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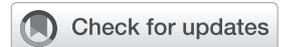
Optimising South African air cargo efficiency through technology and infrastructure development

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Background: South Africa's air cargo industry is a critical driver of international trade and economic growth. However, outdated infrastructure and limited technology integration have led to inefficiencies, notably cargo delays, which undermine operational performance and competitiveness.

Objectives: This study examines the relationship between infrastructural quality, technological adoption and cargo delays in South Africa's air cargo sector. It aims to identify key operational bottlenecks and provide evidence-based recommendations to enhance efficiency.

Method: This study used a survey of 120 key stakeholders across South Africa's major airports, including cargo operators, airport officials and policymakers, to examine how infrastructure quality and technology adoption influence cargo delays.

Results: Findings reveal that improved infrastructural quality and higher levels of technology adoption significantly reduce cargo delays. Regression analysis indicated that each unit increase in infrastructure quality and technology adoption corresponded to marked decreases in delay durations. Additionally, stakeholder perceptions on investment urgency varied, underscoring the importance of aligning operational and regulatory perspectives.

Conclusion: Upgrading physical infrastructure and embracing digital innovations are essential for reducing cargo delays and enhancing the overall efficiency of South Africa's air cargo operations.

Contribution: This study offers empirical evidence that informs policy formulation and operational strategies, emphasising the need for public–private partnerships and regulatory reforms to build a more competitive and sustainable air cargo industry.

Keywords: air cargo; infrastructure modernisation; technology adoption; cargo delays; digitalisation; operational efficiency; regulatory reform; South Africa; e-commerce; investment in logistics.

Introduction

South Africa's air cargo industry plays a pivotal role in facilitating the flow of high-value, time-sensitive goods, both domestically and across international trade networks. As the country positions itself as a key logistics gateway to the African continent, the efficiency of its air cargo infrastructure becomes a strategic economic priority. However, many of South Africa's major international airports – including O.R. Tambo, Cape Town International and King Shaka – continue to suffer from outdated, under-capacitated and fragmented infrastructure. For example, the Airports Company South Africa's 2023 infrastructure report indicates that these airports operate below optimal capacity, with terminal facilities aged over 20 years and cold-chain storage capacities at less than 50% of demand (Airports Company South Africa 2023). Furthermore, Mokhele and Mokhele (2022) underscore fragmented logistics layouts and poor land-use integration around airport precincts as key barriers to effective cargo flows, contributing to congestion and delays. These infrastructural shortcomings manifest in inefficient cargo terminal layouts, insufficient cold-chain storage and limited automation in cargo handling processes. By examining the quality of airport infrastructure and its interplay with technological adoption, the current research aims to provide empirical insights into how addressing spatial and infrastructural barriers can reduce cargo delays and enhance operational efficiency in South Africa's air cargo industry.

The airport infrastructure deficit extends beyond physical design to include technological underdevelopment. Modern cargo operations rely heavily on integrated digital systems such as electronic-Air Way Bills (e-AWB), real-time shipment tracking and automated Warehouse

Management Systems (WMS). However, Adenigbo, Mageto and Luke (2023) reported that South Africa's cargo terminals lag behind global best practices, with many facilities still reliant on manual data entry and siloed systems, insufficient cold-chain storage for perishables, outdated cargo apron designs and limited automation in sorting and tracking processes. This not only slows down cargo throughput but also increases the risk of documentation errors, delays in customs clearance and shipment mismanagement. Zhao and Gao (2017) argued that without infrastructure designed to support digitalisation, even advanced logistics technologies yield limited benefits. This is echoed by Sithole, Wissink and Chiwawa (2022), who find that the quality of terminal infrastructure is a determinant of both service reliability and competitiveness in air cargo logistics.

The problem is further exacerbated by systemic underinvestment in cargo-specific airport upgrades. While policy attention and funding have historically favoured passenger terminal expansions, the cargo handling side has received relatively limited strategic focus. Adenigbo et al. (2023) highlighted that cold-chain infrastructure, essential for pharmaceuticals and fresh produce exports, remained underdeveloped at many major hubs. Furthermore, automation technologies, such as robotic sorting systems, high-speed conveyors and digital customs interfaces, are either missing or inconsistently implemented across the airports. This patchwork of capabilities results in uneven operational standards and missed opportunities for cargo consolidation, multimodal integration and throughput maximisation.

Air cargo transportation in South Africa: Spatial planning, cold chain deficits and policy gaps

The air cargo transportation sector in South Africa is an essential component of the country's logistics and supply chain network, influencing trade and economic performance. Despite its significant role, numerous challenges threaten the industry's efficiency, primarily because of infrastructural deficits, regulatory constraints and increasing demand tied to globalisation and e-commerce growth. Recent studies have highlighted how the air cargo sector must adapt to changing market conditions and customer expectations, necessitating enhancements in service quality, operational processes and technological applications (Adenigbo et al. 2023). The implementation of advanced technologies, particularly in areas such as cargo handling and tracking, is critical for South African air cargo operators to improve service delivery and customer satisfaction, thereby maintaining competitiveness in an increasingly dynamic market environment.

Maharani and Wahyuni (2021) suggested that customer satisfaction levels within the air cargo industry are influenced by the quality of service, brand image and operational efficiency. In the context of South Africa's air cargo sector, these factors are closely linked to the performance of critical infrastructure and the integration of advanced technologies. Effective brand positioning and quality assurance depend heavily on reliable,

timely cargo handling and robust cold chain management, which in turn require modernised cargo terminals and digital tracking systems. Without such infrastructure and technological capabilities, firms struggle to meet global service standards and customer expectations, undermining their competitiveness. Therefore, investing in infrastructure upgrades and technology adoption is not only foundational to operational efficiency but also a strategic enabler for building a strong brand reputation and delivering consistent service quality in the international air cargo market (Hu et al. 2018).

Additionally, the regulatory environment significantly impacts the air cargo transportation framework in South Africa, shaped notably by the Civil Aviation Regulations under the South African Civil Aviation Authority (SACAA) and guided by international standards set forth by the International Civil Aviation Organisation's (ICAO) Annexure 17 on Aviation Security and Annexure 9 on facilitation, which collectively influence operational compliance, security protocols and safety measures within the sector. Concerns regarding security oversights, compliance with international regulations and environmental sustainability continue to shape the operational landscape. Recent findings indicate that regulatory measures, while intended to bolster security, may inadvertently affect pricing structures and demand within the air cargo market (Park et al. 2023). The air cargo sector in South Africa must navigate these complexities by developing integrative strategies that balance compliance with operational efficiency. This necessitates a focus on innovation and collaboration among government entities, industry players and stakeholders, fostering a framework that can respond adeptly to both local and global challenges (Coetzee & Swanepoel 2017; Traguetto, Marques & Ferreira 2013). By addressing these factors comprehensively, the industry can work towards enhancing its efficiency and resilience amidst an evolving logistic ecosystem.

The implications of air cargo operations on environmental factors and public health are integral, particularly given the country's socio-economic context. Research indicates that outdoor air pollution in urban areas of South Africa has notable health impacts, including increased mortality rates attributable to air quality degradation (Lina et al. 2014; Morakinyo et al. 2017). Furthermore, air transport itself contributes to carbon emissions, raising concerns about the environmental sustainability of the air cargo sector as it expands. While the economic benefits of air cargo are significant, they are counterbalanced by the need to address health and environmental risks associated with increased air traffic and pollutants (Edlund et al. 2021; Ncipha, Sivakumar & Malahlela 2020). These intertwined issues highlight the necessity for a balanced approach that accommodates economic growth while ensuring environmental and public health standards are met.

Airport infrastructure

Airport infrastructure has emerged as a central determinant of air cargo efficiency, particularly in developing economies

where systemic underinvestment has created operational bottlenecks. Recent studies argue that the physical layout and design capacity of cargo terminals significantly affect cargo throughput and delay frequency (Adenigbo et al. 2023; Paethrangsi, Laojutaradol & Nitithanprapas 2025). However, infrastructure development has often been misaligned with the evolving demands of high-value and time-sensitive air freight, such as pharmaceuticals, perishables and e-commerce parcels, which require specialised handling facilities, including temperature-controlled storage and rapid processing capabilities. For instance, the global air cargo volume for pharmaceuticals grew at an annual rate of 8% between 2015 and 2022 (International Air Transport Association [IATA] 2023), yet South African airports have lagged in upgrading cold-chain infrastructure to meet this demand (Adenigbo et al. 2023). This mismatch has led to capacity constraints and functionality gaps, impeding the efficient handling of such critical cargo and undermining the competitiveness of South Africa's air freight sector. Paethrangsi et al. (2025) critique airport development programmes for their passenger-terminal focus, sidelining cargo operations despite these growing market needs. This imbalance reflects both policy inertia and limited private sector participation in infrastructure planning, ultimately compromising supply chain fluidity and export competitiveness.

In addition to physical inadequacies, the technological readiness of airport infrastructure remains a key concern. While many global airports have embraced digitisation, South Africa's cargo terminals still rely heavily on manual operations, leading to inefficiencies and data fragmentation (Adenigbo et al. 2023; Chiwawa & Wissink 2024). The integration of advanced technologies such as automated cargo handling systems, artificial intelligence (AI)-based sorting and digital customs platforms – is patchy, with substantial disparities across regional airports. This technological unevenness not only restricts real-time visibility and throughput but also impairs harmonisation across logistics nodes. Chiwawa, Fox and Wissink (2020) further highlighted that without institutional support and cross-sectoral collaboration, digital transformation initiatives remain fragmented and ineffective. The challenge, therefore, lies not merely in acquiring technology, but in embedding it into infrastructure that is designed to support agility, scalability and interoperability across logistics systems.

The governance and planning gap that prevents the growth of coherent airport infrastructure ecosystems is a more complex problem. Essential components like cargo aprons, secure storage and ICT integration are viewed as afterthoughts rather than basic infrastructure because of a strategic misalignment between airport authorities, regulatory agencies and private stakeholders. This lack of coordination causes chokepoints at otherwise modernised terminals, especially in logistics corridors where air cargo capacity exceeds landside integration and customs support. Infrastructure improvements are frequently reactive and siloed without a systems-thinking approach, according to research, which results in cost overruns,

redundancies and underutilisation of capital assets. Therefore, addressing the research questions on how infrastructure influences operational efficiency, infrastructure must be understood not merely as a collection of physical assets but as a strategically regulated, functionally integrated logistics environment that enables seamless cargo flow, reduces delays and supports technology adoption.

Technological challenges in logistics management

Technological challenges in logistics management significantly undermine efficiency and operational effectiveness within the air cargo industry, particularly in developing regions like South Africa, where infrastructural constraints exacerbate these issues. Adenigbo et al. (2023) highlighted the critical need for adopting advanced technologies, such as innovative warehouse operations management, to enhance logistics performance and quality service delivery in South Africa's air cargo sector. Additionally, while the integration of Technologies 4.0, including blockchain, Internet of Things (IoT) and AI, has advanced rapidly in developed economies, it still remains largely unaddressed in South African contexts. This technological lag raises a concern as it diminishes operational transparency and efficiency (Alqarni et al. 2023; Nantee & Sureeyatanapas 2021).

Overcoming these technological bottlenecks is crucial for maintaining a competitive advantage and fostering growth within the air cargo industry. Research indicates a consensus among experts that substantial investments, improved policy frameworks and collaborative efforts across the industry are fundamental to establishing a sound digital logistics ecosystem (Adenigbo et al. 2023; Büyüközkan, Feyzıoǧlu & Havle 2023). The urgent need for strategic alignment between the public and private sectors has been emphasised in recent studies, calling for enhanced training programmes and incentivising regulatory frameworks to ensure technological adoption and progress (Hu et al. 2018). These findings articulate a broader institutional gap that necessitates prompt collective action to mitigate operational inefficiencies rooted in technological dependency.

Another significant technological barrier identified pertains to the implementation challenges associated with adopting emergent logistics technologies. Scholars note that, notwithstanding the potential for these innovations to transform logistics management, many companies encounter resistance driven by high implementation costs, integration complexities and a shortage of skilled labour capable of managing sophisticated logistics technologies (Büyüközkan et al. 2023; Ersöz, Aldemir & Kılıç 2023). This expertise gap is especially prevalent among smaller logistics providers in South Africa, resulting in perpetuated market fragmentation and inequalities, which further hinder growth prospects. The highlighted technical and economic barriers necessitate a multifaceted approach, including incentivisation from governmental bodies and alignment of industry expectations to promote inclusivity and growth (Büyüközkan et al. 2023).

Furthermore, a crucial yet often overlooked dimension in logistics technologies involves cybersecurity risks, including data breaches, ransomware attacks and system intrusions that can disrupt critical operations. For instance, cyberattacks on logistics companies have led to unauthorised access to sensitive shipment data, manipulation of tracking information and temporary shutdowns of automated warehouse systems, severely impacting supply chain continuity (Ersöz et al. 2023; Karunathilake & Fernando 2023). The increasing reliance on interconnected digital platforms, such as IoT devices, cloud-based management systems and blockchain networks, heightens exposure to these cyber threats in logistics, which pose substantial risks not only to operational integrity but also to customer confidentiality and regulatory compliance (Hu et al. 2018; Liu, Li & Yu 2022).

Research methods and design

This study adopted a quantitative research design to examine how infrastructural quality and technological adoption affect cargo delays within South Africa's air cargo industry. The design was chosen to generate statistical evidence and objectively measure relationships between variables, thereby allowing generalisable conclusions. A cross-sectional survey approach was employed to capture data at a single point in time, reflecting current conditions in cargo operations. Primary data were gathered from three key stakeholder groups: cargo operators (e.g. freight forwarders, logistics managers), airport officials (e.g. ground service managers, air traffic coordinators) and policymakers (e.g. civil aviation authorities). To ensure representativeness, participants were sampled from major airports across the country, including O.R. Tambo International Airport, King Shaka International Airport and Cape Town International Airport. The survey instrument was designed to assess perceptions of infrastructure quality, technology adoption and observed cargo delays. A five-point Likert scale was used for questions related to infrastructure and technology, while delay times were collected in minutes for more precise measurement. The final sample included respondents who voluntarily participated after being assured of confidentiality and anonymity. All procedures adhered to ethical guidelines, with institutional approval obtained prior to data collection.

Data collection proceeded in two main phases to ensure validity and reliability. In the first phase, a pilot test was conducted with 10 participants (three cargo operators, four airport officials and three policymakers) to refine the survey items and confirm that questions were clear, unambiguous and contextually relevant. Feedback from this pilot led to minor wording revisions and the removal of redundant items. In the second phase, the final questionnaire was distributed via email and in person at airport facilities, employing a combination of convenience and purposive sampling. While these non-probability sampling methods facilitated access to key stakeholder groups and practical data collection within the logistical constraints of the study, it is acknowledged that they may introduce sampling bias and limit the generalisability of the findings. Potential participants were approached through professional networks, airport bulletins and stakeholder meetings. A 3-week window was allotted for responses, during which periodic reminders were sent to improve the response rate. Completed surveys were screened for missing data and inconsistencies, with incomplete responses discarded. The resulting dataset comprised valid responses from 120 participants, adequately representing the major airports and stakeholder roles. This sample size enhanced the study's capacity to yield statistically meaningful insights into infrastructural and technological factors affecting cargo delays.

Data analysis involved multiple statistical techniques to capture a comprehensive picture of the relationships under investigation. Initially, descriptive statistics, such as means, standard deviations and frequency distributions, were computed to summarise the infrastructure ratings, levels of technology adoption and reported delay times. These descriptive findings informed the subsequent regression analysis, where cargo delays served as the dependent variable and infrastructure quality and technology adoption functioned as independent variables. A standard linear regression model was fitted to quantify how improvements in each predictor variable would reduce delay durations. Additionally, a Chi-square test was performed to examine whether stakeholder job roles (cargo operators vs. airport officials vs. policymakers) influenced perceptions of infrastructure investment urgency. To further visualise differences in delay times across varying infrastructure levels, a box plot analysis was conducted, highlighting the distribution of cargo delays in categories labelled 'Poor', 'Moderate' and 'Good' infrastructure. The inclusion of box plot visualisations served as a complementary method to illustrate the distribution and variability of cargo delays across infrastructure quality categories, offering intuitive, graphical evidence alongside regression results. Together, these quantitative approaches generated a thorough evaluation of how infrastructural and technological dimensions shape operational efficiency.

Validity and reliability were addressed through careful methodological and analytical rigour. Content validity was bolstered by cross-referencing survey items with established logistics and operations management literature, ensuring alignment with recognised constructs. Pilot testing enhanced face validity by allowing participants to provide feedback on question clarity and relevance. To ensure measurement reliability, Cronbach's alpha was calculated for multi-item scales assessing infrastructure ($\alpha = 0.85$) and technology adoption ($\alpha = 0.82$), indicating strong internal consistency. The data analysis adhered to recognised statistical assumptions, including normality checks for regression residuals and ensuring that no multicollinearity issues existed among predictors. Triangulation was indirectly supported by comparing the quantitative results to broader industry reports and prior studies on air cargo efficiency. Ethical considerations were upheld through informed consent, confidentiality guarantees and secure data handling.

Overall, this methodology provided an empirical framework to investigate infrastructural and technological gaps in the South African air cargo industry, enabling evidence-based insights for stakeholders and policymakers. Nonetheless, the limitations inherent in the sampling approach and cross-sectional design are acknowledged, with recommendations for future studies to employ probability sampling and longitudinal designs to strengthen external validity and causal inference.

Ethical considerations

Ethical clearance to conduct this study was obtained on 19 November 2023 from the University of KwaZulu-Natal and Humanities and Social Sciences Research Ethics Committee (No. HSSREC/00000182/2023).

Results

Figure 1 presents the distribution of participants across the key stakeholder groups – Airport Officials, Cargo Operators and Policymakers. This visualisation provides an initial overview of the sample composition, highlighting the predominance of operational perspectives (Airport Officials and Cargo Operators) that underpin the study's insights into infrastructural and technological challenges.

The bar chart reveals that Airport Officials form the largest portion of the sample with 50 participants, followed by Cargo Operators at 45 and Policymakers at 25. This distribution suggests that the data are heavily informed by the perspectives of those directly involved in day-to-day airport and cargo operations. Having a relatively high number of Airport Officials and Cargo Operators in the study could yield more detailed, operational-level insights into the infrastructural and technological factors influencing cargo delays. Meanwhile, although fewer in number, the 25 Policymakers provide important regulatory and strategic viewpoints, ensuring that the study also captures the higher-level policy context within the air cargo industry.

From a methodological standpoint, the prominence of operational voices in the sample implies that findings on infrastructural quality and technological adoption will
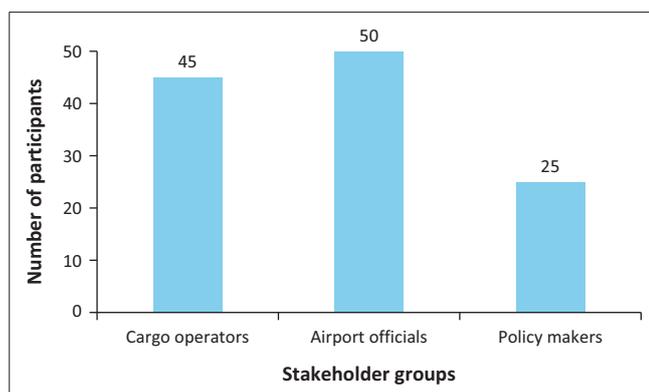
strongly reflect on-the-ground realities. This could be advantageous in identifying practical bottlenecks and areas needing immediate improvement. However, the lower proportion of policymakers means that policy recommendations drawn from the study may rely on a smaller segment's perspective, potentially requiring further consultation or follow-up research for more comprehensive policy-level insights. Overall, the participant distribution highlights a valuable balance of practical and regulatory viewpoints, offering a multifaceted understanding of cargo delays in South Africa's air cargo sector.

Figure 2 further disaggregates the demographic characteristics of the respondents, including age, gender and educational background. This multi-panel bar chart underscores the diversity and representativeness of the sample, supporting the soundness of the findings by illustrating that the data captures both practical operational insights and strategic policy viewpoints.

The multi-panel bar chart offers a comprehensive overview of the demographic composition of participants in the study on South Africa's air cargo industry. The age distribution is weighted towards the 30–49 age range, which together accounts for 62.5% of all respondents. This suggests that the majority of insights come from mid-career professionals, who are likely to hold operational or managerial responsibilities. The gender distribution is nearly balanced, with males comprising 51.7% and females 48.3% of participants, indicating a relatively inclusive sampling in terms of gender representation. Education levels reveal a workforce that is fairly well qualified: 70.8% of respondents hold either a bachelor's or postgraduate degree, suggesting a strong foundation for engaging with technological and operational challenges in the sector. This educational spread supports the credibility of the findings, as respondents likely have the background to offer informed perspectives on infrastructural and digital adoption.

Looking deeper into industry-specific variables, the years of experience data show that 66.7% of respondents have between 5 years and 15 years of experience, implying a mature and seasoned participant base with both historical context and current operational awareness. The roles occupied by participants also highlight a diverse representation across functional domains: operations managers (25%), ground handling personnel (20.8%), regulatory officials (17%), IT specialists (12.5%) and others (25%). This variety ensures that the study captures a range of viewpoints, from policy enforcement to on-the-ground logistics and digital systems. The inclusion of IT specialists, albeit smaller in number, is particularly significant given the study's focus on technology adoption. Together, these demographic patterns validate the representativeness of the sample and enhance confidence in the study's conclusions regarding infrastructural deficiencies, technological readiness and the urgency of modernisation in South Africa's air cargo operations.

FIGURE 1: Participant demographics by stakeholder group (N = 120).
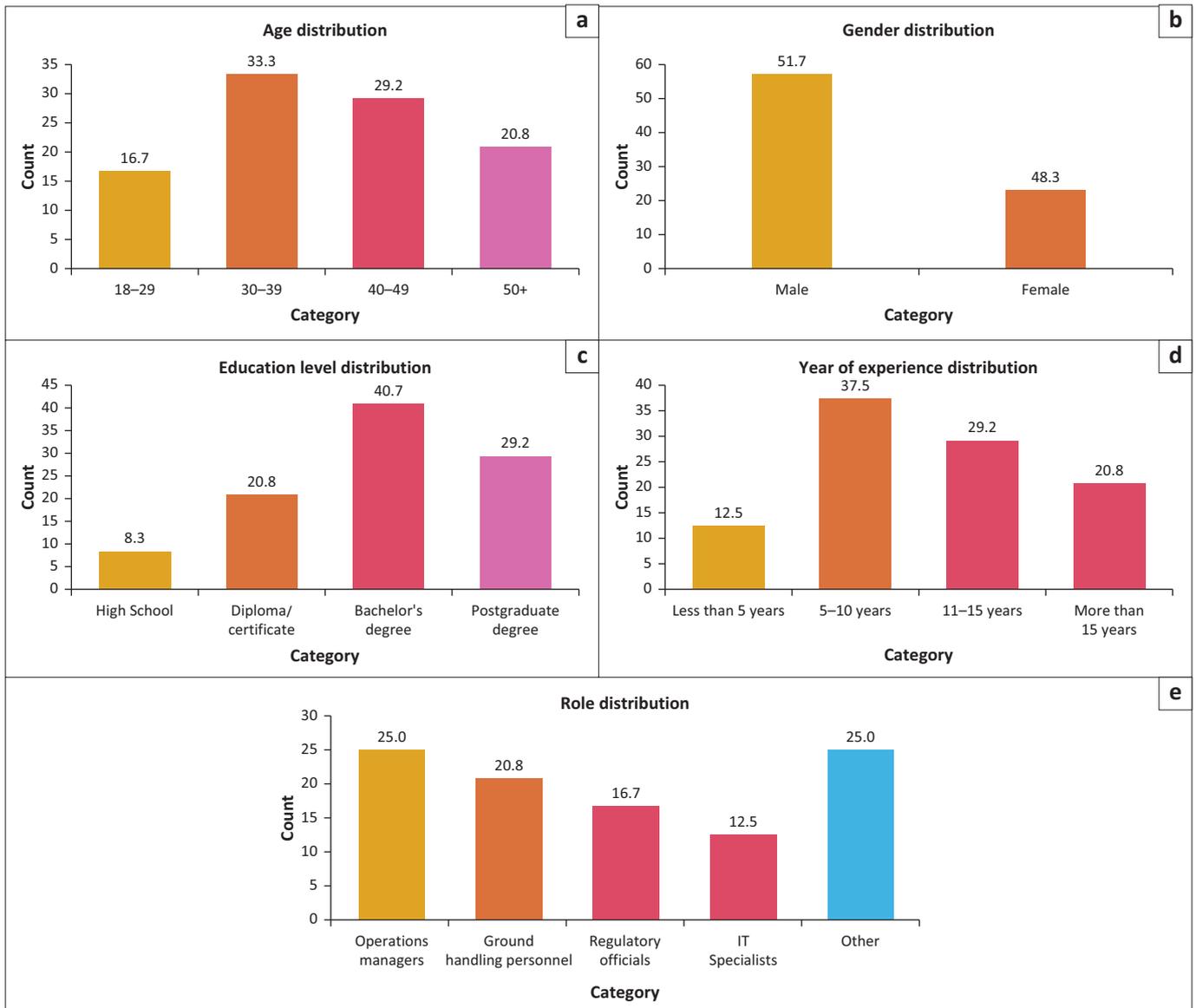
IT, information technology.

FIGURE 2: Multi-panel bar chart of participant demographics: (a) age, (b) gender, (c) education level, (d) years of experience and (e) roles.

Table 1 summarises the key descriptive statistics derived from the survey data, including the mean infrastructure quality rating, the percentage of technology adoption and the range of cargo delays. These baseline figures provide context for understanding the current state of South Africa's air cargo operations and set the stage for the subsequent analytical tests.

The infrastructure quality rating is based on a 5-point Likert scale anchored at 1 = Poor and 5 = Excellent, with a mean score of approximately 2.94, indicating moderate infrastructure conditions. Given the regression findings that better infrastructure significantly reduces cargo delays (−3.34 coefficient), this indicates that investing in infrastructure could lead to noticeable efficiency gains. Additionally, 60% technology adoption shows that digitalisation is gaining traction, but is not yet universal. Since the regression analysis confirms that higher technology adoption leads to shorter

TABLE 1: Descriptive statistics.

Number	Static	Value
1	Mean infrastructure quality	2.940361486756418
2	Technology adoption (%)	60.00000000000001
3	Cargo delays range (minutes)	5.1126539596155467–29.75134625260658

turnaround times (−1.28 coefficient), further increasing automation and digital tracking systems could further minimise delays.

The reported cargo delays ranging from 5 to 30 min align with the regression model's predictive range. The regression analysis suggests that improvements in both infrastructure and technology adoption would shift this distribution towards shorter delays, reinforcing the value of operational enhancements. As infrastructure has a larger impact on delays than technology, the combination of infrastructure upgrades and digitalisation is essential for optimising efficiency. Overall, these descriptive

statistics validate the regression insights, emphasising the need for continued investment in both physical infrastructure and technological advancements to improve cargo handling efficiency.

Table 2 details the results of the regression analysis, presenting coefficients, standard errors, *t*-statistics, *p*-values and confidence intervals (CI) for the intercept, infrastructure quality and technology adoption. This table clearly demonstrates the statistically significant impact of both predictors on cargo delays, thereby reinforcing the argument that enhancements in infrastructure and technology adoption can substantially improve operational efficiency.

The regression analysis confirms that both infrastructure quality and technology adoption significantly impact cargo delays, with a statistically significant model ($p < 0.001$). The negative coefficients indicate that as infrastructure quality improves (–3.34) and technology adoption increases (–1.28), cargo delays decrease. Specifically, for every unit increase in infrastructure quality, delays reduce by approximately 3.34 h, while a unit increase in technology adoption leads to a 1.28-h reduction in delays. The model explains 53.6% of the variance in cargo delays ($R^2 = 0.536$), suggesting these factors are strong predictors of efficiency in cargo operations.

Additionally, the *p*-values for both predictors are highly significant ($p < 0.001$), reinforcing the reliability of these relationships. The CIs further validate these findings, showing that the true effect of infrastructure quality and technology adoption lies within narrow, negative ranges, emphasising their role in reducing cargo delays. This analysis supports the hypothesis that better infrastructure and increased digitalisation improve operational efficiency, highlighting the importance of investment in logistics infrastructure and advanced tracking systems.
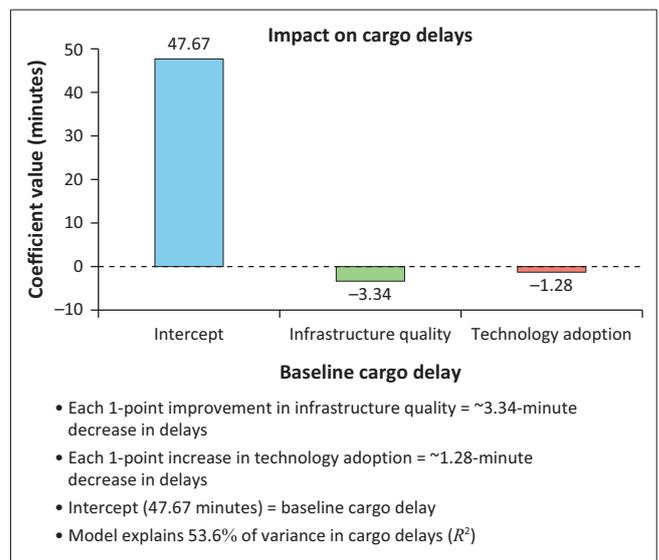
The infographic below provides a visual summary of the regression analysis conducted on South Africa's air cargo industry data. It illustrates how infrastructural quality and technology adoption impact cargo delays. The analysis used a standard linear regression model, yielding coefficients for the intercept, infrastructure quality and technology adoption, along with an R^2 value that quantifies the model's explanatory power. This graph serves as a concise overview of the statistical relationships, setting the stage for a discussion on how improvements in these areas could reduce operational delays.

Figure 3 offers an infographic that visually summarises the regression findings. The bar chart highlights the baseline cargo delay, as well as the negative coefficients for infrastructure quality and technology adoption, along with

the model's R^2 value. This graphic provides a concise overview of how improvements in these key areas can lead to reductions in cargo delays, making it an effective tool for communicating the core analytical outcomes.

The bar chart above reveals that the baseline cargo delay is approximately 47.67 min when both predictors are at zero. Notably, each one-point improvement in infrastructure quality results in a reduction of about 3.34 min in cargo delays, while a one-point increase in technology adoption decreases delays by roughly 1.28 min. The model's R^2 value of 0.536 indicates that 53.6% of the variance in cargo delays is explained by these two factors combined. This suggests that both infrastructure enhancements and increased technology integration are significant drivers in reducing cargo delays, thereby supporting the case for targeted investments in these areas to enhance operational efficiency.

As shown in Table 3, the Chi-square test revealed a statistically significant association between stakeholder job roles and their perceptions of infrastructure investment urgency ($\chi^2 = 35.72$, $df = 4$, $p < 0.001$). Cargo operators were more likely to rate infrastructure investment as highly urgent, reflecting their direct exposure to operational delays and inefficiencies. In contrast, airport officials tended to assign medium or low urgency, likely due to longer-term planning cycles or administrative constraints. Policymakers generally occupied a middle ground. These findings highlight divergent priorities among key stakeholders, suggesting that decision-making processes related to infrastructure upgrades may face challenges without coordinated, cross-sectoral engagement.

- Each 1-point improvement in infrastructure quality = ~3.34-minute decrease in delays
- Each 1-point increase in technology adoption = ~1.28-minute decrease in delays
- Intercept (47.67 minutes) = baseline cargo delay
- Model explains 53.6% of variance in cargo delays (R^2)

Note: $R^2 = 0.536$.

FIGURE 3: Regression analysis summary.

TABLE 2: Results of regression analysis.

| Number	Variable	Coefficient	SE	*t*-Statistic	*P*	95% CI Lower	95% CI Upper
1	Intercept	47.6651	3.6226	13.1576	2.69e-23	40.4752	54.8550
2	Infrastructure quality	-3.3417	0.3338	-10.0121	1.26e-16	-4.0042	-2.6793
3	Technology adoption	-1.2807	0.3388	-3.7806	2.70e-04	-1.9530	-0.6084

CI, confidence interval; SE, standard error; CI, confidence interval.

Complementary to Table 3, Figure 4 displays a stacked bar chart that graphically illustrates the differences in investment urgency perceptions among Cargo operators, Airport officials and policymakers. This visualisation clearly shows that cargo operators perceive a higher urgency for infrastructure investments compared to the other groups, thereby emphasising the need for a collaborative approach to decision-making in infrastructure development.

The stacked bar chart illustrates a clear divergence in investment urgency perceptions between cargo operators and airport officials. Cargo operators predominantly rate investment urgency as high, suggesting that they see immediate infrastructure improvements as critical to their operations. This could stem from their direct reliance on efficient logistics, transportation networks and facility upgrades to maintain business efficiency. In contrast, airport officials show a more balanced distribution, with a noticeable lean toward medium and low urgency ratings. This indicates that they may not perceive the same level of immediacy for infrastructure investments, possibly because of long-term planning cycles or differing priorities in airport management. Policymakers, positioned between the two extremes, have a moderate distribution of urgency ratings, suggesting they acknowledge both perspectives but may not strongly favour one side. The differing perspectives between these stakeholder groups highlight the challenges in aligning infrastructure investment decisions. Cargo operators' emphasis on high urgency suggests that delays in investment could negatively impact supply chain efficiency and economic growth. On the other hand, airport officials' moderate urgency perception may indicate a preference for phased or strategic long-term investments. These variations highlight the need for
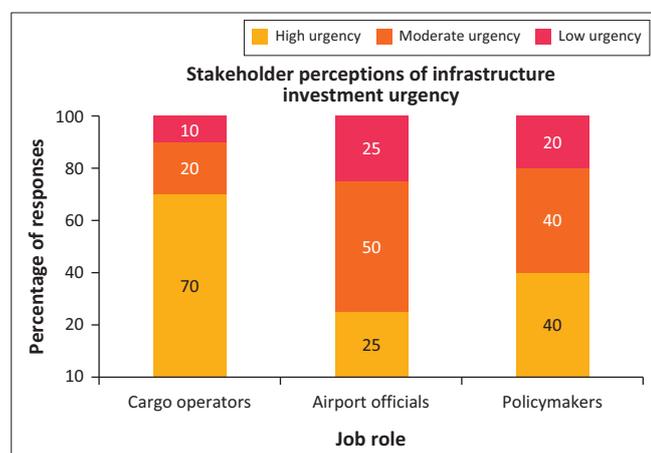
collaborative decision-making processes, ensuring that infrastructure investments align with the interests of multiple stakeholders to optimise overall efficiency and growth within the aviation sector.

Figure 5 provides a box plot comparing cargo delays across different levels of infrastructure quality. The graph vividly demonstrates that poorer infrastructure is associated with higher median delays and greater variability, reinforcing the conclusion that substantial improvements in physical infrastructure are critical for reducing operational inefficiencies in South Africa's air cargo industry. The sample sizes for each group were: Poor infrastructure ($n = 35$), moderate infrastructure ($n = 50$) and good infrastructure ($n = 35$), providing sufficient data to illustrate these trends.

The box plot visualisation clearly demonstrates that poor infrastructure leads to significantly higher cargo delays, as seen in the wider spread and higher median of delay times in this category. The 'Poor' infrastructure category exhibits a large interquartile range (IQR) and some extreme delay values, indicating both consistently high and highly variable delays. In contrast, as infrastructure quality improves, the median cargo delay decreases, and the variability in delays reduces. The 'Good' infrastructure category has the lowest median delay, with a narrower IQR and fewer extreme values, signifying greater efficiency and predictability in cargo handling. These trends suggest that infrastructure quality directly impacts the reliability and speed of logistics operations.

The implications of these findings are significant for policymakers, logistics companies and investors. Investing in better cargo terminals, improved logistics technologies and modernised transport infrastructure could substantially reduce inefficiencies, minimise delays and enhance supply chain reliability. Efficient infrastructure ensures faster turnaround times, lower operational costs and improved customer satisfaction in industries dependent on timely cargo movement. Moreover, reducing cargo delays can have wider economic benefits, such as improved trade competitiveness and reduced wastage of perishable goods. Thus, the data strongly supports the case for increased funding and strategic planning to upgrade logistics infrastructure and optimise cargo handling operations.

TABLE 3: Chi-square test results.

Statistic	Value
Chi-square statistic	35.72
Degrees of freedom	4
p-value	3.31e-07
Significant relationship?	Yes

FIGURE 4: Chi-square test results (Job role vs. investment urgency).
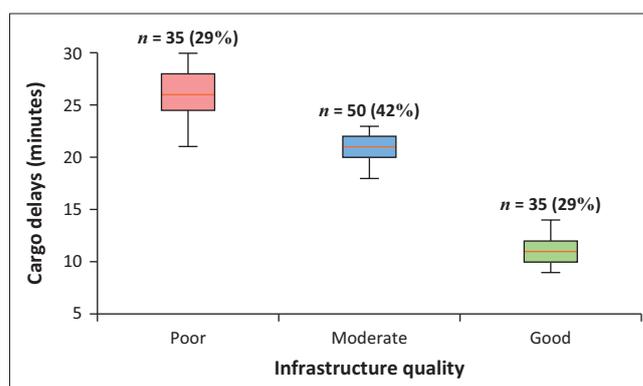
FIGURE 5: Box plot visualisation (infrastructure vs. cargo delays).

Discussion

The study's results affirm a statistically significant and operationally meaningful relationship between infrastructure quality and cargo delays in South Africa's air cargo industry. A one-unit increase in infrastructure quality correlates with a 3.34-min reduction in delays, a substantial effect in time-sensitive logistics contexts. This finding reinforces prior research by Mokhele and Mokhele (2022), who identified ageing infrastructure, particularly fragmented cold chains and outdated handling systems, as a primary contributor to inefficiencies at major South African airports. The wide interquartile range in delays observed under 'Poor' infrastructure conditions mirrors earlier insights from Hu et al. (2018), who demonstrated that suboptimal terminal design increases variability in cargo throughput. As South Africa contends with mounting trade and e-commerce volumes, the delay predictability becomes as crucial as their delay duration, further underscoring the importance of sound infrastructure investment to sustain competitiveness in the global logistics ecosystem.

Technological adoption also emerges as a key driver of operational efficiency, albeit to a slightly lesser extent than physical infrastructure. The regression coefficient of –1.28 for technology adoption suggests that while tools such as IoT-enabled tracking and digital documentation systems are valuable, they function best when embedded within modernised infrastructure. Adenigbo et al. (2023) have similarly emphasised that technological innovations yield the highest performance benefits when supported by appropriate physical logistics platforms. However, with the current adoption rate at just 60%, there is clear room for growth, especially when contrasted with the rapid advancements seen in developed logistics markets (Nantee & Sureeyatanapas 2021). The medium-level digital proficiency observed among participants aligns with findings by Büyüközkan et al. (2023), who noted that skills limitations often constrain the full realisation of logistics 4.0 technologies in emerging markets. Therefore, without capacity-building initiatives, the digital divide in South Africa's cargo sector may persist, limiting the effectiveness of isolated technology investments.

The study also reveals divergent perceptions of investment urgency among stakeholder groups, a subtlety often overlooked in infrastructure policy discourse. Cargo operators, most acutely affected by daily operational bottlenecks, overwhelmingly perceive infrastructure investment as urgent. This supports the findings by Olopade, Simo-Kengne and Ohonba (2022), who highlighted how financial and infrastructural constraints disproportionately affect frontline operators in South Africa. Conversely, airport officials appear more neutral, likely because of bureaucratic structures or long-term capital planning cycles. Policymakers, occupying a median stance, must therefore mediate between these conflicting timelines and priorities. As Coetzee and Swanepoel (2017) argued, alignment across stakeholders is critical for harmonising logistics operations with regional development goals. The study's findings call for collaborative

governance mechanisms, such as inter-agency task forces or public–private investment platforms that incorporate ground-level realities into national infrastructure strategies.

Finally, the data substantiates the compounded effect of poor infrastructure and limited technological integration on cargo delays, highlighting the risk of fragmented interventions. The combined explanatory power of both factors ($R^2 = 0.536$) suggests that isolated efforts, such as digitisation without physical upgrades, may produce marginal or unsustainable results. This aligns with the assertions of Zhao and Gao (2017), who advocated for an integrated approach to airline logistics design, where physical infrastructure and digital systems are co-optimised. Moreover, the study's findings support the recommendations of Adenigbo et al. (2023), who called for investment in smart cargo terminals that combine AI-based planning with streamlined physical handling systems. If South Africa is to assert itself as a regional logistics gateway, holistic reforms must bridge the current gaps in infrastructure, technology and institutional coordination. Only then can systemic inefficiencies be eliminated and long-term gains in cargo handling efficiency be realised.

Conclusion

The evidence presented in this study makes a compelling case for the prioritisation of infrastructure modernisation and technology adoption as dual pillars of efficiency enhancement in South Africa's air cargo industry. Notably, the empirical results show that infrastructure improvements exert a stronger and more substantial effect on reducing cargo delays compared to technological adoption. The regression results clearly demonstrate that improvements in infrastructure quality yield the most significant reductions in cargo delays compared to technological adoption. These findings reinforce the notion that physical infrastructure, particularly cargo terminals, cold-chain facilities and ground handling systems, forms the operational backbone of efficient air logistics. However, the analysis also highlights that technology, while secondary in impact, plays an essential enabling role in streamlining operations, enhancing tracking accuracy and reducing manual inefficiencies. Stakeholder perceptions further reveal a disconnect between operational urgency and policy planning, indicating a need for improved coordination between cargo operators, airport authorities and policymakers to align investment timelines and priorities.

Taken together, the study emphasises that a piecemeal approach to reform will be insufficient. For South Africa to position itself as a competitive logistics hub within the global supply chain, it must adopt a holistic strategy that simultaneously addresses ageing infrastructure, accelerates digital integration and harmonises stakeholder collaboration. Investment must be channelled not only into physical upgrades but also into targeted human capital development, especially in building digital proficiency and systems management capacity. Policy interventions should incentivise integrated development through public-private

partnerships and regulatory streamlining, ensuring that infrastructure and technological improvements translate into measurable performance gains. Ultimately, bridging the infrastructural and technological gaps identified in this study is not only a logistical necessity but also a strategic imperative for driving economic resilience, regional connectivity and global trade competitiveness.

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