages (Pukhova et al. 2021; Rothfeld et al. 2019).

The study delves into multifaceted aspects of intermodal connectivity, encompassing road networks, railway systems, ports, and airports. It evaluates their seamless integration within logistics hubs, considering connectivity and accessibility to vital regional and international trade routes. This investigation aims to gain insights into intermodal connectivity's influence on supply chain efficiency, transit times, cost optimisation, and capacity to manage increased trade volumes.

The 'objectives of the study are twofold: firstly, to assess current intermodal connectivity within Namibian regional logistics hubs, and secondly, to analyse the impact of intermodal connectivity and accessibility on hub functionality. By achieving these objectives, the research provides practical insights and recommendations for policymakers and industry stakeholders to enhance intermodal connectivity, strengthening the overall performance of regional logistics hubs in Namibia.

Theoretical framework

This study is grounded in transport network analysis theory, particularly graph theory, viewing transportation systems as interconnected networks of nodes and links. Network analysis, as highlighted by Arora, Islamia and Pandey (2020), focusses on solving routing issues related to traversability, flow rate, and network connectivity. Graph theory, simplified into sub-graphs, edges, and vertices by Dayalan (2020), is instrumental in describing the spatial structure of transportation networks for geographers and transport planners.

The study simplifies the transport network into links (road and rail, excluding junctions) and nodes (junctions or marshalling yards for rail). The network's accessibility, centrality, and connectivity is measured by applying graph theory indices such as beta, alpha, gamma, diameter, pie, eta, and theta, thus analysing its impact on Namibia's logistics hub realisation.

Namibia's transport system assessment, employing network analysis theory, identifies critical nodes and connectivity patterns through centrality measures such as degree, betweenness, and closeness centrality. Challenges in major transport hubs align with centrality issues, highlighting their significance. Connectivity measures, particularly density, highlight regions with limited links, corresponding to accessibility challenges. Vulnerability analysis pinpoints areas susceptible to disruptions, emphasising threats to resilience. Network theory provides a valuable framework for analysing complex relationships within intermodal transportation systems. This approach offers a nuanced understanding of interdependencies and potential vulnerabilities in Namibia's logistics network, therefore contributing to informed decision-making and strategic planning for enhanced intermodal connectivity.

Recommendations for rail and air network improvements directly address redundancy challenges and reflect the optimistic and well-structured approach of network theory in analysing intermodal connectivity. However, precision in models derived from network theory relies on data quality and availability. While promising for comprehending intermodal connectivity, the precision of results hinges on the reliability and accessibility of the data used in the modelling process.

In the context of Namibia, a critical gateway to Southern African countries, network analysis theory must prioritise cross-border connectivity. This involves explicit evaluation of regional collaborations, trade agreements, and transport links' effectiveness to address complex geopolitical and economic dynamics. A comprehensive understanding, guided by network analysis, forms the basis for targeted, data-driven interventions to enhance efficiency and resilience.

Additionally, network analysis theory is instrumental in assessing intermodal connectivity for Namibia's Regional Logistics Hub, providing insights into efficiency and functionality. The recommended comprehensive, multimodal approach aligns with identified centrality issues, emphasising the need for road, rail, and air infrastructure enhancements to address specific study outcomes, such as reduced transportation bottlenecks, improved supply chain reliability, and increased economic productivity (Bell & Lida 2014)

Literature review

In the dynamic realm of global trade, logistics hubs' efficacy rests on robust intermodal connectivity (McKinnon 2015), underscoring the crucial nature of seamless interconnectivity within a logistics hub. This study examines the intricate web of transportation modes shaping Namibia's Regional Logistics Hub, by evaluating the multifaceted dimensions influencing intermodal functionality. The seamless integration of road, rail, air, and maritime networks emerges as a central element for logistical efficiency and economic competitiveness. Measured through alpha index, connectivity is crucial, while beta index assesses accessibility, emphasising smooth logistic network entry. Gamma index evaluates centrality, providing insights into critical elements for hub efficiency. By drawing on the authoritative work of Reis and Macário (2019) this structured approach ensures a comprehensive examination of intermodal dynamics within the logistics hub. As the study delves into the intricacies of intermodal connectivity, the analysis is grounded in influential studies by Rodrigue et al. (2013) on transport geography, Lowe (2006) on intermodal freight transportation, and with insights from key author McKinnon (2015), who has made significant contributions to the understanding of logistics hub dynamics. This research contributes a detailed perspective to the field, shedding light on the pivotal role of interconnected transport modes in advancing Namibia's prominence as a regional logistics hub.

Types of transport connectivity

Intermodal connectivity

Intermodal connectivity, as defined by Rodrigue (2020), integrates various transportation modes for efficient networks. As highlighted by Zhao, Zhu and Wang (2020), it stimulates long-term growth, reduces transport costs, and enhances supply chain efficiency.

Namibia's logistics hubs, underscored by Savage et al. (2014), facilitate effective transportation solutions by connecting landlocked nations to ports and promoting regional trade. Collaborative efforts and improved intermodal connectivity are vital for success. Intermodal connectivity, as observed by Abdallah, Alfar and Alhyari (2021), optimises processes, increases customer satisfaction, fosters supply chain reliability, and improves centrality within transportation networks (Muller 2016).

Integration of transportation modes, supported by Setiawan, Susilo and Setyadi (2022), boosts operational effectiveness, reduces costs, supports sustainability, and fosters regional trade. However, Namibia faces challenges in infrastructure, particularly in road and rail systems, hindering accessibility and connectivity (Saruchera 2020). To address these issues and enhance the transportation network's centrality, investment in infrastructure development, maintenance, and expansion is crucial (Petrus & Krygsman 2021), ensuring smooth multipurpose activities and overall connectivity in Namibia.

Infrastructure connectivity

Road

Road transportation in Southern Africa plays a pivotal role in fostering accessibility for passenger and freight movement, granting spatial flexibility and accommodating a wide range of purposes, spanning from short-distance shipments to door-to-door distribution. To further enhance the centrality and connectivity of the region's transport networks, concerted efforts are required to address persistent challenges, including fragmented national planning, road infrastructure maintenance, and border congestion alleviation. Solutions proposed in the academic literature include privatisation guided by economic viability and institutional restructuring in alignment with the Southern African Development Community (SADC) Protocol (Engström 2016; Habiyaremye 2020; Monyepao 2015; Rodrigue 2020).

Moreover, as the region anticipates a surge in traffic, the imperative of transport demand management takes on added significance, as it can enhance both accessibility to critical destinations and the overall connectivity of transportation systems. The integration of modern technology into border processes, as highlighted by Joseph (2023) and Tralac (2021), holds the potential to streamline operations, reduce congestion, and foster more efficient centrality within the network. Namibia has set its sights on implementing key road projects to improve the connectivity and infrastructure of its transportation system, as reported by the Roads Authority (2022). By embracing these strategies and innovations, Southern Africa can embark on a transformative journey towards more efficient, accessible, and integrated road transportation systems, reinforcing the centrality of the region's vital transportation networks.

Rail

A comprehensive railway network in Southern Africa is crucial for a safe, efficient, eco-friendly transport solution bridging urban and rural areas (Rodrigue 2020). The prevailing emphasis on resource transportation by the railways in the Southern African region has posed a challenge to regional integration. This is because of the dominance of trucks in the freight market, while the railway systems are not being fully utilised. The underutilisation of railways, coupled with the dominance of trucks in transporting resources hampers the cohesive integration of transportation networks within the region (Avogadro et al. 2021; Lesmin et al. 2017). Challenges in rail infrastructure investment have led to road traffic congestion, environmental concerns, and inefficiencies as road transport has become the preferred choice (Saruchera 2017). To overcome these challenges, the development of integrated logistics hubs (Zeng et al. 2020) and strategic interventions to enhance railway speed, reliability, and interoperability are required (Oumarou 2015). Governments must transition from subsidies to strategic participation, as demonstrated by South Africa's Spoornet (TransNamib case 2023). Innovations emphasising government-driven regulatory improvements and investments in privatisation of railway sector independence are crucial (TransNamib case 2023). In addition, an intermodal approach to supply chain management can offer economic benefits (TransNamib 2022), with proper rail connectivity to ports boosting economic development and capacity growth while reducing urban congestion (TransNamib 2022). In Namibia, TransNamib's 'Road to Rail strategy' aims to shift freight traffic from roads to railways, but modernisation and legal constraints pose challenges (TransNamib 2022). Realising the full potential of the railway sector necessitates addressing historical inadequacies, encouraging strategic government involvement, and repositioning rail transport as a preferred land transportation mode, ultimately leading to a more interconnected and prosperous Africa.

Air

Air transport is vital for global economic integration and regional connectivity, which prompts policymakers worldwide to prioritise airport construction and expansion to support economic progress (Gibbons & Wu, 2017).

Airports have evolved into pivotal components of regional transportation policies, facilitating opportunities in an era of globalisation and trade openness (Elburz, Nijkamp & Pels 2020). Regional development policies must recognise the importance of addressing aviation-related concerns and promoting economic competitiveness and social cohesion, particularly in remote areas (Dimitrios & Maria 2018). Critical policy considerations encompass issues such as infrastructure, dependency, airport governance, regulation, and air traffic control frameworks (Adler et al. 2020). Thus, a regional developmental policy perspective is imperative in evaluating the readiness of air transport systems to serve as logistics hubs.

Functional logistics hub

Supply chain efficiency, as emphasised by Kashem et al. (2023), is essential for streamlined operations, reduced delays, and minimal disruptions. A robust multimodal network enhances coordination among transportation modes by reducing bottlenecks and improving overall performance. In Namibia, the logistics hub is a cornerstone for trade advancement and economic growth (Walvis Bay Corridor Group 2016). Assessing its progress involves considering factors such as supply chain productivity, transit times, cost minimisation, and the capacity to handle growing trade volumes (ed. Ford 2010).

Establishing a thriving logistics hub in Namibia ensures streamlined supply chains, shorter travel times, lower costs, and the ability to meet increasing trade demands, enhancing competitiveness, attracting investment, and promoting sustainable economic development.

Transit time, a critical indicator of logistics hub functionality, encompasses handling, processing, and transportation durations (McKinnon 2015). Effective multimodal connectivity significantly reduces travel times by facilitating interconnections between transportation modes, minimising wait times, and improving overall coordination. Cost optimisation is vital, which impacts trade competitiveness and economic activities. It involves reducing unnecessary detours by establishing efficient transportation routes, and minimising expenses through effective intermodal connectivity (ed. Ford 2010).

Intermodal connectivity is crucial to enhancing the capacity of regional logistics hubs in Namibia. A multimodal network expands logistics centres' capabilities and improves operational flexibility and readiness. This enables them to respond promptly and efficiently to changing trade demands by seamlessly integrating different transportation modes, ensuring successful management of increased trade flows, enhancing operational efficiency, and reducing congestion.

Establishing an efficient multimodal network, optimising transit times and costs, and enhancing intermodal connectivity are vital for achieving supply chain efficiency and maximising the potential of logistics hubs in Namibia. These measures will facilitate economic growth, attract investment, and support sustainable development in the country.

Globally, logistics hubs play a critical role in facilitating the movement of goods (Verschuur, Koks & Hall 2022). Prominent examples include Singapore, Shanghai, and Rotterdam, while in Africa, Durban is a key player (Dewiatena & Bahagia 2023). Singapore's strategic location and world-class infrastructure make it a preferred choice for businesses, handling approximately 36.9 million Twenty-foot Equivalent Units (TEUs) of container traffic in 2020 (Yap 2023). Shanghai, the world's busiest container port, benefits from proximity to China's manufacturing centres, handling around 43.5m TEUs in 2020 (Nesse 2023). Rotterdam serves as a multimodal logistics hub, handling approximately 14.8m TEUs in 2020 (Banu 2022).

In Africa, Durban has emerged as a vital logistics hub, being the largest container port in Southern Africa (Mthembu & Chasomeris 2023). The Port of Mombasa in Kenya and the Port of Dar es Salaam in Tanzania are powerhouses in East Africa, overseeing substantial cargo movements in 2020 (Dooms & Muganga 2022; World Bank 2023). In contrast, the Port of Walvis Bay in Namibia, while growing, managed modest statistics in the same year (Namport 2020). The ability to seamlessly switch between different transport modes is crucial for Durban's prominence.

These logistics hubs collectively underscore the importance of strategic location, state-of-the-art infrastructure, connectivity, and the crucial role of multimodal transportation in shaping the global logistics landscape.

Measures of transport connectivity

Transport connectivity is crucial in various aspects, including trade, economic growth, regional integration, social accessibility, and sustainable development (Rodrigue 2020). It catalyses the efficient movement of people, goods, and information by enhancing market access, social inclusion, and resilience and promoting economic and environmental sustainability (Chakwizira 2022). Namibia predominantly relies on road and rail transportation as its primary modes of transport. In terms of air transport, the challenges, including the cessation of Air Namibia operations and the broader disruptions caused by the coronavirus disease 2019 (COVID-19) pandemic, pose significant risks to the success of the logistics hub. These issues introduce uncertainties in air connectivity, thus potentially impacting the hub's accessibility and operational efficiency. Hence, the measures of transport connectivity have primarily concentrated on road and rail transportation.

The beta (β) index (Equation 1), which measures the level of connectivity in a network, is determined by the ratio of the number of links (e) to the number of nodes (n) (v). A higher β value from 0 to 1 indicates a more interconnected and efficient transport network. Networks with a value of 1 have one cycle and one connection, while complex networks have a value greater than 1. In networks with a constant number of nodes, more links create more alternative paths, leading to greater network connectedness in general (Equation 1: Beta Index formula [Rodrigue 2020]):

$$\beta = \frac{e}{v} \quad \text{[Eqn 1]}$$

The gamma index (road and rail network)

The gamma (γ) index (Equation 2) calculates the ratio of the actual number of edges to the maximum possible number of edges in a network. In the case of a planar graph, this index can be computed as the number of actual links divided by the maximum number of links. It is vital to compare the structures of different networks, such as Namibia's road and rail network structures. The γ index ranges from 0 to 1 and can provide valuable insights into the accessibility and connectivity of a network. The study conducted in the context of this discussion utilised the γ index to measure the accessibility and connectivity of the rail and road networks, as shown in Figure 5. This analysis's results help to assess the efficiency and effectiveness of these networks in facilitating transportation, which is denoted by the formula in Equation 2: Gamma Index formula (Rodrigue 2020):

$$\gamma = \frac{e}{3(v-2)} \quad \text{[Eqn 2]}$$

The alpha index (road and rail network)

The alpha (α) index is an essential connectivity index used to evaluate the structure of a network. It is defined as the ratio of the actual number of circuits in the network to the maximum number of circuits possible (Chou 1999). A circuit refers to a loop within the network composed of nodes and links. This index allows for comparing different networks based on their connectivity levels by assessing the network topology regarding the number of paths between nodes. The calculation of the α index in a planar graph, as shown in Equation 3, produces a value ranging between 0 and 1 and it's denoted by the formula in Equation 3: Alpha index formula (Rodrigue 2020):

$$\alpha = \frac{e-v+1}{2v-5} \quad \text{[Eqn 3]}$$

Degree centrality

The significance of intermodal connectivity in regional logistics hubs has been the subject of extensive academic research that has considered various dimensions such as degree centrality, betweenness centrality, and network density (Van Klink 2018). According to Liu, Xie and Lyu (2023), the concept of degree centrality is crucial in determining the degree of intermodal connectivity within these hubs.

A degree centrality metric measures how many connections or links a transportation node has within the logistics hub network. As stated by Zhang and Luo (2017), a transportation node with a higher degree of centrality has a greater number of connections that facilitates the smooth transportation of goods and services and enhances its integration into the more extensive logistics network. For effective intermodal operations to be carried out, the logistics hub must incorporate road, rail, and maritime transportation modes. Munim and Schramm (2018) conducted a study that found that transportation nodes with a high degree of centrality have better accessibility, a greater flow of goods, and shorter transit times. The ability of highly interconnected nodes to effectively allocate and centralise shipments across various transportation modes, optimising the hub network's overall logistics operations, is the source of the advantages mentioned earlier.

In addition, shippers, carriers, and service providers all benefit significantly from a high level of centrality when it comes to fostering productive collaboration and coordination among the various stakeholders involved in logistics. As per Bahadur (2017), it cultivates the foundation of joint efforts and connections that work with the usage of aggregate assets, trade of information, and upgrade of functional adequacy. By facilitating the smooth transfer of cargo across various modes of transportation and fostering collaboration among multiple stakeholders, intermodal connectivity contributes significantly to supply chains' resilience and responsiveness.

However, some challenges must be overcome to achieve and maintain a high degree of centrality. One of the chief hindrances lies in the foundation of an adequate framework to maintain multipurpose tasks and empower a consistent network (Ensermu 2018). According to Saruchera (2020), Namibia's inadequate road and rail infrastructure makes it difficult to establish effective intermodal connectivity. Investing in infrastructure development, such as expanding and maintaining transportation networks, is essential to meet this challenge and increase the centrality of transportation nodes.

The potential for improving transportation productivity and infrastructural development through multipurpose availability in Namibia is enormous. The country's unique geographical and demographic characteristics and the absence of robust road and rail networks present obstacles that necessitate targeted infrastructure development investments. In order to align stakeholders' interests, facilitate resource sharing, and develop comprehensive strategies to enhance intermodal connectivity, it is also essential to encourage collaboration and coordination among various stakeholders. Namibia has the potential to effectively utilise the benefits of intermodal connectivity, increase the resilience of its logistics hub network, and promote the achievement of sustainable economic growth by successfully overcoming these obstacles. This contribution emphasises the significance of focussed infrastructure investments and stakeholder collaboration efforts for Namibia to achieve effective intermodal connectivity.

Betweenness centrality

Betweenness centrality measures the degree to which a transportation node serves as a bridge or intermediary between other nodes, and this is crucial in logistics hub networks (Rodrique 2020). This measurement is instrumental in working with the productive development of merchandise inside such organisations. Wu et al. (2022) highlight that nodes with a high degree of betweenness centrality are strategically placed to make it easier for goods to move between different routes and modes of transportation. The overall connectivity is improved and transit times are cut down as a result. Zhang and Luo (2017) state that these nodes help to improve accessibility, optimise distribution, and consolidate goods within the logistics hub network. As a result, supply chain responsiveness and efficiency are enhanced. Advanced technology solutions such as real-time data sharing and predictive analytics, in conjunction with investments in infrastructure like intermodal terminals and transhipment facilities, can improve betweenness centrality and optimise the function of transportation nodes as intermediaries (Rodrigue 2020).

The challenges posed by Namibia's limited and underdeveloped infrastructure, particularly in the road and rail networks, impede the country's pursuit of optimal betweenness centrality and intermodal connectivity. Inadequate infrastructure makes it difficult to strategically position transportation nodes and make it easier for goods to be transferred between various routes and modes of transportation effectively. Focussed investments in infrastructure development and novel strategies considering the country's distinct demographic and geographic characteristics are vital to overcoming these obstacles.

Network density

Another measure of intermodal connectivity is network density, which measures how interconnected transportation nodes are in the logistics hub network (Forslund 2022). A greater level of integration and coordination is indicated by a higher density of networks, which makes it possible for stakeholders in logistics operations to collaborate and share resources effectively. Network density is an essential indicator of the degree of collaboration and interconnection among transportation nodes in the logistics hub network in Namibia. By encouraging a higher network density, Namibia can encourage improved integration and coordination among stakeholders involved in logistics operations (Eva 2016). This, in turn, makes it easier to work together effectively, share resources, and form strategic partnerships, all of which improve intermodal connectivity throughout the nation. Namibia has the potential to develop a logistics ecosystem in which stakeholders collaborate seamlessly, optimise resources, and fuel economic expansion by concentrating on increasing network density.

Weber (2016) conducted an empirical study that examined topological network connectivity measures and their application in the United States' (US) urban freeway networks. The study primarily focussed on the effectiveness of the γ measure as an indicator of network connectivity. While γ was found to be proficient in gauging the level of connectivity within a network, the research also unveiled a limited correlation between γ and freeway structure. This observation suggested a potential weakness in utilising γ as a measure of connectivity within urban freeway networks. In contrast, the α measure emerged as a valuable tool, offering fundamental insights into network connectivity and complexity. However, the study did not explicitly outline any limitations associated with α within the given abstract and context.

The research on road network connectivity and accessibility in less accessible airport regions in India, by Sharma and Ram (2023), conducted a comprehensive analysis leveraging the α, *β*, and γ indices. These measures played a pivotal role in evaluating transport network connectivity and identifying structural variations. Notably, the research did not specify any weaknesses in its methodology or findings.

In a study focussing on the global air transport complex network, Guo et al. (2019) conducted an analysis that examined the robustness and intricacies of the global air transport network. This examination employed the α, *β*, and γ indices to gain insights into the network's structural stability and complexity. These indices proved to be valuable tools for detecting shifts within the network structure, particularly in system and traffic analyses. However, the study found a limitation with the α index, which does not account for the number of potential paths in the network, potentially affecting the comprehensiveness of the findings.

Finally, the study conducted by Gankhuyag, Myagmarsuren and Altankhuyag (2021) on the spatial analysis of Mongolia's road network underscored the strengths of the α, *β*, and γ indices in system and traffic analyses. The *β*index was particularly instrumental in assessing road connectivity levels, while the αindex provided insights into network connectivity and complexity. Nevertheless, a limitation became apparent in the αindex, which did not consider the number of feasible paths in the network, potentially affecting the overall comprehensiveness of the study's findings.

Literature gap

The impact of intermodal connectivity on the operation of Namibia's regional logistics hubs has been the subject of research in the literature. However, there are still some voids that require filling in. Firstly, there is a pressing need to investigate the particular difficulties and obstacles that stand in the way of effective intermodal connectivity in Namibia, such as the deficient road and rail infrastructure (Savage et al. 2013). Policymakers and stakeholders will benefit significantly from gaining an understanding of these obstacles to develop specific plans for infrastructure development (Forslund 2022). Secondly, the literature emphasises the advantages of intermodal connectivity in terms of capacity handling, cost optimisation, transit times, and supply chain efficiency (Edward 2021). According to Forslund (2022), there is a need to delve further into the commonsense procedures and best practices for accomplishing these results. Savage et al. (2013) found that Namibia could benefit from learning from successful case studies and examining the actions to enhance intermodal connectivity in other countries or regions.

For creating a collaborative ecosystem that supports intermodal connectivity and enhances the functionality of logistics hubs in Namibia, it will be helpful to examine successful collaboration models, identify key stakeholders, and comprehend the incentives and barriers to collaboration.

In summary, the literature emphasises the significance of intermodal connectivity in enhancing the functionality of regional logistics hubs in Namibia. It highlights the benefits of intermodal connectivity, including improved supply chain efficiency, reduced transit times, cost optimisation, and increased capacity to handle growing trade volumes. However, several gaps need to be addressed, such as understanding the challenges related to infrastructure development, identifying practical strategies, exploring the role of technology, and fostering collaboration among stakeholders. By addressing these gaps, policymakers and stakeholders can make informed decisions and develop comprehensive strategies to enhance intermodal connectivity, strengthen logistics hubs, and drive economic growth in Namibia.

Research methodology

The research study adopted a pragmatic philosophy, allowing for a mixed-method design that combined quantitative and qualitative methods. Data were collected simultaneously, allowing the researcher to employ any necessary technique at each study stage.

Study site

The study site for this research is Walvis Bay, in the Erongo region in Namibia, as it hosts the logistics hub and is, therefore, central for all stakeholders.

Namibia, with a vast land area of approximately 825 418 sq km, ranks among the largest countries in Africa. Notably, despite its expansive territory, Namibia's population of around 2.5m people as of 2020, with a population density of approximately 3 people per square kilometre, underscores the low population density characteristic of the country. This demographic feature further highlights the vast and sparsely populated nature of Namibia. In terms of transportation infrastructure, Namibia faces notable challenges in establishing efficient road and rail networks because of its vast size and low population density. The road network comprises around 45 000 km of paved roads and over 34 000 km of unpaved roads, while the country operates approximately 2382 km of rail lines (Saruchera 2017).

These infrastructure limitations, combined with the country's geographical expanse, contribute to the complexities associated with enhancing transport connectivity and accessibility in Namibia (World Bank 2020). Namibia's transport connectivity and accessibility can be compared to South Africa, its neighbouring SADC country with a highly developed transport network. In 2020, the Port of Walvis Bay in Namibia handled approximately 1 005 000 TEUs of containers, showcasing its significance as a regional transportation hub (Namport 2020). In contrast, Port of Durban, one of South Africa's major seaport, managed over 2.7m TEUs of containers and more than 81m tonnes of cargo in the same year, highlighting its substantial capacity and connectivity (Mthembu & Chasomeris 2023).

South Africa maintains an extensive road network with over 750 000 km of roads, a substantial portion of which is paved, facilitating efficient transport across the country (Road Traffic Management Corporation 2021). Namibia's road network comprises around 45 000 km of paved and over 34 000 km of unpaved roads, which presents challenges for access and interconnectivity, especially in more remote areas (RA 2020). While Namibia is actively working on improving its transport infrastructure, South Africa's well-established and extensive network provides it with a more advanced level of transport connectivity and accessibility. This comparison underscores the significant disparities in transport infrastructure development between the two neighbouring SADC countries.

The map in Figure 2 provides an overview of Namibia's extensive transport corridor networks, encompassing railways, town selection, ports, the coastline, and trunk road corridors. Notably, the map highlights the significant connectivity of the Walvis Bay port, facilitated by both road and rail transportation modes, thus promoting intermodal accessibility. Furthermore, the Walvis Bay port is intricately linked to all five major transportation corridors: Trans-Kalahari, Trans-Caprivi, Trans-Kunene, Windhoek-Luanda, and Trans-Oranje corridors. These corridors establish vital connections with neighbouring countries, including Botswana, Zimbabwe, Zambia, Angola, and South Africa, underlining the port's role as a pivotal regional hub.

The map underscores the selective distribution of rail infrastructure within Namibia, with conspicuous missing links in specific regions. Notably, the country's rail network exhibits limited interconnectivity with neighbouring nations such as Botswana, Zambia, and Zimbabwe. In contrast, the railway system within Namibia primarily establishes connections with Angola and South Africa but lacks compatibility with the broader regional railway network. As depicted in Figure 2, the railway tracks predominantly traverse central regions, driven by historical military considerations, resulting in inadequate linkages within Namibia and neighbouring countries.

The study population, drawn from the Walvis Bay port stakeholders list provided by Namport in 2020, included 745 port users. To account for the diverse sectors represented in this study, a combination of probability and non-

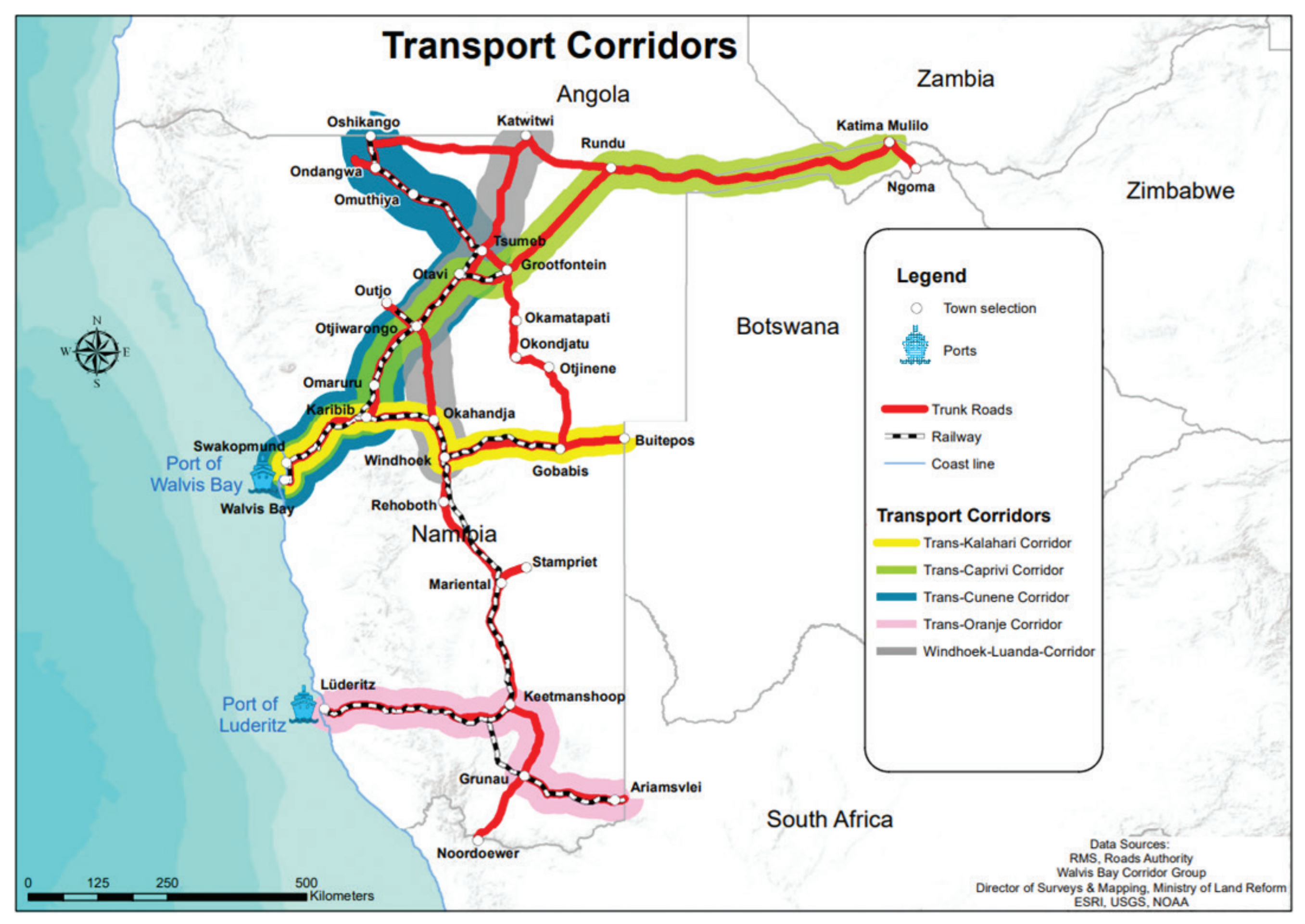


FIGURE 2: Transport corridors in Namibia.

probability sampling strategies was employed. Recognising the multisector nature of the study, it utilised a stratified sampling approach, which involved categorising the research population into distinct strata corresponding to various sectors, including regulatory customs and border control, direct stakeholders, freight forwarders, trucking companies, and vessel agents. Subsequently, the researcher used convenience sampling by individually selecting participants within strata based on availability or convenience. The study used Cochran's formula to calculate the sample size. Hence, the study sample size was determined to be 384 (Equation 4: Cochran's formula [Sekaran & Bougie 2016]):

$$n_0 = \frac{Z^2 pq}{e^2} \quad \text{[Eqn 4]}$$

Where:
- $Z = 1.96^2$
- e is the desired level of precision of 0.05^2
- p is the (estimated) proportion of the population, which has the attribute in the question of 0.5
- q is $1 - p$ or 1–0.5

Sample size calculations:
$n_o = 1.96^2 \times 0.5 \times (1–0.5)$
0.05^2
$n_o = 384$

The data collection tools utilised in this study, namely documentary analysis, semi-structured interviews, and a validated questionnaire, were selected to effectively capture and assess the role of intermodal connectivity in enhancing the functionality of the Namibian regional logistics hub. Cronbach's alpha and the sample adequacy test were utilised to assess the study's reliability, revealing a Cronbach alpha value ranging from 0.706 to 0.875 and a significant Kaiser–Meyer–Olkin (KMO) test value of 0.908 ($p < 0.001$).

The study's validity was established through multiple means: (1) Content validity was ensured by reviewing pertinent literature to identify relevant variables and constructs. (2) Criterion validity was achieved by analysing comparable studies, considering their strengths and limitations, and adopting a mixed-method approach. (3) Confirmatory validity was achieved by comparing the study's findings with existing cases, which confirmed the alignment of strategies for establishing Namibia as a logistics hub with established characteristics.

The study adopted a comprehensive approach to analyse the collected data, encompassing a combination of both qualitative and quantitative methodologies. Qualitative techniques, such as thematic analysis, were applied to scrutinise documentary sources and conduct semi-structured interviews. Complementary to the qualitative approaches, quantitative analysis involved the use of descriptive statistics and inferential methods. The inferential analysis employed analysis of variance (ANOVA) to discern variations in cargo volumes across distinct modes of transportation. In addition, descriptive statistical measures, including α, *β*, and γ indices, were employed to assess the extent of network connectivity, particularly within the domains of road and rail transport. This comprehensive analytical framework laid the groundwork for the investigation and elucidation of transportation dynamics and network performance within the research scope. Furthermore, this all-encompassing approach facilitated a thorough assessment of the data, enabling an exploration of intermodal connectivity and its influence on the operational efficiency of the Namibian regional logistics hub.

Ethical considerations

Ethical clearance to conduct this study was obtained from the University of KwaZulu-Natal Humanities and Social Sciences Research Ethics Committee (HSSREC). (No. HSSREC/00002928/2021), which protected the participants, ensured informed consent, upheld the principles of confidentiality, fostered research integrity, and guaranteed adherence to ethical guidelines and regulations.

Results

Transport modes used in Namibia

Documentary analysis was undertaken to determine the diverse methods of cargo transportation in use, and in this article rail, road and sea were the modes used. Air transportation was not used because the national airline, Air Namibia, was liquidated; thus no data were readily available. This analysis resulted in the compilation of a comprehensive dataset, visually presented in Figure 3. The figure clearly illustrates the distribution and relative importance of each mode of transportation within the specific geographical context under study.

As illustrated in Figure 3, 57.0% of exports in 2021 were shipped via sea, while air and road transport contributed 25.0% and 18.4% of the total export volume, respectively. Imports, as reported in the Namport annual report (Namport 2020), heavily favoured road transportation at 70.0%, with sea transport at 25.0% and air transport at a mere 5.0%. These statistics emphasise a significant challenge: Namibia, acting as a crucial gateway via the Walvis Bay port, plays a pivotal role in granting access to international shipping routes for landlocked neighbouring nations and countries in the SADC (AFDB 2023). Nevertheless, the prevalent reliance on road networks to transport export freight from neighbouring countries has placed considerable stress on Namibia's road infrastructure. This strain has had adverse consequences for infrastructure quality and maintenance, in addition to raising concerns about general traffic safety because of the increased volume of heavy vehicle traffic (AFDB 2023).

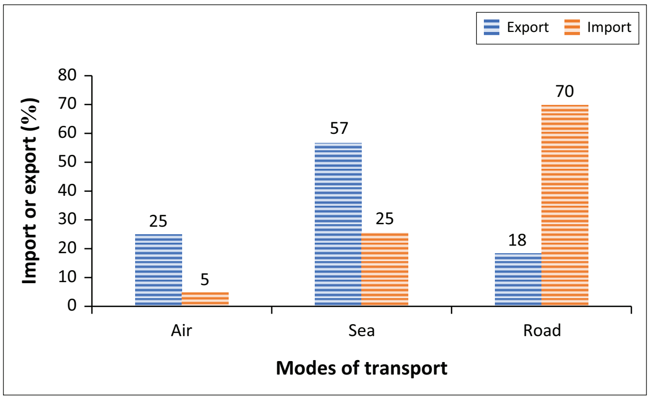
Conversely, there is a clear indication of enhanced capacity at the port with the Walvis Bay port expansion completed in 2019, tripling the port's container handling capacity from 355 000 TEUs to 1 005 000 TEUs per annum (Namport 2019), and sea transport currently representing 57% of the export volume (Namport 2022). However, the underutilisation of railway transportation exposes a gap in the overall transport system's interconnectivity and efficiency as TransNamib only railed 1.6m tonnages of freight rail in 2021, less than half the projected cargo for 2020 (TransNamib 2020). These findings further underscore the heavy reliance of the Namibian transportation system on road and maritime modes, with limited integration into other transport options, particularly the strategically important railway system for efficient logistics. Furthermore, the study utilised α, *β*, and γ indices to assess the road and rail network's connectivity using the towns, ports, and destination outside of Namibia as the nodes. The results are presented in Table 1.

The results are interpreted as follows:

Road network

Beta index

With a value of 1.11 (road) and 0.79 (rail), the *β* index represents the average path length between any two nodes in the rail and road network. The higher road *β* index suggests that, on average, it takes longer to travel between nodes in the road network. This could indicate a relatively less efficient or direct road network in Namibia. While the lower rail *β* index indicates that, on average, it takes less time to travel between nodes in the network. This suggests a relatively efficient and direct railway network in Namibia, as the average path lengths are shorter than the road network.



Source: Namport, 2020, *Integrated annual report 2019/20*, viewed from https://www.namport.com.na/files/documents/af7_Annual%20Report%2012%20months%20ended%2031%20March%202020.pdf

FIGURE 3: Exports and imports by modes of transport.

TABLE 1: Beta Index results on Namibia's road and railway connectivity.

Index	Formula	Road	Rail
Beta	$\beta = \frac{e}{v}$	*β* = 38/34 1.11	*β* = 27/34 0.79
Gamma	$\gamma = \frac{e}{3(v-2)}$	γ = 38/3(34–2) γ = 0.39	γ = 27/3(34–2) γ = 0.28
Alpha	$\alpha = \frac{e-v+1}{2v-5}$	α = 38–34+1 2(34)–5 α = 0.079	α = 27–34 + 1 2(34)–5 α = -0.095

Gamma index

The lower γ index suggests a more evenly distributed network without significant hierarchy levels. This indicates a relatively decentralised railway network in Namibia, like the road network. Gamma Index value of 0.39 (road) and 0.28 (rail) suggests that there may be some gaps or challenges in infrastructure, connectivity or transportation services within the rail and road transportation network, implying room for improvement to enhance the efficiency and effectiveness of the transportation system to facilitate smoother movement and trade. These results, compared with the *β* index, suggest that factors might hinder the seamless connectivity and coordination of transportation modes, potentially affecting the overall functionality of the network.

Alpha index

The study also used the α index to evaluate network topology regarding the number of paths between nodes in a rail and road transportation network. With a value of 0.09 (road) and -0.095 (rail), the α index represents the ratio of the actual number of circuits to the maximum number of circuits in the network. The lower α index results suggest a lower network connectivity level. It indicates that there may be limited paths or routes between nodes, potentially leading to reduced accessibility and options for reaching different locations within the network. Albeit, the street network in Namibia shows a more significant level of organisation availability considering the *β* and γ files; it is as yet lacking in the quantity of most extreme circuits that could be associated. The road network assumes a tree structure, radiating from the port of Walvis Bay to various locations (via corridors) without branch connections, which could account for this. The negative α index result for rail indicates that the α index's estimate of rail connectivity is insufficient to calculate.

Road and railway degree of centrality

The study measured the degree of centrality to quantify the importance or prominence of a node within the rail and road network based on the number of its connections. Figure 4 shows the result for the road degree of centrality.

Figure 4 highlights that Windhoek and Otavi are the most connected and accessible towns, with a centrality value of 64%, followed by Otjiwarongo, Okahandja and Keetmanshoop at 45% relative to the maximum possible connections. This means these nodes can be accessed via links, like the hub with many spokes around. Furthermore, the coastal towns, Walvis Bay and Luderitz, have low centrality measuring at 14%. This result implies limited accessibility and connectivity to inland, which can result in outbound and inbound congestion. The fewer connections could lead to longer transport routes, increased costs, and potential delays in the movement of goods and services, hindering the ability of these towns to serve as efficient regional logistics hubs. The findings also raise concerns about the connectivity of border posts in the context of regional integration. Specifically, the centrality measurements indicate relatively low levels for Oshikango (14%), Buiepost (18%), and Sesheke (23%). More so, connections to landlocked countries are relatively low, Livingstone measuring at 23%, Upington 9% and Gaborone at 14%, linking further to Pretoria and Johannesburg.

	Wal	Kari	Otj	Okah	Whk	Hkut	Gob	Bui	Bot	Kee	Ari	Upi	Lud	Ota	Osha	Opu	Cap	Osh	Gro	Run	Ban	Ses	Liv	Σ	(n-1)	Degree
Wal		1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	22	0.14
Kari	1		1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	22	0.18
Otj	0	1		1	1	0	0	0	0	1	1	1	1	1	1	1	0	1	0	0	0	0	0	10	22	0.45
Okah	1	1	1		1	0	0	0	0	1	1	1	1	1	1	0	0	1	0	0	0	0	0	10	22	0.45
Whk	1	1	1	1		1	1	1	1	1	1	1	1	1	1	0	0	1	0	0	0	0	0	14	22	0.64
Hku	0	0	0	0	1		1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	22	0.18
Gob	0	0	0	0	1	1		1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	22	0.18
Bui	0	0	0	0	1	1	1		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	22	0.18
Bot	0	0	0	0	0	1	1	1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	22	0.14
Kee	0	0	1	1	1	0	0	0	0		1	1	1	1	1	1	0	1	0	0	0	0	0	10	22	0.45
Ari	0	0	0	0	0	0	0	0	0	1		1	1	0	0	0	0	0	0	0	0	0	0	2	22	0.09
Upi	0	0	0	0	0	0	0	0	0	1	1		1	0	0	0	0	0	0	0	0	0	0	2	22	0.09
Lud	0	0	0	0	1	0	0	0	0	1	1	1		0	0	0	0	0	0	0	0	0	0	3	22	0.14
Ota	0	0	1	1	1	0	0	0	0	1	1	1	0		1	1	1	1	1	1	1	1	1	14	22	0.64
Osha	0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	1	1	1	1	1	1	1	8	22	0.36
Opu	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1		0	0	0	0	0	0	0	2	22	0.09
Cap	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0		1	0	0	0	0	0	2	22	0.09
Osh	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0		1	0	0	0	0	3	22	0.14
Gro	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1		1	1	1	1	6	22	0.27
Run	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1		1	1	1	5	22	0.23
Ban	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1		1	1	5	22	0.23
Ses	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1		1	5	22	0.23
Liv	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1		5	22	0.23
Σ	3	4	6	6	10	4	4	4	4	7	7	7	6	6	8	4	2	12	7	6	6	6	6			

Cities outside Namibia | Ports | Border-post | Cities inside Namibia

FIGURE 4: Road degree of centrality.

The study further measures the degree of centrality for the railway as depicted in Figure 5.

As shown in Figure 5, the analysis reveals that Windhoek exhibits the highest accessibility and connectivity through the railway, with a centrality measure of 41% from the port of Walvis Bay. However, it is worth noting that approximately 36% of the central nodes lack railway connections, indicating significant fragmentation within the railway network. This fragmentation poses limitations on the functionality of the regional logistics hub. Consequently, the reliance on road transportation is increased, further straining the hub's transportation system.

Road and railway closeness centrality

The study employed closeness centrality to assess the efficiency and accessibility of the transportation network. Figure 6 highlights the closeness centrality of road transport.

Figure 6 highlights that Upington has the lowest closeness centrality with a value of 10% for road transport. In contrast, Okahandja has the highest closeness centrality with a value of 24%, followed by Otjiwarongo, Windhoek and Otavi, measuring 23%. This means Okahandja can be accessed via many links, like a hub with many spokes around.

Figure 7 highlights that Walvis Bay has the lowest closeness centrality for railway transport. In contrast, Windhoek has the highest closeness centrality. Closeness centrality is a measure of the average shortest distance between two points. This means that the port of Walvis Bay has the shortest distance from it to the next node of influence, that is, Swakopmund, Karibib and other vital nodes in the transport network of Namibia.

Rail and road network connectivity

Figure 8 shows the extent of rail network connectivity in Namibia to and from the port of Walvis to various economic nodes. The Ports are shown in blue (Walvis Bay, Cape Fria and Luderitz), the nodes (towns) are shown in green, and the respective links (roads and rail in blue lines and dotted yellow lines, respectively).

This study used a disaggregated approach by examining the extent to which each transportation corridor is connected by road and rail. Figure 8 elucidates a topological abstraction used to analyse this railway network map using a collection of vertices (nodes) and edges (links). In addition, several indices have been created to describe the degree to which a network approaches maximum connectivity (Kansky 1963), which necessitates the existence of a direct link to each node. The foundation for each of these indices is the link between edges and vertices in a network that is regarded as a topological graph. The results revealed the missing links within the railway network, which are Okahandja-Otjiwarongo, Grootfontein-Rundu, Rundu-Bangani, Sesheke-Livingstone, Bangani-Oshakati, Oshakati-Opuwo, Opuwo-Cape Fria, Gobabis-Buitepos and Ariamsvlei-Upington, consequently reducing

	Wai	Kari	Otj	Oka	Whk	HKA	Gob	Bui	Gab	Kee	An	Upi	Lud	Ota	Osha	Opu	Gap	Osh	Gro	Run	Ban	Ses	Liv	Σ	(n-1)	Degree
Wai		1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	22	0.14
Kari	1		1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	22	0.18
Otj	0	1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	22	0.05
Okah	1	1	0		1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	4	22	0.18
Wlik	1	1	0	1		1	1	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	9	22	0.41
HKA	0	0	0	0	1		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	22	0.09
Gob	0	0	0	0	1	1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	22	0.09
Bui	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0.00
Gab	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0.00
Kee	0	0	0	1	1	0	0	0	0		1	1	1	0	0	0	0	0	0	0	0	0	0	5	22	0.23
Ari	0	0	0	0	0	0	0	0	0	1		1	1	0	0	0	0	0	0	0	0	0	0	4	22	0.18
Upi	0	0	0	0	0	0	0	0	0	1	1		1	0	0	0	0	0	0	0	0	0	0	3	22	0.14
Lud	0	0	0	0	0	0	0	0	0	1	1	1		0	0	0	0	0	0	0	0	0	0	3	22	0.14
Ota	0	0	1	0	0	0	0	0	0	0	0	0	0		1	0	0	1	1	0	0	0	0	4	22	0.18
Osha	0	0	0	0	0	0	0	0	0	0	0	0	0	1		0	0	0	0	0	0	0	0	1	22	0.05
Opu	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	22	0.00
Cap	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	22	0.00
Osh	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0		0	0	0	0	0	2	22	0.09
Gro	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0		0	0	0	0	1	22	0.05
Run	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	22	0.00
Ban	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	22	0.00
Ses	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	22	0.00
Liv	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	22	0
Σ	3	4	2	4	6	2	2	0	0	5	5	5	5	3	2	0	0	1	1	0	0	0	0			

Cities outside Namibia | Ports | Border-post | Cities inside Namibia

FIGURE 5: Railway degree of centrality.

connectivity and negatively impacting the regional logistics hub functionality. This demonstrates that Namibia is better connected by road than by rail. This shows that Namibia has low rail availability contrasted with the road network because of certain breaks in the rail joins in the towns.

Infrastructural challenges

The study utilised NVivo as a qualitative data analysis tool, employing a hierarchical structure with 'parent' and 'child' nodes to organise themes. Nodes represent identified coding themes, with parents encapsulating

	Wal	Kan	Otj	Oka	Whk	HKA	Gob	Bui	Bot	Kee	Ari	Upi	Lud	Ota	Osha	Opu	Cap	Osh	Gro	Run	Ban	Ses	Liv	Σ	n-1	Closeness
Wal		3	5	4	5	6	7	8	9	8	11	12	11	6	9	10	11	10	7	8	9	10	11	180	22	0.12
Kari	3		2	1	2	3	4	5	6	5	8	9	8	3	6	7	8	7	4	5	6	7	8	114	22	0.19
Otj	5	2		1	2	3	4	5	6	5	8	9	10	1	4	5	6	5	2	3	4	5	6	96	22	0.23
Oka	4	1	1		1	2	3	4	4	4	7	8	7	2	5	6	7	6	3	4	5	6	7	93	22	0.24
Whk	5	2	2	1		1	2	3	4	3	6	7	6	3	6	7	8	7	4	5	6	6	7	96	22	0.23
HKA	6	3	3	2	1		1	2	3	4	7	8	8	4	7	8	9	8	5	6	7	8	9	113	22	0.19
Gob	7	4	5	4	2	1		1	2	5	8	9	8	5	8	9	10	8	6	7	8	9	10	129	22	0.17
Bui	8	5	5	4	3	2	1		1	6	9	10	9	6	9	10	11	9	7	8	9	10	11	145	22	0.15
Bot	9	6	6	5	4	3	2	1		7	10	11	10	7	10	11	12	11	8	9	10	11	12	166	22	0.13
Kee	8	5	5	4	3	4	5	6	7		3	4	3	6	9	10	11	10	7	8	9	10	11	140	22	0.16
Ari	11	8	8	7	6	7	8	9	10	3		1	6	9	12	13	14	13	10	11	12	13	14	194	22	0.11
Upi	12	9	9	8	7	8	9	10	11	4	1		7	10	13	14	15	14	11	12	13	14	15	214	22	0.10
Lud	11	8	10	7	6	8	9	10	11	3	6	7		9	13	14	15	13	10	11	12	13	14	209	22	0.11
Ota	6	3	1	2	3	4	5	6	7	6	9	10	9		3	4	5	4	1	2	3	4	5	96	22	0.23
Osha	9	6	4	5	6	7	8	9	10	9	12	13	12	3		1	2	1	4	5	6	7	8	138	22	0.16
Opu	10	7	5	6	7	8	9	10	11	10	13	14	13	4	1		1	2	5	6	7	8	9	156	22	0.14
Cap	11	8	6	7	8	9	10	11	12	11	14	15	14	5	2	1		2	6	7	8	9	10	175	22	0.13
Osh	10	7	5	6	7	8	9	10	11	10	13	14	13	4	1	2	3		5	6	7	8	9	158	22	0.14
Gro	7	4	2	3	4	5	6	7	8	7	10	11	10	1	4	6	7	5		1	2	3	4	110	22	0.20
Run	8	5	3	4	5	6	7	8	9	8	11	12	11	2	5	7	8	6	1		1	2	3	124	22	0.18
Ban	9	6	4	5	6	7	8	9	10	9	12	13	12	3	6	7	8	7	2	1		1	2	138	22	0.16
Ses	10	7	5	6	7	8	9	10	11	10	13	14	13	4	7	8	9	8	3	2	1		1	156	22	0.14
Liv	11	8	6	7	8	9	10	11	12	11	14	15	14	5	8	9	10	9	4	3	2	1		176	22	0.13
Σ	180	117	102	99	103	119	136	155	175	148	205	226	214	102	148	169	190	165	115	130	147	165	186			

FIGURE 6: Road transport closeness centrality.

	Wal	Kari	Otj	Oka	Whk	HKA	Gob	Bui	Bot	Kee	Ari	Upi	Lud	Ota	Osha	Opu	Cap	Osh	Gro	Run	Ban	Ses	Liv	Σ	(n-1)	Closeness
Wal		3	5	4	5	6	7	0	0	8	11	12	11	6	9	0	0	10	7	0	0	0	0	104	22	0.21
Kari	3		2	1	2	3	4	0	0	5	8	9	8	3	6	0	0	7	4	0	0	0	0	62	22	0.35
Otj	5	2		0	2	3	4	0	0	5	8	9	10	1	4	0	0	5	2	0	0	0	0	55	22	0.40
Oka	4	1	0		1	2	3	0	0	4	7	8	7	2	5	0	0	6	3	0	0	0	0	49	22	0.45
Whk	5	2	0	1		1	2	0	0	3	6	7	6	3	6	0	0	7	4	0	0	0	0	48	22	0.46
HKA	6	3	0	2	1		1	0	0	4	7	8	8	4	7	0	0	8	5	0	0	0	0	58	22	0.38
Gob	7	4	0	4	2	1		0	0	5	8	9	8	5	8	0	0	8	6	0	0	0	0	68	22	0.32
Bui	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0.00
Bot	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0.00
Kee	8	5	0	4	3	4	5	0	0		3	4	3	6	9	0	0	10	7	0	0	0	0	63	22	0.35
Ari	11	8	0	7	6	7	8	0	0	3		1	6	9	12	0	0	13	10	0	0	0	0	90	22	0.24
Upi	12	9	0	8	7	8	9	0	0	4	1		7	10	13	0	0	14	11	0	0	0	0	101	22	0.22
Lud	11	8	0	7	6	8	9	0	0	3	6	7		9	13	0	0	13	10	0	0	0	0	99	22	0.22
Ota	6	3	0	2	3	4	5	0	0	6	9	10	9		3	0	0	4	1	0	0	0	0	59	22	0.37
Osha	9	6	0	5	6	7	8	0	0	9	12	13	12	3		0	0	1	4	0	0	0	0	86	22	0.26
Opu	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	22	0.00
Cap	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	22	0.00
Osh	10	7	0	6	7	8	9	0	0	10	13	14	13	4	1	0	0		5	0	0	0	0	97	22	0.23
Gro	7	4	0	3	4	5	6	0	0	7	10	11	10	1	4	0	0	5		0	0	0	0	70	22	0.31
Run	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	22	0.00
Ban	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	22	0.00
Ses	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	22	0.00
Liv	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	22	0.00
Σ	104	65	7	54	55	67	80	0	0	76	109	122	118	66	100	0	0	111	79	0	0	0	0			

FIGURE 7: Rail transport closeness centrality.

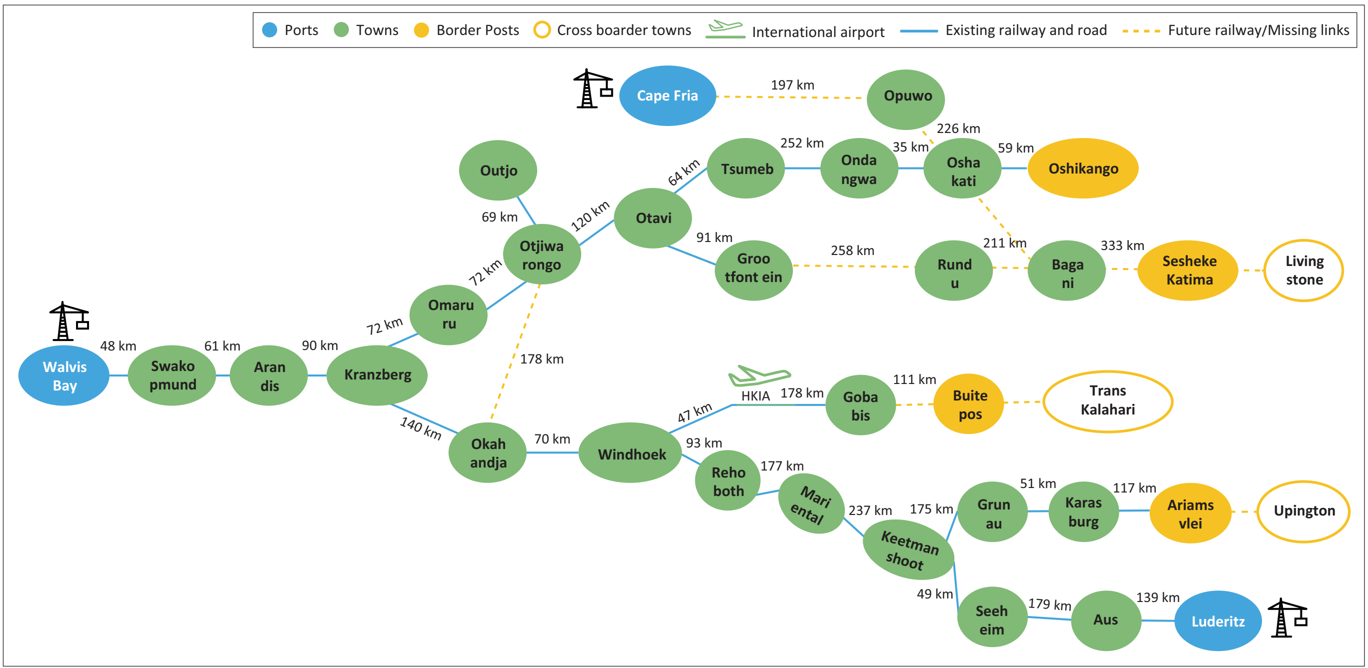


FIGURE 8: The road and rail transport network in Namibia.

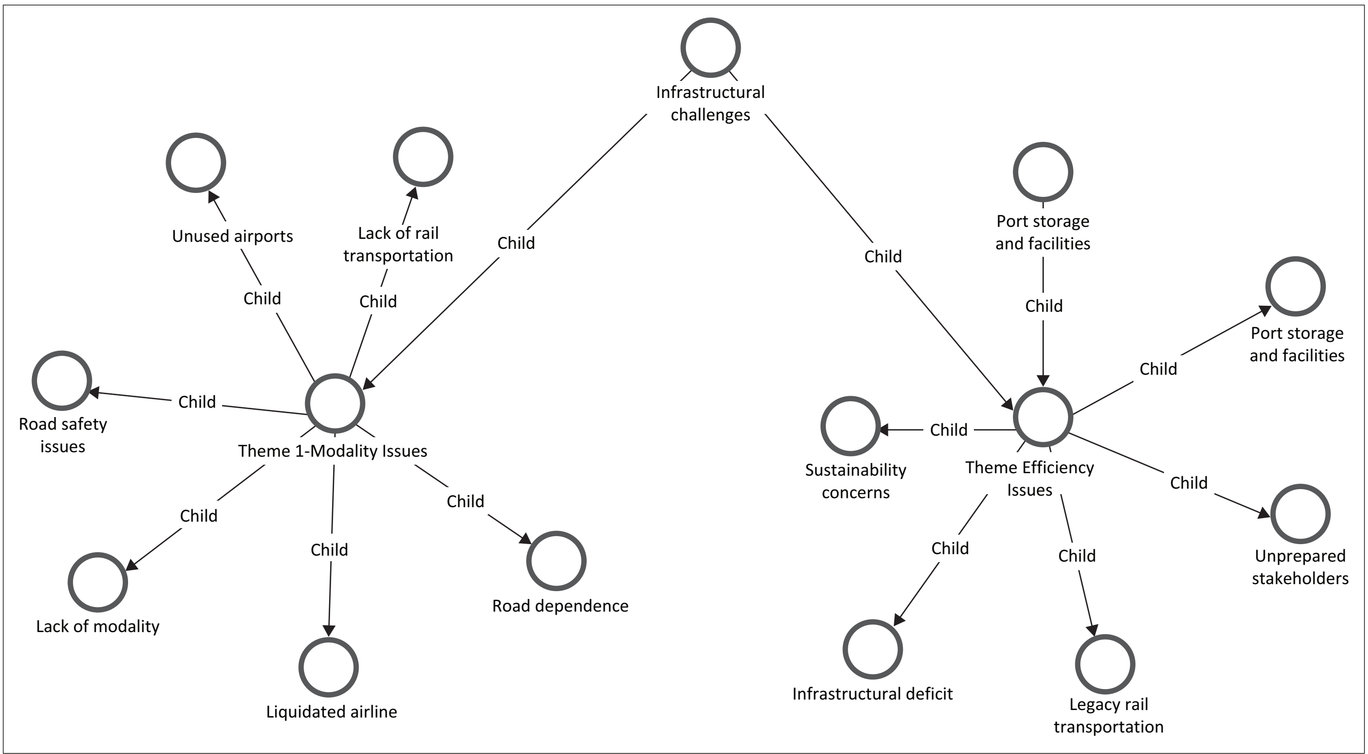


FIGURE 9: Infrastructural challenges subthemes.

broader categories and 'child' representing sub-themes. Challenges in preparing for a regional logistics hub in Namibia were centred around infrastructural issues ('parent'), specifically modality and efficiency ('child'). The hierarchical relationship is reflected in the NVivo analysis, where child nodes such as 'Modality and Efficiency' address specific aspects within the broader theme. The emerging sub-themes encompassed modality and efficiency issues, are illustrated in Figure 9.

In order to determine transport condition and the need to improve transport systems, ANOVA test was conducted on rail, road and sea. The ANOVA test findings would determine if there are any changes needed on any mode of transport gauging with the tonnages being carried on each mode.

ANOVA on Rail cargo

This section presents the ANOVA for 2015–2019 on railway cargo. The hypotheses were:

H_0: There is no significant difference in cargo received between 2015 and 2019

H_1: There is at least 1 year with a different mean cargo from the rest

A lower *p*-value often less than 0.05 signifies that the observed data are unlikely under the assumption of the null hypothesis. Therefore, this evidence rejects the null hypothesis in favour of the alternative hypothesis. A large *p*-value greater than 0.05 signifies that the observed data are likely under the assumption of the null hypothesis, thus there is insufficient evidence to reject the null hypothesis.

Data extracted shows cargo in tonnes received in 2015, 2016, 2017, 2018 and 2019 as 128.166658, 122.38667, 118.35433, 123.46458, 138.96325 and 126.26706, respectively.

Table 2 shows a significance result of 0.038; therefore, the null hypothesis (H_0) is rejected. A significance value of 0.038 implies that at least 1 year had significantly different cargo from the rest. This finding suggests that notable variation in rail cargo volumes might have been experienced in certain years. With such notable changes in tonnages, there is need to improve the rail transport system. However, ANOVA is an omnibus test that does not specify which years show a difference or the direction of the tonnage changes; it only indicates that a difference exists. It is important to note that these differences can be positive, implying an increase in tonnage, which calls for improvements in the rail transport system.

ANOVA on Road cargo

This section presents the ANOVA for 2015–2019 on road cargo. The hypotheses were as follows:

H_0: There is no significant difference in cargo received on the road from 2015 to 2019

H_2: There is at least 1 year with a different mean cargo from the rest

To conduct ANOVA, tests such as Levene are carried out first on which progression to ANOVA may not be necessarily performed if data Significance results fall in the range of higher than 0.05. Table 3 illustrates Levene's test results that were conducted to see if data can be subjected to ANOVA. However, the significance result of 0.189 renders the data not necessary to conduct ANOVA analysis because the Levene test results of Sig is 0.189, which is a significant outcome higher than the α (0.05), thus the null hypothesis is accepted as there are no significant variances in tonnages. Noticeable, as much as the null hypothesis is accepted showing that there are no significant variations in tonnages, still the road network systems need to be improved based on tonnages being carried if they are to be maintained at the level of 255.5275, 262.0789, 254.2593, 276.5891 and 319.9152 in 2015, 2016, 2017, 2018 and 2019, respectively.

TABLE 2: ANOVA on Rail Cargo.

Variable	Sum of Squares	*df*	Mean Square	*F*	Sig.
Between groups	3003.888	4	750.972	-	-
Within groups	15076.326	55	274.115	-	-
Total	**18080.214**	**59**	**-**	**2.74**	**0.038**

TABLE 3: Road Cargo Levene's Test.†

Road cargo: Levene statistic	*df*1	*df*2	Sig.
1.595	4	55	0.189

df, degrees of freedom; Sig., significance.
†, Test of homogeneity of variances.

ANOVA on sea-landed cargo

This section presents the ANOVA for 2015–2019 on sea-landed cargo. The hypotheses were as follows:

H_0: There is no significant difference in cargo received between 2015 and 2019.

H_3: There is at least 1 year with a different mean cargo from the rest

Similar to ANOVA on road cargo, Levene test on sea-landed cargo was conducted and the Sig value of 0.797 above 0.05 would render conducting ANOVA unnecessary, as the Levene test results above 0.05 already show that there are no significant variations. Once more again, the tonnages of 273.4683, 277.0348, 253.2513, 295.7488 and 296.2191 in 2015, 2016, 2017, 2018 and 2019, respectively, would require a re-look into building capacities and facilities on the sea-cargo because the volumes are high on the current capacities, and having an insignificant variation means these volumes will maintain being high.

As seen in Table 4, the significance value is 0.797, which is greater than 0.05. Thus, the cargo for each year is not significantly different and there is insufficient evidence to reject the null hypothesis (H_0) and hence, it is unreliable to run an ANOVA.

Discussion

Namibia's intra-regional export on the SADC mainland has been increasing for the last 10 years and is expected to double by 2044. Furthermore, the port capacity expansion at Walvis Bay has attracted increased volumes from international markets to the SADC region. This trend indicates an expected increased inbound and outbound movement of goods through the Walvis Bay Port coupled with Namibia's strategic location. Namibia has the potential to facilitate a regional logistics hub, as alluded to by other authors (Lee et al. 2022; Savage, Fransman & Jenkins 2013). However, it takes more than a strategic location to facilitate a functional regional logistics hub. The increasing trend of container volumes is affected by the development of transport network connectivity and accessibility. Hence, this study focusses on analysing the intermodal connectivity

TABLE 4: Sea-landed Cargo Levene's Test.†

Sea landed: Levene Statistic	*df*1	*df*2	Sig.
0.414	4	55	O.797

df, degrees of freedom; Sig., significance.
†, Test of homogeneity of variances.

for the functionality of Namibia's regional logistic hub. Regional logistics hubs are meant to serve beyond borders. This is even more true for Namibia, which borders more than four landlocked countries with a combined nominal gross domestic product (GDP) of USD 158.5 billion (World Economic Outlook Database, April 2022).

Therefore, for a functional regional logistics hub, intermodal connectivity is crucial. The study's findings highlight the fragmentations within the railway network and connectivity and accessibility limitations within the road network. The key findings allude that the Namibian transport system is moderately connected through road transportation. Based on these results, Namibia's railway connectivity faces similar challenges as the road transport network. While the railway network may have shorter average path lengths (lower β index) and relatively decentralised structure (lower γ index), it still exhibits a low level of connectivity (lower α index). This suggests limited connectivity and options for travel within the railway network. However, the heavy reliance on roads poses challenges such as congestion, safety, increased transportation costs, environmental impacts, and vulnerability to disruptions. Diversifying and improving intermodal connectivity, incorporating alternative modes such as rail and implementing sustainable transport solutions are crucial for enhancing the performance and long-term viability of the Namibian regional logistics hub.

Managerial implications

The research emphasises the importance of addressing intermodal connectivity, infrastructure development, sustainability, and collaboration to establish a functional and thriving regional logistics hub in Namibia. By examining the extent to which intermodal connectivity contributes to the functionality of regional logistics hubs, policymakers, industry professionals, and stakeholders will gain valuable insights into the challenges, opportunities, and strategies for improving transportation networks.

Limitations and future research

This study did not consider other factors, such as geographical characteristics, population density and infrastructure investments, to comprehensively understand the railway and road network's performance and potential areas for improvement. Thus, the suggestion is made to examine how the aforementioned factors impact the functionality of regional logistics hubs.

Study delimitation

This study focusses exclusively on examining road networks parallel to railway lines. By narrowing the scope to this specific context, the study aims to investigate the dynamics, connectivity, and performance of the road infrastructure adjacent to railways. Figure 2 presents the map of the existing corridors and can be pivotal in developing the regional logistics hub in Namibia.

Conclusion and recommendations

In summary, Namibia holds significant potential as a regional logistics hub, driven by its strategic location, expanding exports, and the growth of the Walvis Bay Port. Quantitatively, the study exposes deficiencies and fragmentation in current railway and road networks, adversely impacting goods movement and the overall efficiency of the logistics hub. The data emphasises suboptimal connectivity levels within the existing transport infrastructure. Stakeholders' interviews qualitatively reveal a moderate intermodal connectivity, stressing the need for collaborative efforts to comprehensively address connectivity limitations. Both quantitatively and qualitatively, sustainable transport practices are deemed crucial. The study quantifies environmental impacts from heavy reliance on road transportation, underlining the necessity for sustainable alternatives. Stakeholders emphasise prioritising sustainability and integrating alternative modes such as rail for enhanced efficiency and resilience. The research advocates a crucial investment in infrastructure development, supported by data showcasing the pivotal role of improved infrastructure in overcoming connectivity challenges. Strategic planning, policy support, and collaborative efforts are underscored as essential, echoing sentiments from stakeholder interviews.

The study recommends substantial investment in infrastructure, improved intermodal connectivity, and the adoption of sustainable transport solutions for Namibia to realise its vision as a regional logistics hub. Collaboration among stakeholders is crucial, aligning with both quantitative and qualitative insights. Addressing these findings is expected to optimise the logistics hub's functionality, fostering regional trade and economic growth in the SADC region.

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Competing interests

The author declares that there are no financial or personal relationships that may have inappropriately influenced her in writing this article.

Authors' contributions

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Data availability

The study's data set is available upon request for academic use. The request must be given in writing to the author, clearly stating its goal.

Disclaimer

The views and opinions expressed in this article are those of the author and do not necessarily reflect the official policy or position of any affiliated agency of the author, and the publisher.

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